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(ASTPE) for Hypersonic Scramjet Vehicle Design/Analysis***

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Abstract

For air-breathing hypersonic vehicles with scramjet engines, waverider-like forebodies are employed in order to reduce pressure leakage from the lower to upper surface and/or satisfy a shock-on-cowl lip condition to achieve superior inlet flow quality at a given design condition. However, any aeroelastic or dynamic perturbations will give rise to a non-ideal inlet flow field. This may induce vehicle instability in terms of the interaction of hypersonic aerodynamic, aeroelastic, aeroservoelastic, as well as aerothermoelastic interaction.

This STTR Phase II project is to develop a “Conceptual-Design/Analysis” (CDA) tool for precisely the purpose of rapid assessment of vehicle stability and control law implementation. Resulting ASTPE package includes Aero-Servo-Thermo-Propulso-Elasticity disciplines and a Graphical User Interface (GUI) has been created to assist driving individual modules in ASTPE package. Case studies include Single Engine Missile (SEM) and Single Engine Demonstrator (SED).

In this report, Chapter 1 provides background of this work, previous investigations and a brief introduction of ASTPE package. Chapter 2 ~ 7 give theoretical details of individual modules in ASTPE. Chapter 2 describes UCDA, which is a scramjet vehicle design and analysis code. In Chapter 3, UPTOP, a trajectory optimization code is presented. Chapter 4 documents TPSOPT, which is a Thermal Protection System (TPS) optimization program. SMB, a Structural Modal Base program, is included in Chapter 5. Chapter 6 and 7 describe implemented trim module and aeroservoelasticity module respectively. Case studies of SEM and SED are demonstrated in Chapter 8 and 9.

Chapter 1 Introduction

1.1 Background

Emerging hypersonic technology from space access and the global-strike vehicle to hypersonic Unmanned Air Vehicles (UAVs) demands effective hypersonic methodology for vehicle design and analysis. Air-breathing hypersonic vehicle concepts employing scramjet engines for cruise, space access, and hypersonic strike capabilities are currently being developed through several ongoing R&D efforts. Notably, these include the Waverider/Single Engine Demonstrator (WR-SED/X-51) by the Air Force, the Force Application and Launch from the Continental U.S. (FALCON) by DARPA, Hyper-X (X-43) by NASA (Figure 1.1), and HyFly by the Navy. Most of these designs take advantage of waverider or waverider-like forebodies to either minimize pressure leakage from the lower to upper surface and/or satisfy a shock-on-cowl lip condition to achieve superior inlet flow quality at a given design condition. However, any aeroelastic or dynamic perturbations will give rise to a non-ideal inlet flowfield. This would then induce vehicle instability in terms of the interaction of hypersonic aerodynamic, aeroelastic, aeroservoelastic, and propulsive forces, let alone the important aerothermoelastic interaction.

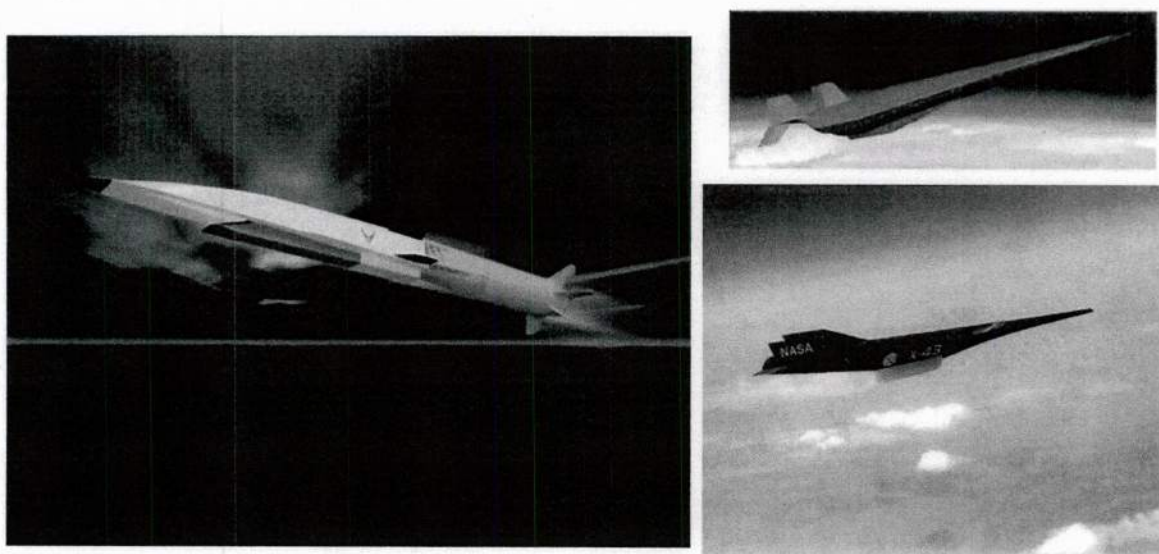


Figure 1.1 WaveRider-SED (X-51), FALCON and HyperX

To provide control to such types of instability in such extreme environments with aerothermal considerations is a challenging endeavor. McRuer [1.1] has warranted that the integration of airframe, propulsion, control, and dynamics should be a central issue for hypersonic vehicle design whereby forbidden zones appear in the hypersonic flight/operation corridor (bounded by the 1-g-upper and the thermal-load-lower boundaries) due to control limits as shown in Figure 1.2. Bowcutt [1.2] also ranked high the importance of the vehicle control system development for X-43s, HyFly and X-51.

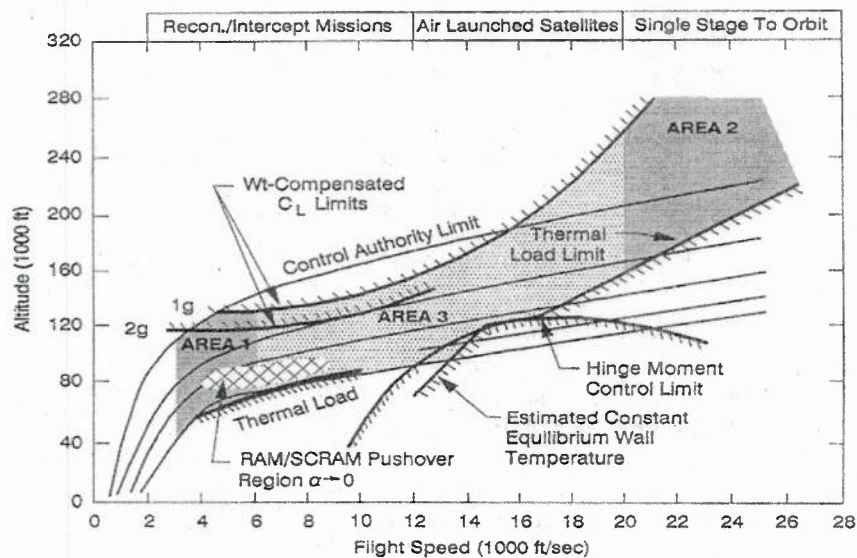


Figure 1.2 Excluded operational regions in flight corridor (taken from Ref. [1.1])

The development and optimization of hypersonic vehicles is a challenging endeavor with the design closure of missile-scale vehicles proving even more elusive. This complexity was extremely evident in NASA's Hyper-X program where there was a vast difference between the vehicle design scale and the scale of the flight test vehicle. The Boeing Dual-Fuel vehicle (shown in Figure 1.3) was designed as a Mach 10, 200 foot class, global reach cruise vehicle, but was photographically scaled down to 14 feet while preserving most of the original length scale of the scramjet engine to emerge as the NASA's Hyper-X, Mach 7 configuration (shown in Figure 1.4). The resulting vehicle then required silane to initiate and sustain combustion in the small-scale engine and utilized a 1000 pound block of tungsten in the forebody to balance the lift and moment. Clearly, the effort which goes into evolving and refining a complex, hypersonic vehicle design is substantial, especially when including the intricate synergy required between the

disciplines of aerodynamics, propulsion, aeroelasticity, stability and control, and aerothermodynamics.

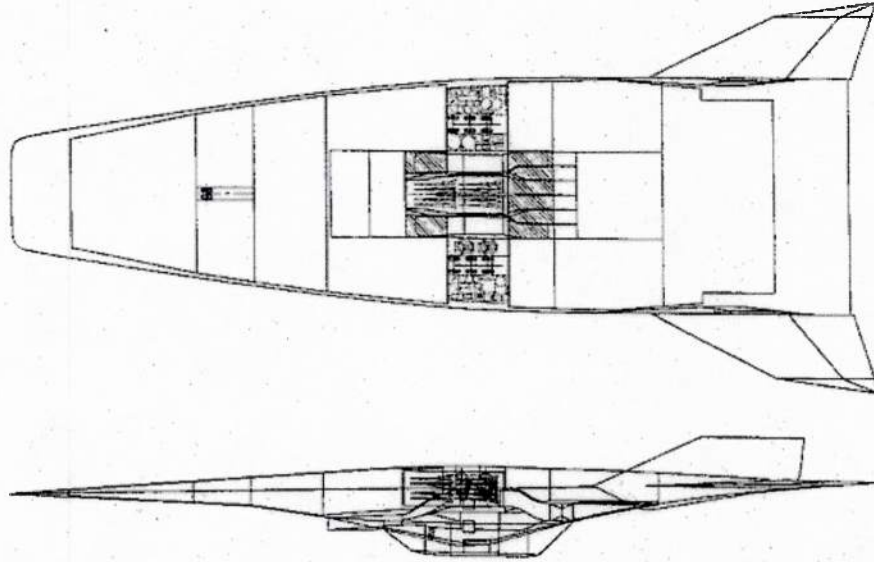


Figure 1.3 Boeing global reach, Mach 10, dual-fuel vehicle

The thought that some feel that it is better to use an existing vehicle as a baseline configuration rather than initiate the design process for a new mission and vehicle scale is troubling. It is in this area where our STTR Phase II research effort becomes essential; understanding the physics involved with many competing disciplines and developing an efficient vehicle design and optimization process. This is the original design philosophy and the approach of Starkey and Lewis [1.3]. Based on their work, the ZONA Team has developed some lower fidelity models in the interest of computational expense and understanding discipline trade-offs. Increasing the fidelity of the design tools for any given discipline can be done, as needed, in the future, but understanding the underlying process and intricate synergy must be made a priority.

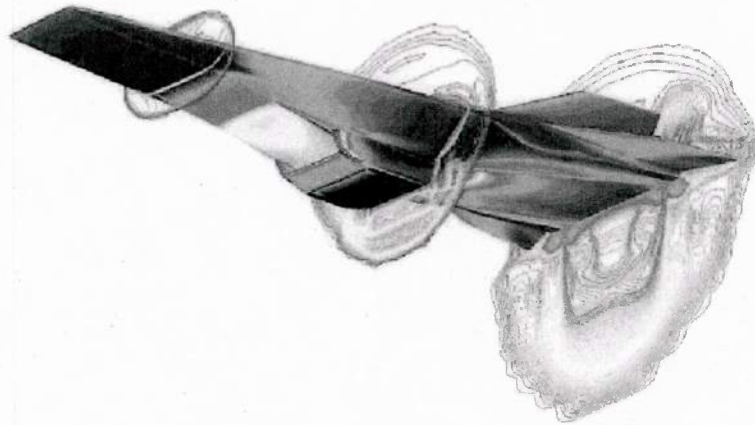


Figure 1.4 NASA's Mach 7 Hyper-X test vehicle

A baseline hypersonic vehicle geometry (in this case a missile configuration) and some of the design variables required are shown in Figure 1.5. In all, a vehicle of this type can be generated with as few as 20 design variables. Although increasing the number of design variables makes the optimization process more complex, modern day parallel processing techniques make this convergence achievable within a number of hours on a computer cluster. Due to the highly non-linear nature of the design variable interactions and disjoint design space, hybrid evolutionary/gradient optimization schemes are favored, as outlined in Figure 1.6.

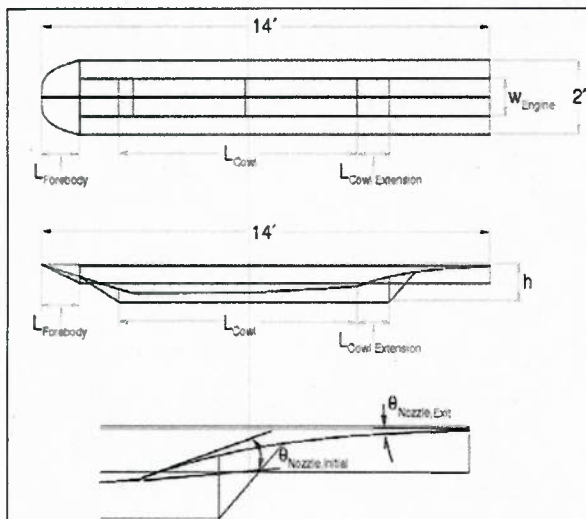


Figure 1.5. Waverider based, air-breathing hypersonic missile with some external design variables labeled.

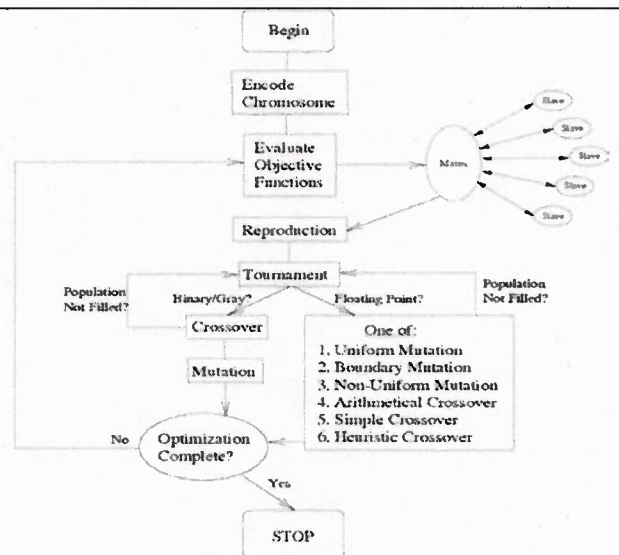


Figure 1.6. Parallelized genetic algorithm optimization methodology.

1.2 Previous Findings

Physical understanding and formulation to account for these complex interactions for hypersonic air-breathing vehicles are lacking at present, with the exception of a simple model suggested by Chavez and Schmidt [1.4]. With greatly simplified component forces and a dummy engine in their model, it can be concluded that the propulsive and aeroelastic interactions alone could indeed be destabilizing.

A brief survey of the current literature in the system consideration of the scramjet vehicle is presented in Table 1.1. It is disappointing to find that little of the current research has followed the pursuit of Chavez/Schmidt, who has mapped out a conceptual design/analysis path for future R&D efforts.

Although Chavez/Schmidt's work has been widely quoted in the literature [1.4], few followed to tackle the interactive AeroServoPropulsoElastic (ASPE) impact on the dynamic stability of the scramjet vehicles. Their work clearly indicated that such a type of analysis can be effectively handled through a "Conceptual-Design/Analysis" (CDA) approach. This is needed because the multi-disciplinary nature of ASPE would be otherwise far too complex as a system to handle. To do so, however, requires in depth physical understanding of the mechanism and interactions of all disciplines involved. This is in fact the physical-based model that is currently established by the ZONA Team.

Previous experience in the last decade also indicates that large discrepancies exist between measured data (wind-tunnel model) and flight data. This is so because the scaling law for different sizes of scramjet inlet/engine is simply non-existent at present. It is not clear in fact whether such scaling laws can ever be established. In the presence of vehicle aeroelasticity, the ASPE interactions of a scramjet vehicle would be vastly different between that derived from the measured and the flight test. For this reason, an analytical model for rapid assessment of the ASPE interaction as to the vehicle stability and control is badly needed.

The ZONA Team has created such a "Conceptual-Design/Analysis" (CDA) tool for precisely the purpose of rapid assessment of vehicle stability and control law implementation. In almost

every aspect, ZONA's CDA model has largely refined the features of Chavez/Schmidt's model. In particular, the essential improvements of the ZONA model over that of Chavez/Schmidt lies in the scramjet inlet/engine design feature and in the closed-loop control methodology, whereby both are lacking in Chavez/Schmidt's model. Details of our "Conceptual-Design/Analysis" (CDA) model will be described in what follows.

Table 1.1 Survey of Current Literature in the System Consideration of the Scramjet Vehicle

	<i>Chavez et al [1.4]</i>	<i>ZONA/UMD Team [1.5]</i>	<i>Mirmirani et al[1.6]</i>	<i>Bolender et al[1.7]</i>	<i>Baker et al[1.8]</i>	<i>Johnson et al[1.9]</i>
<i>Configuration</i>	2D Diamond	SEM Model of SED/ Waverider	X43A	2D Diamond	IHAT Geometry Models	Simple TSTO Wave-Rider
<i>Conceptual Design Capability</i>	Yes	Yes	-	-	Some	-
<i>Aerodynamic Method for Design of Analysis</i>	Shock Expansion (CD)	Hypersonic/ Euler & Viscous Aerodynamic Methods	CFD(A)	-	CFD	-
<i>Inlet Design</i>	-	Yes	-	-	-	-
<i>Scramjet Combustion Model</i>	Simple 1-D	2D Scramjet w/ Finite Rate Chemistry	Simple 1-D	Simple 1-D	-	-
<i>Propulsion Dynamic Interaction</i>	-	Yes	-	-	-	-
<i>Flight Dynamics</i>	Yes	Yes	-	(F) only	-	Yes
<i>Elastic Vehicle/Aeroelastic Consideration/ASE</i>	Yes	Yes	-	(F) only	-	Yes
<i>Open/Close Loop Control & Methodology</i>	-	Yes	-	-	-	-
<i>Design Procedure: Formulation (F) & Solutions (S)</i>	Yes	Yes	-	Mostly (F)	-	-
<i>Thermal Protection System</i>	No	Yes			Ablator	
<i>Vehicle Optimization</i>		Yes			Airframe	
<i>Trajectory Optimization</i>	No	Yes				

1.3 The ASTPE (Aero-Servo-Thermo-Propulso-Elasticity) Code

The ASTPE Software Architecture is shown in Figure 1.7.

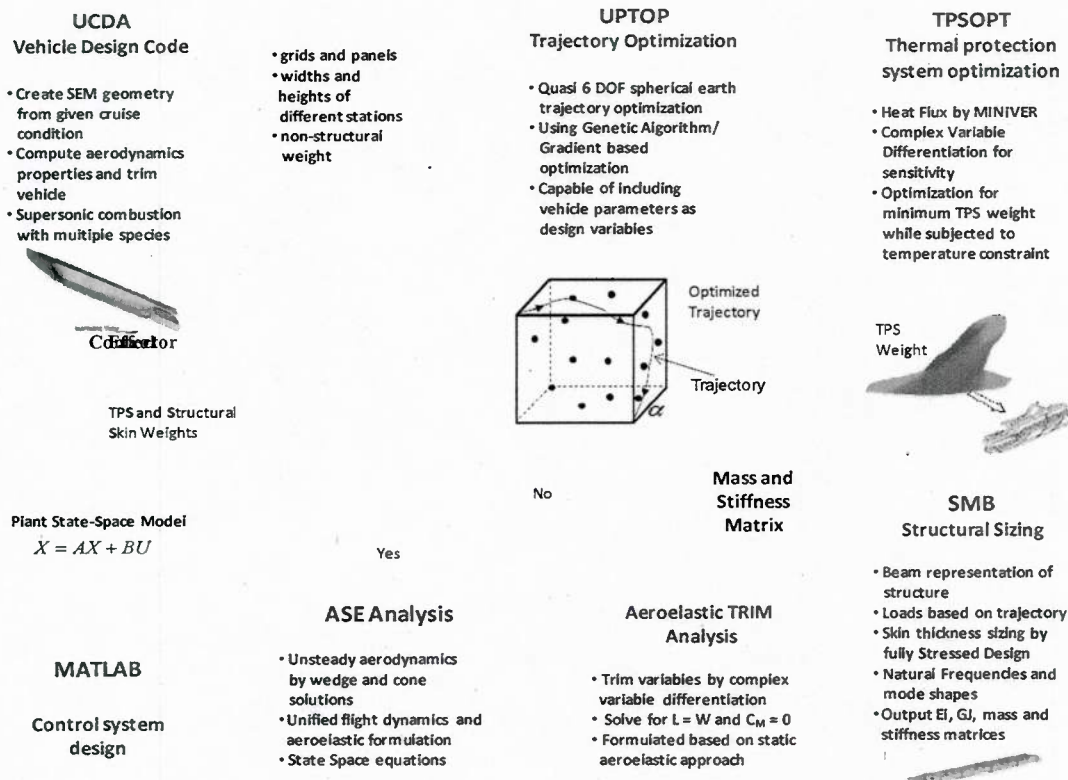


Figure 1.7 ASTPE Software Architecture

The ASTPE code consists of several modules as shown in Figure 1.7. The University of Colorado Design and Analysis code (UCDA) is used to design the vehicle and analyze it at some given trajectory. The University of Maryland Parallel Trajectory Optimization Program (UPTOP) optimizes the trajectory of the vehicle using the maximum range condition and the vehicle design. The Thermal Protection System Optimization (TPSOPT) code optimizes the TPS weight and sends the information to UCDA back so that the TPS weight can be updated for the vehicle. Using a fully stressed design method, Structural Modal Base (SMB) Module then optimizes the weight of the skin thickness subjected to the aerodynamic loads computed based on the optimized trajectory from UPTOP. SMB also generates the structural natural frequencies and their corresponding mode shapes that are needed to trim the vehicle with the structural flexibility effects in the next step considering an elastic vehicle using UCDA. Finally, once the

trim condition is computed, the aerodynamic stability derivatives at the trim condition are calculated which are the input of the Aero-Servo-Elasticity (ASE) module. The ASE module computes the longitudinal dynamics with structural flexibility effects and generates a state-space equation of the plant ready for flight control law design.

It should be noted that the procedure described above is for a single design cycle. The new trim solution and the change of the geometry of the vehicle due to the structural deformation as well as the additional weight due to the added thermal protection system and structural skin are used to update the design trim condition and the total vehicle weight, respectively, for the next design cycle. The design cycle will be repeated several times to arrive at a final design solution.

Chapter 2 University of Colorado Vehicle Design and Analysis (UCDA) Program

The University of Colorado Vehicle Design Code (UCDA) systematically creates a vehicle/combustor geometry based on inputs for forebody, inlet, combustor, nozzle, airframe, and control surface definitions. This works in either a one-off mode or interacts with the optimization software to develop a new design. Each major component has multiple methods of describing the geometry to increase/decrease the complexity and number of design variables required.

The current aerodynamic design and analysis methodology for both the waverider forebody and the vehicle aftbody are detailed below. There are a number of different ways to develop a waverider forebody; wedge generated flows, conically generated flow, blended flows, and osculating cone generated flows. The simplest of these is the analytical variable wedge angle method of Starkey and Lewis [2.1]; while the most flexible (and computationally expensive) is the osculating cone method of Sobiesky [2.2].

2.1 Waverider Design

The extreme sensitivities inherent in a missile-scale, hypersonic vehicle scramjet performance relative to the inlet conditions require detailed modeling of all associated components in order to capture the true physics [2.3]. When coupling this combustor sensitivity with aeroelastic effects the situation becomes much more complex.

In order to reduce the complexity of the models, the vehicle will utilize a two-dimensional keel-line flowpath, similar to that used in the Hyper-X program. As detailed in Figure 2.1, the main aerodynamic-propulsive components to be analyzed are: a waverider forebody, a scramjet combustor, and a simple two-dimensional nozzle.

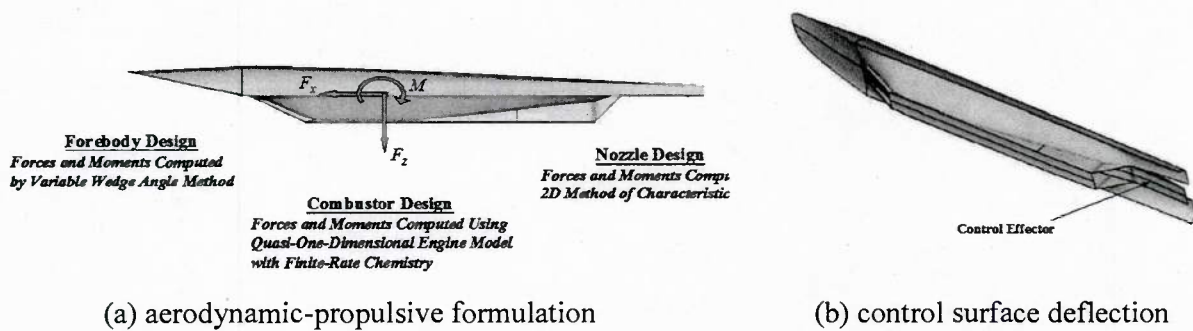


Figure 2.1 Generic single engine missile configuration

2.2 Variable Wedge-Angle Derived Waverider

The Variable Wedge-Angle waverider methodology was developed at the University of Maryland for reduced order, modeling of hypersonic waveriders [2.1]. The power in this method is in that the waverider forebody can be designed and analyzed analytically using only seven geometric design variables, as shown in Figure 2.2.

The computational fluid dynamics validation cases shown in Figure 2.3 show the power of the variable wedge angle method as a quick estimate of a waverider flowfield by producing an attached shock-wave at the design condition. Also shown is the minimal cross-flow (other than at the inflection point at the leading edge) thereby giving uniform flow into the airbreathing engine and demonstrating the applicability of strip theories to analyze the aftbody flow.

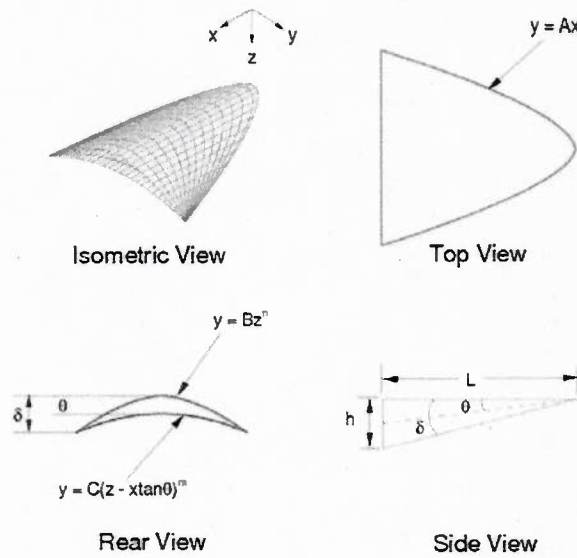


Figure 2.2 Variable wedge-angle waverider forebody

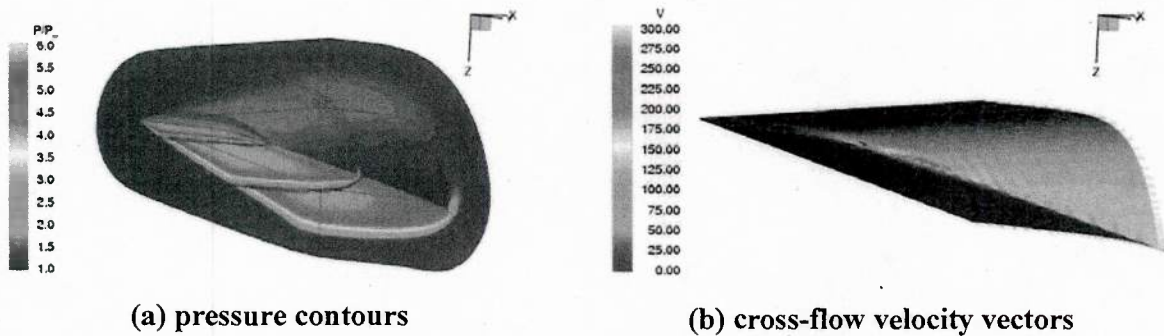


Figure 2.3 CFD validation of VWA methodology

For a Mach 8, zero degree angle-of-attack design point of the forebody, off-design performance at various Mach numbers and angles of attack is shown in Figure 2.4. The only discrepancy is near the zero-lift point where the absolute difference is small, but the % difference is large. Therefore, the variable wedge angle methodology is shown to be comparable to the osculating cone method and CFD analysis for changes in Mach number and angle of attack.

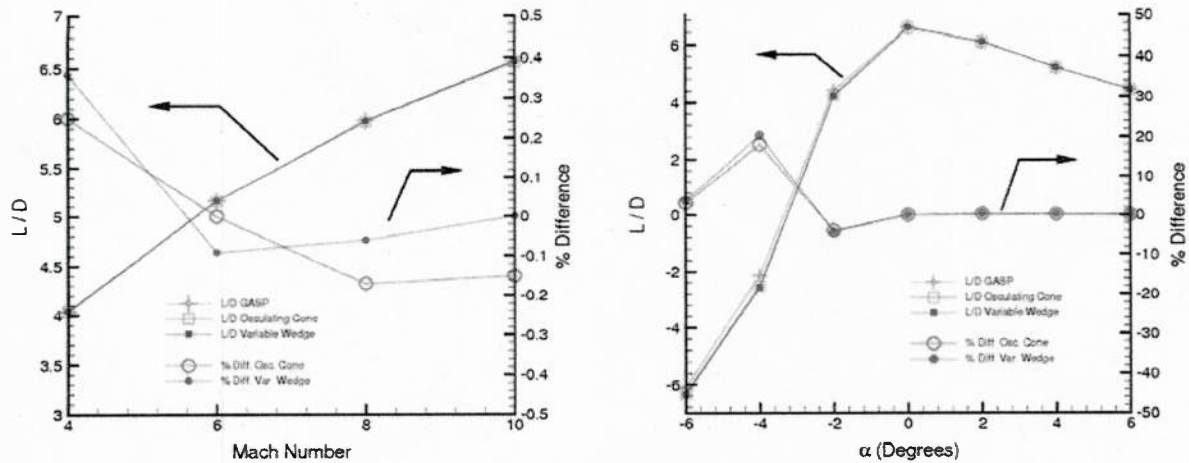


Figure 2.4 L/D ratio and % difference for CFD, osculating cone, and variable wedge angle analyses of a Mach 8 forebody

2.3 Osculating Cone Waverider

True waveriders are generated using an inverse design method; one where the desired flowfield is chosen and the vehicle that generates that flowfield is produced. One method of waverider generation, first conceived of by Sobieczky et al. [2.2], where multiple slices of a conical flowfield are placed side-by-side to build up the desired flowpath, is referred to as the method of osculating cones [2.4], as shown in Figure 2.5. The keel-line flowfield can be generated in this manner to provide uniform flow to a two-dimensional combustor while providing the high lift-to-drag ratio (L/D) at a high lift coefficient (C_L) that waveriders are well known for. In addition to the compression provided by the waverider, the inlet system also utilizes a number of planar compression ramps which satisfy an on-design shock-on-lip constraint.

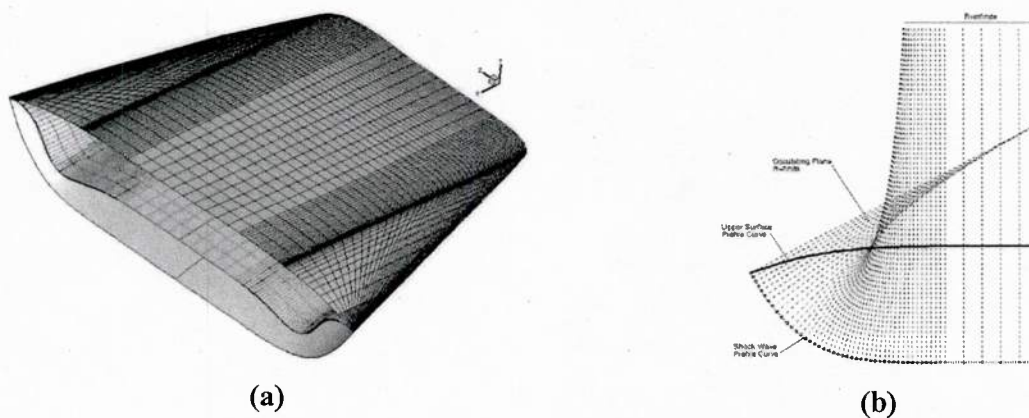


Figure 2.5 Osculating cone waverider with a) shock flowfield at combustor inlet plane and b) inlet plane compression surface generation [2.5]

2.4 Modified Shock-Expansion Method Formulation

Another innovation used in this stage of the vehicle analysis (for fast optimization studies) is a modified shock-expansion method. Shock-expansion theory is inaccurate for this application because it determines the flowfield using single Prandtl-Meyer expansions (hypersonic slender body theory) assuming two-dimensional streamlines. Due to the highly curved nature of these missile airframes, the shock-expansion method results in an over-prediction in peak surface pressure by as much as 50%. The modified method uses a combination of the oblique shock relations and Taylor-Maccoll cone flow equations to solve the local flow properties (for compression) while marching down a 'two-dimensional' streamline. As with the shock-expansion theory, the local flow conditions and the relative inclination angle at a point are used to calculate the properties at the next point. The blending of the properties predicted by the oblique shock and Taylor-Maccoll methods is based on the local radius of curvature in the spanwise direction. This attempts to predict the pressure relieving effects a three-dimensional body has on a two-dimensional streamline approximation to local flow conditions. Expansion regions are calculated using traditional shock-expansion theory.

A similar method using a blend of Tangent Wedge and Tangent Cone approximations to off-design flowfield predictions for osculating cone generated waveriders was developed by Grantz [2.6]. Grantz's method was not applicable to this study since it requires a known generating

body with a known flowfield (i.e., streamline locations), such as the method of osculating cones, to determine the surface properties of the body.

Continuing with the assumption of two-dimensional flow, the surface properties at a point are solved using the known properties at the previous point and the local body angle, relative to that point. For oblique shock theory, the wedge angle used to determine the new properties, and for cone flow the cone half angle is used. For a known surface point, with initial properties, P_1 , T_1 , and M_1 , the relative surface angle is used to determine the new properties. Assuming only wedge flow the results are given by P_{2w} , T_{2w} , and M_{2w} , with completely conical flow given by P_{2c} , T_{2c} , and M_{2c} .

The local radius of curvature R is determined in the spanwise plane by:

$$R = \frac{[1 + (y')^2]^{3/2}}{|y''|} \quad (2.1)$$

The actual surface properties for compression surfaces are found by linear interpolation in the form $\lambda = R\lambda_w + (1-R)\lambda_c$ where w values are calculated from oblique-shock theory, c values are determined from solution to the Taylor-Maccoll equations, and λ indicates each of P , T , and M at a given location. Results using this methodology have been validated using Euler computational fluid dynamics (CFD) calculations as shown in Figure 2.6.

Figure 2.6(a) shows the missile airframe neglecting the engine flowpath, since Figure 2.6(b) demonstrated the two-dimensional nature of the keel-line flow. The top half of each vehicle pictured in Figure 2.6 is the Euler CFD solution while the bottom half is the modified shock-expansion method. As can be seen, there are only minor differences in the solutions, but the solution run-times are many orders of magnitude apart since the analytical blending function takes only a fraction of a second to compute. Figure 2.6(b) is a close-up view of the peak pressure location.

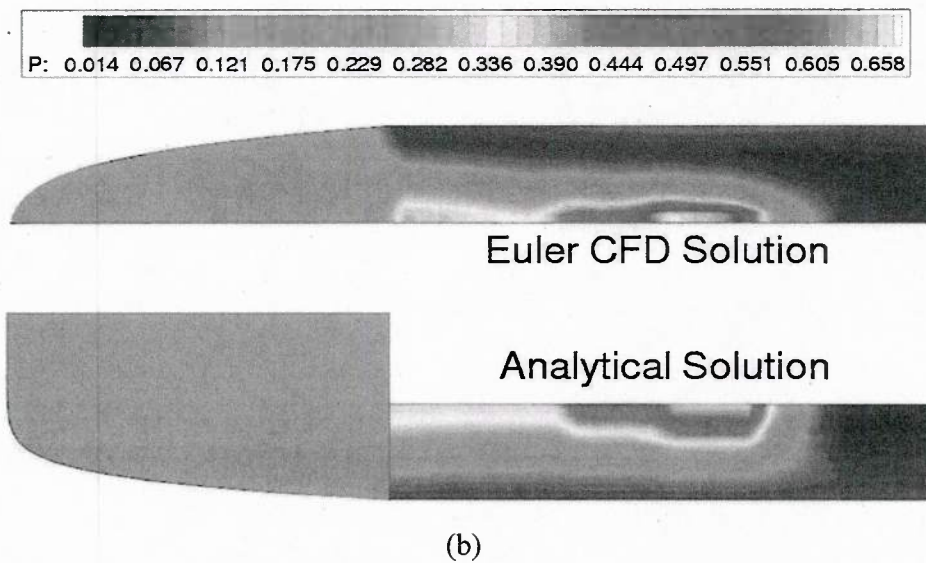
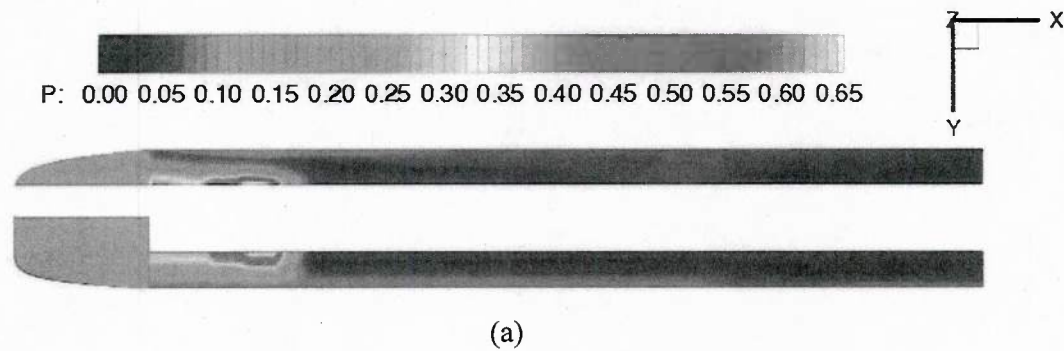


Figure 2.6 Validation of modified shock-expansion methodology for three-dimensional pressure relieving effects along two-dimensional streamlines

2.5 Scramjet Combustor

The scramjet combustor is generated in a two-dimensional manner with an isolator section followed by one or more expanding sections, as shown in Figure 2.7(a). The fuel (and pilot agent if desired) can be injected through any number of ports in any position throughout the combustor. Figure 2.7(b) shows a mixing profile and burning efficiency are then applied to determine the effects of the inlet conditions, fuel, and geometry on the combustion using finite-rate chemistry computations [2.7].

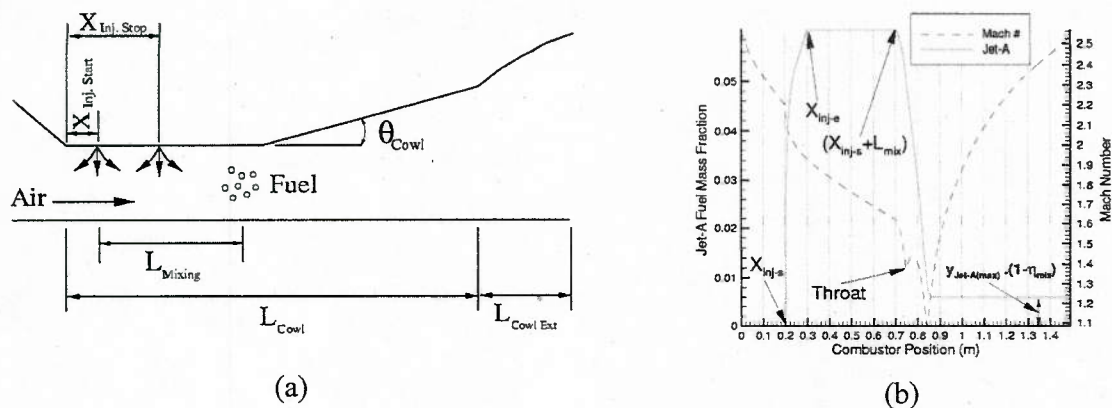


Figure 2.7 (a) Scramjet combustor model, (b) sample Jet-A fuel Mass fraction and mach number as a function of combustor position

The elegance of this scramjet model is in the formulation of the finite-rate chemistry inclusion in the quasi-one-dimensional equations of fluid motion. Using this model the design sensitivities of various fuel types, chemistry mechanisms, injector locations and angles, viscous effects, and wall heat transfer can be determined in a computationally efficient manner. The inclusion of chemical kinetics allows for a prediction of fuel ignition, a finite-rate process that inherently cannot be predicted using equilibrium methods. Chemistry also allows for off-design calculations to determine what conditions are needed for the fuel to burn, and what conditions will cause the combustor to choke. These prediction abilities are crucial in flowfield regimes where the limits of the scramjet concept are seen (i.e., hydrocarbon missile scramjets, ram/scram transition, etc.).

The series of ordinary differential equations that model the governing equations of motion are shown below. Along with a user specified cross-sectional area profile, mass and reaction mixing profile, viscous model, and a reaction mechanism, the ordinary differential equations are integrated to solve for the combustor flowfield.

Equations for continuity, momentum, state, mixture molecular weight, species conservation, and energy are shown below, respectively.

$$\frac{1}{\dot{m}} \frac{d\dot{m}}{dx} = \frac{1}{\rho} \frac{d\rho}{dx} + \frac{1}{U} \frac{dU}{dx} + \frac{1}{A} \frac{dA}{dx} \quad (2.2)$$

$$\frac{1}{p} \frac{dp}{dx} + \frac{\gamma M^2}{2U^2} \frac{dU^2}{dx} + \frac{2\gamma M^2 C_f}{D} + \frac{\gamma M^2 (1-\varepsilon)}{\dot{m}} \frac{d\dot{m}}{dx} = 0 \quad (2.3)$$

$$\frac{1}{p} \frac{dp}{dx} = \frac{1}{\rho} \frac{d\rho}{dx} + \frac{1}{T} \frac{dT}{dx} - \frac{1}{\overline{MW}} \frac{d\overline{MW}}{dx} \quad (2.4)$$

$$\frac{d\overline{MW}}{dx} = -\overline{MW}^2 \left(\sum_i \frac{1}{MW_i} \frac{dY_i}{dx} \right) \quad (2.5)$$

$$\frac{dY_i}{dx} = \frac{\dot{\omega}_{i,mix} MW_i}{\rho U} + \frac{1}{\dot{m}} \frac{d\dot{m}_{i,added}}{dx} - \frac{Y_i}{\dot{m}} \frac{d\dot{m}}{dx}, \quad (2.6)$$

$$\frac{dT}{dx} = \frac{1}{\hat{c}_p} \left[-\sum_i h_i \frac{dY_i}{dx} + \frac{1}{\dot{m}} \sum_i \left(h_i \frac{d\dot{m}_i}{dx} \right)_{added} - \frac{2C_f c_p (T_{aw} - T_w)}{Pr^{2/3} DA} - \frac{h_o}{\dot{m}} \frac{d\dot{m}}{dx} - U \frac{dU}{dx} \right] \quad (2.7)$$

where

$$\hat{c}_p \equiv \tilde{c}_p - \frac{1}{\dot{m}} \left\{ \sum_i \left[\dot{m}_i (c_{pi} + \tilde{c}_{pi} T) \right]_{added} \right\} \quad (2.8)$$

and

$$\tilde{c}_p \equiv c_p + \sum_i T \tilde{c}_{pi} Y_i \quad (2.9)$$

$$\tilde{c}_{pi} \equiv \frac{R_u}{MW_i} (a_{2i} + 2a_{3i} T + 3a_{4i} T^2 + 4a_{5i} T^3) \quad (2.10)$$

These equations constitute a stiff set of ordinary differential equations (ODE) due to the chemical production terms from combustion. Solution of these equations a stiff ODE solver which can account for differing time scales. A code named VODPK [2.8], developed by Lawrence Livermore National Lab, was used to accomplish this task. VODPK uses a backward differentiation formula to integrate the set of stiff ODEs. Values for the individual chemical species molecular weight, specific heat, heat of formation, and reaction rates are obtained by CHEMKIN-II [2.9] for a user-supplied reaction mechanism.

For this study only Jet-A fuel was investigated, although any fuel could be used. The Jet-A reaction mechanism used in this study is a subset of the full reaction mechanism from Kundu et. al [2.10]. The reaction mechanism consists of 17 species and 14 reactions and was chosen because it has been validated by Chang and Lewis [2.11]. The ambient air composition is assumed to be 78% nitrogen, 21% oxygen and 1% argon by volume.

Solving the equations for conservation of mass, momentum, energy, and the equation of state for the derivative in velocity yields:

$$\begin{aligned} \frac{dU}{dx} = \frac{1}{\alpha} \left\{ -\frac{1}{A} \frac{dA}{dx} + \frac{1 + \gamma M^2 (1 - \varepsilon) - (h_o / \hat{h})}{\dot{m}} \frac{d\dot{m}}{dx} + \frac{1}{\hat{h}} \left[-\sum_i h_i \frac{dY_i}{dx} + \frac{1}{\dot{m}} \sum_i \left(h_i \frac{d\dot{m}_i}{dx} \right)_{added} \right] \right. \\ \left. - \frac{1}{MW} \frac{dMW}{dx} + \left[\gamma M^2 - \frac{c_p (T_{aw} - T_w)}{\hat{h} Pr^{2/3} A} \right] \frac{2C_f}{D} \right\} \end{aligned} \quad (2.11)$$

where

$$\alpha \equiv \frac{1}{U} \left(1 - \gamma M^2 + \frac{U^2}{\hat{h}} \right) \quad (2.12)$$

and

$$\hat{h} \equiv \hat{c}_p T \quad (2.13)$$

Each term in the dU/dx derivative can be calculated, or is a prescribed quantity. The first term is the cross-sectional area profile dA/dx which is assumed to be prescribed by the user. The second term is the mass flow addition term of $\dot{dm}/dx$ and represents the mass mixing profile prescribed by the user. The quantity $\hat{h}$ can be calculated using CHEMKIN-II. The solution of the change in mixture molecular weight $d\overline{MW}/dx$ is found by first solving the species conservation equation. Given the mixing profile and chemical information from CHEMKIN-II, the conservation of species is a known quantity which may then be substituted into the mixture molecular weight equation to solve for the change in mixture molecular weight. The friction terms involving the friction coefficient are all known quantities or may be calculated using CHEMKIN-II. The remaining terms in dU/dx are known quantities, quantities that have already been calculated, or quantities that may be calculated using CHEMKIN-II. Thus, the velocity derivative derived in dU/dx is a known quantity at a particular x -location in the combustor.

With knowledge of the velocity derivative, the density derivative may be found from the continuity equation. The pressure derivative may be calculated from the momentum equation. The temperature derivative is then found from the equation of state. The derivatives of all the variables are then integrated using VODPK to find the flow solution. The full engine flowfield may be calculated in a fraction of a second on a standard take-off computer. Thus, this method allows for rapid design of full vehicle concepts that include a detailed engine flowfield.

The mixing model used is that of Rogers [2.12], tabulated by Henry and Anderson [2.13]

$$\dot{m}_r = \dot{m}_f \frac{\alpha \bar{x}^b \exp(c \bar{x})}{d \bar{x} + f} \quad (2.14)$$

$$\bar{x} \equiv \frac{x}{L_{inj}} \quad (2.15)$$

where L_{inj} is the length between the start and end of the injection and the curve-fit constants are $a = 1.1703$, $b = 0.62925$, $c = 0.42632$, $d = 1.4615$, and $f = 0.32655$.

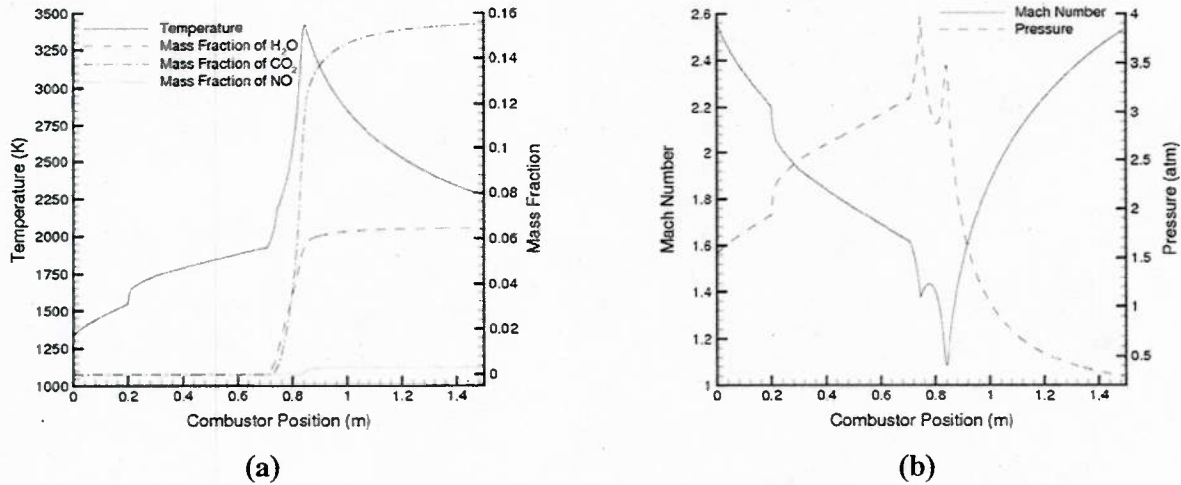


Figure 2.8 Sample scramjet performance with (a) Mach number and pressure distribution, and (b) temperature and species mass fraction distributions

The importance of using finite-rate chemistry to accurately predict the fuel ignition point and the effects of the combustor geometry and the energy release can be seen in Figure 2.7. The Mach number and pressure distribution for a sample combustor are shown in Figure 2.8 (a), while the temperature and species mass fractions (to show fuel burning efficiency) are shown in Figure 2.8 (b). In this instance, the combustor is 1.5 meters long with the constant area portion of 0.75 meters long and the expansion section the following 0.75 meters. The fuel ignition occurs just before the expansion area and the interplay between the combustor geometry and heat release are

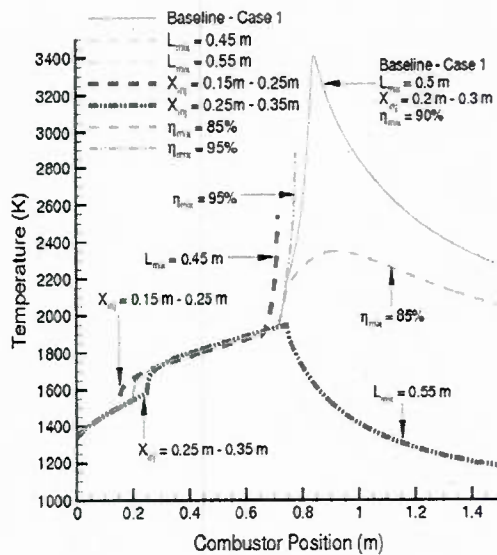


Figure 2.9 Combustor temperature contours for off-baseline conditions

performance was the lower mixing efficiency case, otherwise the engine would unstart.

evident. The sensitivity of the combustor performance relative to the ignition point is detailed in Figure 2.9. By varying a few of the combustor design conditions slightly off of baseline, the performance degraded very quickly with most of the variations resulting in thermally choked flow. Only two conditions did not result in a choked flow state: 1) lowering the mixing efficiency from 90% to 85% (lowering the heat release), and 2) increasing the mixing length from 0.5 meters to 0.55 meters (delaying ignition until after the mechanical throat). The only off-baseline condition which retained a moderate amount of

Although some of the design conditions were altered to determine the sensitivity, similar results occur for off-design flight performance is especially once the angle-of-attack increases a few degrees or the Mach number increases past the design point (both causing increased inlet pressure). Alleviating these concerns can only be done through bleeds, spillage, bypass, or geometry variations [2.3] and [2.14].

2.6 Nozzle

Following the combustor are the internal and external nozzle sections, which are calculated using the frozen, non-rotational, two-dimensional method of characteristics, as shown in Figure 2.10. Since part of the nozzle is utilized as a control surface in this configuration the combustor flowfield directly affects the vehicle trim state.

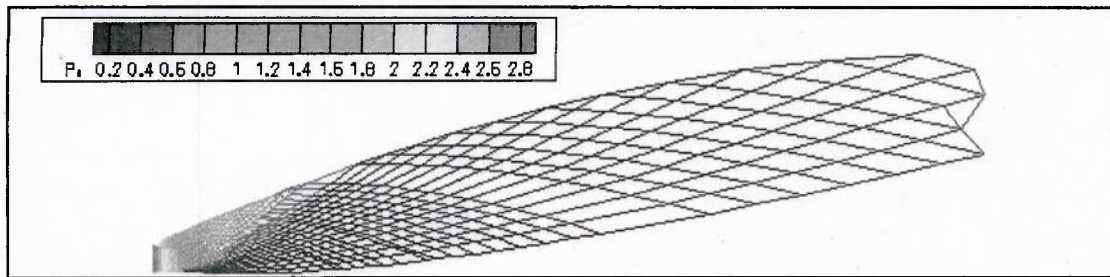


Figure 2.10 Sample method of characteristics nozzle design showing pressure contours

Using the design fuel equivalence ratio as the combustor state, the control surface effectiveness can be determined, as shown in Figure 2.11. The trim state in this instance is at a slightly downward control surface deflection, as shown in Figure 2.12.

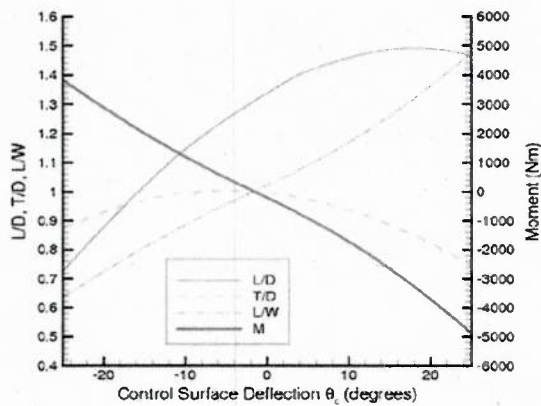


Figure 2.11 Control surface effectiveness at the design fuel equivalence ratio

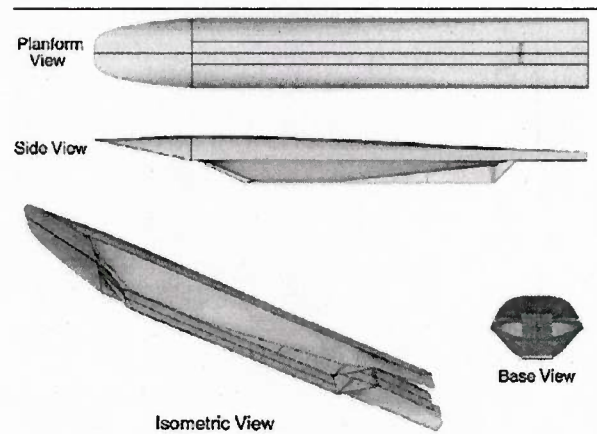


Figure 2.12 Baseline vehicle configuration

2.7 Superformula of the Superellipse

The superformula of the superellipse [2.15] is one option for generating the top surfaces of both the forebody and afterbody of the vehicle models. The typical superellipse formula can transform a parallelogram into an ellipse with the Cartesian equation

$$\left| \frac{x}{a_1} \right|^v + \left| \frac{y}{b_1} \right|^v = 1$$

whereas the superformula of the superellipse can transform a polygon into an ellipse or a concave polygon using the equation by determining a radial displacement r along each angle ϕ .

$$r(\phi) = \left[\left| \frac{\cos(\frac{1}{4} m \phi)}{a_1} \right|^{n_2} + \left| \frac{\sin(\frac{1}{4} m \phi)}{b_1} \right|^{n_3} \right]^{-1/n_1}$$

In this equation, the exponents n_1 , n_2 , and n_3 alter the curvatures while the variables a_1 and b_1 control the axis lengths. Finally, the variable m controls the number of sides or lobes. Examples of certain parameter settings are given in Fig. 2.13 with a more thorough listing in Fig 2.14 (with many non-ideal geometries).

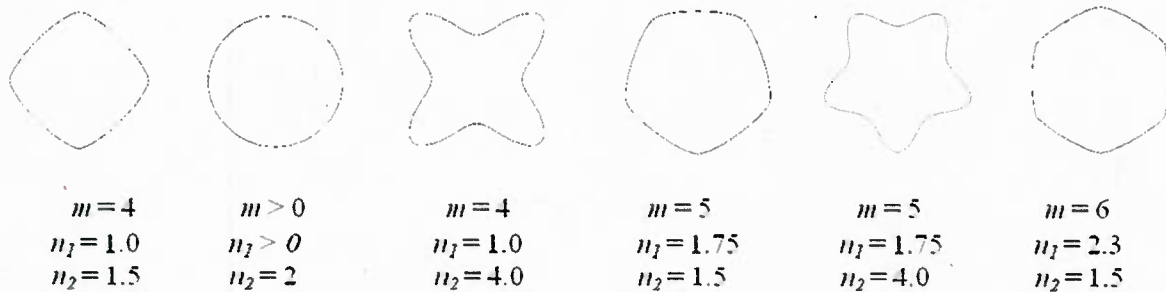


Figure 2.13 Example geometries created using the superformula of the superellipse.

Rotational symmetry m	$m = n_2 = n_3 = 1$	$n_1 = 1000$		$n_1 = n_2 = n_3 = 1/2$	$n_1 = 30$ $n_2 = n_3 = 15$	$n_1 = 80$ $n_2 \neq n_3$	n_i as column 3 $a = 2$
			$n_2 = n_3$				
0			2				
1			500				
2			500				
3			1980				
4			1000				
5			620				
6			390				
7			320				
8			250				

Figure 2.14 Example geometries created using the superformula of the superellipse.

Chapter 3 University of Maryland Parallel Optimization Program (UPTOP) Program

3.1 Introduction

The University of Maryland Parallel Trajectory Optimization Program (UPTOP) is a generalized atmospheric and near-earth orbit trajectory optimization program written in Fortran 95. UPTOP combines a Differential Evolutionary Scheme (DES) with a gradient-based optimizer to provide optimal results without requiring a feasible initial condition. UPTOP is capable of optimizing multi-stage trajectories where the vehicle may have multiple engines and fuel tanks. Input to the code consists of two simple input decks and interpolation tables to define the aerodynamic characteristics and engine performance. The current capabilities of the code also allow for elementary sizing studies and provide the user with the ability to optimize vehicle parameters such as fuel weight and reference areas. Additionally, the user can define a set of relationships between the vehicle parameters so that the effects of a change in one vehicle parameter will be accurately reflected in the vehicle's performance. Users can also define new variables to be tracked or used throughout the trajectory optimization. UPTOP is a modular code written with expansion in mind, and provides a solid base for delving into guidance and control issues.

UPTOP calculates up to 200 parameters, providing information on vehicle states and orientations, atmospheric states, orbital elements, etc. User-defined variables can also be integrated into the code, allowing for easy addition of heating or weight analysis, for example. Additionally, simple tracking operators, such as average, max/min, or standard deviation, can be applied to all variables.

User inputs consist of initial conditions (i.e., initial altitude, velocity, etc.) and variable profile definitions (i.e. angle of attack or throttle profiles, as a function of time). Most variable profiles can be specified using one of four methods:

Constant definition – user defines a constant value for the variable.

Curve Fit - user defines the value of the function at user-specified points in time, and UPTOP fits a series of piecewise curves to the data, using a function of a user-specified order. Dependencies between the individual variables in the table can also be established (for example, point 4 can occur 20 seconds after point 3).

Look-up Table - user includes a look-up table that provides the variable value based on up to 10 independent variables. UPTOP then uses linear interpolation to calculate the variable value.

Event Driven - user specifies events in terms of independent variables that, when triggered, result in changes to the dependent variable.

Most trajectory input values and vehicle parameters can be included in the optimization process, unless they are specified as a look-up table. Further, relationships between the vehicle parameters can easily be built in order to perform elementary sizing studies. More information is included in the UPTOP Usage Manual

3.2 Simulation

UPTOP uses a 4th-order Runge Kutta scheme and information regarding the vehicle's aerodynamic and engine performance to propagate the vehicle position, velocity, and orientation throughout time. The simulation aspects of UPTOP are discussed in more detail below.

3.2.1 Coordinate Systems

UPTOP maintains four coordinate systems for tracking the vehicle position and orientation.

- Earth-Centered Inertial (ECI) - positioned at planet center, with the 1-axis pointing through the northern pole, the 2-axis aligned with 0 deg longitude at time = 0, and the 3-axis at 90 deg longitude at time = 0. This frame does not rotate with the earth, however the earth rotates around the ECI 1-axis.
- North-East-Down - positioned at A/C c.g. and serves as local horizon. The 1-axis always points North and the 3-axis always points to the center of the earth, with the 2-axis pointing East. The relation between the ECI and NED frames is shown in Fig. 3.1.
- Velocity frame (VEL) – positioned at A/C c.g., with the 1-axis pointing in the opposite direction as the freestream velocity vector. VEL begins with NED frame, rotates around 3-axis by heading angle, then about 2-axis by flight path angle.
- Aircraft Body Coordinates - positioned at A/C c.g., with the 1-axis aligned with A/C nose, the 2-axis along the A/C right wing, and the 3-axis pointing down (with respect to pilot in level flight). The relation between the VEL and ABC frames is shown in Fig. 3.2.

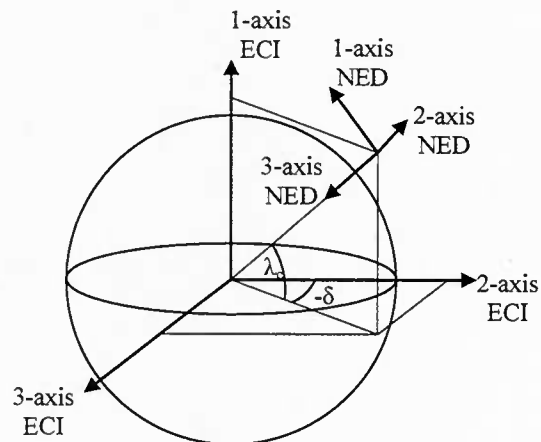
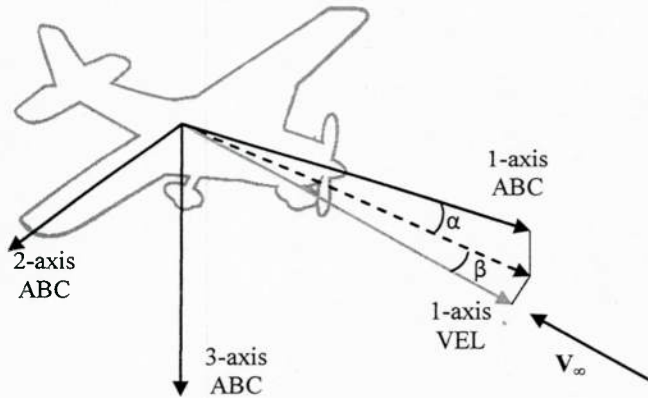


Figure 3.1 ECI and NED reference frames



UPTOP uses direction cosine matrices to change vectors from one reference frame to another. For more information regarding reference frames, see Refs. [3.7] and [3.10].

Figure 3.2 ABC and VEL reference frames

3.2.2 Planet Modeling

UPTOP assumes a rotating, oblate spheroid earth with a flattening parameter of 0.0033528. In UPTOP, the vehicle's geocentric latitude, geodetic latitude and longitude (both over an inertial and rotating planet) are tracked.

The gravity vector, $\mathbf{g}$, is defined in UPTOP as:

$$\mathbf{g} = -\frac{GM}{\|\mathbf{p}\|^3} \begin{bmatrix} \bar{p}_x \\ \bar{p}_y \\ \bar{p}_z \end{bmatrix}$$

where $\mathbf{p}$ is the position of the aircraft in the ECI frame and GM is the Earth-mass gravitational constant ($3.9860 \times 10^{14} \text{ m}^3/\text{s}^2$). The values of $\bar{p}$ are used to account for the oblateness of the earth by incorporating the J_2 gravitational harmonic constant, such that:

$$\begin{aligned} \bar{p}_x &= p_x \left[1 + 1.5J_2 \left(\frac{r_e}{\|\mathbf{p}\|} \right)^2 (3 - 5 \sin^2 \lambda) \right] \\ \bar{p}_y &= p_y \left[1 + 1.5J_2 \left(\frac{r_e}{\|\mathbf{p}\|} \right)^2 (1 - 5 \sin^2 \lambda) \right] \\ \bar{p}_z &= p_z \left[1 + 1.5J_2 \left(\frac{r_e}{\|\mathbf{p}\|} \right)^2 (1 - 5 \sin^2 \lambda) \right] \end{aligned}$$

where $J_2 = 1.08263 \times 10^{-3}$, r_e is the equatorial radius of the Earth, and λ is the geocentric latitude.

UPTOP incorporates two atmosphere models, the 1976 US Standard Atmosphere [3.1] and NRLMSISE-00 [3.5]. The 1976 US Standard Atmosphere is used by default for altitudes below 88km. Above 88km, UPTOP uses NRLMSISE-00 model. The user may also select NRLMSISE-00 for all altitudes. Winds are not modeled in UPTOP.

3.2.3 Vehicle Dynamics

The equations of motion for rigid-body flight are given by:

$$\frac{d\mathbf{p}}{dt} = \mathbf{V} \quad (3-1)$$

$$\frac{d\mathbf{V}}{dt} = B \frac{1}{m} \mathbf{F}_b + \mathbf{g} \quad (3-2)$$

$$\frac{dm}{dt} = - \left(\frac{dm}{dt} \right)_f \quad (3-3)$$

$$\frac{d\mathbf{q}}{dt} = -\frac{1}{2} \Omega_q \mathbf{q} \quad (3-4)$$

Eqs. (3-1) and (3-2) describe the changes in the inertial position, $\mathbf{p}$, and velocity, $\mathbf{V}$, vectors as a function of the vehicle mass, m , gravity, $\mathbf{g}$, and external force vector as specified in the ABC frame, $\mathbf{F}_b$. The direction cosine matrix, B , is used to rotate the external forces from the ABC frame to the ECI frame. Eq. (3-3) describes the vehicle mass change as a function of fuel mass consumption. Finally, Eq. (3-4) provides the update for the quaternion vector, $\mathbf{q}$, used to track vehicle orientation.

Missing from this set of equations is the rate of change of the angular rate values as a function of vehicle mass moment of inertia and external torques. UPTOP is a trimmed-vehicle code, and does not consider the effects of torque on the vehicle. Instead, the user specifies the vehicle orientation profile as a function of time. This defines the angular rates, and allows the body-axis angular rate vector in the inertial frame, $\omega_{B/I} = [P, Q, R]$, to be calculated. Then,

$$\Omega_q = \begin{bmatrix} 0 & P & Q & R \\ -P & 0 & -R & Q \\ -Q & R & 0 & -P \\ -R & -Q & P & 0 \end{bmatrix}$$

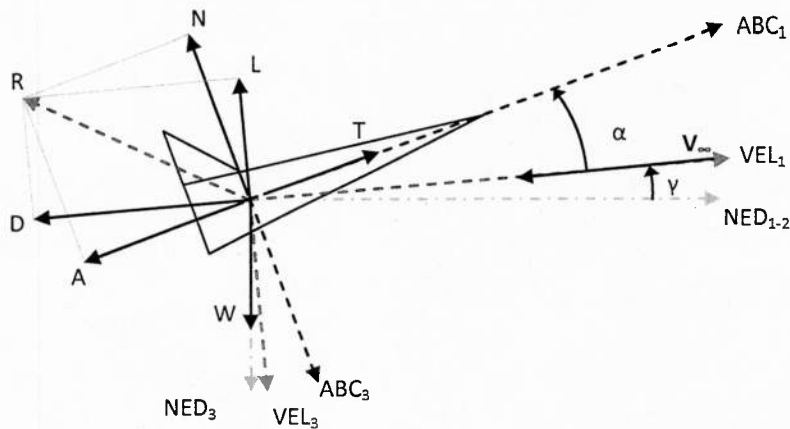


Figure 3.3 Vehicle external forces

The vehicle angular rotation rates are discussed further in Sec. 3.2.5. Additional details regarding rigid body dynamics and reference frames can be found in standard vehicle dynamics texts, including Refs. [3.7] and [3.10].

UPTOP uses a 4th order Runge-Kutta routine to propagate the equations of motion while minimizing numerical inaccuracies. The user must specify a time-step and a maximum allowed time to aid in memory allocation.

3.2.4 Vehicle Forces

UPTOP accounts for the effects of aerodynamic and thrust forces on the vehicle's path, however, UPTOP does not account for vehicle moments (see Sec. 3.2.5). The aerodynamic forces can be specified relative to the velocity vector (lift and drag) or relative to the vehicle axes (normal and axial). Alternatively, the force coefficients can also be defined, such that

$$X = C_x q S$$

where X is replaced with the appropriate parameter, q is the dynamic pressure, and S is the corresponding reference area (planform area for aerodynamic values, engine exit area for thrust).

Figure 3.3 shows a graphic representation of the forces on the vehicle. Lift and drag ('L' and 'D') lay on the axes of the velocity vector (VEL) frame, whereas the normal and axial forces ('N' and 'A') lay on the aircraft body fixed (ABC) axes. The resultant of the aerodynamic forces, R, is included in the figure for the convenience of the reader when relating the forces in the two frames. The vehicle weight always points towards the center of the earth (along the NED 3-axis), and the thrust vector, T, always points along the 1-axis of the ABC frame. Figure 3.3 also shows that the angle γ , at which the velocity vector meets the NED 1-2 plane (i.e., the local horizon) defines the flight-path angle.

3.2.5 Vehicle Position and Orientation Calculation

UPTOP does not consider vehicle aerodynamic moments or the effects of external torques from control surfaces or thrust vectoring when calculating the vehicle's trajectory. Instead, the user specifies the vehicle orientation as a function of time. Usually, this is done by defining the vehicle aeroballistic angles (angle of attack, bank, and yaw angle) or the vehicle Euler angles or angular rates relative to the NED frame.

With the vehicle orientation, known at time t_i , UPTOP then calculates the aerodynamic and thrust forces applied to the vehicle and uses the information provided by the user (these data are assumed to apply to a trimmed vehicle). The external forces, along with the current position and velocity, are used to determine the vehicle position and velocity at t_{i+1} using Eqs. (3-1) and (3-2).

Depending on the orientation input mode, Eq. (3-4) may require closer attention. The quaternion update is dependent on the angular rotation rate of the ABC frame relative to the ECI frame, $\{\omega_B\}_I$. If the user specifies the vehicle orientation using inertial angles, P , Q , and R are simply the derivatives of those angles with respect to time. However, typically the user will wish to specify the vehicle orientation in more familiar terms, such as pitch relative to the local horizon, or angle of attack. For the former, the rotation of the ABC frame relative to the NED frame is defined. In that case, the angular rate of the ABC frame relative to the NED frame must be added to the angular rate of the NED frame with respect to the ECI frame (since the local horizon rotates as the vehicle moves around the spherical earth), such that $\{\omega_B\}_I = \{\omega_B\}_N + \{\omega_N\}_I$.

If the user specifies the vehicle orientation in terms of the aeroballistic angles, the process to find $\{\omega_B\}_I$ requires an iterative scheme. The aeroballistic angles define the ABC frame relative to the VEL frame, so the body-axis angular rates are now $\{\omega_B\}_I = \{\omega_B\}_V + \{\omega_V\}_N + \{\omega_N\}_I$. However, the rotation of the VEL frame with respect to the NED frame is not known beforehand, and must be iterated upon by guessing and refining values for the change in flight path angle and heading with respect to time, until Eqs. (3-1) and (3-2) are consistent, and the desired values of angle of attack and sideslip angle have been acquired at the following time step.

3.2.6 Stagnation Point Heating

UPTOP employs a simple heating model, due to Tauber, to estimate the vehicle stagnation point heating rate. The heating equation is a function of the vehicle nose radius and wall temperature. The user may specify a fixed wall temperature, or allow UPTOP to estimate the equilibrium wall temperature. See Ref. [3-8] for more details.

3.3 Optimization Overview

Although random-based evolutionary algorithms (EA's) are generally praised for their ability to find global optima, their efficiency as the objective function approaches the optimum typically

decreases significantly. In the near-optimal space, the classical gradient-based optimization techniques excel. This leads to the concept of hybrid optimization techniques that combine the strengths of the two disciplines.

Madavan [3.3, 3.4] provides an overview of efforts to hybridize differential evolutionary schemes, and also shows increased performance by combining Differential Evolutionary Scheme (DES) with dynamic hill climb (DHC). The current work uses the Design Optimization Tool (DOT) package [3.9]; more specifically calling the sequential quadratic programming (SQP) routine. SQP is an efficient constrained optimization technique that minimizes a quadratic approximation to the objective function subject to linearized constraints. Details of the method are available throughout literature and included in the DOT manual [3.9].

Previous work using UPTOP has shown that coupling SQP with DES provides an effective method of optimization that is more powerful than either method alone. The results obtained from the hybrid method shows a consistency and reliability that is greatly desired in optimization work, since it may reduce the amount of tuning required when examining a new problem.

3.3.1 Differential Evolutionary Scheme Overview

DES shares a framework with most evolutionary algorithms, beginning with a random initial population of design variables and progressing to the next generation through some form of mutation, recombination, and selection. DES is a simple scheme that uses straightforward methods for mutation, recombination, and selection. Given a set of N design parameter vectors, $\mathbf{X} = [x_1, x_2, \dots, x_N]$, that define the population members at a particular generation, a set of N trial vectors $\mathbf{T}$ can be developed using a general mutation operator for each individual member, t_i

$$t_i = Gx_* + (1 - G)x_a + \sum_{q=1}^Q F_q (x_{b_q} - x_{c_q})$$

where the $*$ subscript denotes the best performing vector in the current generation, and the a , b , and c subscripts denote randomly selected members of the population. G is the coefficient of the convex combination, F the mutation coefficient, and Q the number of differential terms. Finally, if an element of the trial vector lies outside of the specified variable bounds, the element is reset to the nearest bound.

Each trial vector then passes through the recombination stage, wherein the population of children vectors, $\mathbf{C} = [c_1, c_2, \dots, c_N]$ is developed. Each element, j , of a particular child vector, c_i is determined by a simple recombination operator:

$$c_{n_j} = \begin{cases} t_{n_j} & \text{if } r_j \leq R \\ x_{n_j} & \text{if } r_j > R \end{cases}$$

where r_j is a random number ($0 \leq r_j < 1$) and the crossover probability, R , is user defined ($0 < R < 1$).

In the selection stage, every member of the parent population is compared to its corresponding child vector. If the child vector performs better than the parent vector, the parent vector is replaced. Otherwise, the parent vector remains a member of the population and the child is rejected. A generation is complete once this process is complete for all population members.

For the most efficient optimization using DES, some amount of tuning is required to determine the best values for N , G , F , Q and R . The population size, N , should generally be 10-20 times the number of design variables, although for optimization problems with relatively few design variables and a clear, easy-to-find optimum, values as low as $N=20$ may provide quick convergence to the optimum. Higher values of G , F , and R tend to increase the population's rate of convergence to the design space near the best performing population member. Although this may push the population towards an optimum value, generally that optimum is a local one, and the loss of population diversity generally proves undesirable. Low values, on the other hand, tend to prevent the population from making adequate process towards any optimum. As suggested by Madavan [3.4], randomizing the values of G , F , and R typically provides good optimizer performance in the lack of extensive tuning data.

Evolutionary algorithms generally lack a method of determining convergence to the global maxima, so the user must use his/her best judgment in determining how many generations to calculate when using DES. Because of the random nature of the optimizer, the user should also not necessarily expect repeatability in results, especially when comparing results after relatively low numbers of generations. DES coupled with SQR provides a very effective means of finding global optima, however it should be noted that there usually a significant computational cost associated with this effectiveness.

3.3.2 Objective Function Calculation

Objective and constraint function calculations depend on several user inputs:

variable being considered – all variables calculated by UPTOP can be used in optimization or constraint functions. Further, the user will often need to define a tracking variable to perform a simple operation on an existing variable. Operators such as maximum/minimum and average values are available for use, and these operators can be applied across the entire trajectory or only user-specified segments.

objective/constraint type – currently, UPTOP only allows for straightforward objective or constraint functions, i.e., maximize a particular variable, subject to the value of another variable not exceeding a maximum value. For objective functions, a variable can be maximized or minimized. Additionally, a truncated maximum/minimization mode is available, which requires

a target value also be specified. In the case of a truncated maximization of variable x , the objective function, f , is

$$f(x)_i = \begin{cases} x_i & \text{if } x_i < \text{target}_i \\ \text{target}_i & \text{if } x_i \geq \text{target}_i \end{cases}$$

A constraint function, g_i , is considered satisfied when $g_i \leq 0$. In UPTOP, the constraint functions are defined as

$$g(y)_i = m(C_{lim-i} - y_i) - t_i$$

where y is the value of the variable under consideration, C_{lim} is the constraint limit, and t_i is the constraint tolerance. m is the constraint mode; if $m = 1$, the constraint is violated if y drops below the constraint limit, and if $m = -1$, the constraint is violated if y exceeds the constraint limit. The constraint tolerance provides some leeway in the constraint status, and is mainly included in UPTOP to allow DOT to distinguish between active, satisfied, and violated constraints.

objective/constraint weighting – the DES-SQP optimizer can only optimize a single objective function. Further, DES compares population members based on a single constraint function. Therefore, when multiple objective and constraint functions are specified, the respective functions must be summed into a single objective function and single constraint function. To allow the user more control over the influence of the individual functions, a weighting value, w , may be specified, such that

$$F = \sum_{i=1}^{\text{num\_goals}} w_i f(x)_i$$

for the objective functions, and similar for the constraint functions.

when to compute the function value – the user must select the moment at which to compute the objective or constraint function value. This moment can be chosen based on time or percentage of trajectory/stage length, or tied to user-defined events in the trajectory. For instance, the user may want to constrain the altitude below a certain value at the end of the trajectory.

Alternatively, the user may wish to constrain the Mach number below a certain limit until the vehicle reaches 10km in altitude. The objective and constraint functions are not computed by UPTOP until after completion of the trajectory, when full-knowledge of the vehicle states is available.

3.3.3 Member Competition

DES relies heavily on competition between existing population members and members of the child population. Therefore, it becomes important to define a set of rules for selection. For unconstrained optimization, the objective functions, F , are simply compared, and the better

performing member wins the competition. In this version of DES, the overall constraint value, G - which is the weighted sum of the individual constraint functions - is first compared. If member 1's G is less than the member 2's, member 1 wins the competition. If the values of G are equal, the objective functions are then considered as before to determine a winner.

3.3.4 Hybrid Optimization

After some experimentation with various methods, the current version of UPTOP uses a very straightforward method of combining DES with DOT. The optimization process begins with DES and progresses for a number of generations, as specified by the user. At that point, the best performing member of the population is sent to a 'front-end' subroutine used to scale the constraint gradients and reconfigure the population member for use by DOT. DOT is allowed to run to conclusion, and then restarted. The final design from DOT is then compared to the original population member, and if the new design is better, it replaces the original member. If not, the new design is randomly compared to several other members, and may replace one of those or be rejected entirely. With DOT completed, the DES continues to run for the set number of generations. The next time DOT is called, the best performing member will be sent to DOT only if it has been changed by the recent DES calls. Otherwise, a random population member is sent to DOT, and the above process repeated.

3.3.5 Parallel Optimization

Due to the nature of DES, UPTOP is well suited towards parallelization when run in optimization mode. UPTOP incorporates Message Passing Interface (MPI) to facilitate its use across multi-computer networks, and uses a self-scheduling job controller to ensure the best use of resources. Further, UPTOP makes use of multiple processors when calculating gradients in DOT, minimizing the idle time of processors throughout the entire optimization.

3.4 Validation

UPTOP has been validated against sample problems solved by Program to Optimize Simulated Trajectories (POST) [3.6] with good agreement, and although it makes sacrifices in overall computational time when optimizing, UPTOP guarantees a thorough examination of the entire design space while searching for the optimal solution.

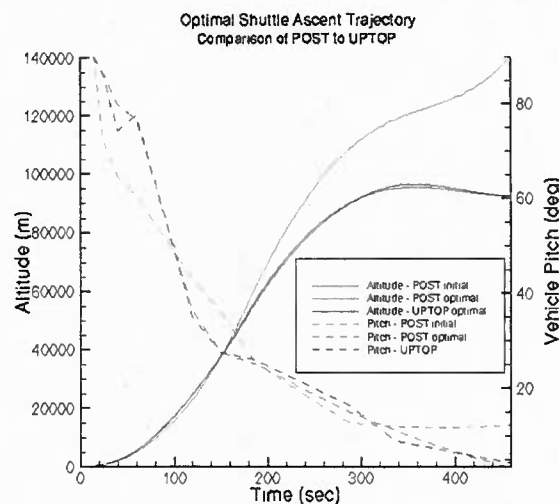


Figure 3.4 Comparison of POST to UPTOP

Figure 3.4 shows the excellent agreement in the optimal Space Shuttle model ascent profiles as determined by POST and UPTOP. The POST solution reports an optimal second stage dry mass of 140,747.0 kg, whereas UPTOP reports an optimal second stage dry mass of 140,796.8 kg. Figure **Error! Reference source not found.** shows the optimal vehicle altitude and pitch profiles as functions of time, as determined by both codes. For comparison, the Figure also shows the trajectory computed by UPTOP when using the optimal POST results as input. With the exception of the discrepancy near $t=50$ s, the optimal vehicle pitch profiles match closely.¹

This sample problem is solved by POST relatively quickly using the projected gradient method, and requires roughly 5,000 function calls to optimize using UPTOP. Although there is a significantly greater computation expense using UPTOP, there is an additional consideration for the user of both codes. Also shown in Fig. **Error! Reference source not found.** is the initial trajectory given in the POST input deck that serves as the starting point for the POST optimization. Considering the wide bounds of the design variables, this initial trajectory should be considered to be in the neighborhood of the optimal solution, and there may be considerable effort involved in determining this initial trajectory. In general, gradient-based optimizers require an initial set of design variables, and a clear, uninterrupted path between the initial and optimal designs. Although there exists numerous methods for extracting the optimizer from local optima or even overcoming discontinuities in the design space, these methods generally increase the amount of problem-specific user tuning. UPTOP, on the other hand, does not require the knowledge of an initial trajectory, and for more complex optimization problems, this tradeoff may make UPTOP more useful.

More information regarding this validation case is provided in the Usage Manual, and additional information regarding the validation of UPTOP can be found in Ref. [3.2].

¹ The differences in pitch angles in that region may be due to the fact that UPTOP does not account for thrust vectoring losses due to the solid rocket booster gimbaling. Such a feature is currently being developed for UPTOP.

Chapter 4 Thermal Protection System Optimization (TPSOPT) Program

The development of TPSOPT was supported by a two-year AFRL contract [4.1] with the goal of developing a automated design software for Thermal Protection System (TPS) optimization of hypersonic flight vehicles. Using a feasible direction optimization method, TPSOPT minimizes the weight of the TPS while subjected to the temperature constraints at each layer of the TPS. TPSOPT equip with a TPS material library that contains several hundreds of the thermal properties of various TPS from which the users can select to construct a multi-layer thermal protection system. It also has several built-in TPS structural arrangement concepts such as slab, radiation, gap, honeycomb, corrugated standoff, Z-standoff, ablator subliner, etc. to reduce the user's burden for input set-up.

In order to streamline TPSOPT with UCDA and UPTOP, several modifications are made to the original TPSOPT: (1) the surface mesh of the vehicle is automatically imported from UCDA; (2) the trajectory along which the heat flux at each surface mesh is computed is automatically imported from UPTOP; and (3) the aerothermodynamic methodology of the MINIVER code [4.2] is incorporated in TPSOPT to compute the heat flux on the surface mesh at each time step of the trajectory.

4.1 Optimization Strategy

Because the surface mesh defined by UCDA is divided by several patches as the one shown in Figure 4.1, TPSOPT optimizes the TPS on each patch individually. This is to say that on each patch, a TPS with the same type of structure but with varying thickness distribution of each layer can be specified. In order to ensure the smoothness of the optimized TPS thickness distribution over the patch, only some selected panels, called design panels, participated the optimization computation, while other panel's thicknesses are interpolated through the design panel's thicknesses. Polynomial interpolation is employed which serves as a set of shape functions over those selected panels. Thus, the design variables are the coefficients of those shape functions;

not the thickness of the TPS layers. This approach can largely reduce the number of design variables in the optimization problems and can ensure the smoothness of the thickness distribution of the TPS thickness.

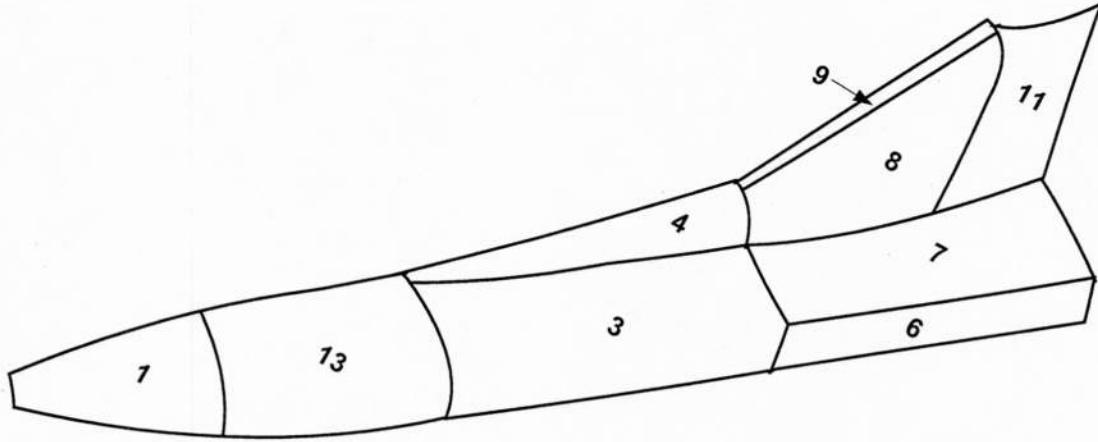


Figure 4.1 Patches of the surface Mesh for optimization

The panels within one patch are classified into three types of panels, as shown in Figure 4.2, namely the design variable patches (marked using ellipses), the hot panels (marked using diamonds), and the thickness panels (all panels). The thickness panels are subjected to the thickness constraints where the upper and lower limits of the thickness of each TPS layer are imposed. The hot panels are those panels on which the temperature distributions through the thickness of the TPS are computed and temperature constraints of each layer are imposed. Thus, the heat conduction computation is only performed for those hot panels to reduce the computational time. The design variable panels are a subset of the hot panels. They are used to define a set of shape functions to represent the thickness distribution of the TPS over the entire patch. Thus, the number of design variables becomes the coefficients of the shape functions, greatly reducing the unknowns of the optimization problem.

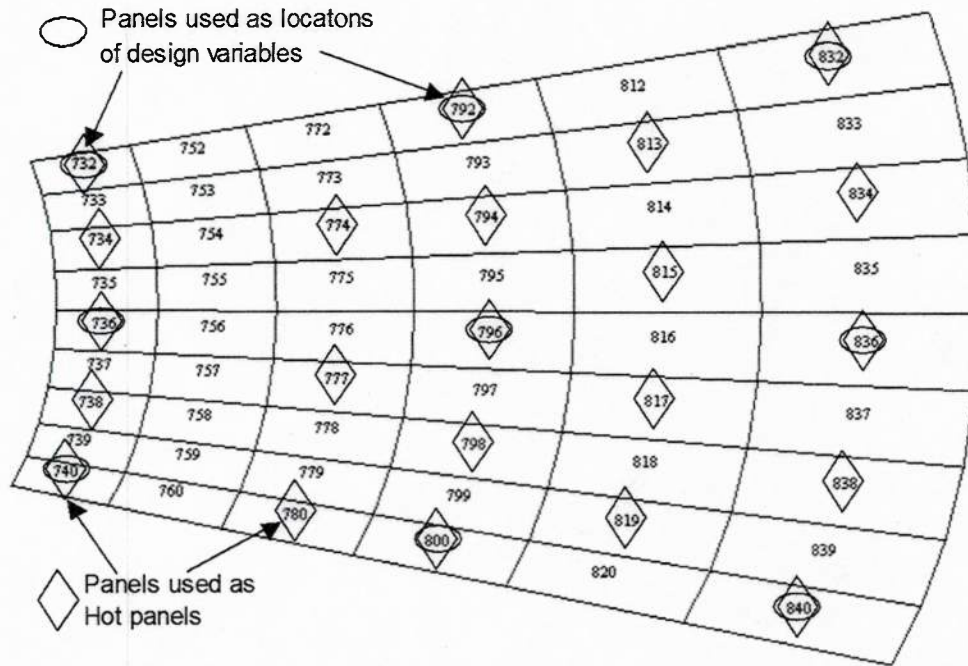


Figure 4.2 Different panels over a patch

4.2 Polynomial Approximation of Thickness

In order to reduce the number of design variables, rather than selecting the thickness of the TPS on all panels within a patch as the design variables, the thickness of each layer over the patch is expressed as a polynomial of coordinates as follows

Linear variation:
$$h = a_0 + a_1x + a_2y + a_3z \quad (4.1)$$

Quadratic variation:
$$h = a_0 + a_1x + a_2y + a_3z + a_4x^2 + a_5y^2 + a_6z^2 + a_7xy + a_8yz + a_9yz \quad (4.2)$$

It is not the thickness, h , over each panel to be taken as the design variables. Instead, the coefficients, a_i , are defined as design variables. Once these coefficients are determined, the thickness over each panel can be obtained by substituting the coordinates of each panel into

Equation (4.1) or (4.2). This strategy can result in a smooth variation of thickness over the patch and the number of design variables can be reduced significantly.

Although Equations (4.1) and (4.2) are easy to understand conceptually, the design variables, a_i , have no physical meaning and are not convenient to be numerically implemented. In order to overcome this disadvantage, shape functions used in the finite element method and in the boundary element method are adopted in TPSOPT.

4.3 Shape Functions for Interpolation of Thickness

Shape functions are defined over an “element” characterized by element nodes (Figure 4.3).

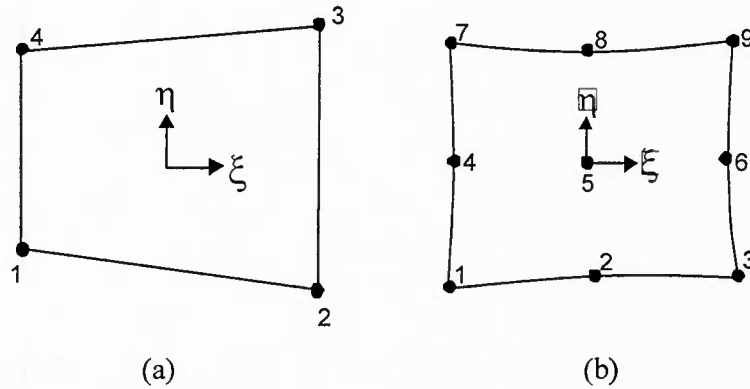


Figure 4.3 Quadrilateral elements: (a) linear, (b) quadratic

Over an element, the thickness h at point (ξ, η) can be expressed in terms of the nodal values of h [4.3] as:

$$h(\xi, \eta) = \sum_{\alpha=1}^M N_{\alpha}(\xi, \eta) h^{\alpha} \quad (4.3)$$

where ξ and η are curvilinear coordinates, usually normalized to a value in the range of -1 to $+1$, h^{α} is the thickness of the α -th node over the element under consideration and M is the number of nodes over the element. The shape function for linear variation can be expressed as:

$$\begin{aligned}
N_1(\xi, \eta) &= \frac{1}{4}(1 - \xi)(1 - \eta) \\
N_2(\xi, \eta) &= \frac{1}{4}(1 + \xi)(1 - \eta) \\
N_3(\xi, \eta) &= \frac{1}{4}(1 + \xi)(1 + \eta) \\
N_4(\xi, \eta) &= \frac{1}{4}(1 - \xi)(1 + \eta)
\end{aligned} \tag{4.4}$$

and for quadratic variation are:

$$\begin{aligned}
N_1(\xi, \eta) &= \frac{1}{4}\xi(1 - \xi)\eta(1 - \eta) \\
N_2(\xi, \eta) &= -\frac{1}{2}(1 - \xi^2)\eta(1 - \eta) \\
N_3(\xi, \eta) &= -\frac{1}{4}\xi(1 + \xi)\eta(1 - \eta) \\
N_4(\xi, \eta) &= -\frac{1}{2}\xi(1 - \xi)(1 - \eta^2) \\
N_5(\xi, \eta) &= (1 - \xi^2)(1 - \eta^2) \\
N_6(\xi, \eta) &= \frac{1}{2}\xi(1 + \xi)(1 - \eta^2) \\
N_7(\xi, \eta) &= -\frac{1}{4}\xi(1 - \xi)\eta(1 + \eta) \\
N_8(\xi, \eta) &= \frac{1}{2}(1 - \xi^2)\eta(1 + \eta) \\
N_9(\xi, \eta) &= \frac{1}{4}\xi(1 + \xi)\eta(1 + \eta)
\end{aligned} \tag{4.5}$$

Only linear and quadratic shape functions are given above. In the TPSOPT program, a shape function family with $n \times m$ nodes has been coded, in which n and m are the numbers of the nodes along the ξ and η direction, respectively.

The shape functions have an important feature [4.4] that is when the curvilinear coordinates (ξ, η) take nodal values, the shape function of that node is 1, while other shape functions are 0. This feature makes the h^α in Equation (4.3) to be the value of the thickness, h , at the α -th node. In the optimization computation, the nodal values h^α of the thickness are taken as design variables, while the thicknesses of the other panels are interpolated using Equation (4.3).

4.4 TPS Optimization Formulations

Figure 4.4 depicts a typical TPS design problem, which consists of n layers of different TPS materials. This design process can be automated by formulating an optimization problem to minimize the following objective function:

$$F = \sum_{l=1}^L \sum_{p=1}^P A_p \rho_p^l h_p^l \quad (4.6)$$

where

- A_p is the area of the panel p .
- ρ_p^l is the density of the panel p on layer l .
- h_p^l is the thickness of the panel p on layer l .
- L is the number of layers.
- P is the number of all panels over the patch.

The thickness h_p^l can be expressed with the thickness of element nodes by applying Equation (4.3) to each layer of the patch, as follows

$$h_p^l = \sum_{\alpha=1}^{M_l} N_\alpha^l(\xi_p, \eta_p) h^{\alpha l} \quad (4.7)$$

where

- $h^{\alpha l}$ is the thickness of node α on layer l .

$N_{\alpha}^l(\xi_p, \eta_p)$ is the value of shape function α on layer l for panel p .

ξ_p and η_p is the intrinsic coordinates of panel p .

M_l is the number of element nodes on layer l .

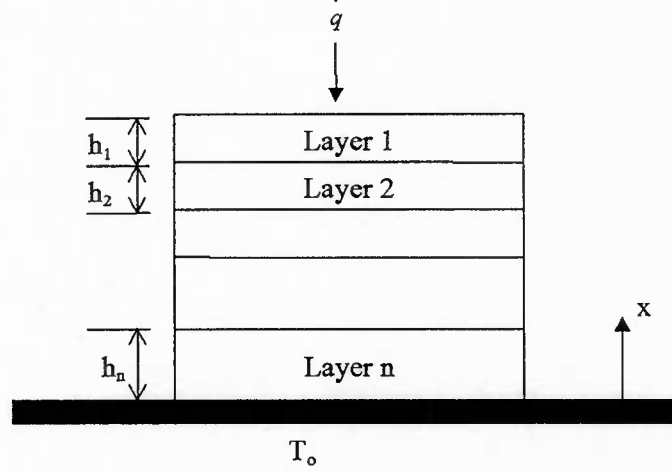


Figure 4.4 Typical TPS sizing problem

This optimization problem can be solved by linking a TPS analysis code such as the MINIVER/EXITS [4.5] module with an optimization driver like the usable/feasible direction method imbedded in ADS [4.6]. In this methodology, the nodal thickness, $h^{\alpha l}$, on each layer is taken as design variables which are related to the objective function by Equation (4.6). The optimization is performed by minimizing the objective function, F , shown in Equation (4.6) subjected to the following constraints.

Thickness constraints:

$$H_{\min}^l < h_p^l < H_{\max}^l \quad (4.8)$$

$$T_{nms}^{\beta} < T_{\max}^{\beta} \quad (4.9)$$

where

$H_{\min}^l$ and $H_{\max}^l$ is the allowable minimum and maximum thickness for layer l.

T_{nms}^β is the temperature of hot panel n on the side s for trajectory m at the heat point β .

$T_{\max}^\beta$ is the allowable maximum temperature of layer heat point β .

The temperature distribution through the thickness is computed by the thermal analysis software MINIVER/EXITS.

In computation, gradients of the objective function and the constraints are used to accelerate the iteration convergence. They can be easily obtained from Equations (4.6) and (4.7) as

$$\frac{\partial F}{\partial h^{cl}} = \sum_{p=1}^P A_p \rho_p^l N_\alpha^l(\xi_p, \eta_p) \quad (4.10)$$

$$\frac{\partial h_p^l}{\partial h^{cl}} = N_\alpha^l(\xi_p, \eta_p) \quad (4.11)$$

$$\frac{\partial T_{nms}^\beta}{\partial h^{cl}} = N_\alpha^l(\xi_n, \eta_n) \frac{\partial T_{nms}^\beta}{\partial h_n^l} \quad (4.12)$$

where ξ_n and η_n are intrinsic coordinates of the hot panel n and $\partial T_{nms}^\beta / \partial h_n^l$ is determined by running MINIVER/EXITS.

4.5 Determination of Intrinsic Coordinates for Panels

In the above equations, the intrinsic coordinates, (ξ_p, η_p) and (ξ_n, η_n) , for thickness panels and for hot panels are used. Since the shape function $N_\alpha(\xi, \eta)$ is a nonlinear function of the intrinsic coordinates ξ and η (see Equation (4.5)), an iteration process is employed to determine the intrinsic coordinates by given global coordinates of a panel [4.7].

For convenience here, we denote the complete set of intrinsic coordinates by the notation ξ_i , signifying the two intrinsic axes ξ and η on an element ($i=1-2$). With this notation, the global Cartesian coordinates at the center of the panel, p , can be expressed in terms of the nodal coordinates in the form:

$$x_j^p = \sum_{\alpha=1}^M N_\alpha(\xi_i) x_j^\alpha \quad (4.13)$$

where x_j^α are the coordinates of element nodes. First, we begin with some starting guess (ξ_i^0) of the intrinsic coordinates of the point p and we let r_j^0 be the resulting error of Equation (4.13). Now, the notation R_j^k, ξ_i^k is used to denote the values after the k -th iteration, that is:

$$R_j^k = \sum_{\alpha=1}^M N_\alpha(\xi_i^k) x_j^\alpha - x_j^p \quad (4.14)$$

To obtain improved values of ξ_i , we expand this equation using Taylor's theorem:

$$R_j^{k+1} = R_j^k + \frac{\partial R_j}{\partial \xi_i} \Delta \xi_i = R_j^k + \sum_{\alpha=1}^M \frac{\partial N_\alpha}{\partial \xi_i} x_j^\alpha \Delta \xi_i \quad (4.15)$$

where $\Delta \xi_i$ are the changes in ξ_i . Setting R_j^{k+1} equal to zero, we obtain (in matrix form), the Newton-Raphson iterative scheme:

$$[K^k]\{\Delta\xi\} = -\{R^k\} \quad (4.16)$$

where the coefficients of the matrix are:

$$[K_{ji}^k] = \sum_{\alpha=1}^M \frac{\partial N_{\alpha}}{\partial \xi_i} x_j^{\alpha} \quad (4.17)$$

Since there is one less intrinsic coordinate than global coordinate and hence Equation (4.16) is over-prescribed. The least-squares approximation will suffice, i.e.:

$$[K^k]^T [K^k] \{\Delta\xi\} = -[K^k]^T \{R^k\} \quad (4.18)$$

where the superscript T denotes the matrix transpose. Solving for $\{\Delta\xi\}$, the current values of ξ_i can be updated, thus:

$$\xi_i^{k+1} = \xi_i^k + \Delta\xi_i \quad (4.19)$$

These calculations (Equations 4.14 - 4.19) are iterated until satisfactory convergence (of R^k) is attained. Typically, three iterations are sufficient to attain sufficient convergence, given an initial guess at the element centroid.

4.6 Computation of Sensitivity Matrices Using Complex Variable Differentiation Technique

To perform an optimization computation using feasible direction method, it is required to compute the derivatives of the temperature with respect to the thickness. Many techniques, such as Finite Difference Method (FDM), Automatic Differentiation (ADIFOR), Symbolic Differentiation, or the Complex Variable Differentiation (CVD) technique, can be adopted and applied to the MINIVER/EXITS module to provide sensitivity. Among them, the CVD

technique is selected because by comparison it is a “numerically-exact” method and requires the least programming effort [4.8].

The Complex Variable Differentiation (CVD) technique was first originated by Lyness and Moler [4.9]. In the complex variable approach, the variable x of a real function $f(x)$ is replaced by a complex one, $x + i\Delta h$. For small Δh , $f(x + i\Delta h)$ can be expanded into a Taylor’s series as follows:

$$f(x + i\Delta h) = f(x) + i\Delta h \frac{d}{dx} f - \frac{\Delta h^2}{2} \frac{d^2}{dx^2} f - i \frac{\Delta h^3}{6} \frac{d^3}{dx^3} f + \frac{\Delta h^4}{24} \frac{d^4}{dx^4} f \dots \quad (4.20)$$

The first and second derivatives of the above equation can be expressed as:

$$\frac{df}{dx} = \frac{\text{Im}[f(x + i\Delta h)]}{\Delta h} + O(\Delta h^2) \quad (4.21)$$

$$\frac{d^2 f}{dx^2} = \frac{2[f(x) - \text{Re}(f(x + i\Delta h))]}{\Delta h^2} + O(\Delta h^2) \quad (4.22)$$

where the symbols “ Im ” and “ Re ” denote the imaginary and real parts, respectively. From Equations (4.20) and (4.21), it can be seen that the derivatives using the CVD approach only require function evaluations. This feature is very attractive particularly when the function is sufficiently complicated, in which case to obtain an analytic derivative is cumbersome and error-prone. Unlike the finite difference method, where the accuracy of the derivative depends on the step-size, Equation (4.21) shows that the first derivative does not involve differencing two functions followed by magnification of the subtraction error (because of the division by the step size Δh). In fact, no cancellation errors exists for the first derivative in the CVD technique, thus the first derivative is step-size independent. Note that the second derivative in Equation (4.22) is prone to cancellation errors (because of the subtraction of two close numbers), but is not used here.

Because CVD does not introduce cancellation (round off) error for the first derivative, the step-size, Δh , can be chosen as small as the machine zero, e.g., $\Delta h = 10^{-30}$. Hence, the truncation error due to Taylor's series of the order of $\Delta h^2 = 10^{-60}$ that approaches essentially a machine zero in a 32-bit computer. For first derivative, CVD does not seem to introduce any approximation in its numerical differentiation; rather it is a nearly "numerically-exact" differentiation technique.

To incorporate CVD into the MINIVER/EXTIS module for sensitivity is rather straightforward. One can simply declare all variables in the code as complex variable and introduce a small imaginary perturbation ($i\Delta h = i \times 10^{-30}$) in the design variable, h_i . Division of the imaginary part of the temperature time history in each layer by Δh yields the sensitivity.

4.7 Optimization Examples

To validate the accuracy of the sensitivity MINIVER/OPT, two examples are given in this section. The first one is concerned with a single panel sizing optimization which can clarify the design concept presented in this chapter. The second example is focused on the performance of the TPSOPT software in the overall vehicle design.

4.7.1 Example 1: Advanced Flexible Reusable Surface Insulation

We select the constructed prototypical TPS system using an AFRSI (Advanced Flexible Reusable Surface Insulation) module, Figure 4.5.

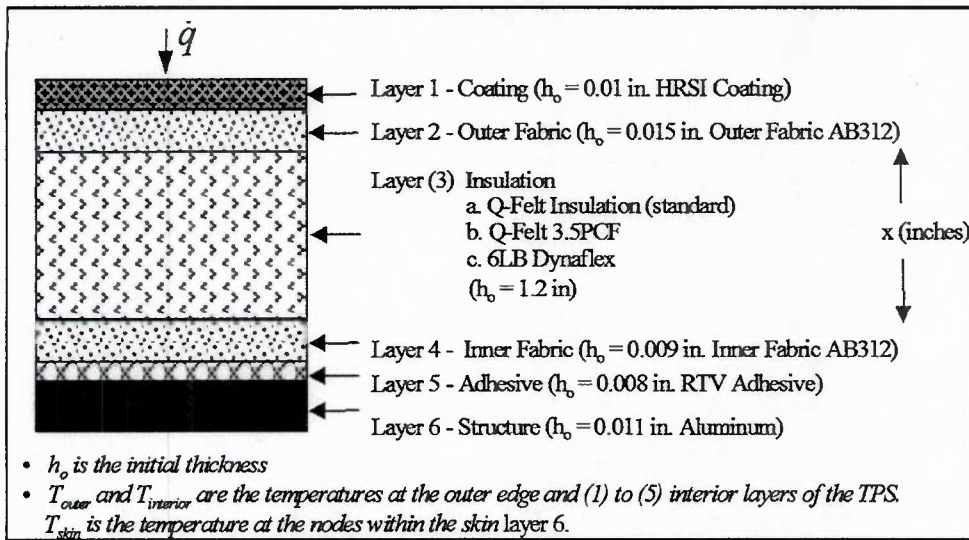


Figure 4.5 Description of the model TPS system

With the given heat/flux $\dot{q}$ at time history depicted in Figure 4.6, we focus on the temperature sensitivity of layer 6. The sensitivity $\partial T_6 / \partial h_3$, which precisely corresponds to the temperature change at the aluminum structure due to the thickness perturbation of the Q-Felt insulation material (layer No. 3), computed by TPSOPT is shown in Figure 4.7. The negative values of the sensitivity indicate a decrease of temperature due to the increase of thickness; as expected. Comparing to the results of CVD, the relative error of the sensitivity computed by FDM with various step sizes is depicted in Figure 4.8. It can be seen that the error of FDM decreases while the step size decreasing. But with a very small step size ($\Delta h = 10^{-8}$), the error increases, showing that the accuracy of FDM is step-size dependent.

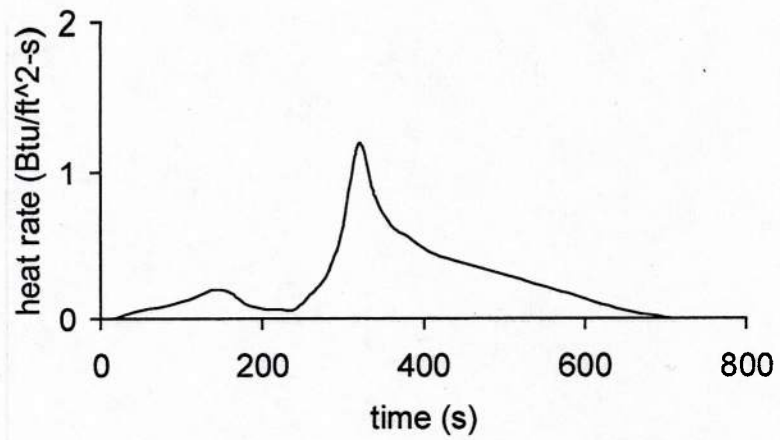


Figure 4.6 A given heat flux time history

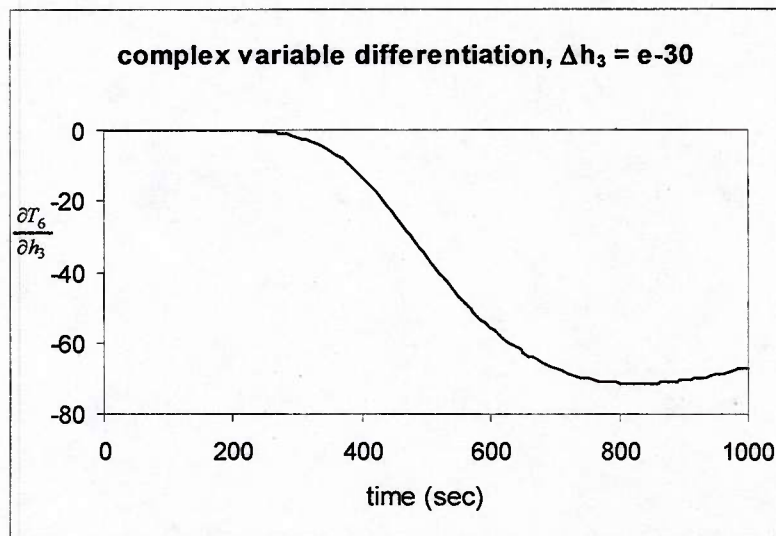


Figure 4.7 Sensitivity $\partial T_6 / \partial h_3$ by TPSOPT in the entire history

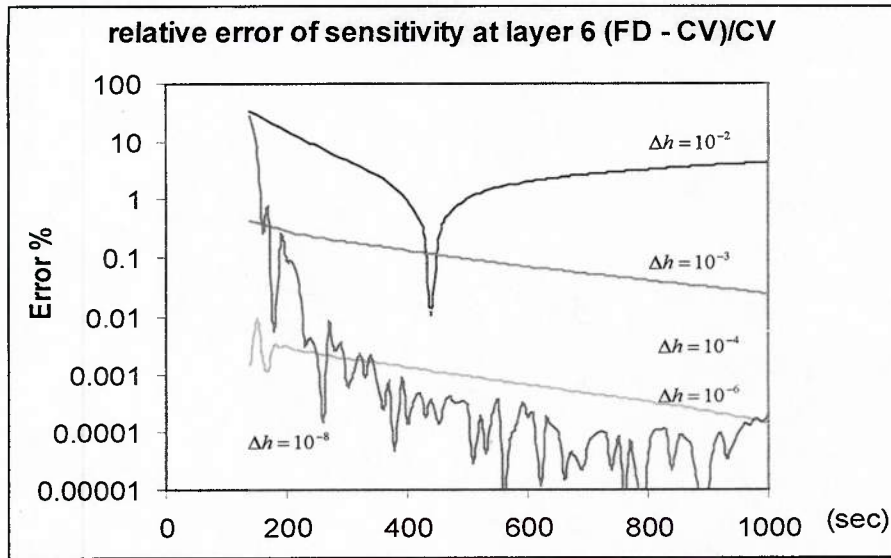


Figure 4.8 Relative error of FDM and CVD for sensitivity $\partial T_6 / \partial h_3$

Table 4.1 Case A optimization Results

Layer	Material and Temp limit (°F)	Density (lbm/ft ³)	Specific heat (But/lbm°F)	Initial thick-ness (in)	$T_{\max}$ in layer (°F)	Optimized thickness (in)
1	HRSI Coating 2300	104	0.20	0.01	705.2	0.0072
2	AB312 Fabric 2024	61.5	0.166	0.015	704.9	0.0072
3	Q-Felt 1800	3.5	0.1875	1.2	701.6	0.66849
4	AB312 Fabric 2024	61.5	0.166	0.009	300.0	0.0072
5	RTV-560 550	88	0.285	0.008	300.0	0.0072
6	Aluminum 300	173	0.22	0.011	300.0	0.011

- Layer Thickness: upper bound 1.0", lower bound 0.0072"
- Given Input heat flux $\dot{q}$, see Figure 4.6
- Optimized Weights $W_{\text{initial}} = 0.777 \text{ lbm/ft}^2$, $W_{\text{final}} = 0.543 \text{ lbm/ft}^2$

Shown in Table 4.1 are the optimization results of the AFRSI TPS system (Case A). In this optimization problem, the thicknesses of the first five layers are defined as design variables with

initial thickness and maximum operational temperature shown in Table 4.1. The upper bound and lower bound of these five design variables are assumed to be 1.0" and 0.0072", respectively. The thickness of the aluminum layer (layer 6) remains unchanged because it represents the load-carry structure and is not a part of the TPS system. It can be seen that all design variables reach the lower bound (0.0072") except the Q-Felt layer. This is expected because the Q-Felt layer has the lowest density and thermal conductivity that provides the highest thermal insulation capability with least structural weight.

Table 4.2 Case B Optimization Results

Layer	Material and Temp limit (°F)	Density (lbm/ft ³)	Specific heat (Btu/lbm°F)	Initial thick-ness (in)	$T_{\max}$ in layer (°F)	Optimized thickness (in)
1	HRSI Coating 2300	104	0.20	0.01	814.5	0.0072
2	AB312 Fabric 2024	61.5	0.166	0.015	814.3	0.0072
3	Q-Felt 1800	3.5	0.1875	1.2	810.0	0.6000
4	AB312 Fabric 2024	61.5	0.166	0.009	300.0	0.0072
5	RTV-560 550	88	0.285	0.008	300.0	0.02705
6	Aluminum 300	173	0.22	0.011	300.0	0.011

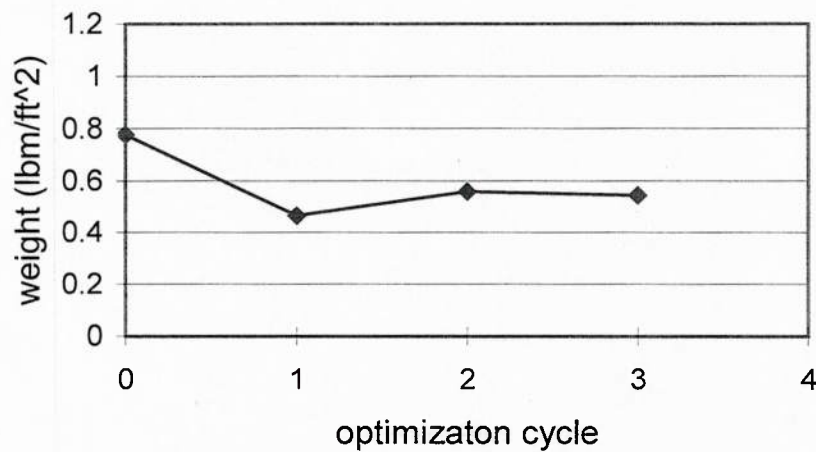
- Layer Thickness: upper bound 0.6", lower bound 0.0072"
- Given Input heat flux $1.5\dot{q}$, see Figure 4.6
- Optimized Weights $W_{\text{initial}} = 0.777 \text{ lbm/ft}^2$, $W_{\text{final}} = 0.668 \text{ lbm/ft}^2$

Table 4.2 presents the optimization results of the same AFRSI TPS system but with a magnified heat flux (by a factor of 1.5) and a reduced upper bound of layer thickness (Case B). The optimized result shows that the thickness of the Q-Felt layer reaches the upper bound and that of the RTV-560 layer become 0.02705" while the thickness of other layers remain at the lower bound. This indicates that because of the higher heat flux input, the Q-Felt layer with the upper bound thickness alone is not sufficient to satisfy the temperature constraints at all layers. Other than the Q-Felt layer, the next best thermal protection material is the RTV-560 layer because of

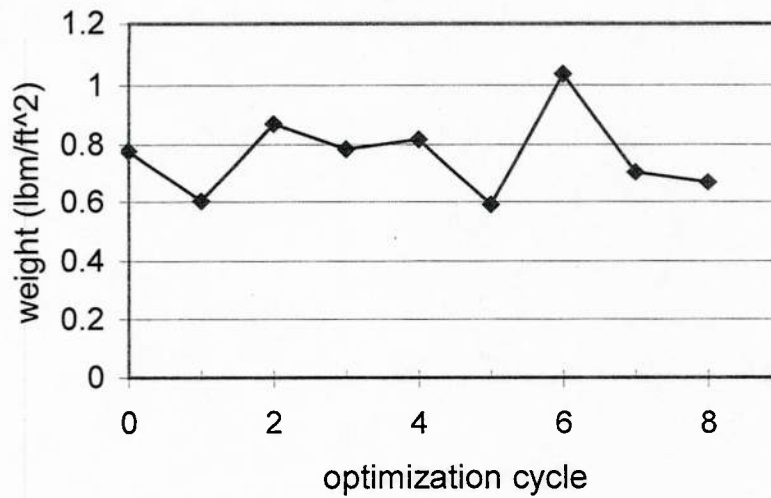
its high specific heat (c_p) value. Although, the RTV-560 layer has a high density ρ which may not be structurally efficient, however, its higher ρc_p value can offer a good thermal protection capability. Indeed, TPSOPT can detect this capability and thereby increase the thickness of the RTV-560 layer from the lower bound to 0.02705".

Figure 4.9 presents the weight variance versus design cycles during the optimization process. Note that in Case A the nominal heat-flux achieves optimized weight with 3 cycles in 4.5 minutes; whereas in Case B (with 1.5 times heat-flux) takes 8 design cycles in 6.5 minutes.

Figure 4.10 presents the time history of the temperature of Case B of the aluminum layer during its eight optimization design cycles. With the maximum operational temperature being 300°F of the aluminum as one of the design constraints, it can be seen that the initial thickness is over-designed because its maximum temperature is only approximately 230°F. Meanwhile, an intermediate design offers a minimum weight but its maximum temperature (400°F) violates the constraint. The maximum temperature of the final design is exactly 300°F, indicating that it is an optimum design.



(a) Case A with a given $\dot{q}$ (in 263 Sec)



(b) Case B with $1.5 \times \dot{q}$ (in 396 Sec)

Figure 4.9 Weight variation of the modeled TPS system (AFRSI) during optimization

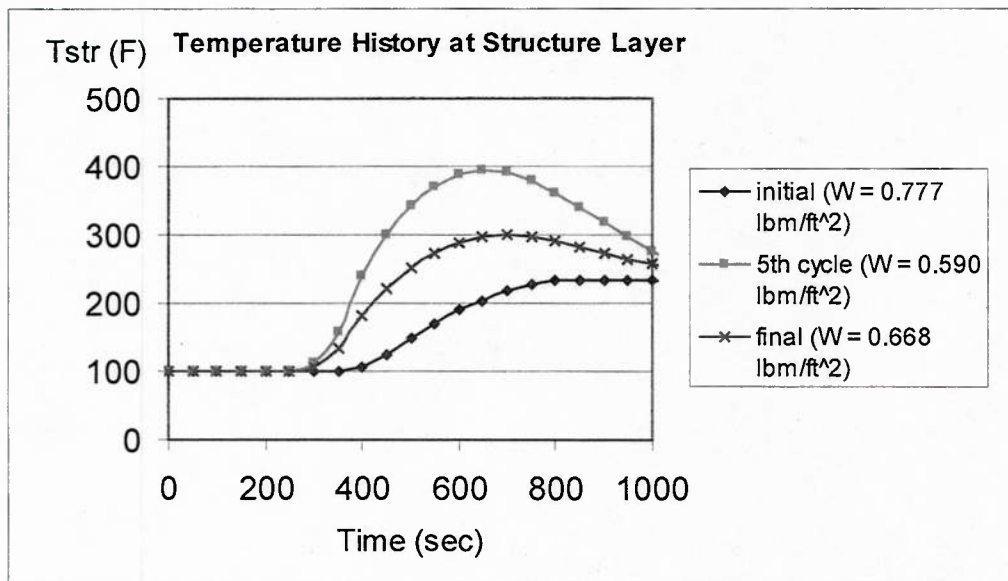


Figure 4.10 Case B temperature history at the structure layer (layer 6) during the optimization process

4.7.2 Example 2: TPS Design on the X-34

For the demonstration of the capability in handling complex configurations, TPSOPT is applied to the full configuration of the X-34 whose surface is divided into 14 patches as shown in Figure 4.1. Two types of TPS structural arrangement concepts are selected; one called TPS (A) for those patches located on the nose and leading edges and the other called TPS (B) for those patches on the fuselage and wing surfaces.

These structural arrangement concepts are shown in Figure 4.11. In Figure 4.12, it can be seen that the final optimization thickness of TPS on patches in the nose region (Patches 1 and 2) is about one order of magnitude thinner than its initial thickness. The optimized total TPS weight is found to be reduced by 22% terminated after the 20th design cycle while satisfying all TPS temperature constraints (Figure 4.13).

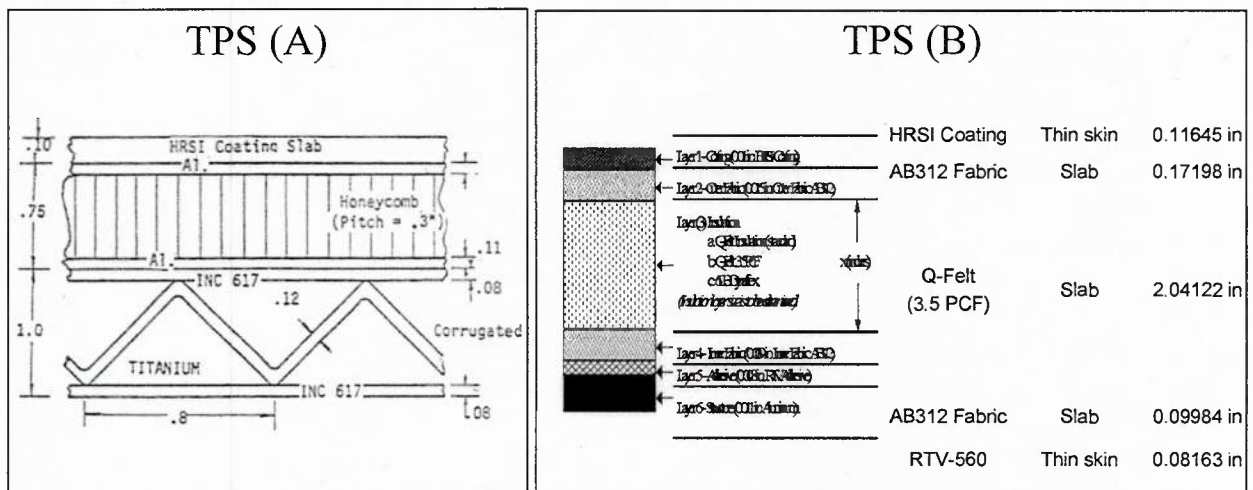


Figure 4.11 Two TPS structural arrangement concepts

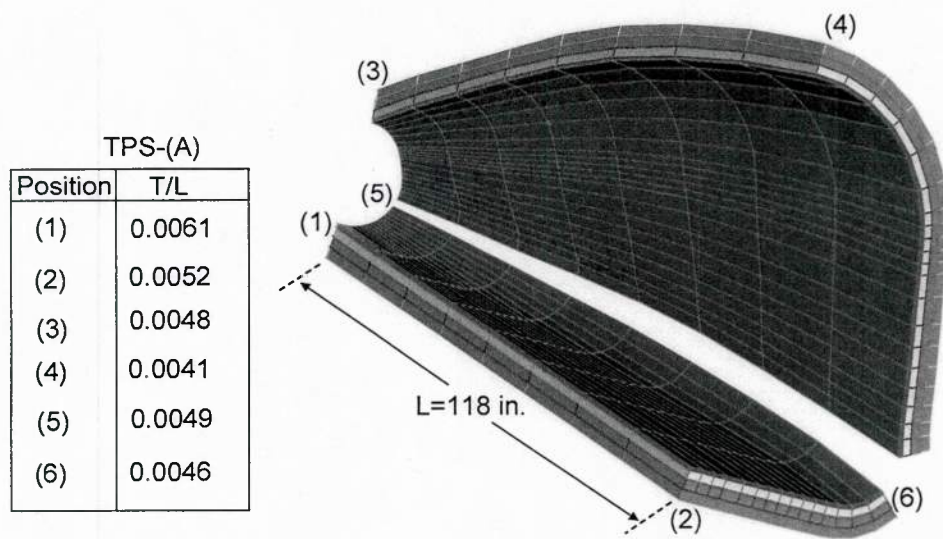


Figure 4.12 Optimal thickness for patches 1 and 2

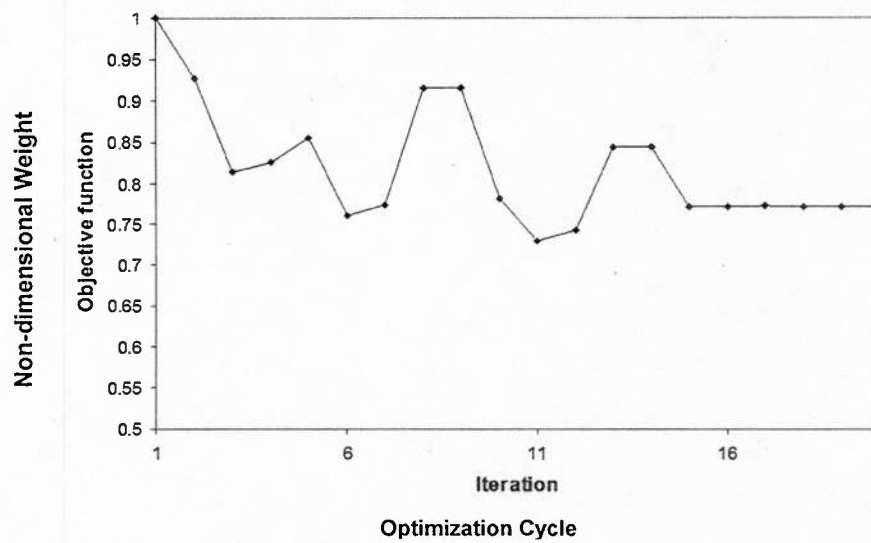


Figure 4.13 Iteration history of the objective function during optimization process

Chapter 5 Structural Modal Base (SMB) Program

The purpose of this Structural Modal Base (SMB) module is to minimize the weight of the structural skin while subjected to the stress constraints at each axial station along the vehicle using a fully stressed design (FSD) method. These stress constraints are evaluated by applying the aerodynamic loads computed based on the trajectory provided by UPTOP with an assigned load factor to simulate the worst loads condition. The optimized skin weight is used to update the total vehicle weight for the next design cycle. In addition, SMB computes the structural natural frequencies and their corresponding mode shapes that are used by the TRIM and ASE modules to include the structural flexibility effects in the analysis.

To this end, the structure is simplified to a simple beam structure with free-free support. The cross section of the beam at each axial station is assumed to be a rectangular box whose width and height are determined from the surface mesh provided by UCDA. The non-structural masses are obtained from the vehicle weight calculated by UCDA and distributed at each nodes along the beam. The design variables to be determined by the fully stressed design method are the skin thicknesses of the rectangular box at each axial station. This beam approximation of the structure is illustrated in Figure 5.1.

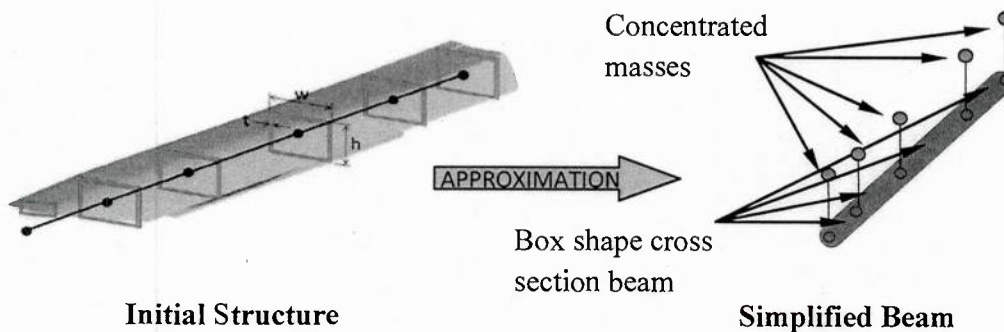


Figure 5.1 Beam approximation

Figure 5.2 shows the total program architecture of SMB. There are generally 8 steps involved in the SMB computation described as follows:

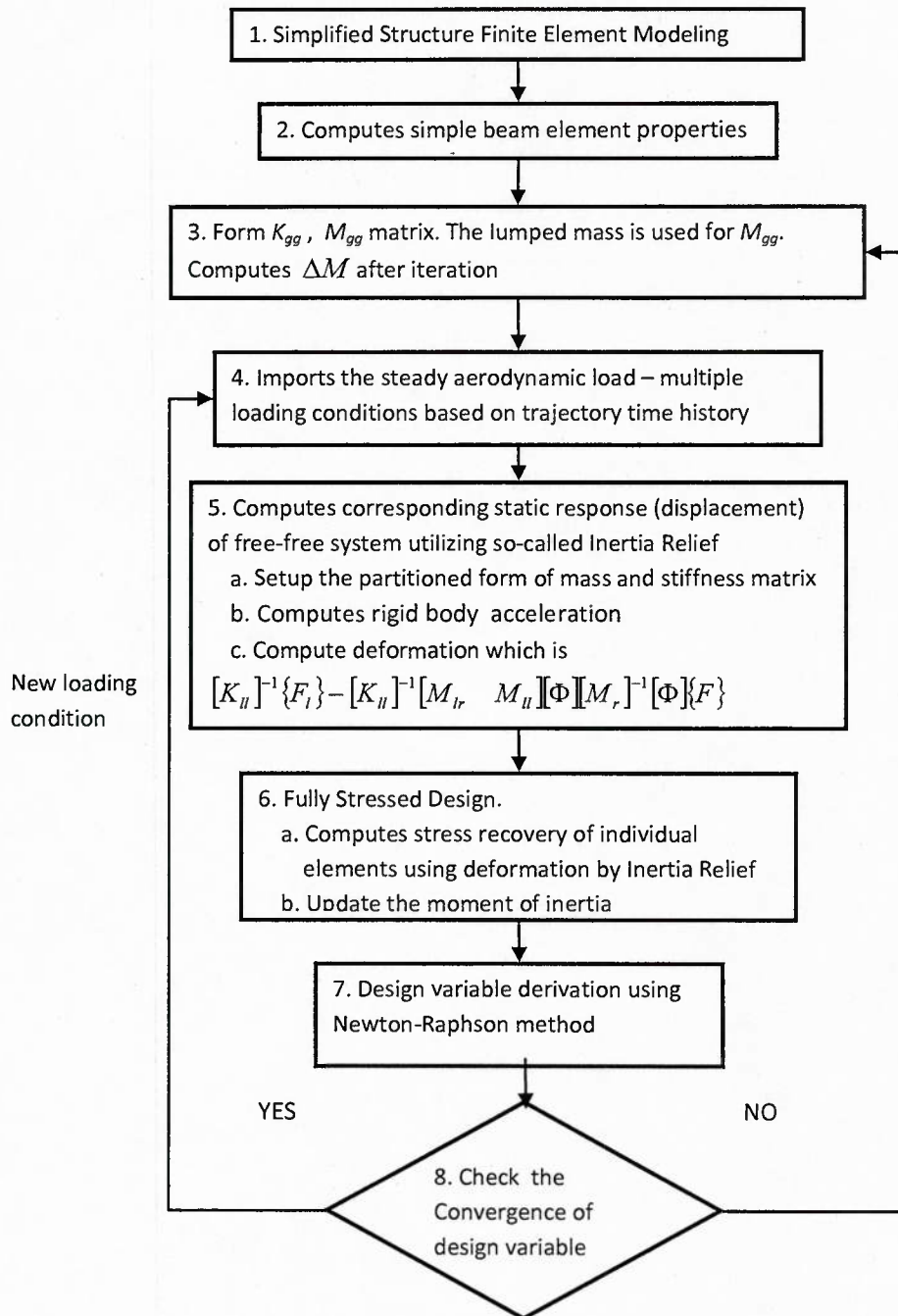


Figure 5.2 Flow chart of SMB module

(1) Finite element modeling

For the finite element modeling, the structure is discretized first where within each axial station of the discretized structure; the cross section is simplified to have an approximate and constant width, height and length. Having considered the proper meshing size for the convergence, those given section length are directly used for the beam finite element model meshing.

For the mass element matrix composition, whole structural and non-structural masses are lumped into one value and then it is divided in proportion to each element volume and distributed to each section.

(2) Beam property computation

Here, in the finite element modeling, the beam neutral axis matches the x axis. Consequently the area moments of inertia with respect to y and z axis are required. Based on the geometry information from the UCDA the beam properties are determined. All the beam properties are updated after the fully stressed design (FSD). Material property is considered homogeneous for whole structure.

(3) Element stiffness/mass matrix construction

Using those beam properties, the stiffness matrix is computed. The mass matrix is adjusted due to the addition/reduction of the thickness after FSD process, see Equation (5.1). The Euler beam theory is used for the stiffness matrix because of the unavailability of the area factor for shear in the FSD.

$$M_{new}^i = M_{init}^i + \left\{ (2 * t_{new}^i + w^i) * (2 * t_{new}^i + h^i) - (2 * t_{init}^i + w^i) * (2 * t_{init}^i + h^i) \right\} * l^i * \rho \quad (5.1)$$

M_{new}^i is the updated mass for the i^{th} element

M_{init}^i is the lumped initial mass

t_{new}^i is the new design variable of i^{th} element

h^i is the height

w^i is the width
 l^i is the length
 ρ is the structure material density

(4) Load import

Initially the aerodynamic load is distributed on the surface but here those are converted and given as equivalent concentrated loads at nodes. The designed thickness must satisfy the stress constraints under all the loading conditions along the trajectory given by UPTOP with an assigned load factor to simulate the worst loading conditions. In order to do so, except the first loading condition, at each load condition the thickness of the box at each axial station is only allowed to increase; thus avoiding the possible violation of the stress constraint.

(5) Response computation – Inertia Relief

Structure has the free-free boundary condition to simulate the free flight condition. This implies that without considering the inertia force by those rigid body motions, the stiffness matrix of the beam finite element model is singular. This singularity in the stiffness matrix can be removed by using the inertia relief approach. The first grid point is used as the support point in this inertia relief approach.

(6) Fully stressed design algorithm

The cross section of each beam element is assumed to be constant. Thus, the number of the total design variables is the same as the element number in this structure finite element model. Those design variables are updated by the stress ratio in the FSD algorithm. Because of the compatibility, the design variable could not reach the value satisfying the requirement without iteration. The updated design variable is compared with the minimum requirement. If it is less than the requirement, the minimum requirement is substituted for the optimized value.

(7) Design variable derivation from the moment of inertia

The relationship between the thickness of the box shape cross section and the area moment of inertia is a 3rd order polynomial. To compute the skin thickness from the moment of inertia requires an iterative search algorithm. Here, a Newton-Raphson method is used.

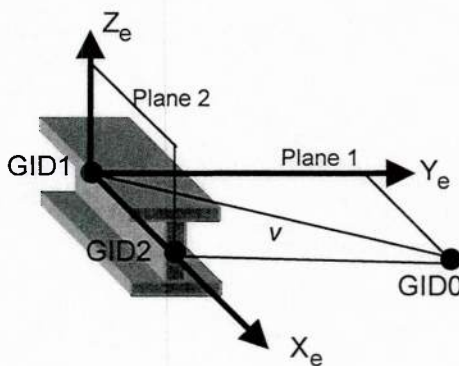
(8) Check the convergence

The difference between the updated value and previous design variable value is computed to check the convergence by a small tolerance. If it is not converged, the whole process of analysis and FSD are all repeated until the change of each design variable between two consecutive iterations is within such a tolerance.

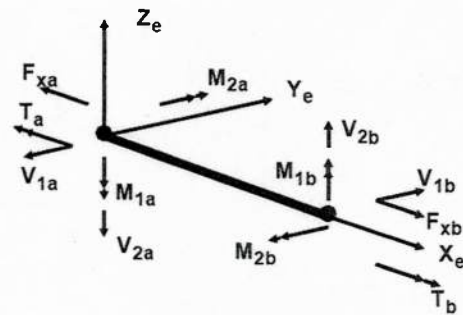
In summary, the whole routine is mainly composed of 'finite element modeling', 'Inertia Relief computation', and 'Fully-Stressed Design algorithm'. Those processes are explained in detail in the following.

5.1 Finite Element Modeling

The finite element model shown in Figure 5.3 is a beam model along a straight line. It includes extension, torsion and bending in two perpendicular planes with associated transverse shear properties and may carry bending, shear, axial, torsional loadings. The shear center is assumed to coincide with the neutral axis [5.1].



a. Element Coordinate System



b. Element Force and Sign Convention

Figure 5.3 Beam element

The beam element has the following modeling features and limitations

- a. The area properties are constant. Therefore, it can not represent the tapered element.
- b. Stress can be recovered at four points on the cross section on each end. Those points are determined by the width, height, and thickness.

As Figure 5.3a indicates that six degrees of freedom are present at each node and each element has 12 degrees of freedom resulting in a 12 x 12 elements stiffness matrix. Two reference planes are defined by the orientation vector v which can be drawn from GID1 to GID0. GID0 is at (1, 1, 0) in the element coordinate system. The first reference plane 1 is defined by the x-axis and vector v . The element coordinate system coincides with the global coordinate system. The beam neutral axis is assumed to be on the x-axis.

The internal forces in beam elements are: the bending moments at each end for each reference plane, M_{1a} , M_{1b} , M_{2a} , and M_{2b} ; the shear forces, V_{1a} , V_{2a} , V_{1b} , and V_{2b} ; the average axial force, F_{xa} , F_{xb} ; and the torque, T_a , T_b . These forces and their sign conventions are illustrated in Figure 5.3b.

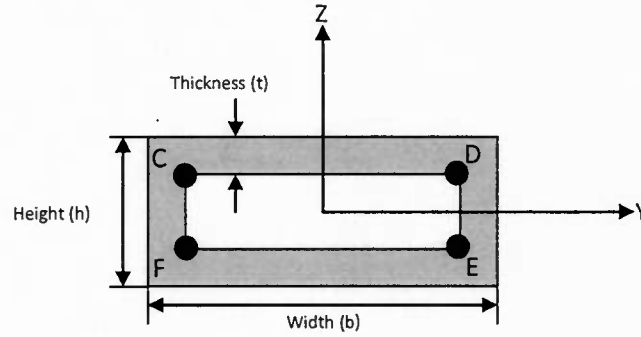
When using a single design variable for the bar element such as the thickness, there is a fixed relationship between the design variable (thickness, t) and moments of inertia of the element.

$$\begin{aligned}
 I_1 &= \frac{(h_i + 2t) \cdot (b_i + 2t)^3}{12} - \frac{h_i b_i^3}{12} \\
 I_2 &= \frac{(b_i + 2t) \cdot (h_i + 2t)^3}{12} - \frac{b_i h_i^3}{12} \\
 I_3 (= J) &= \frac{2t^2 (b_i + t)^2 (h_i + t)^2}{b_i t + h_i t + 2t^2}
 \end{aligned} \tag{5.2}$$

Implementation of the relationships dictates that the total element stiffness matrix is made up of a term that is linear in the cross sectional area and a second term that is linear in the moment of inertia and polar moment of inertia:

$$K_e = A \cdot K_e^E + I \cdot K_e^R \quad (5.3)$$

where the E and R superscripts refer to extensional (axial) and rotational (bending and torsional) stiffness terms, respectively.



$b = b_i + 2t$	$I_2 = \frac{bh^3}{12} - \frac{b_i h_i^3}{12}$	A is the area of bar cross section
		J is the torsional constant
$h = h_i + 2t$	$J = \frac{2t^2(b-t)^2(h-t)^2}{bt + ht - 2t^2}$	I_1 is the area moment of inertia for the bending about Z axis
$A = bh - b_i h_i$	$K_1 = \frac{h_i t}{A} \cdot 2$	I_2 is the area moment of inertia for the bending about Y axis
$I_1 = \frac{hb^3}{12} - \frac{h_i b_i^3}{12}$	$K_2 = \frac{b_i t}{A} \cdot 2$	K_1 is the area factor for shear
		K_2 is the area factor for shear

Figure 5.4 Beam element cross section and property computation

Figure 5.4 shows beam properties for the finite element model of the beam. Considering the shear deformation, the total transverse deflection is

$$w = w_b + w_s$$

$$\frac{dw_s}{dx} = -\frac{V}{GA_s} \quad (5.4)$$

Where G is shear modulus and A_s is the beam cross sectional area effective in shear. The w_b and w_s are transverse deflections due to bending and shear load respectively. This beam is called Timoshenko beam. The element stiffness matrix is derived as following [5.1].

$$K_{12 \times 12} = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix}_{12 \times 12} \quad (5.5)$$

$$K_{11} = K_{22} = \begin{bmatrix} \frac{EA}{L} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{12EI_z}{L^3\alpha_y} & 0 & 0 & 0 & \frac{6EI_z}{L^2\alpha_y} \\ 0 & 0 & \frac{12EI_y}{L^3\alpha_z} & 0 & -\frac{6EI_y}{L^2\alpha_z} & 0 \\ 0 & 0 & 0 & \frac{GJ}{L} & 0 & 0 \\ 0 & 0 & -\frac{6EI_y}{L^2\alpha_z} & 0 & \frac{\beta_z EI_y}{L\alpha_z} & 0 \\ 0 & \frac{6EI_z}{L^2\alpha_y} & 0 & 0 & 0 & \frac{\beta_z EI_z}{L\alpha_y} \end{bmatrix} \quad (5.6)$$

$$K_{12} = K_{21}^T = \begin{bmatrix} -\frac{EA}{L} & 0 & 0 & 0 & 0 & 0 \\ 0 & -\frac{12EI_z}{L^3\alpha_y} & 0 & 0 & 0 & -\frac{6EI_z}{L^2\alpha_y} \\ 0 & 0 & -\frac{12EI_y}{L^3\alpha_z} & 0 & \frac{6EI_y}{L^2\alpha_z} & 0 \\ 0 & 0 & 0 & -\frac{GJ}{L} & 0 & 0 \\ 0 & 0 & -\frac{6EI_y}{L^2\alpha_z} & 0 & \frac{\gamma_z EI_y}{L\alpha_z} & 0 \\ 0 & \frac{6EI_z}{L^2\alpha_y} & 0 & 0 & 0 & \frac{\gamma_z EI_z}{L\alpha_y} \end{bmatrix} \quad (5.7)$$

where $\alpha_y = (1 + \Phi_y)$, $\alpha_z = (1 + \Phi_z)$, $\beta_y = (4 + \Phi_y)$, $\beta_z = (4 + \Phi_z)$

$$\Phi_y = \frac{12EI_z}{GA_{s_y}L^2}, \Phi_z = \frac{12EI_y}{GA_{s_z}L^2}, \gamma_y = (2 - \Phi_y), \gamma_z = (2 - \Phi_z)$$

For the FSD process, the area factor for shear cannot be considered because if the shear stress is taken into account the nonlinearity of the stiffness matrix with respect to the moment of inertia is brought up. In the FSD, the stress ratio is assumed to be proportional to the ratio of the moment of inertia. The shear deformation, thus, is neglected. Therefore the Timoshenko beam is not used here. If the shear deformation is not considered, the beam is referred to as Euler beam and the element stiffness matrix is computed as follows.

$$K_{12 \times 12} = \begin{bmatrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{bmatrix}_{12 \times 12} \quad (5.8)$$

$$K_{11} = K_{22} = \begin{bmatrix} \frac{EA}{L} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{12EI_z}{L^3} & 0 & 0 & 0 & \frac{6EI_z}{L^2} \\ 0 & 0 & \frac{12EI_y}{L^3} & 0 & -\frac{6EI_y}{L^2} & 0 \\ 0 & 0 & 0 & \frac{GJ}{L} & 0 & 0 \\ 0 & 0 & -\frac{6EI_y}{L^2} & 0 & \frac{4EI_y}{L} & 0 \\ 0 & \frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{4EI_z}{L} \end{bmatrix} \quad (5.9)$$

$$K_{12} = K_{21}^T = \begin{bmatrix} -\frac{EA}{L} & 0 & 0 & 0 & 0 & 0 \\ 0 & -\frac{12EI_z}{L^3} & 0 & 0 & 0 & -\frac{6EI_z}{L^2} \\ 0 & 0 & -\frac{12EI_y}{L^3} & 0 & \frac{6EI_y}{L^2} & 0 \\ 0 & 0 & 0 & -\frac{GJ}{L} & 0 & 0 \\ 0 & 0 & -\frac{6EI_y}{L^2} & 0 & \frac{2EI_y}{L} & 0 \\ 0 & \frac{6EI_z}{L^2} & 0 & 0 & 0 & \frac{2EI_z}{L} \end{bmatrix} \quad (5.10)$$

The mass matrix is composed with the given lumped mass which includes all the structural and non-structural masses of the whole aircraft. It is not a consistent mass matrix so that there are not off-diagonal terms. The rotary inertia is neglected as a result of simplification by lumping those non/structural masses. The following matrix is used for the element mass matrix.

$$M_{12 \times 12} = \begin{bmatrix} M_{11} & 0 \\ 0 & M_{22} \end{bmatrix}_{12 \times 12}$$

$$M_{11_{6 \times 6}} = \begin{bmatrix} M_{init}^i + \Delta M & 0 & 0 & 0 & 0 & 0 \\ 0 & M_{init}^i + \Delta M & 0 & 0 & 0 & 0 \\ 0 & 0 & M_{init}^i + \Delta M & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (5.11)$$

$$M_{22_{6 \times 6}} = \begin{bmatrix} M_{init}^{i+1} + \Delta M & 0 & 0 & 0 & 0 & 0 \\ 0 & M_{init}^{i+1} + \Delta M & 0 & 0 & 0 & 0 \\ 0 & 0 & M_{init}^{i+1} + \Delta M & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\Delta M = 0.5 \cdot \{(2 \cdot t_{new}^i + w^i) \cdot (2 \cdot t_{new}^i + h^i) - (2 \cdot t_{init}^i + w^i) \cdot (2 \cdot t_{init}^i + h^i)\} \cdot l^i \cdot \rho \quad (5.12)$$

ΔM is the mass adjustment

M_{init}^i is the lumped initial mass

t_{new}^i is the new design variable of i^{th} element

h^i is the height

w^i is the width

l^i is the length

ρ Is the structure material density

ΔM is computed after FSD. FSD computes the optimal thickness which is resulting in the change of the mass. This computation is repeating until convergence.

5.2 Fully Stressed Design (FSD) Algorithm

While FSD methods are, by definition, severely limited in scope, this method is chosen because of the rapidity in achieving a feasible strength design. The implementation of FSD recognizes the inherent limitations of this method, so the FSD is intended to be used as a preliminary step to achieve a feasible or near optimal strength design. It is, of course, useful for problems in which only stress constraints for static disciplines are applied.

The FSD resizing is for problems where static strength constraints play an important role in determining the structural sizes and the FSD can find a reasonable initial design very quickly. Therefore, while the FSD method itself can treat only the static stress constraints, the FSD may be used in almost any optimization problem where stress constraints are applied. Since the determination of an initial design is the typical purpose for FSD, the algorithm has been implemented in such a way that the user selects some number of initial design cycles to be performed using FSD.

In the implementation of the FSD resizing concept, the new local design variable (which represents the physical property of one finite element; e.g., the area of cross section) is found based on the ratio of stress to the allowable stress [5.2]:

$$t_{i_{new}} = \max \left[\left(\frac{\sigma}{\sigma_{allowable}} \right)_i^\alpha, t_{i_{old}}, t_{i_{min}} \right] \quad (5.13)$$

The stress ratio is determined from the applied maximum stress and safety factor constraints. The only difficulty in performing this operation is in the bookkeeping to determine which stress constraint corresponds to a particular local design variable. More important is the treatment of stress constraints applied to un-designed elements for which there is no corresponding local variable. Since the implementation of this method is intended to be approximate, it is decided to ignore these stress constraints in the computation of the new local design variable vector. This is consistent with the fact that all the other constraint types are also ignored.

To offer an improved convergence behavior for this FSD algorithm, the exponential factor, α , has been provided in Equation (5.13). Small values of α result in the better convergence at the expense of additional iterations. The value of this parameter is user selectable in the alpha field in BEAMFSD card, but defaults to 0.90. This value was chosen for its rapid movement toward a fully stressed design in the initial iterations. If FSD is intended to be used to achieve a final converged solution, a value of 0.50 or less is preferred. In this module, the design variable is not directly updated in the FSD module but rather the moment of inertia is updated as the Equation (5.14).

$$I_i = \max \left[\left(\frac{\sigma_i}{\sigma_{allowable}} \right)^\alpha I_{i-1}, I_{\min} \right] \quad (5.14)$$

Where it assumed to be converged if $|I_i - I_{i-1}| < chkcon1$ and it iterates until the convergence. $I_{\min}$ is computed from the minimum design variable value. The $chkcon1$ is given by the user inputs in the BEAMFSD card. If the structure is statically deterministic one iteration of analysis and $\alpha = 1$ are enough condition to get the final design. However the statically in deterministic system requires iterations because of the compatibility. The design variable is updated in the current element by FSD algorithm and then the whole structure's response is changed due to the variation of the design variable. This makes the different stress in the adjacent elements. However the stress value for the adjacent elements under consideration is from the structure before updating the design variable of the element. Therefore it needs iteration until convergence.

In addition, the converged values in each loading condition are compared and the maximum values are chosen to get the final design. This algorithm is shown as Equation (5.15).

$$I_i^j = \max_{k=1, NLC} \left(\max \left[I_{i-1}^j \frac{\sigma_{j,k}}{\sigma_{allowable}}, I_{\min} \right] \right) \quad (5.15)$$

Where I is moment of inertia, superscript j is element number, subscript i is iteration number, k is loading condition, NLC is number of loading condition, $\sigma_{j,k}$ is current element's stress under k^{th} loading condition, and $\sigma_{allowable}$ is allowable stress.

5.3 Inertia Relief

After removing the depending degree of freedoms (DOF) in multi-point constraints (MPC), one can get the n-set DOF. Then the single point constraints (SPC) are eliminated from n-set and the f-set DOF is given. After taking account of the DOF for Guyan reduction, finally the a-set DOF is available. This a-set DOF can be separated into the r and l -sets of DOF and the corresponding equation of motion can be expressed as follows.

$$\begin{bmatrix} M_{rr} & M_{rl} \\ M_{lr} & M_{ll} \end{bmatrix} \begin{Bmatrix} \ddot{u}_r \\ \ddot{u}_l \end{Bmatrix} + \begin{bmatrix} K_{rr} & K_{rl} \\ K_{lr} & K_{ll} \end{bmatrix} \begin{Bmatrix} u_r \\ u_l \end{Bmatrix} = \begin{Bmatrix} F_r \\ F_l \end{Bmatrix} \quad (5.16)$$

The r -set is given by the 6 degree of freedoms from the supported grid point. The given structure under consideration is the free-free supported and there are not either MPC or SPC. The Guyan reduction is not used either so that g -set is same as the a -set in this SMB module. Using rigid-body transformation (Craig-Bampton 1965 [5.3]),

$$\begin{Bmatrix} \ddot{u}_r \\ \ddot{u}_l \end{Bmatrix} = \begin{bmatrix} I_{rr} \\ -K_{ll}^{-1}K_{lr} \end{bmatrix} \{\ddot{u}_r\} = [\Phi] \{\ddot{u}_r\} \quad (5.17)$$

$$\begin{bmatrix} I_{rr} \\ -K_{ll}^{-1}K_{lr} \end{bmatrix} = [\Phi]$$

Multiplying both sides in Equation (5.16) by $[\Phi]$.

$$\{0\} = [\Phi]^T \{F\} - [\Phi]^T [M] [\Phi] \{\ddot{u}_r\} \quad (5.18)$$

Thus, $\{\ddot{u}_r\}$ is derived from Equation (5.18).

$$\{\ddot{u}_r\} = [\Phi]^T [M] [\Phi]]^{-1} \cdot [\Phi]^T \cdot \{F\} \quad (5.19)$$

The acceleration vector can be substituted by the Equation (5.19) and then the Equation (5.16) can be rewritten.

$$\begin{bmatrix} K_{rr} & K_{rl} \\ K_{lr} & K_{ll} \end{bmatrix} \begin{Bmatrix} u_r \\ u_l \end{Bmatrix} = \begin{Bmatrix} F_r \\ F_l \end{Bmatrix} - \begin{bmatrix} M_{rr} & M_{rl} \\ M_{lr} & M_{ll} \end{bmatrix} [\Phi] \{\ddot{u}_r\} \quad (5.20)$$

The $\{u_r\}$ can be equal to $\{0\}$ and the Equation (5.19) can be substituted for the $\{\ddot{u}_r\}$ in Equation (5.20) [5.4].

$$[K_{ll}] \{u_l\} = \{F_l\} - [M_{lr} \quad M_{ll} \Phi] [\Phi]^T [M] [\Phi]]^{-1} [\Phi] \{F\} \quad (5.21)$$

Thus, the elastic deformation due to the rigid body acceleration is

$$\{u_l\} = [K_{ll}]^{-1} \{F_l\} - [K_{ll}]^{-1} [M_{lr} \quad M_{ll} \Phi] [\Phi]^T [M] [\Phi]]^{-1} [\Phi] \{F\} \quad (5.22)$$

Where the $[M_r]$ equal to $[\Phi]^T [M] [\Phi]$.

The derived deformed shapes are used to get the stress computation. In this module the supporting point is the first grid point which is (0, 0, 0) in the basic coordinate system.

Chapter 6 Trim Module

The objective of the Trim module is to compute the trim solution with structural flexibility effects and the structural deformation by solving a two-degree nonlinear longitudinal trim problem. This trim problem involves two trim variables, namely, the angle of attack (α) and the control surface deflection angle (δ) whose solutions satisfy the lift-equal-weight and zero-pitch-moment trim conditions. The nonlinearity of the trim problem arises from the fact that the aerodynamics of the hypersonic flight vehicle is nonlinear with respect to the angle of attack and control surface deflection. To solve such a nonlinear trim problem requires a search algorithm that iterates on a linearized two-degree trim equation. This two-degree trim equation involves the linearized aerodynamic stability derivatives as well as the aerodynamic derivatives due to structural deformation at each trim iteration. These aerodynamic derivatives are obtained by applying the Complex Variable Differentiation (CVD) technique to UCDA.

6.1 Generation of Aerodynamic Derivatives by Applying CVD to UCDA

As already discussed in Section 4.6, the CVD technique is a numerically exact differentiation technique and is easy to be implemented. To apply the CVD technique to UCDA is very straightforward, simply converting all real variables in the code to complex variables. However, there are several intrinsic functions such as ATAN, ASIN, and ACOS whose complex counterparts do not exist in the standard FORTRAN. The mathematical expressions of those intrinsic functions are available. However, it is found that directly coding these mathematical expressions into a FORTRAN program leads to incorrect results due to the numerical truncation error if the imaginary part of the input complex value is very small. For instance, the complex version of ATAN is:

$$\text{CATAN}(x+iy) = \frac{1}{2} \text{ATAN}(2x, 1-x^2-y^2) + i \left(\frac{1}{4} \log(a_1) - \frac{1}{4} \log(a_2) \right) \quad (6.1)$$

$$\text{where } a_1 = x^2 + y^2 + 2y + 1.0$$

$$a_2 = x^2 + y^2 - 2y + 1.0$$

For a very small y , for example $y = 10^{-30}$, the imaginary part of Equation (6.1) becomes computational zero which is obviously incorrect. This is because in the 32-bit computer the function $\log(a_1) - \log(a_2)$ is below machine zero even using double precision computations. To circumvent this problem, we have derived a special case for the complex version of ATAN for very small y . This is done by simply taking the Taylor's expansion of $\text{ATAN}(x + iy)$ for small y which gives,

$$\text{CATAN}(x + iy) = \text{ATAN}(x) + i \frac{y}{(1 + x^2)} \quad (6.2)$$

Since $y \approx 10^{-30}$, the truncation error due to the higher order terms is 10^{-60} which is below machine zero. Thus, Equation (6.2) provides a numerically exact result of the complex function ATAN.

Similar Taylor's expansion can be applied to other intrinsic functions such as ASIN and ACOS.

Typical aerodynamic stability derivatives obtained from the complex version of UCDA are shown in Figures 6.1, 6.2 and 6.3. Figures 6.1 through 6.3 compare the aerodynamic stability derivatives of axial force, lift force and pitching moment respectively with respect to angle of attack, control surface deflection, Mach number and altitude for SEM at a given mean flow condition. Clearly, CVD compares well with Finite Difference (FD) for at least one choice of step size used by FD. This goes to show that for a highly nonlinear flow as prevalent in hypersonic aerodynamics, CVD is a good choice of finding the right derivative because different choices of the difference parameters for independent variables can lead to different derivatives, making FD a non reliable method of evaluating derivatives.

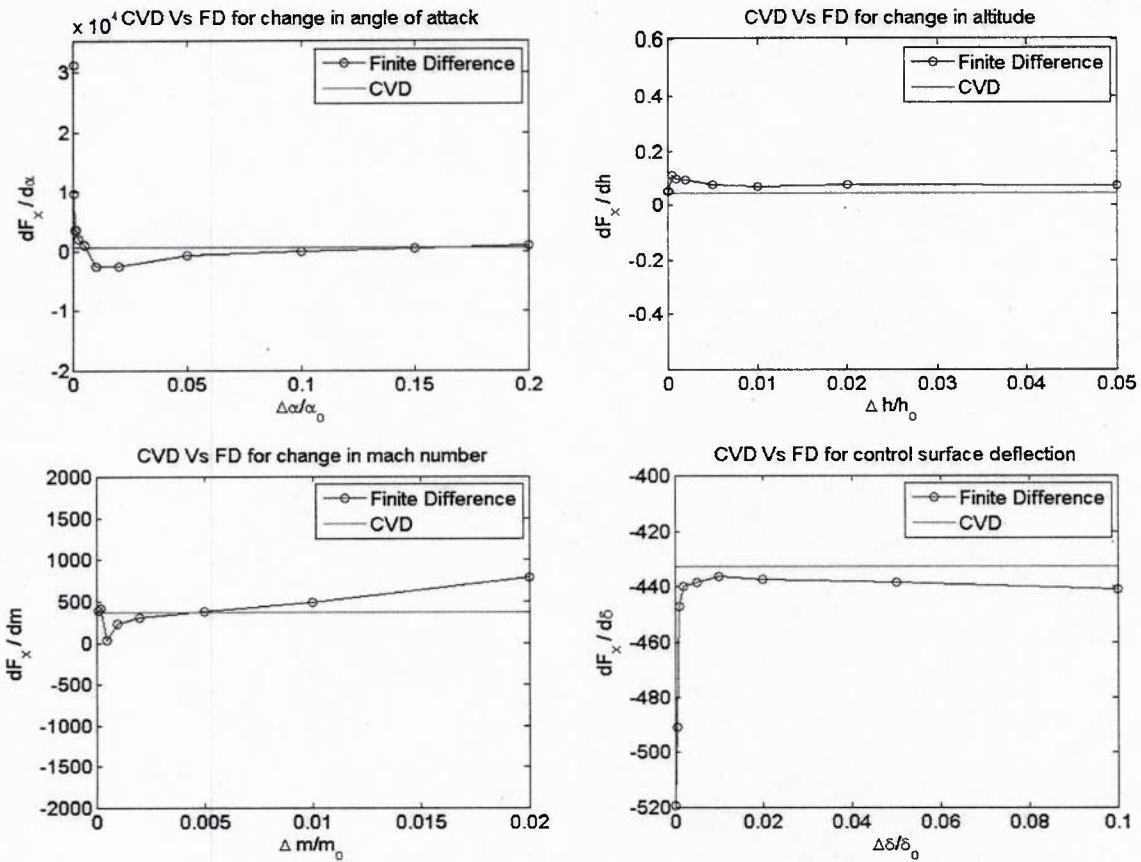
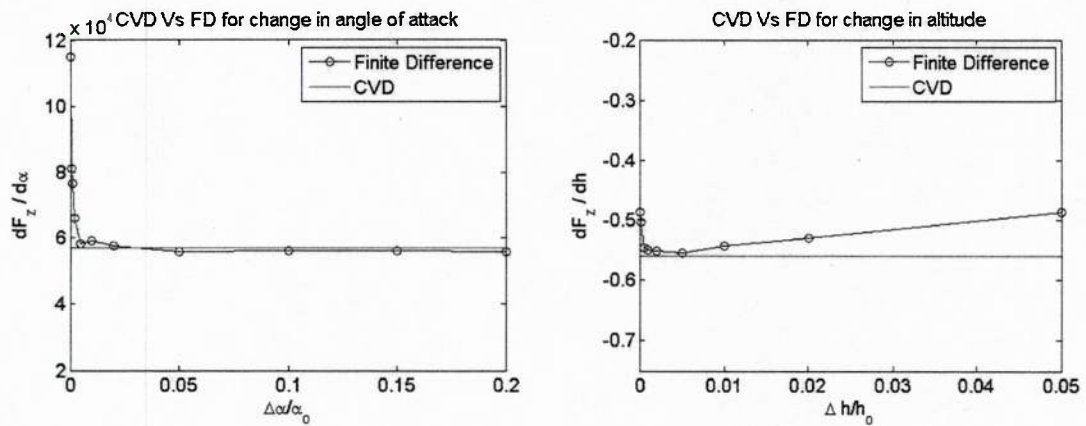


Figure 6.1 Sensitivity of axial force (F_x) with respect to angle of attack, altitude, Mach number and control surface deflection



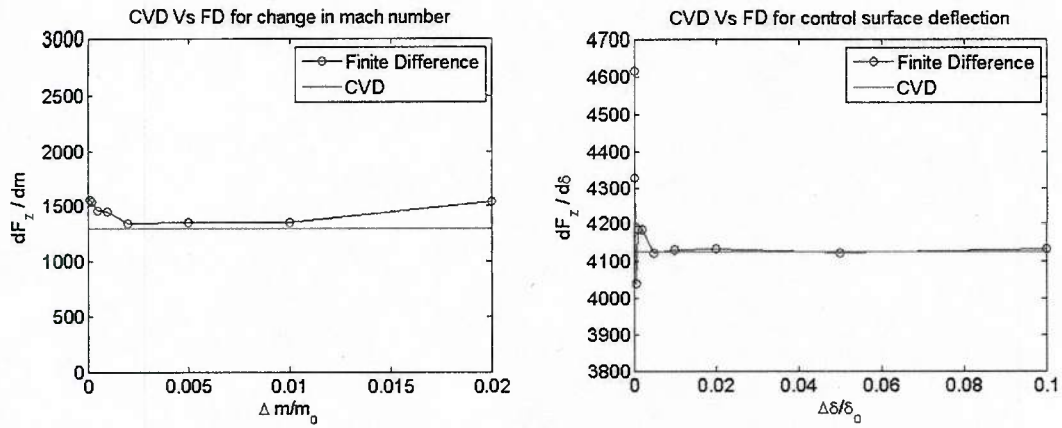


Figure 6.2 Sensitivity of lift force (F_z) with respect to angle of attack, altitude, Mach number and control surface deflection

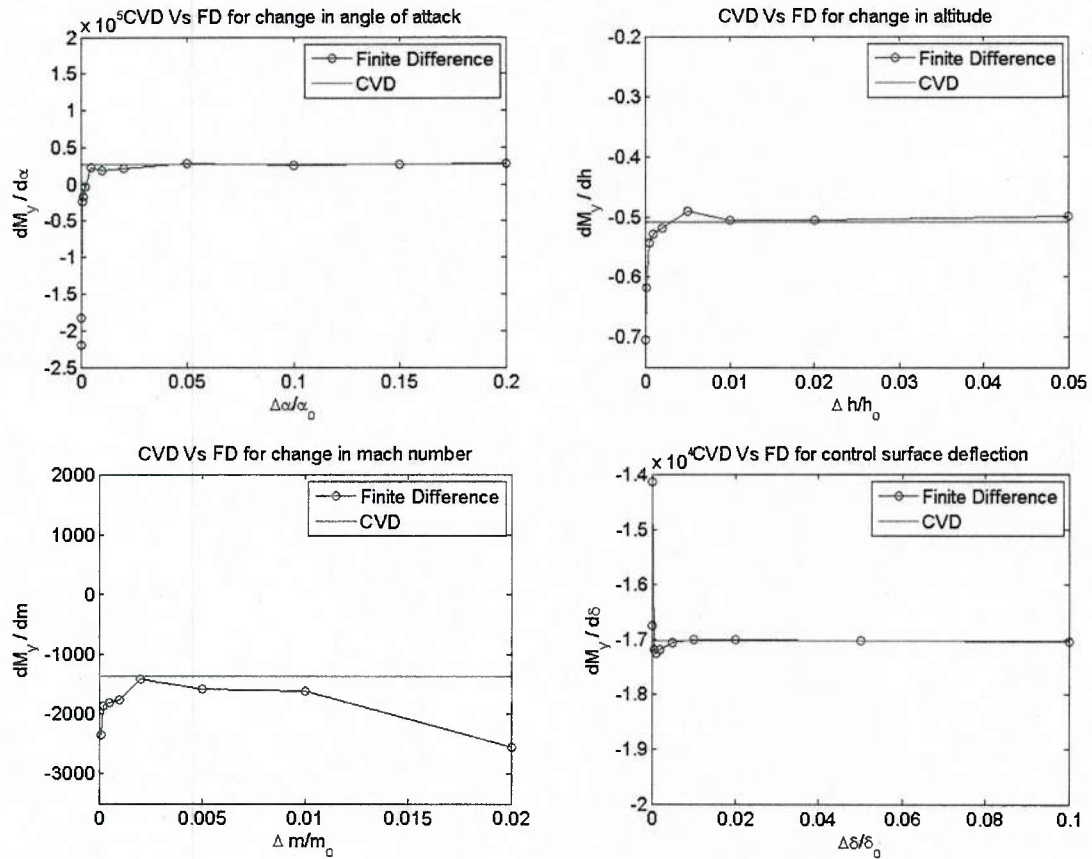


Figure 6.3 Sensitivity of pitching moment (M_y) with respect to angle of attack, altitude, Mach number and control surface deflection

6.2 Derivation of the Linearized Trim Equation

Considering angle of attack (α), control surface deflection (δ) and generalized coordinates (η) of the structural mode shapes as the dependent variables, the total force at a particular mean flow condition expressed as a function of the mean angle of attack (α_0), and the mean control surface deflection angle (δ_0) on a flying vehicle can be summed up as:

$$F_T = F_0(\alpha_0, \delta_0) + F_\alpha(\alpha_0, \delta_0)\alpha + F_\delta(\alpha_0, \delta_0)\delta + F_\eta(\alpha_0, \delta_0)\eta \quad (6.3)$$

where F_T is the total aerodynamic force, F_0 is the aerodynamic force at the mean flow condition, F_α , F_δ and F_η are forces due to small perturbations in angle of attack α , control surface deflection δ and generalized coordinate η . In terms of the deformation of the structure, the force F_T can also be written as:

$$F_T = KX \quad (6.4)$$

where K is the stiffness matrix of the structure and X is the structural deformation.

Assuming the structural deformation can be expressed as a superposition of the mode shapes, the structure deformation can be written as:

$$X = \phi_\eta \eta \quad (6.5)$$

where ϕ_η is the mode shape corresponding to each generalized coordinate.

Pre-multiplying ϕ_η^T with Equation (6.4) and using Equation (6.3), we arrive at:

$$[\phi_\eta^T K \phi_\eta] \eta = \phi_\eta^T F_T = \phi_\eta^T F_0 + \phi_\eta^T F_\alpha \alpha + \phi_\eta^T F_\delta \delta + \phi_\eta^T F_\eta \eta \quad (6.6)$$

The generalized stiffness can be defined as

$$K_\eta = \phi_\eta^T K \phi_\eta = \omega_\eta^2 m_\eta \quad (6.7)$$

where ω_η and m_η are natural frequencies and generalized mass matrix, respectively. Note that ϕ_η , ω_η and m_η are provided by the SMB module.

Combining Equation (6.6) and Equation (6.7), we get:

$$\left[K_\eta - \phi_\eta^T F_\eta \right] \eta = \phi_\eta^T F_0 + \phi_\eta^T F_\alpha \alpha + \phi_\eta^T F_\delta \delta \quad (6.8)$$

Now if we consider,

$$K_{ae} = \left[K_\eta - \phi_\eta^T F_\eta \right] \quad (6.9)$$

Then,

$$\eta = K_{ae}^{-1} \left[\phi_\eta^T F_0 + \phi_\eta^T F_\alpha \alpha + \phi_\eta^T F_\delta \delta \right] \quad (6.10)$$

Putting Equation (6.10) in Equation (6.3), we have,

$$F_T = F_0 + F_\alpha \alpha + F_\delta \delta + F_\eta K_{ae}^{-1} \phi_\eta^T F_0 + F_\eta K_{ae}^{-1} \phi_\eta^T F_\alpha \alpha + F_\eta K_{ae}^{-1} \phi_\eta^T F_\delta \delta \quad (6.11)$$

Equation (6.11) can be rewritten as,

$$F_T = [I + A] F_0 + [I + A] F_\alpha \alpha + [I + A] F_\delta \delta \quad (6.12)$$

where

$$A = F_\eta K_{ae}^{-1} \phi_\eta^T \quad (6.13)$$

Now, for trim condition, we satisfy two equations:

$$L = \phi_Z^T F_T = \eta_Z W \quad (6.14)$$

and

$$M = \phi_R^T F_T = 0 \quad (6.15)$$

where L is lift, M is pitching moment about the center of gravity (C.G.), W is weight of the vehicle, ϕ_Z^T is unit vector along the direction of the lift, ϕ_R^T is a vector containing pitching moment arm and η_Z is the load factor. For a level flight, $\eta_Z = 1$.

Using Equation (6.12), we finally arrive at the following 2 X 2 linearized trim equations:

$$\begin{bmatrix} \phi_Z^T [I + A] F_\alpha & \phi_Z^T [I + A] F_\delta \\ \phi_R^T [I + A] F_\alpha & \phi_R^T [I + A] F_\delta \end{bmatrix} \begin{Bmatrix} \alpha \\ \delta \end{Bmatrix} = \begin{bmatrix} \eta_Z W - \phi_Z^T A F_0 \\ -\phi_R^T A F_0 \end{bmatrix} \quad (6.16)$$

6.3 Trim Iterations for the Nonlinear Trim Problem

All aerodynamic derivatives involved in Equation (6.16) can be considered as the gradient of the trim variables at the current mean flow condition. The trim solution can be immediately calculated by adding the trim variable solutions (α and δ) to their respective mean flow conditions (α_0 and δ_0) if the aerodynamics and propulsion are linearly varying with respect to the trim variable, i.e. the gradient of the trim variable is constant. However, in hypersonic flow, not only are these aerodynamic derivatives known to be nonlinear but also the propulsion strongly depend on the mean flow condition. Therefore, to reach a final trim solution that satisfies the lift-equal-weight and zero-pitch-moment conditions requires an iterative process. In

this iterative process, the solution of the trim variables is added to the current mean flow condition to serve as a new mean flow condition for the next trim iteration such as:

$$\begin{aligned}\alpha_{0_{new}} &= \alpha_{0_{old}} + \alpha \\ \delta_{0_{new}} &= \delta_{0_{old}} + \delta\end{aligned}\quad (6.17)$$

At the new mean flow condition, the complex version of UCDA is executed again to generate a new set of aerodynamic forces and the stability derivatives that are plugged into Equation (6.16) to solve for the trim variables. This process is repeated until the change of the mean flow condition between two consecutive iteration steps is sufficiently small.

A typical iteration history of such an iterative process is shown in Figure 6.4. It can be seen that this iterative process requires only less than 10 iterations to achieve a fully converged solution. In fact, the mean flow condition in terms of α_0 and δ_0 does not change significantly after 5 iterations. Meanwhile, the lift and moment at the fifth iteration have already nearly satisfied the lift-equal-weight and zero-pitch-moment conditions. From the fifth to the tenth iteration, the trim solution remains nearly the same; indicating that this iterative process is stable and provides a fast converging rate.

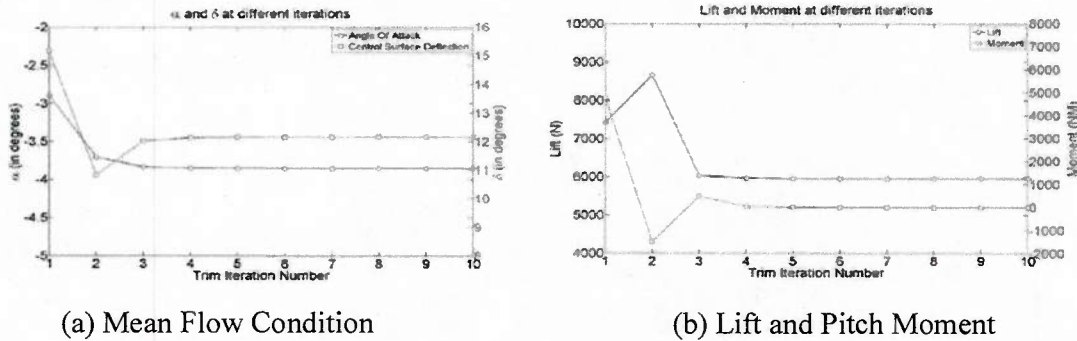


Figure 6.4 Iteration history of the iterative process for solving the nonlinear trim problem

Chapter 7 AeroServoElasticity (ASE) Module

Because of the waverider-like design, the forebody of the scramjet flight vehicle normally produces a large amount of lift when compared to the rest of the vehicle and consequently creates a large pitch-up moment. This implies that, most likely, the waverider design is statically unstable. This probably was the reason why NASA's Hyper-X, Mach 7 configuration required a 1000 pound block of tungsten in the forebody to balance the pitch-up moment. Apparently, this 1000 pound block of tungsten gives a large weight penalty to the NASA's Hyper-X configuration and significantly reduces its performance. Thus, the stability and controllability of the scramjet design must be analyzed in the early design stage. In addition, the structural flexibility and unsteady aerodynamic effects may have a large impact on the stability and must be included in the analysis. All of these call for an aeroservoelastic (ASE) capability that can analyze the coupling mechanism among the aerodynamics, structure and control system. It is for this reason that we have developed an ASE module as an integral part of the ASTPE system.

The functionality of the ASE module is two-fold. First, it calculates the longitudinal stability of the flight dynamics system with structural flexibility and unsteady aerodynamic effects. Then, it generates a state-space equation of the plant that can be directly adopted by MATLAB for a flight control system design.

The ASE module operates on the complex version of UCDA to obtain the aerodynamic stability derivatives for the construction of the state-space equation. However, since UCDA produces only the steady aerodynamics, we have incorporated a Local Pulsating Cone Method [7.1] in UCDA to compute the unsteady aerodynamics and the aerodynamic damping derivatives. Furthermore, in addition to the aerodynamic stability derivatives of angle of attack and control surface, these of the pitch rate (q) and forward velocity (u) are also developed in UCDA. Finally, the ASE module generates a state-space equation of the plant using a unified aeroelastic and flight dynamic formulation described in reference [7.2].

7.1 The Local Pulsating Cone (LPC) Method for Unsteady Aerodynamics

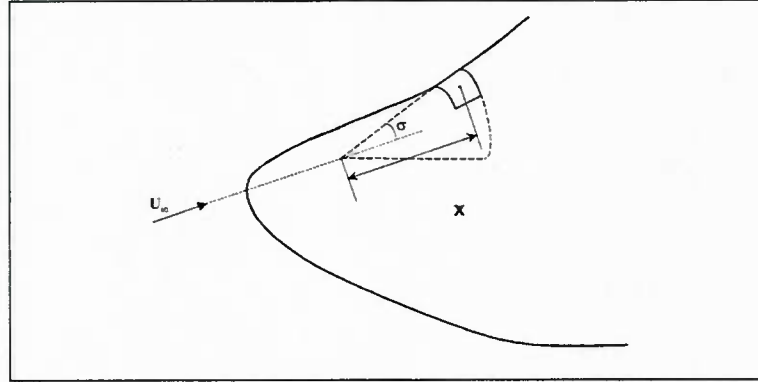


Figure 7.1 Local pulsating cone analogy showing rotations

Since the mean flow is hypersonic / supersonic, the time required for it to travel a unit reference length L (say body length) is much faster than that required for one cycle of body oscillation. Therefore, the corresponding unsteady problem can be treated as mildly unsteady in that flow history is only accounted for in the neighborhood of each panel. Thus, considered a panel located on a body such as the one shown in Figure 7.1, the real part (ΔC_{P_R}) and the imaginary part (ΔC_{P_I}) of the unsteady pressure coefficient on this panel can be approximated as:

$$\Delta C_{P_R} = \left(\frac{dC_{P_R}}{d\delta} \right)_\sigma \cos \theta \quad (7.1)$$

$$\Delta C_{P_I} = \left(\frac{dC_{P_I}}{d\delta} \right)_\sigma \bar{x} \cos \theta$$

where:

θ is the azimuthal angle and σ is the semi-angle of the local cone (Figure 7.1)

$\bar{x}$ is the axial distance between the panel and the local cone apex (Figure 7.1)

$\left(\frac{dC_{P_R}}{d\delta} \right)_\sigma$ and $\left(\frac{dC_{P_I}}{d\delta} \right)_\sigma$ are respectively the in-phase and out-of-phase pressure coefficients of the local cone undergoing a unit pulsating motion.

In fact, they can be related by the normal force derivatives in pitch, i.e.:

$$\begin{aligned}
\Delta C_{N_\alpha} &= \frac{1}{\pi \tan^2 \sigma} \int_0^1 \int_0^{2\pi} \left(\frac{dC_{P_R}}{d\delta} \right)_\sigma r (\cos^2 \theta) d\theta d\bar{x} \\
&= \frac{1}{2 \tan \sigma} \left(\frac{dC_{P_R}}{d\delta} \right)_\sigma
\end{aligned}
\tag{7.2}$$

$$\begin{aligned}
\Delta C_{N_q} &= \frac{1}{\pi \tan^2 \sigma} \int_0^1 \int_0^{2\pi} \left(\frac{dC_{P_I}}{d\delta} \right)_\sigma \bar{x} r (\cos^2 \theta) d\theta d\bar{x} \\
&= \frac{1}{3 \tan \sigma} \left(\frac{dC_{P_I}}{d\delta} \right)_\sigma
\end{aligned}$$

where ΔC_{N_α} and ΔC_{N_q} are respectively the stiffness and pitch-damping derivatives of the local cone. The exact Euler values of C_{N_α} and C_{N_q} for an oscillating cone were given by Sims [7.3] and Brong [7.4]. Once the real part (ΔC_{P_R}) and the imaginary part (ΔC_{P_I}) are obtained, they can be integrated to generate the static and dynamic aerodynamic stability derivatives due to a given unsteady motion. The accuracy of the Local Pulsating Cone Method has been validated with many other methods and wind-tunnel data.

The coefficients of out-of-phase forces with varying Mach numbers for a pitching 10° cone and a 20° cone about the apex are presented respectively in Figures 7.2 and 7.3. It is seen that the Local Pulsating Cone (LPC) results largely follow the same trend as Brong's Exact Euler solutions [7.4], but with acceptable discrepancy, throughout the Mach number range from shock detachment to $M_\infty = 20$. Much larger discrepancies were found between results of Tobak-Wehrend's first order theory [7.5] and that of Brong's Exact Euler solution. McIntosh's numerical solution [7.6] agrees very well with Brong's Exact Euler Solution at high Mach numbers, but it yields large discrepancies at low supersonic Mach numbers.

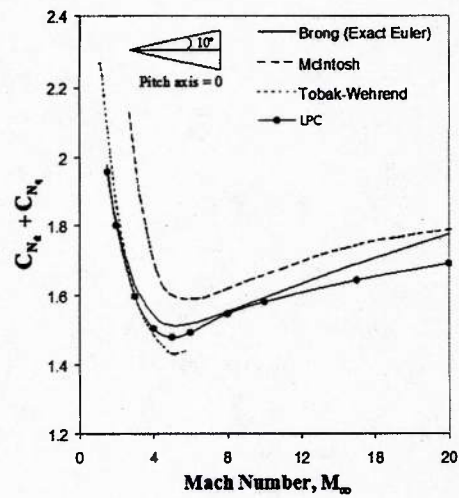


Figure 7.2 Variation with Mach number of the stability derivative (at cone angle = 10°)

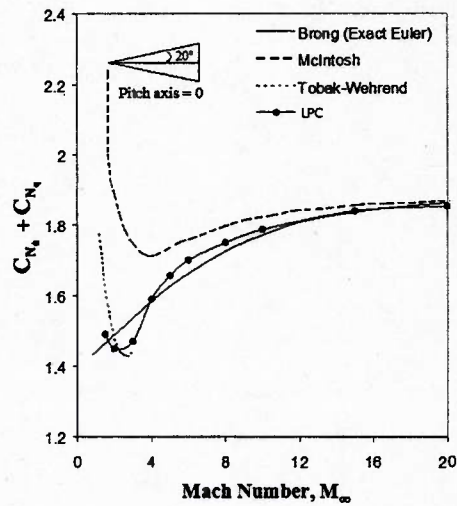


Figure 7.3 Variation with Mach number of the stability derivative (at cone angle = 20°)

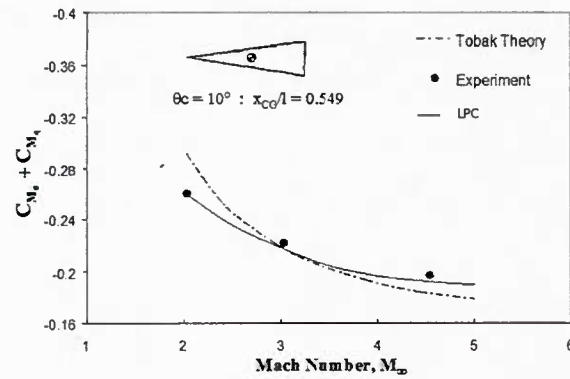


Figure 7.4 Predicted and measured damping of a 10-deg sharp cone

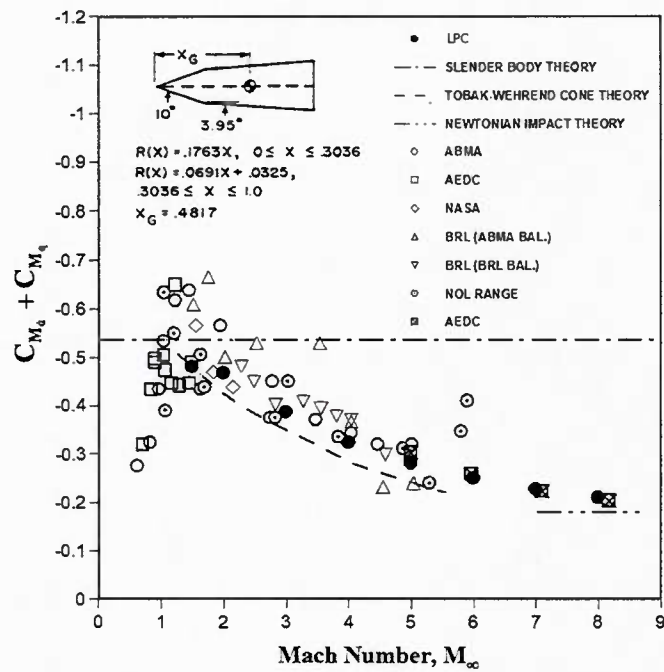


Figure 7.5 Comparison of theoretical and experimental damping-in-pitch moment coefficients for a cone frustum at various Mach numbers

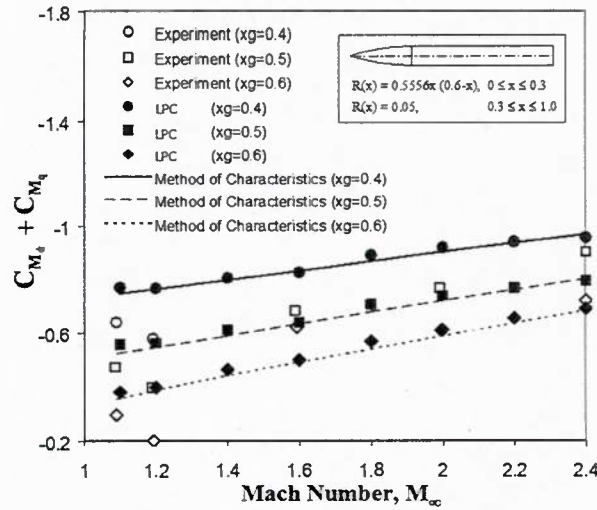


Figure 7.6 Effect of Mach number on fixed axis damping in pitch moment coefficient for an Ogive cylinder

Figures 7.4, 7.5 and 7.6 compare respectively the pitch-damping results computed by the Local Pulsating Cone Method with the measure data for an oscillating 10° cone frustum and for a slender ogive-cylinder body at various range of moderate supersonic Mach numbers. Excellent agreements were found for all cases considered.

7.2 The Unified Aeroelastic and Flight Dynamic Formulation for the State-Space Equation Generation

The unified aeroelastic and flight dynamic formulation described in Reference [7.2] starts from the state-space equation based on the structural generalized coordinates including the rigid body and elastic modes. For longitudinal dynamics, there are three rigid body modes, namely T_x for fore-aft mode, T_z for plunge mode and R_y for pitch mode and a set of generalized coordinates (η) of the elastic mode. Thus the deformation vector $\{X\}$ can be expressed as

$$\{X\} = \begin{bmatrix} \phi_x \phi_z \phi_\theta \phi_\eta \end{bmatrix} \begin{bmatrix} T_x \\ T_z \\ R_y \\ \eta \end{bmatrix} \quad (7.3)$$

Where ϕ_x is the fore-aft mode, ϕ_z is the plunge mode, ϕ_θ is the pitch mode and ϕ_η are the elastic modes. Introduce a state vector:

$$\{x_a\}^T = \{T_x T_z R_y \eta \dot{T}_x \dot{T}_z \dot{R}_y \dot{\eta}\} \quad (7.4)$$

The state space equation of the aeroelastic model can be expressed as:

$$\{\dot{X}_{ae}\} = [A]\{X_{ae}\} + [B]\{\delta\} \quad (7.5)$$

where

$$[A] = \begin{bmatrix} 0_{4 \times 4} & I_{4 \times 4} \\ -M^{-1}[K + q_\infty A_{s0}]_{4 \times 4} & -M^{-1}\left[C + \frac{q_\infty}{V_\infty} A_{s1}\right]_{4 \times 4} \end{bmatrix} \quad (7.6)$$

$$[B] = \begin{bmatrix} 0_{4 \times n_c} \\ -q_\infty [M]^{-1} [A_{c0}]_{4 \times n_c} \end{bmatrix} \quad (7.7)$$

where

c is the reference chord and S is the reference area

q_∞ is the dynamic pressure

V_∞ is the freestream velocity

n_c is the number of control inputs

and M , K , and C are the generalized mass, stiffness and damping matrices, respectively, and are expressed as:

$$M = \begin{bmatrix} m & 0 & 0 & 0 \\ 0 & m & 0 & 0 \\ 0 & 0 & I_{yy} & 0 \\ 0 & 0 & 0 & m_\eta \end{bmatrix} \quad (7.8)$$

$$K = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \omega_\eta^2 m_\eta \end{bmatrix} \quad (7.9)$$

$$C = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 2m_\eta \omega_\eta \zeta \end{bmatrix} \quad (7.10)$$

where

m is the mass of the vehicle.

I_{yy} is the moment of inertia about Y axis.

m_η are the generalized masses of the elastic modes.

ω_η are the natural frequencies of the elastic modes and,

ζ are the damping ratio of the elastic modes.

A_{s0} contains the static aerodynamic stability derivatives of the angle of attack and the elastic modes:

$$[A_{s0}]_{sym} = \begin{bmatrix} 0 & 0 & -S(C_{D_\alpha} - C_{L_0}) - \frac{mg}{q_\infty} & -C_{D_\eta} S \\ 0 & 0 & -S(C_{L_\alpha} + C_{D0}) & -C_{L_\eta} S \\ 0 & 0 & -ScC_{m_\alpha} & -C_{M_\eta} Sc \\ 0 & 0 & -\phi_\eta^T F_\alpha / q_\infty & -\phi_\eta^T F_\eta / q_\infty \end{bmatrix} \quad (7.11)$$

where

F_α is the distributed aerodynamic force due to angle of attack.
 F_η is the distributed aerodynamic force due to the elastic modes, and
 $C_{D\eta}$, $C_{L\eta}$, $C_{M\eta}$ are the non-dimensional drag, lift and pitch moment coefficients due to the elastic modes

It should be note that in Equation (7.11) the weight of the vehicle (mg) is also included. This is an essential term to obtain the correct phugoid mode.

A_{s1} contains the aerodynamic damping derivatives of the forward velocity (u), the angle of attack (α), the pitch rate (q) and the elastic modes (η):

$$[A_{s1}]_{sym} = \begin{bmatrix} 2S(C_{D_u} + C_{D_0}) & S(C_{D_\alpha} - C_{L_0}) & -0.5S \left(cC_{D_\alpha} + C_{D_q} \right) & -C_{D_\eta} S \\ 2S(C_{L_u} + C_{L_0}) & S(C_{L_\alpha} + C_{D_0}) & -0.5S \left(cC_{L_\alpha} + C_{L_q} \right) & -C_{L_\eta} S \\ 2Sc(C_{M_u} + C_{M_0}) & ScC_{M_\alpha} & -0.5Sc^2 \left(C_{M_\alpha} + C_{M_q} \right) & -C_{M_\eta} Sc \\ 2\phi_\eta^T \frac{[F_u + F_0]}{q_\infty} & \phi_\eta^T \frac{[F_\alpha]}{q_\infty} & -0.5c\phi_\eta^T \frac{[F_q]}{q_\infty} & -\phi_\eta^T \frac{F_\eta}{q_\infty} \end{bmatrix} \quad (7.12)$$

where

F_u is the distributed aerodynamic force due to unit change in forward speed (u).

F_0 is the distributed aerodynamic force at trim.

F_q is the distributed aerodynamic force due to the pitch rate (q).

$F_{\dot{\eta}}$ is the distributed aerodynamic force due to $\dot{\eta}$.

Note that $F_{\dot{\eta}}$ is obtained by applying the Local Pulsating Cone method described in Section 7.1, and C_{D_η} , C_{L_η} , C_{M_η} are the drag, lift and pitch moment due to the rate of the elastic modes ($\dot{\eta}$).

They are computed by integrating $F_{\dot{\eta}}$ over the surface mesh.

A_{c0} contains the aerodynamic stability derivatives of the control surfaces:

$$[A_{c0}]_{sym} = \begin{bmatrix} -SC_{D\delta} \\ -SC_{L\delta} \\ -cSC_{M\delta} \\ -\phi_\eta^T F_\delta / q_\infty \end{bmatrix} \quad (7.13)$$

F_δ is the distributed aerodynamic forces due to unit change of control surface deflection δ .

The state vector shown in Equation (7.4) is expressed in terms of the structural rigid body modes and the elastic modes. However, the states of the flight dynamic model are expressed in terms of the airframe states. To be compatible with the flight dynamic model, it is required to transform the rigid body modes to the airframe states. This transformation matrix for the longitudinal dynamics is shown in the following equation:

$$\{X_{ae}\} = [T_A] \{\xi\} \quad (7.14)$$

Where $\{\xi\}$ is the airframe states expressed as:

$$\{\xi\} = \begin{bmatrix} x & u & h & \alpha & \theta & q & \eta & \dot{\eta} \end{bmatrix}^T \quad (7.15)$$

and

$$[T_A] = \begin{bmatrix} -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -V_\infty & V_\infty & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (7.16)$$

Substituting Equation (7.16) in to Equation (7.5) yields a state-space equation defined in the airframe states:

$$\begin{Bmatrix} \dot{\xi} \\ \xi \end{Bmatrix} = \begin{bmatrix} \bar{A} \\ \bar{B} \end{bmatrix} \begin{Bmatrix} \xi \\ \delta \end{Bmatrix} \quad (7.17)$$

where

$$\begin{bmatrix} \bar{A} \end{bmatrix} = [T_A]^{-1} [A] [T_A] \quad (7.18)$$

and

$$\begin{bmatrix} \bar{B} \end{bmatrix} = [T_A]^{-1} [B] \quad (7.19)$$

The stability of the flight dynamic system with aeroelastic effects can be computed by performing an eigenvalue analysis of the matrix $\begin{bmatrix} \bar{A} \end{bmatrix}$. This state-space equation can then be imported into MATLAB for a subsequent flight control law design.

7.3 Validation of the ASE module

The validation of the ASE module can be achieved by first excluding the elastic modes then comparing the eigenvalues of the matrix $\begin{bmatrix} \bar{A} \end{bmatrix}$ to those of analytical flight dynamic equations such as those in Reference [7.7] and shown in the following equations:

For Phugoid mode:

$$\omega_{np} = \frac{\rho S U \sqrt{-C_{L_u} C_{L_o}}}{2m} \quad (7.20)$$

$$\zeta_p = \frac{-C_{x_u}}{2 \frac{mU}{Sq} \sqrt{-C_{L_u} C_{L_o}}} = \frac{-C_{D_u}}{2 \sqrt{-C_{L_u} C_{L_o}}} \quad (7.21)$$

For short period mode:

$$\omega = \left(\frac{\frac{c}{2U} C_{m_q} C_{L_\alpha} - \frac{mU}{Sq} C_{m_\alpha}}{\left(\frac{I_y}{Sq c} \right) \left(\frac{mU}{Sq} \right)} \right)^{1/2} \quad (7.22)$$

$$\zeta = -\frac{1}{4} \left(C_{m_q} + C_{m_\alpha} + \frac{2I_y}{mc^2} C_{L_\alpha} \right) \left(\frac{mc^2}{I_y \left(\frac{C_{m_q} C_{L_\alpha}}{2} - \frac{2mC_{m_\alpha}}{pSc} \right)} \right)^{1/2} \quad (7.23)$$

The aerodynamic stability derivatives are computed first on the selected scramjet flight vehicle at the trim condition of $\alpha = -3.85^\circ$, $\delta = 12.16^\circ$. These aerodynamic stability derivatives are shown in Table 7.1. Other parameters required by the analytical flight dynamic equations are: mass (m) = 607.0464, moment of inertia (I_y) = 3346.629, velocity (U) = 2423.220, surface area (S) = 12.84184, dynamic pressure (q) = 36829.69 and reference chord (c) = 4.267200.

Table 7.1 Aerodynamic Stability Derivatives of a Scramjet Flight Vehicle

Airframe State	C_D	C_L	C_M
Mean Flow	1.3070413E-02	1.2589106E-02	-1.2727222E-06
Forward Velocity	1.5813446E-05	1.5713536E-05	-2.7891413E-06
Angle of Attack	-2.0686770E-02	0.2707167	7.3831538E-03
Pitch Rate	7.5796391E-03	1.8302677E-03	2.0127750E-03

It can be seen in Table 7.1 that the pitch moment stability derivative of angle of attack (C_{m_α}) is positive; indicating a statically unstable flight vehicle.

Two sets of the ASE module of ASTPE are computed, one without the elastic mode (rigid body modes only) and the other with the first bending mode with natural frequency = 9.755 Hz, and compared to the analytical solution. This comparison is presented in Table 7.2 where an excellent agreement between the ASE module result without the elastic mode and the analytical solution can be seen. Meanwhile, the ASE module result with the first bending mode shows only a slight difference from that with only the rigid modes. This suggests that the structure designed by the SMB module provides sufficient stiffness by which the impact of aeroelastic effects on the flight dynamics is minimized.

Table 7.2 Validation of the ASE module with Analytical Solution.

Longitudinal Dynamics	ASTPE				Analytical (Rigid)	
	+ Bending		Rigid			
	Damping	Frequency	Damping	Frequency	Damping	Frequency
Short Period	-1.0	0.3278 (Hz)	-1.0	0.343 (Hz)	-1.0	0.343 (Hz)
Phugoid	0.772	0.00079 (Hz)	0.729	0.00091(Hz)	0.734	0.00091(Hz)

Note that the negative damping of the short period mode is due to the unstable C_{m_α} , leading to a statically unstable flight vehicle that must be stabilized by a flight control system.

7.4 A Demonstration Case of Flight Control System Design

The state-space equation shown in Equation (7.17) of the plant model is first imported into MATLAB. Subsequently, a Linear Quadratic Guassian Control Method (LQG) compensator shown in Figure 7.7 is designed using the Single Input Single Output (SISO) design tool of the MATLAB Control System Toolbox.

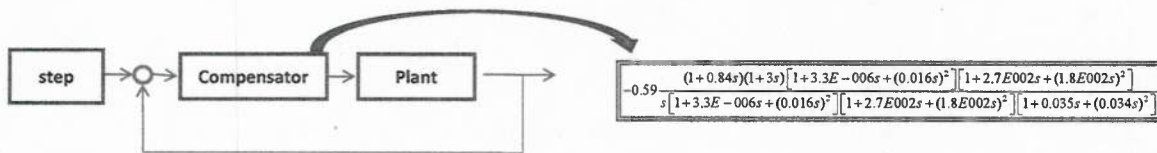
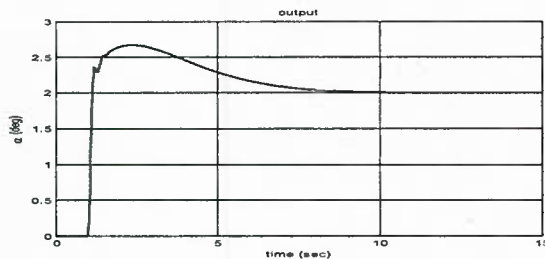


Figure 7.7 A LQG controller

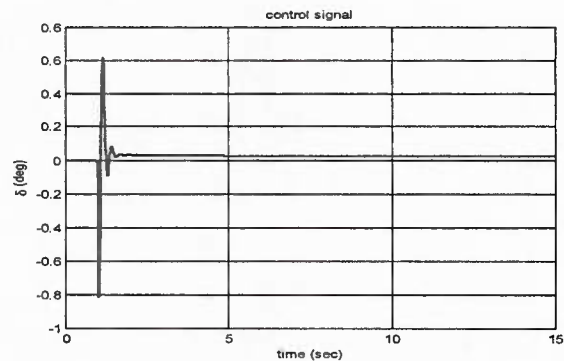
The comparison of the closed-loop result and the open-loop result is presented in Table 7.3. It can be seen that, indeed, the closed-loop is stabilized by the LQG controller. In order to evaluate the performance of the LQG controller, a step input of angle of attack of 2 degrees is introduced and the response the flight vehicle's angle of attack as well as the control surface input shown in Figure 7.8a and 7.8b, respectively. The flight vehicle takes only 7 seconds to reach the desired 2 degrees angle of attack, indicating that the performance of the LQG controller is acceptable.

Table 7.3 Closed-Loop and Open-Loop Results

	Open Loop		Closed Loop	
	damping	frequency	damping	frequency
short period	-1	0.3278 Hz	0.873	0.675 Hz
phugoid	0.772	0.00079 Hz	0.75	0.00565 Hz



(a) Response of Angle-of-Attack



(b) Control Surface Input

Figure 7.8 Performance of the LQG controller

Chapter 8 Case Study 1 - Single Engine Missile (SEM)

8.1 Introduction

The Single Engine Missile (SEM) constraints chosen for this study were imposed by maximum allowable dimensions for a missile deployed from either a standard Naval vertical launch system tube (VLS) or an aircraft's missile pylon, as shown in Figure 8.1.1. The work presented in this study could also be applied to other scale vehicles with relatively little effort. The maximum length for this study is constrained to 4.27 m [14 feet] with the maximum width and height being 0.61 m [2 feet] each. These box dimensions result in a maximum available volume $V_{\max}$ of 1.59 m³ [56 ft³]. An implicit goal in this optimization is to fill this box as much as possible to allow for maximum mass (structural, payload, and fuel) to take advantage of the high lift offered by waverider geometries, while also maximizing the potential for increased missile range (due to the increased fuel volume). However, an increase in volume usually comes at the expense of increased drag (both wave and viscous) which places higher demands on the propulsion system resulting in increased fuel consumption. This is a highly coupled system where only an integrated approach to optimization can lead to a viable result. Due to the nature of the coupling between engine and airframe, the optimal result is not a combination of an optimal engine with an optimal airframe.

One unique additional constraint was imposed on the design: no deployable control surface be integrated into the missile. Since only pitch control was originally investigated, this resulted in a thrust vectored nozzle segment integrated into the scramjet flowpath. For more complex scenarios, this would likely be an undesirable configuration. The baseline configuration is shown in Figure 8.1.2.

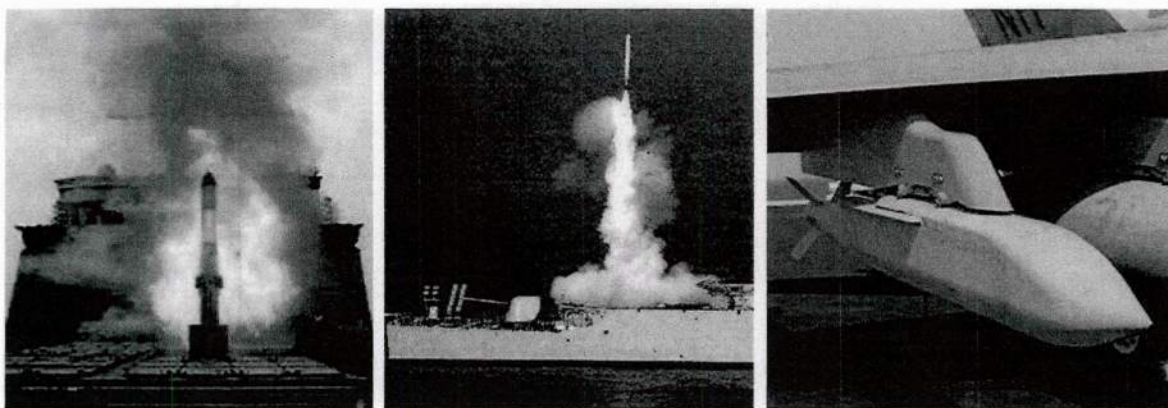


Figure 8.1.1 a) Tomahawk missile exiting a Naval vertical launch tube, b) Tomahawk missile leaving ship, c) Example missile hanging from aircraft pylon (on left side of picture).

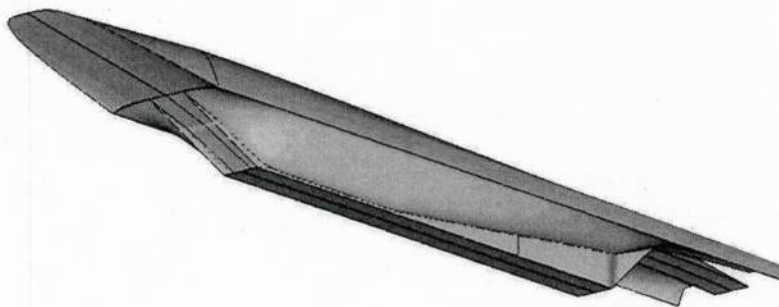


Figure 8.1.2 Baseline SEM model

8.2 Run UCDA to Design the Vehicle

Input Files:

File Name	Type	Remarks	See Listing
vehicle.inp	Standard input file	Also look at Table 8.2.1a and 8.2.1b	Shown in Listing 8.2.1
chem.bin	Engine chemistry information	Required	Shown in Listing 8.2.2

Output Files:

File Name	Type	Remarks	See Listing
plotM060A-010.dat	Standard Tecplot output file	See Fig. 8.2.1	Shown in Listing 8.2.3

Input File descriptions

vehicle.inp: This is a standard input file for UCDA. See listing 8.2.1 for the entire input file. The part that is used to generate the geometry of the vehicle is shown in Tables 8.2.1a and 8.2.1b. Table 8.2.1a shows different patches that are needed to generate the vehicle. There are 16 patches in this SEM vehicle. Each patch should have a name of the patch, the number of grids in the x direction and the number of grids in the y direction. Table 8.2.1b shows the other necessary geometrical and engine input parameters necessary to design the vehicle. The details of the definitions and explanations can be found in the User's Manual.

chem.bin: This is a required input file for the engine chemistry of the vehicle. Chem.bin is generated using ChemKin Version 2 and for this case is a Jet-A reaction mechanism. Please see Listing 8.2.2.

Output File descriptions

plotM060A-010.dat: The output file is a Tecplot format file that can easily be plotted. The plot of the designed vehicle is shown in Figure 8.2.1.

The output file is shown in Listing 8.2.3. The name of this file implies that after designing the vehicle, it was run at Mach 6 (Mxyz in plot file name implying Mach number xy.z) and with an angle of attack -1.0 degrees (A-xyz in plot file name implying angle of attack -xy.z).

The computational run time for UCDA to design a vehicle is about a few seconds.

Table 8.2.1a: Different Zones of SEM Vehicle (see Figure 8.2.2)

ZONE DATA AND GRID SIZES:		
16	NUMBER OF ZONES	
'forebody : top'	31	31
'keel : top'	101	6
'aftbody : top'	101	31
'forebody : bot'	31	31
'ramps : bot'	55	6
'comb : bot'	101	6
'cowl : top'	101	6
'nozzle : bot'	31	6
'ramp walls : inside'	35	6
'comb wall : inside'	101	7
'nozzle wall : inside'	21	7
'aftbody : bot'	101	31
'cowl : bot'	101	6
'ramp walls : outside'	35	6
'comb wall : outside'	101	7
'nozzle wall : outside'	21	7

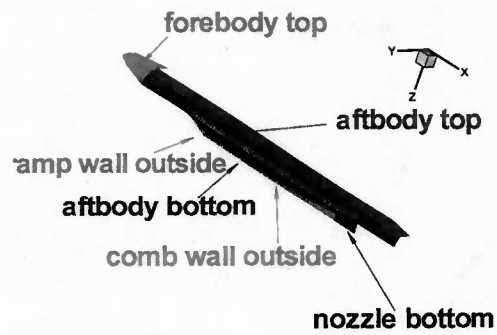
Table 8.2.1b: Geometrical and Engine Input Parameters of SEM Vehicle

6.0	4	'Mdes' - design Mach number
1.0	0	'AOAdes' - design angle of attack
21800.	1	'Zdes' - design altitude
4.2672	1	'lvehicle' - vehicle length
6.0000	0	'thforclu' - forebody upper surface angle
5.2797	0	'thforcli' - forebody ramp angle
0.5873	1	'lcontrol' - control surface length
7.73	0	'th_control' - control surface deflection angle
0.9920	0	'th_expn' - nozzle initial expansion angle
10.8958	0	'th_exit' - nozzle exit angle
0.0	4	'p_nozpoly' - % diff between nozzle designs [DON'T USE-defaulted to 1.]
1.901	1	'lcowl' - cowl length (isolator/combustor)
.3	1	'lcowlex' - cowl extension length (internal nozzle)
0.545	4	'p_iso' - percent of lcowl that is isolator
.3238	1	'height' - height of vehicle (if required)
20.0	1	'linlet' - inlet length of vehicle (if required)
.26	1	'wengine' - width of the engine (currently defaulted to unit width)
3.00	4	'iramps' - number of inlet ramps in addition to the forebody
6.4012	0	'th_ramp1' - inlet ramp 1 angle
5.2383	0	'th_ramp2' - inlet ramp 2 angle
5.5	0	'th_ramp3' - inlet ramp 3 angle
0.0	0	'th_ramp4' - inlet ramp 4 angle

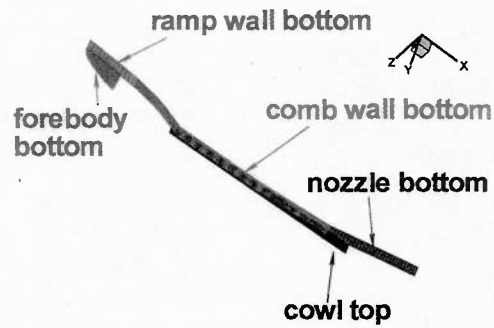
0.0	0	'th_ramp5' - inlet ramp 5 angle
3.09	0	'th_div1' - first combustor expansion angle
0.2	0	'th_div2' - second combustor expansion angle
0.01	1	'Xinjs' - beginning of injectors (m)
0.02	1	'Xinje' - end of injectors (m)
0.01	1	'Lmix' - fuel mixing length (m)
1.00	4	'eta_mix' - fuel mixing and burning efficiency
3000.	4	'Tlimit' - maximum engine temperature (K)
90.	0	'Thetainj' - injector angle (degrees) [90 deg. is normal to flow]
1200.	4	'Tw' - adiabatic wall temperature (K)
0.1527	4	'nfor' - forebody exponent n
2.0	2	'wfor' - forebody width
1.5	2	'lfor' - forebody length
0.2427	4	'mfor' - forebody exponent m
5.797	0	'thforle' - forebody leading edge angle
21.519	0	'th_le' - leading edge attachment angle
0.0000	4	'p_kl' - keel-line height percentage
0.25	4	'fuelfrac' - vehicle fuel volume fraction
0.0104	2	't_plate' - shell plate thickness (Tungsten)
0.0	4	'mass_smb' - mass due to Structural Modal Base (SMB) analysis
0.0	4	'mass_tps' - mass due to Thermal Protection System (TPS) analysis
0.0	4	'mass_nose' - lumped mass at the nose to manipulate CG



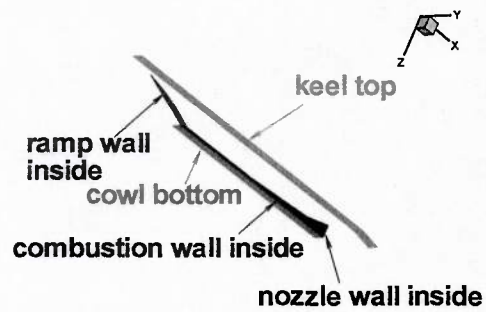
Figure 8.2.1 SEM Vehicle Plot



(a) Selected Zones of SEM Vehicle



(b) Selected Zones of SEM Vehicle



(c) Selected Zones of SEM Vehicle

Figure 8.2.2 Different Zones of SEM Vehicle

Listing 8.2.1: Vehicle.inp Input File

```

TEST INPUT DECK: Note - this line must be here!
2 ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1 ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle
1 iunits - Output unit switch: SI (1) or English (2)
3 ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1 iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2 inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1 iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
2 itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0 icone - cone flow data: exact (0), curve-fit approximation (1)
1 imodel - Forebody type: WA (1), VWA (2), or VWA + cone flow (3)
0 itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0 ideriv - Calculate derivatives: no (0), yes (1)
0 itps - If itps is 1, then prepare for tps and smb. ideriv and itps cannot be 1 at one time
0 ifeedback - If 1, then gets weight and Cg information from SMB and TPSOPT

OUTPUT FILE SWITCHES AND NAMES:
1 'plot.dat' VEHICLEFIG: off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23 1st # -> # of variables to read, others -> vars to plot
1 'metrics.dat' METRICS: off (0), on (1)
0 'cowlexit.dat' COWLEXIT: off (0), on (1)
0 'moc.dat' NOZFIG: off (0), P,T,M (1), all (2)
2 'offdesign.dat' AOA: off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0 'scramjet.dat' CKENGINE: off (0), on (1)
0 IPRINTINLET: off (0), all (1), results (2), all-real (3), results-real (4)
0 IPRINTENGINE: off (0), on (1)
0 IDEBUG: off (0), on (1) [print debugging info]

ZONE DATA AND GRID SIZES:
16 NUMBER OF ZONES
'forebody : top' 31 31
'keel : top' 101 6
'aftbody : top' 101 31
'forebody : bot' 31 31
'ramps : bot' 55 6
'comb : bot' 101 6
'cowl : top' 101 6
'nozzle : bot' 31 6
'ramp walls : inside' 35 6
'comb wall : inside' 101 7
'nozzle wall : inside' 21 7
'aftbody : bot' 101 31
'cowl : bot' 101 6
'ramp walls : outside' 35 6
'comb wall : outside' 101 7
'nozzle wall : outside' 21 7

INPUT DATA: (0 = degrees, 1 = m, 2 = ft, 3 = atm, 4 = dimensionless, K or kg, 5 = psf)
xl x xu unit res name
22500. 26000. 30000. 1 2500. 'altitude' - altitude (if required)
2000. 2200. 2400.0 5 200. 'q0' - dynamic pressure (if required)
.50 1.099 1.0 4 .250 'equiv' - equivalence ratio
1. 1. 0.0 4 -.05 'throttle' - engine throttle (if required)
6.0 6.00 8.00 4 .5 'mo' - Mach number
-2.0 -1.0 3.00 0 .5 'AOA' - angle of attack
6.0 4 'Mdes' - design Mach number
1.0 0 'AOAdes' - design angle of attack
21800. 1 'Zdes' - design altitude
4.2672 1 'lvehicle' - vehicle length
6.0000 0 'thforclu' - forebody upper surface angle
5.2797 0 'thforcll' - forebody ramp angle
0.5873 1 'lcontrol' - control surface length
7.73 0 'th_control' - control surface deflection angle
0.9920 0 'th_expn' - nozzle initial expansion angle
10.8958 0 'th_exit' - nozzle exit angle
0.0 4 'p_nozpoly' - % diff between nozzle designs [DON'T USE-defaulted to 1.]
1.901 1 'lcowl' - cowl length (isolator/combustor)
.3 1 'lcowlext' - cowl extension length (internal nozzle)
0.545 4 'p_iso' - percent of lcowl that is isolator
.3238 1 'height' - height of vehicle (if required)
20.0 1 'linlet' - inlet length of vehicle (if required)
.26 1 'wengine' - width of the engine (currently defaulted to unit width)
3.00 4 'iramps' - number of inlet ramps in addition to the forebody
6.4012 0 'th_ramp1' - inlet ramp 1 angle
5.2383 0 'th_ramp2' - inlet ramp 2 angle
5.5 0 'th_ramp3' - inlet ramp 3 angle
0.0 0 'th_ramp4' - inlet ramp 4 angle
0.0 0 'th_ramp5' - inlet ramp 5 angle
3.09 0 'th_div1' - first combustor expansion angle
0.2 0 'th_div2' - second combustor expansion angle
0.01 1 'Xinjs' - beginning of injectors (m)
0.02 1 'Xinje' - end of injectors (m)
0.01 1 'Lmix' - fuel mixing length (m)
1.00 4 'eta_mix' - fuel mixing and burning efficiency
3000. 4 'Tlimit' - maximum engine temperature (K)
90. 0 'Thetainj' - injector angle (degrees) [90 deg. is normal to flow]
1200. 4 'Tw' - adiabatic wall temperature (K)
0.1527 4 'nfor' - forebody exponent n
2.0 2 'wfor' - forebody width

```

```

1.5      2      'lfor'      - forebody length
0.2427   4      'mfor'      - forebody exponent m
5.797    0      'thforle'   - forebody leading edge angle
21.519   0      'th_le'     - leading edge attachment angle
0.0000   4      'p_kl'      - keel-line height percentage
0.25     4      'fuelfrac'   - vehicle fuel volume fraction
0.0104   2      't_plate'    - shell plate thickness (Tungsten)
0.0      4      'mass_smb'   - mass due to Structural Modal Base (SMB) analysis
0.0      4      'mass_tps'   - mass due to Thermal Protection System (TPS) analysis
0.0      4      'mass_nose'  - lumped mass at the nose to manipulate CG

```

Listing 8.2.2: Chem.bin Input File

```

"3.6      " "DOUBLE      " .F.
462 624 22 5 17 23 6 10 3 5 3 2 8 3 0 0 0 0 0 10 0.00100000005
"H      " 1.00796998
"O      " 15.9994001
"C      " 12.0111504
"N      " 14.0066996
"AR     " 39.9480019
"O2     " 0 2 0 0 0 0 0 31.9988003 3 300. 1000. 5000. 3.212936
0.001127486 -5.75615E-07 1.313877E-09 -8.768554E-13 -1005.249 6.034738
3.697578 0.0006135197 -1.258842E-07 1.775281E-11 -1.136435E-15 -1233.93
3.189166
"C12H23 " 23 0 12 0 0 0 0 167.317114 3 273. 1000. 5000.
2.0869217 0.13314965 -8.1157452E-05 2.9409286E-08 -6.5195213E-12 -35912.814
27.355289 24.880201 0.078250048 -3.1550973E-05 5.78789E-09 -3.9827968E-13
-43110.684 -93.655255
"H2     " 2 0 0 0 0 0 0 2.01593995 3 300. 1000. 5000. 3.298124
0.0008249442 -8.143015E-07 -9.475434E-11 4.134872E-13 -1012.521 -3.294094
2.991423 0.0007000644 -5.633829E-08 -9.231578E-12 1.582752E-15 -835.034
-1.35511
"H      " 1 0 0 0 0 0 0 1.00796998 3 300. 1000. 5000. 2.5 0.
0. 0. 0. 25471.63 -0.4601176 2.5 0. 0. 0. 25471.63 -0.4601176
"O      " 0 1 0 0 0 0 0 15.9994001 3 300. 1000. 5000. 2.946429
-0.001638166 2.421032E-06 -1.602843E-09 3.890696E-13 29147.64 2.963995
2.54206 -2.75506E-05 -3.102803E-09 4.551067E-12 -4.368052E-16 29230.8
4.920308
"OH     " 1 1 0 0 0 0 0 17.0073701 3 300. 1000. 5000. 3.637266
0.000185091 -1.676165E-06 2.387203E-09 -8.431442E-13 3606.782 1.35886
2.88273 0.001013974 -2.276877E-07 2.174684E-11 -5.126305E-16 3886.888
5.595712
"H2O    " 1 2 0 0 0 0 0 33.0067703 3 300. 1000. 5000. 2.979963
0.004996697 -3.790997E-06 2.354192E-09 -8.089024E-13 176.2274 9.222724
4.072191 0.002131296 -5.308145E-07 6.112269E-11 -2.841165E-15 -157.9727
3.476029
"H2O    " 2 1 0 0 0 0 0 18.0153401 3 300. 1000. 5000. 3.386842
0.003474982 -6.334696E-06 6.968581E-09 -2.506588E-12 -30208.11 2.590233
2.672146 0.003056293 -8.73026E-07 1.200996E-10 -6.391618E-15 -29899.21
6.862817
"CH     " 1 0 1 0 0 0 0 13.0191203 3 300. 1000. 5000. 3.200202
0.002072876 -5.134431E-06 5.73389E-09 -1.955533E-12 70452.59 3.331588
2.196223 0.002340381 -7.058201E-07 9.007582E-11 -3.85504E-15 70867.23
9.178373
"CO2    " 0 2 1 0 0 0 0 44.0099506 3 300. 1000. 5000. 2.275725
0.009922072 -1.040911E-05 6.866687E-09 -2.11728E-12 -48373.14 10.18849
4.453623 0.003140169 -1.278411E-06 2.393997E-10 -1.669033E-14 -48966.96
-0.9553959
"CO     " 0 1 1 0 0 0 0 28.0105505 3 300. 1000. 5000. 3.262452
0.001511941 -3.881755E-06 5.581944E-09 -2.474951E-12 -14310.54 4.848897
3.025078 0.001442689 -5.630828E-07 1.018581E-10 -6.910952E-15 -14268.35
6.108218
"C2H2   " 2 0 2 0 0 0 0 26.0382407 3 300. 1000. 5000. 2.013562
0.01519045 -1.616319E-05 9.078992E-09 -1.912746E-12 26124.44 8.805378
4.43677 0.005376039 -1.912817E-06 3.286379E-10 -2.15671E-14 25667.66
-2.800338
"N      " 0 0 0 1 0 0 0 14.0066996 3 300. 1000. 5000. 2.503071
-2.180018E-05 5.420529E-08 -5.64756E-11 2.099904E-14 56098.9 4.167566
2.450268 0.0001066146 -7.465337E-08 1.879652E-11 -1.025984E-15 56116.04
4.448758
"NH     " 1 0 0 1 0 0 0 15.0146695 3 300. 1000. 5000. 3.339758
0.001253009 -3.491646E-06 4.218812E-09 -1.557618E-12 41850.47 2.507181
2.760249 0.001375346 -4.451914E-07 7.692792E-11 -5.017592E-15 42078.28
5.857199
"NO     " 0 1 0 1 0 0 0 30.0060997 3 300. 1000. 5000. 3.376542
0.001253063 -3.302751E-06 5.21781E-09 -2.446263E-12 9817.961 5.82959
3.245435 0.001269138 -5.01589E-07 9.169283E-11 -6.275419E-15 9800.84
6.417294
"AR     " 0 0 0 0 1 0 0 39.9480019 3 300. 1000. 5000. 2.5 0.
0. 0. 0. -745.375 4.366001 2.5 0. 0. 0. -745.375 4.366001
"N2     " 0 0 0 2 0 0 0 28.0133991 3 300. 1000. 5000. 3.298677
0.00140824 -3.963222E-06 5.641515E-09 -2.444855E-12 -1020.9 3.950372
2.92664 0.001487977 -5.684761E-07 1.009704E-10 -6.753351E-15 -922.7977
5.980528
-5 2 4.35E+09 0. 15098.1385 -1 2 -1 17 0 0 12 9 11 4 1 17 5 3 1.E+15 0.
39255.16 -1 3 -1 17 -1 9 1 9 2 14 0 0 6 3 1.6E+09 0.5 22093.6093 -1 5 -1 17
-1 7 2 15 1 4 1 5 4 2 3.E+13 1. 19124.3087 -1 3 -1 1 0 0 1 8 1 5 0 0 4 2
2.5E+15 0. 3019.62769 -1 3 -1 5 0 0 1 4 1 6 0 0 4 2 4.E+14 0. 9058.88307
-1 4 -1 1 0 0 1 5 1 6 0 0 4 2 1.E+18 0. 61519.3782 -1 17 -1 1 0 0 2 5 1 17 0

```



```

0 3 2 4.E+20 -1. 0. -1 3 -2 4 0 0 2 3 0 0 0 0 3 2 1.E+15 -1.15 0. -1 4 -1 1
0 0 1 7 0 0 0 0 4 2 1.E+13 0. 0. -1 6 -1 7 0 0 1 8 1 1 0 0 4 2 6.5E+13 0.
0. -1 4 -1 7 0 0 1 3 1 1 0 0 4 2 2.5E+13 0. 0. -1 5 -1 7 0 0 1 6 1 1 0 0 4
2 15100000. 1.28 -381.479632 -1 11 -1 6 0 0 1 10 1 4 0 0 4 2 1.5E+17 0.
-381.479632 -1 17 -2 9 0 0 1 12 1 17 0 0 4 2 3.E+15 0. 9562.15435 -1 12 -1 1
0 0 2 11 1 3 0 0 4 2 3.E+13 0. 3019.62769 -1 9 -1 6 0 0 1 11 1 3 0 0 4 2
3.E+12 0.6 0. -1 9 -1 5 0 0 1 11 1 4 0 0 4 2 1.E+11 0. 0. -1 9 -1 15 0 0
1 14 1 11 0 0 4 2 9.E+13 0. 37745.3461 -1 17 -1 5 0 0 1 13 1 15 0 0 4 2
6.3E+09 1. 3170.60907 -1 13 -1 1 0 0 1 15 1 5 0 0 4 2 1.E+12 0.
24157.0215 -1 15 -1 4 0 0 1 13 1 6 0 0 4 2 25000. 2.64 0. -1 14 -1 5 0 0 1
15 1 4 0 0 4 2 2.E+15 -0.8 0. -1 14 -1 15 0 0 1 17 1 6 0 0
2 1.95E+15 0. 0.3 2.5E+10 0. 4026.17025 7 4.E+18 0. 0.

```

Listing 8.2.3: PLOTM060A-010.DAT TECPLOT output file

```

variables =
"x"
"y"
"z"
zone f=block, t="forebody : top", i= 31
,j= 31
0.0000000000E+00
0.9738366363E-10
0.9117331778E-08
0.1297335075E-06
0.8535901657E-06
0.3680378768E-05
0.1214601616E-04
0.3333144195E-04
0.7991550956E-04
0.1728295756E-03
0.3445673501E-03
0.6432000082E-03
0.1137144165E-02
0.1920724637E-02
0.3120583249E-02
0.4902962130E-02
0.7481913548E-02
0.1112846565E-01
0.1618078910E-01
0.2305538580E-01
0.3225936368E-01
0.4440378770E-01
0.6021819264E-01
0.8056626469E-01
0.1064626127E+00
0.1390910000E+00
0.1798236370E+00
.....
.....
.....
.....
.....
0.2112343460E+00
0.2393971682E+00
0.2393971682E+00
0.9475558996E-01
0.1236315519E+00
0.1525074989E+00
0.1813834608E+00
0.2102594078E+00
0.2391353548E+00
0.2391353548E+00

```

8.3 Run UCDA to Generate Tables and Input Files for UPTOP

This section corresponds to the Step 1 in the Graphical User Interface (GUI). See Figure 8.3.1 below.

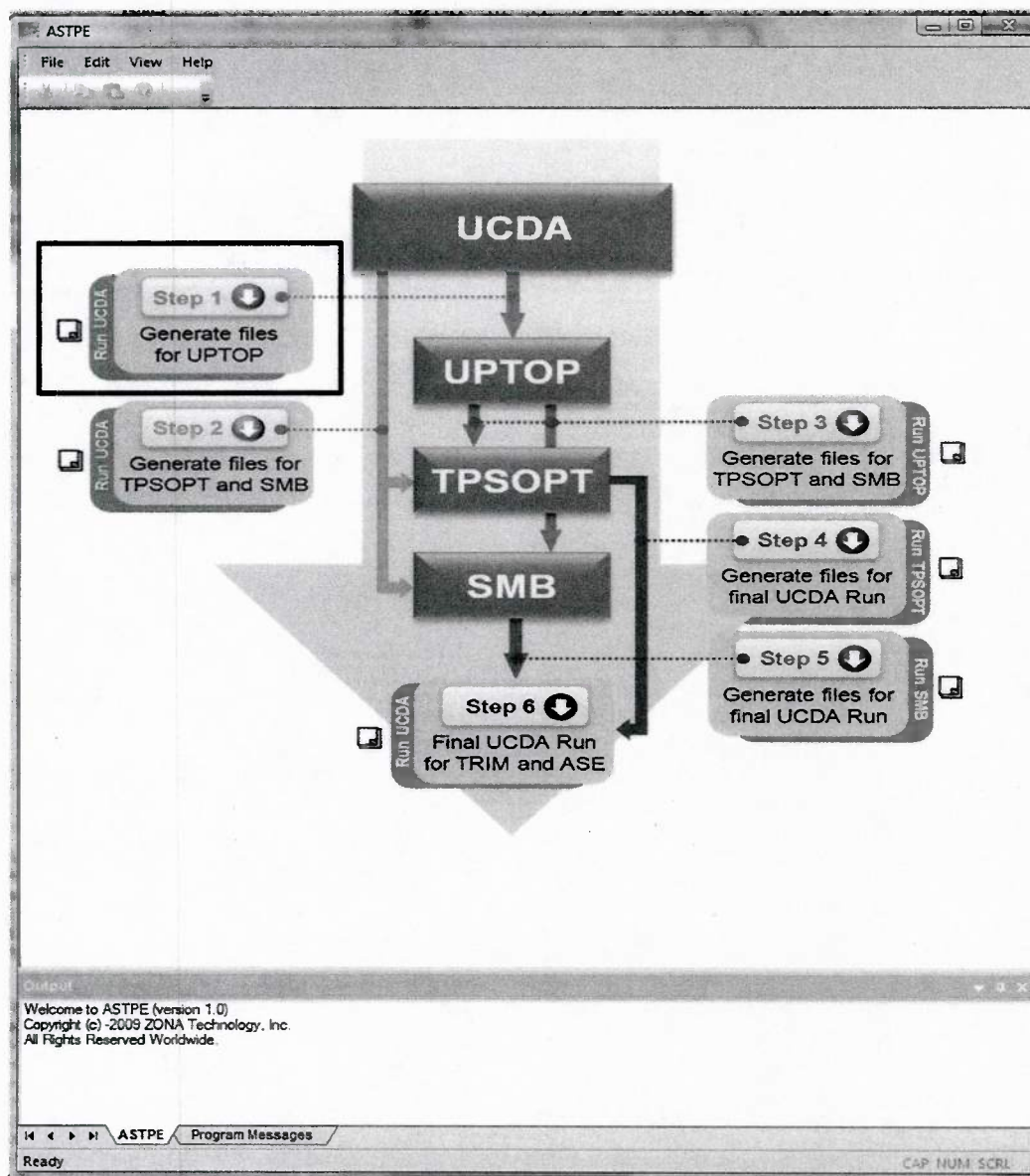


Figure 8.3.1 Section Corresponding to Step 1 of GUI

8.3.1 Generate Tab Files

Input Files:

File Name	Type	Remarks	See Listing
vehicle.inp	Standard input file	Also look at Table 8.3.1.a 8.3.1b	Shown in Listing 8.3.1
chem.bin	Engine chemistry information	Required	Shown in Listing 8.2.2

Output Files:

File Name	Type	Remarks	See Listing
lift.tab	Tabular format	Aerodynamic information for UPTOP	Shown in Listing 8.3.2
drag.tab	Tabular format	Aerodynamic information for UPTOP	Shown in Listing 8.3.3
fuel.tab	Tabular format	Aerodynamic information for UPTOP	Shown in Listing 8.3.4
thr.tab	Tabular format	Aerodynamic information for UPTOP	Shown in Listing 8.3.5

Input File descriptions

vehicle.inp: See Listing 8.3.1 for the entire input file. The parts of the input file that are used to generate the tables for UPTOP are displayed in Tables 8.3.1a and 8.3.1b. Table 8.3.1a shows the necessary parameters to control the creation of such tables and Table 8.3.1b shows a matrix of trajectory points. It can be noted that to generate tables for UPTOP, **itrajectory** has to be set to **2** and **offdesign.dat** switch has to be set to **2**. These are the only change needed from the earlier run of Section 8.2.

Different points on the trajectory are defined by the way shown in Table 8.3.1b. There are six lines in Table 8.3.1b. Each line has its own parameter such as altitude, dynamic pressure, throttle etc. Since **ialtdyn** is set to **2** (Table 8.3.1a), the code does not need to run corresponding to the altitude. Also, since **ithrottle** is set to **1**, the line with the Equivalence ratio is not used. More discussions on this can be found in the User's Manual. Thus, the code goes through the rest of the four variables. Each variable has got its lower bound and upper bound defined in the

first and third number from the left. Also, the fifth variable is the value of its interval. For example, for Mach number, the lower bound is 6.0, upper bound is 8.0 and interval is 0.5. Thus, the code will run through 5 points for Mach number. Similarly, each of these four parameters has such bounds and intervals. Thus, the code runs a combination of all possible points, which is a total of 3 dynamic pressure points x 21 throttle points x 5 mach number points x 11 angle of attack points = 3465 points.

chem.bin: This file remains the same for all UCDA runs. Please see Section 8.2 for description on this file.

Table 8.3.1a Necessary Blocks Controlling TAB File Creation for UPTOP

TEST INPUT DECK: Note - this line must be here!	
2	ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1	ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle
1	iunits - Output unit switch: SI (1) or English (2)
3	ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1	iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2	inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1	iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
2	itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0	icone - cone flow data: exact (0), curve-fit approximation (1)
1	imodel - Forebody type: WA (1), VWA (2), or VWA + cone flow (3)
0	itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0	ideriv - Calculate derivatives: no (0), yes (1)
0	tps - If itps is 1, then prepare for tps and smb. nderiv and itps cannot be 1 at one time
0	ifedback - If 1, then gets weight and Cg information from SMB and TPSOPT
OUTPUT FILE SWITCHES AND NAMES:	
1	'plot.dat' VEHICLEFIG: off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23	1st # -> # of variables to read, others -> vars to plot
1	'metrics.dat' METRICS: off (0), on (1)
0	'cowlexit.dat' COWLEXIT: off (0), on (1)
0	'moc.dat' NOZFIG: off (0), P,T,M (1), all (2)
2	'offdesign.dat' AOA: off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0	'scramjet.dat' CKENGINE: off (0), on (1)
0	IPRINTINLET: off (0), all (1), results (2), all-real (3), results-real (4)
0	IPRINTENGINE: off (0), on (1)
0	IDEBUG: off (0), on (1) [print debugging info]

Table 8.3.1b Necessary Blocks to Run a Matrix of Points to Generate Table

INPUT DATA: (0 = degrees, 1 = m, 2 = ft, 3 = atm, 4 = dimensionless, K or kg, 5 = psf)					
xl	x	xu	unit	res	name
22500.	26000.	30000.	1	2500.	'altitude' - altitude (if required)

2000.	2200.	2400.0	5	200.	'q0'	- dynamic pressure (if required)
.50	1.099	1.0	4	.250	'equiv'	- equivalence ratio
1.	1.	0.0	4	-.05	'throttle'	- engine throttle (if required)
6.0	6.00	8.00	4	.5	'm0'	- Mach number
-2.0	-1.0	3.00	0	.5	'AOA'	- angle of attack

Output File Descriptions

lift.tab: For each of the points described above, lift is tabulated in this file. Please see Listing 8.3.2.

drag.tab: For each of the points described above, drag is tabulated in this file. Please see Listing 8.3.3.

fuel.tab: For each of the points described above, fuel is tabulated in this file. Please see Listing 8.3.4.

thr.tab: For each of the points described above, thrust is tabulated in this file. Please see Listing 8.3.5.

UPTOP requires these four tabulated results to find the optimized trajectory.

The computational run time to generate the *.tab files for UPTOP is approximately 1 hour for sample SEM.

8.3.2 Generate Input Files

Input Files:

File Name	Type	Remarks	See Listing
vehicle.inp	Standard input file	Also look at Table 8.3.2	Shown in Listing 8.3.6
chem.bin	Engine chemistry information	Required and does not change	Shown in Listing 8.2.2

Output Files:

File Name	Type	Remarks	See Listing
traj.inp	Standard input for UPTOP	Main input file for UPTOP	Shown in Listing 8.3.7
model.inp	Standard input for UPTOP	Information about model	Shown in Listing 8.3.8

Input File Descriptions

vehicle.inp: See Listing 8.3.6 for the entire input file. The part of the input file that is used to generate the input files model.inp and traj.inp for UPTOP is shown in Tables 8.3.2. It can be seen comparing Listings 8.3.1 and 8.3.6 that the only changes between these two vehicle.inps are in the parameters **itrajectory** and **offdesign.dat** file switch. For the generation of the *.tab files, **itrajectory** was set to 2. Here, as noted in Table 8.3.2, **itrajectory** is set to 0. The flag for **offdesign.dat** is changed to 3 from 2. These changes will generate model.inp and traj.inp.

Table 8.3.2: Changes in Input from Table 8.3.1a for Generating INP Files

TEST INPUT DECK: Note - this line must be here!			
2	ialtdyn	- Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)	
1	ithrottle	- Run engine as a function of: (0) equivalence ratio, (1) % throttle	
1	iunits	- Output unit switch: SI (1) or English (2)	
3	ivisc	- Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)	
1	iequiv	- find max equiv ratio for choked flow: off (0) -> single run, on (1)	
2	inozorder	- Nozzle polynomial order: 1st (flat plate) -> 3rd	
1	iheight	- Height constrained vehicle: no (0) = inlet set, yes (1) = height set	
0	itrajectory	- Run multiple trajectory points: no (0), discrete (1), matrix (2)	
0	icone	- cone flow data: exact (0), curve-fit approximation (1)	
1	imodel	- Forebody type: WA (1), VWA (2), or VWA + cone flow (3)	
0	itrim	- Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)	
0	ideriv	- Calculate derivatives: no (0), yes (1)	
0	itps	- If itps is 1, then prepare for tps and smb. nderiv and itps cannot be 1 at one time	
0	ifedback	- If 1, then gets weight and Cg information from SMB and TPSOPT	
OUTPUT FILE SWITCHES AND NAMES:			
1	'plot.dat'	VEHICLEFIG:	off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23	1st # -> # of variables to read, others -> vars to plot		
1	'metrics.dat'	METRICS:	off (0), on (1)
0	'cowlexit.dat'	COWLEXIT:	off (0), on (1)
0	'moc.dat'	NOZFIG:	off (0), P,T,M (1), all (2)
3	'offdesign.dat'	AOA:	off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0	'scramjet.dat'	CKENGINE:	off (0), on (1)
0		IPRINTINLET:	off (0), all (1), results (2), all-real (3), results-real (4)
0		IPRINTENGINE:	off (0), on (1)
0		IDEBUG:	off (0), on (1) [print debugging info]

Output File descriptions

traj.inp: See Listing 8.3.7 for this output. This file is the main input file for UPTOP. It contains information about orientation parameters, optimization parameters, event parameters, engine throttle control etc. Please see Section 4.5.1 of User's Manual for detailed description.

model.inp: See Listing 8.3.8 for this output that is used by UPTOP as a standard input file. This file contains information about number of components, engine, fuel tank etc. The detailed explanation of this file can be found in Section 4.5.4 of User's Manual.

The computational run time to generate the input files for UPTOP is about a few seconds.

Listing 8.3.1: Vehicle.inp Input File for UPTOP Tab File Generation

```

TEST INPUT CHECK: Note - this line must be here!
2      ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1      ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle
1      iunits - Output unit switch: SI (1) or English (2)
3      ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1      iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2      inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1      iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
2      itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0      icone - cone flow data: exact (0), curve-fit approximation (1)
1      imodel - Forebody type: WA (1), VWA (2), or VWA + cone flow (3)
0      itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0      ideriv - Calculate derivatives: no (0), yes (1)
0      itps - If itps is 1, then prepare for tps and smb. ideriv and itps cannot be 1 at one time
0      ifeedback - If 1, then gets weight and Cg information from SMB and TPSOPT

OUTPUT FILE SWITCHES AND NAMES:
1      'plot.dat'          VEHICLEFIG:      off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23          1st # -> # of variables to read, others -> vars to plot
1      'metrics.dat'      METRICS:      off (0), on (1)
0      'cowlexit.dat'     COWLEXIT:      off (0), on (1)
0      'moc.dat'          NOZFIG:      off (0), P,T,M (1), all (2)
2      'offdesign.dat'    AOA:         off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0      'scramjet.dat'    CKENGINE:     off (0), on (1)
0      IPRINTINLET:      off (0), all (1), results (2), all-real (3), results-real (4)
0      IPRINTENGINE:     off (0), on (1)
0      IDEBUG:           off (0), on (1) [print debugging info]

ZONE DATA AND GRID SIZES:
16      NUMBER OF ZONES
'forebody : top'          31          31
'keel : top'              101         6
'aftbody : top'           101         31
'forebody : bot'          31          31
'ramps : bot'             55          6
'comb : bot'              101         6
'cowl : top'              101         6
'nozzle : bot'            31          6
'ramp walls : inside'     35          6
'comb wall : inside'      101         7
'nozzle wall : inside'    21          7
'aftbody : bot'           101         31
'cowl : bot'              101         6
'ramp walls : outside'    35          6
'comb wall : outside'     101         7
'nozzle wall : outside'   21          7

INPUT DATA: (0 = degrees, 1 = m, 2 = ft, 3 = atm, 4 = dimensionless, K or kg, 5 = psf)
xl      x      xu      unit      res name
22500.  26000.  30000.  1      2500.      'altitude' - altitude (if required)
2000.   2200.   2400.0   5      200.       'q0'       - dynamic pressure (if required)
.50     1.099   1.0        4      .250       'equiv'    - equivalence ratio
1.       1.       0.0        4      -.05       'throttle' - engine throttle (if required)
6.0     6.00    8.00       4      .5         'm0'       - Mach number
-2.0    -1.0    3.00       0      .5         'AOA'      - angle of attack
6.0     4       'Mdes'      - design Mach number
1.0     0       'AOAdeg'    - design angle of attack
21800.  1       'Zdes'      - design altitude
4.2672  1       'lvehicle'  - vehicle length
6.0000  0       'thforclu'  - forebody upper surface angle
5.2797  0       'thforcil'  - forebody ramp angle
0.5873  1       'lcontrol'  - control surface length
7.73    0       'th_control' - control surface deflection angle
0.9920  0       'th_expn'   - nozzle initial expansion angle
10.8958 0       'th_exit'   - nozzle exit angle
0.0     4       'p_nozpoly' - % diff between nozzle designs [DON'T USE-defaulted to 1.]
1.901   1       'lcowl'     - cowl length (isolator/combustor)

```

.3	1	'lcowlex'	- cowl extension length (internal nozzle)
0.545	4	'p_iso'	- percent of lcowl that is isolator
.3238	1	'height'	- height of vehicle (if required)
20.0	1	'linlet'	- inlet length of vehicle (if required)
.26	1	'wengine'	- width of the engine (currently defaulted to unit width)
3.00	4	'iramps'	- number of inlet ramps in addition to the forebody
6.4012	0	'th_ramp1'	- inlet ramp 1 angle
5.2383	0	'th_ramp2'	- inlet ramp 2 angle
5.5	0	'th_ramp3'	- inlet ramp 3 angle
0.0	0	'th_ramp4'	- inlet ramp 4 angle
0.0	0	'th_ramp5'	- inlet ramp 5 angle
3.09	0	'th_div1'	- first combustor expansion angle
0.2	0	'th_div2'	- second combustor expansion angle
0.01	1	'Xinjs'	- beginning of injectors (m)
0.02	1	'Xinje'	- end of injectors (m)
0.01	1	'Lmix'	- fuel mixing length (m)
1.00	4	'eta_mix'	- fuel mixing and burning efficiency
3000.	4	'Tlimit'	- maximum engine temperature (K)
90.	0	'Thetainj'	- injector angle (degrees) [90 deg. is normal to flow]
1200.	4	'Tw'	- adiabatic wall temperature (K)
0.1527	4	'nfor'	- forebody exponent n
2.0	2	'wfor'	- forebody width
1.5	2	'lfor'	- forebody length
0.2427	4	'mfor'	- forebody exponent m
5.797	0	'thforle'	- forebody leading edge angle
21.519	0	'th_le'	- leading edge attachment angle
0.0000	4	'p_kl'	- keel-line height percentage
0.25	4	'fuelfrac'	- vehicle fuel volume fraction
0.0104	2	't_plate'	- shell plate thickness (Tungsten)
0.0	4	'mass_smb'	- mass due to Structural Modal Base (SMB) analysis
0.0	4	'mass_tps'	- mass due to Thermal Protection System (TPS) analysis
0.0	4	'mass_nose'	- lumped mass at the nose to manipulate CG

Listing 8.3.2: Lift.tab Output File From UCDA / Input File for UPTOP

```

1
    4
    3      10
    5      11
    11     30
    21     201

1 0
95760.52
105336.6
114912.6
6.000000
6.500000
7.000000
7.500000
8.000000
-2.000000
-1.500000
-1.000000
-0.500000
0.000000E+00
0.500000
1.000000
1.500000
2.000000
2.500000
3.000000
1.000000
0.950000
0.900000
0.850000
0.800000
0.750000
0.700000
0.650000
0.600000
0.550000
0.500000
0.450000
0.400000
0.350000
0.300000
0.250000
0.200000
0.150000

*** END ***

6.1231308E-02
6.0872644E-02
6.0495283E-02

```

```

5.9861157E-02
5.9576988E-02
7.5901493E-02
7.5594895E-02
7.5364500E-02
7.5144343E-02
7.4288003E-02
7.3953614E-02
7.3910423E-02
7.3712774E-02
7.3261432E-02
7.2765857E-02
7.2147928E-02
7.2014943E-02
7.1837217E-02
7.1294241E-02
7.0829764E-02
7.0054948E-02
6.9974072E-02
6.9765061E-02
6.9011092E-02
6.8698600E-02
6.8210095E-02

```

Listing 8.3.3: Drag.tab Output File From UCDA / Input File for UPTOP

```

1
      4
      3      10
      5      11
      11     30
      21     201
1 0
95760.52
105336.6
114912.6
6.000000
6.500000
7.000000
7.500000
8.000000
-2.000000
-1.500000
-1.000000
-0.500000
0.000000E+00
0.500000
1.000000
1.500000
2.000000
2.500000
3.000000
1.000000
0.950000
0.900000
0.850000
0.800000
0.750000
0.700000
0.650000
0.600000
0.550000
0.500000
0.450000
0.400000
0.350000
0.300000
0.250000
0.200000

-----
-----
-----
-----
8.3374046E-03
9.0313768E-03
9.6361507E-03
1.0392137E-02
1.1000030E-02
1.1595636E-02
1.2130089E-02
1.2826661E-02
1.3497436E-02
1.4106624E-02
1.4658505E-02
1.5280219E-02
1.5944134E-02

```

```

1.6530558E-02
1.7155927E-02
1.7733576E-02
1.8403927E-02
1.9007692E-02
1.9560510E-02
2.0167571E-02
2.0705635E-02
1.1527042E-02
1.2119142E-02
1.2714200E-02
1.3287483E-02
1.3990060E-02
1.4618386E-02
1.5112401E-02
1.5638512E-02
1.6221626E-02
1.6789125E-02
1.7442724E-02
1.7956434E-02
1.8487418E-02
1.9095829E-02
1.9659458E-02
2.0250056E-02
2.0792818E-02
2.1308286E-02
2.1880256E-02
2.2395287E-02
2.2949908E-02

```

Listing 8.3.4: Fuel.tab Output File From UCDA / Input File for UPTOP

```

1
    4
    3      10
    5      11
    11     30
    21     201
1 0
  95760.52
  105336.6
  114912.6
   6.000000
   6.500000
   7.000000
   7.500000
   8.000000
  -2.000000
  -1.500000
  -1.000000
 -0.500000
  0.000000E+00
  0.5000000
  1.000000
  1.500000
  2.000000
  2.500000
  3.000000
  1.000000
  0.950000
  0.900000
  0.850000
  0.800000
  0.750000
  0.700000
  0.650000
  0.600000
  0.550000
  0.500000
  0.450000
  0.400000
  0.350000
  0.300000
  0.250000

*** END ***

*** END ***

*** END ***

  0.2366534
  0.2208765
  0.2050996
  0.1893227
  0.1735458
  0.1577689
  0.1419920
  0.1262151
  0.1104382
  9.4661348E-02
  7.8884453E-02
  6.3107565E-02

```

```

4.7330674E-02
3.1553783E-02
1.5776888E-02
-4.7018802E-09
0.2897106
0.2752251
0.2607396
0.2462541
0.2317685
0.2172830
0.2027974
0.1883119
0.1738264
0.1593409
0.1448553
0.1303698
0.1158843
0.1013987
8.6913191E-02
7.2427660E-02
5.7942126E-02
4.3456595E-02
2.8971061E-02
1.448528E-02
-4.3170250E-09

```

Listing 8.3.5: Thr.tab Output File From UCDA / Input File for UPTOP

```

1
      4
      3      10
      5      11
     11      30
     21      201
1 0
 95760.52
105336.6
114912.6
 6.000000
 6.500000
 7.000000
 7.500000
 8.000000
-2.000000
-1.500000
-1.000000
-0.500000
0.000000E+00
0.500000
 1.000000
 1.500000
 2.000000
 2.500000
 3.000000
 1.000000
0.950000
0.900000
0.850000
0.800000
0.750000
0.700000
0.650000
0.600000
0.550000
0.500000
0.450000
0.400000
0.350000
0.300000
0.250000
0.200000
0.150000
 9.9999987E-02
 4.9999986E-02
-1.4901161E-08
 5.6110002E-02

*** END ***

*** END ***

*** END ***

0.1552322
0.1324296
0.1117751
 9.2845812E-02
 7.2162598E-02
 5.3708833E-02
 0.4407576

```

```

0.0      4      'p_nozpoly' - % diff between nozzle designs [DON'T USE-defaulted to 1.]
1.901    1      'lcowl'    - cowl length (isolator/combustor)
.3        1      'lcowext'  - cowl extension length (internal nozzle)
0.545     4      'p_iso'    - percent of lcowl that is isolator
.3238     1      'height'   - height of vehicle (if required)
20.0      1      'linlet'   - inlet length of vehicle (if required)
.26       1      'wengine'  - width of the engine (currently defaulted to unit width)
3.00      4      'iramps'   - number of inlet ramps in addition to the forebody
6.4012    0      'th_ramp1' - inlet ramp 1 angle
5.2383    0      'th_ramp2' - inlet ramp 2 angle
5.5       0      'th_ramp3' - inlet ramp 3 angle
0.0       0      'th_ramp4' - inlet ramp 4 angle
0.0       0      'th_ramp5' - inlet ramp 5 angle
3.09      0      'th_div1'  - first combustor expansion angle
0.2       0      'th_div2'  - second combustor expansion angle
0.01      1      'Xinjs'    - beginning of injectors (m)
0.02      1      'Xinje'    - end of injectors (m)
0.01      1      'Lmix'     - fuel mixing length (m)
1.00      4      'eta_mix'   - fuel mixing and burning efficiency
3000.     4      'Tlimit'    - maximum engine temperature (K)
90.       0      'Thetainj' - injector angle (degrees) [90 deg. is normal to flow]
1200.     4      'Tw'       - adiabatic wall temperature (K)
0.1527    4      'nfor'     - forebody exponent n
2.0       2      'wfor'     - forebody width
1.5       2      'lfor'     - forebody length
0.2427    4      'mfor'     - forebody exponent m
5.797     0      'thforle'  - forebody leading edge angle
21.519    0      'th_le'    - leading edge attachment angle
0.0000     4      'p_kl'     - keel-line height percentage
0.25      4      'fuelfrac'  - vehicle fuel volume fraction
0.0104    2      't_plate'  - shell plate thickness (Tungsten)
0.0       4      'mass_smb'  - mass due to Structural Modal Base (SMB) analysis
0.0       4      'mass_tps'  - mass due to Thermal Protection System (TPS) analysis
0.0       4      'mass_nose' - lumped mass at the nose to manipulate CG

```

Listing 8.3.7: Traj.inp Output File From UCDA / Input File for UPTOP

```

RUN METHOD
10 (0-single case, 1-new GA, 2-restart, 3-mapspace)

OPTIMIZATION VARIABLES
INITIAL CONDITIONS
ON/OFF      Xo      XL      XU      VARIABLE NAME
-----
1  23693.8  21233.2  26154.4  initial altitude (m)
0   0.0    -10.0    10.0    initial gamma
1  -6.2    -8.0    -6.0    initial velocity (m/s)

ORIENTATION PARAMETERS
2 Mode (1 - rpy, 2 - aeroballistic angles)
-----
30 angle 1 id
0 Variable Mode
1 Curve fit order
1 Independent Variable type
2 Number of Control Points
0 0 0.0 1.0 10.0
0 0 500.0 1.0 10.0
1 0 -1.5 -2.0 3.0
1 0 -1.0 -2.0 3.0

32 angle 1 id
2 Variable Mode
0 0 0 0

31 angle 1 id
2 Variable Mode
0 0 0 0

EVENT PARAMETERS
0 Number of Control Points
Type info(2) info(3) Type Var Xo XL Xu
-----

ENGINE THROTTLE CONTROLS
1 Number of engine specifications
-----
1 Engine Number
2 Specification Type
0 1 0 0

TERMINATION PARAMETERS
Opt Info(1) Var Value XL Xu
-----
0 0 -551 1. 0 0

NAVIGATION PARAMETERS
-----
0 0. 0. 10. mu

```



```

0.4207702
0.4006385
0.3812354
0.3575782
0.3362620
0.3194262
0.3015297
0.2817416
0.2624639
0.2402709
0.2227190
0.2045566
0.1838708
0.1646255
0.1444584
0.1258453
0.1081174
8.8576645E-02
7.0929833E-02
5.1928550E-02

```

Listing 8.3.6: Vehicle.inp Input File for UPTOP Input (INP) File Generation

```

TEST INPUT DECK: Note - this line must be here!
2 ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1 ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle
1 iunits - Output unit switch: SI (1) or English (2)
1 ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1 iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2 inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1 iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
0 itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
1 icone - cone flow data: exact (0), curve-fit approximation (1)
1 imodel - Forebody type: WA (1), VWA (2), or VWA + cone flow (3)
0 itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0 ideriv - Calculate derivatives: no (0), yes (1)
0 itps - If itps is 1, then prepare for tps and smb. ideriv and itps cannot be 1 at one time
0 ifeedback - If 1, then gets weight and Cg information from SMB and TPSOPT

OUTPUT FILE SWITCHES AND NAMES:
1 'plot.dat' VEHICLEFIG: off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23 1st # -> # of variables to read, others -> vars to plot
1 'metrics.dat' METRICS: off (0), on (1)
0 'cowlexit.dat' COWLEXIT: off (0), on (1)
0 'moc.dat' NOZFIG: off (0), P,T,M (1), all (2)
3 'offdesign.dat' AOA: off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0 'scramjet.dat' CKENGINE: off (0), on (1)
0 IPRINTINLET: off (0), all (1), results (2), all-real (3), results-real (4)
0 IPRINTENGINE: off (0), on (1)
0 IDEBUG: off (0), on (1) [print debugging info]

ZONE DATA AND GRID SIZES:
16 NUMBER OF ZONES
'forebody : top' 31 31
'keel : top' 101 6
'aftbody : top' 101 31
'forebody : bot' 31 31
'ramps : bot' 55 6
'comb : bot' 101 6
'cowl : top' 101 6
'nozzle : bot' 31 6
'ramp walls : inside' 35 6
'comb wall : inside' 101 7
'nozzle wall : inside' 21 7
'aftbody : bot' 101 31
'cowl : bot' 101 6
'ramp walls : outside' 35 6
'comb wall : outside' 101 7
'nozzle wall : outside' 21 7

INPUT DATA: (0 = degrees, 1 = m, 2 = ft, 3 = atm, 4 = dimensionless, K or kg, 5 = psf)
x1 x xu unit res name
22500. 26000. 30000. 1 2500. 'altitude' - altitude (if required)
2000. 2200. 2400.0 5 200. 'q0' - dynamic pressure (if required)
.50 1.099 1.0 4 .250 'equiv' - equivalence ratio
1. 1. 0.0 4 -.05 'throttle' - engine throttle (if required)
6.0 6.00 8.00 4 .5 'm0' - Mach number
-2.0 -1.0 3.00 0 .5 'AOA' - angle of attack
6.0 4 'Mdes' - design Mach number
1.0 0 'AOA des' - design angle of attack
21800. 1 'Zdes' - design altitude
4.2672 1 'lvehicle' - vehicle length
6.0000 0 'thforclu' - forebody upper surface angle
5.2797 0 'thforcll' - forebody ramp angle
0.5873 1 'lcontrol' - control surface length
7.73 0 'th_control' - control surface deflection angle
0.9920 0 'th_expn' - nozzle initial expansion angle
10.8958 0 'th_exit' - nozzle exit angle

```

```

0 0. 0. 10. longitude
0 90. 0. 10. heading

```

VARIABLE TRACKING

```

1 Number of Variables to Track
Var      Trig Var Start  End
-----
2        6          0    0    0    -1

```

OPTIMIZATION AND CONSTRAINT PARAMETERS

```

1 Number of Optimization Variables
Var  Type  Weight  Ending Trig  Target
60 1 .001 0 -1. 0.

2 Number of Constraint Variables
Var  Type  Weight  Ending Trig  Start Trig  Tol  Target
1001 1 1.00 0 -1.00 0 0.0000 1000.0000 0.0000
1001 -1 1.00 0 -1.00 0 0.0000 1000.0000 0.0000

```

IO FILES

```

1 number of output files

3 5 output format, number of output variables
1 del(time) if >0; stride if <0
1 11 2 30 32 variable ids (from varlist.txt)
traject.dat output filename

```

Listing 8.3.8: Model.inp Output File from UCDA / Input File for UPTOP

GENERAL INFORMATION

```

1 Number of vehicle components

```

Stage/Component Linking

```

num no comps component numbers
1 1 1

```

Stage Reference Areas

```

aref opt switch xu xl
0 1.282013 0. 0. stage(1)

```

Nose Radius

```

Rn Opt Flag -Bn +bn
0 6.4000001E-06 0. 100.

```

VEHICLE COMPONENT PARAMETERS

```

***** Component 1 Information *****
0 572.6713 0. 0. Dry Vehicle Mass (kilograms)

```

Engine Information

```

1 Total Number of Engines groups
Eng No. Exit Area (m^2) tswitch fswitch orientation
1 0 0 0
0 7.8376569E-02 0 0 engine area

```

Fuel Tank Information

```

1 Total Number of Fuel Tanks
Tank no. fuel mass (kg) stage association
1 0 93.72025 0. 0.

```

ENGINE/TANK LINKING + LIMITS

```

1 Total number of links
engine tank earliest on latest off
1 1

```

DIMENSION CONVERSIONS

```

1. 0 .1 1. length
1. 0 .1 1. mass

```

VEHICLE CONSTRAINTS

```

0
on/off var type limit

```

8.4 Run UPTOP to Generate Optimized Trajectory for Use in TPSOPT and SMB

This section corresponds to the Step 3 in the Graphical User Interface (GUI). See Figure 8.4.1 below.

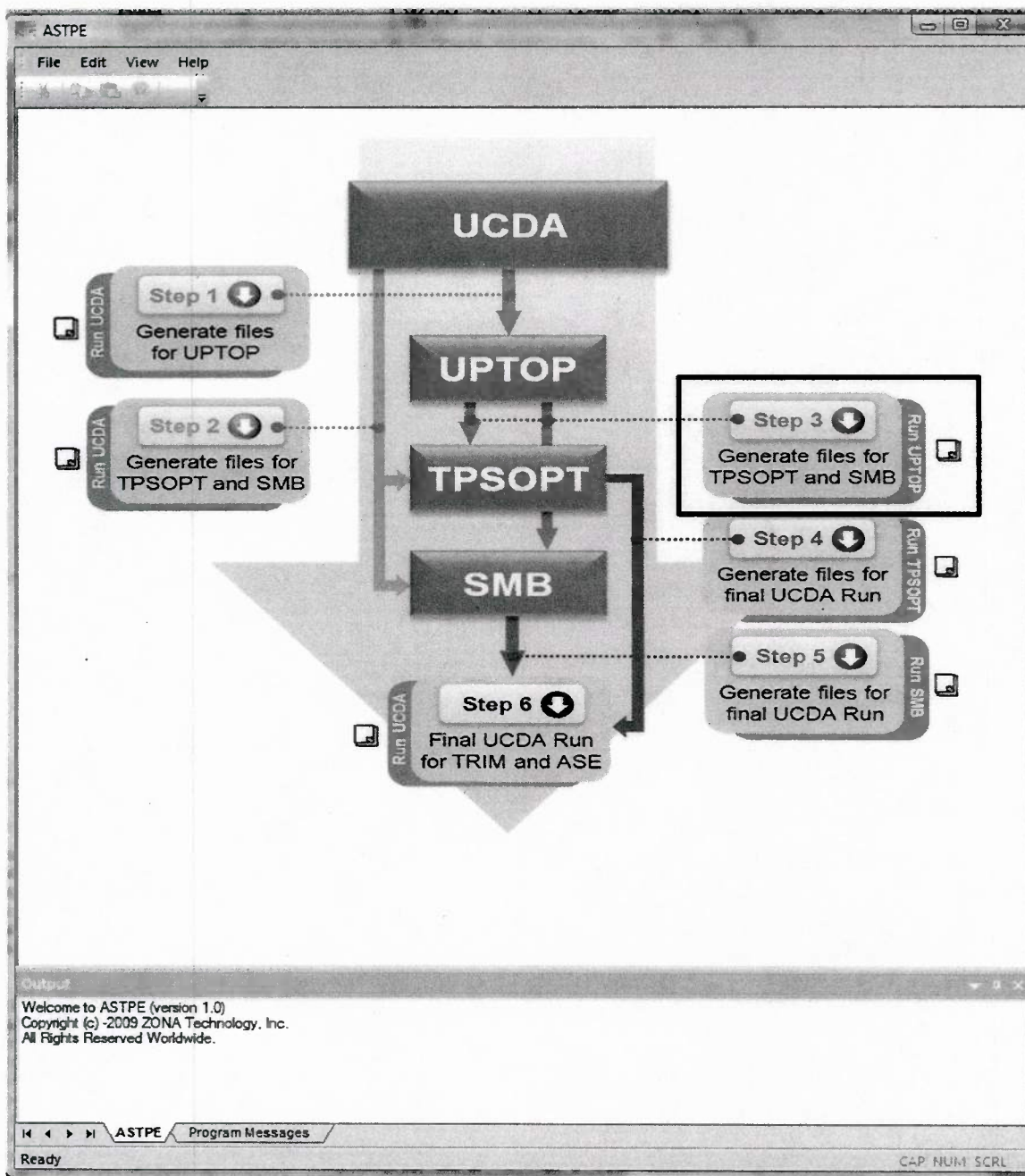


Figure 8.4.1 Section Corresponding to Step 3 of GUI

Input Files:

File Name	Type	Remarks	See Listing
des.inp	Standard input file	Required	Shown in Listing 8.4.1
params.inp	Standard input file	Required	Shown in Listing 8.4.2
traj.inp model.inp lift.tab drag.tab fuel.tab thr.tab	Input and Table files needed to generate optimized trajectory	Generated by UCDA (described in Section 8.3)	Shown in Listing 8.3.2-8.3.5, 8.3.7-8.3.8

Output Files:

File Name	Type	Remarks	See Listing
trajct.dat	Optimized trajectory as input to TPSOPT and SMB	Time, Altitude, Angle of attack and Mach number information	Shown in Listing 8.4.3
output.dat	TECPLOT format	Plotted in Fig. 8.4.2	Not Shown

Input File descriptions

des.inp: See Listing 8.4.1 for des.inp input file to UPTOP. This file specifically caters to DES optimizer. If the optimization method is fixed, this input is fixed. Thus, this file is used for all the cases in ASTPE.

params.inp: See Listing 8.4.2 for params.inp input file to UPTOP. This file contains different necessary parameters about trajectory, earth/orbit, optimization etc.

The details on each of these files are listed in the User's Manual (Sections 4.5.2 and 4.5.3).

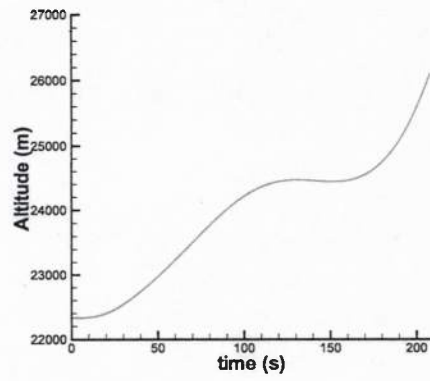
Output File descriptions

trajct.dat: See Listing 8.4.3 for this file. This file is a necessary input file for TPSOPT and SMB. Both TPSOPT and SMB need this file to compute heat flux and load respectively. The number

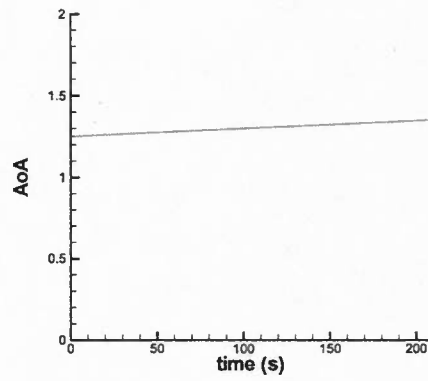
of points in trajct.dat is kept at 25 to maintain enough information about the trajectory without giving up computational efficiency.

OUTPUT.DAT: This is a TECPLOT format file and it contains optimized trajectory information. Figure 8.4.2 plots altitude, angle of attack and Mach number with respect to time using this file.

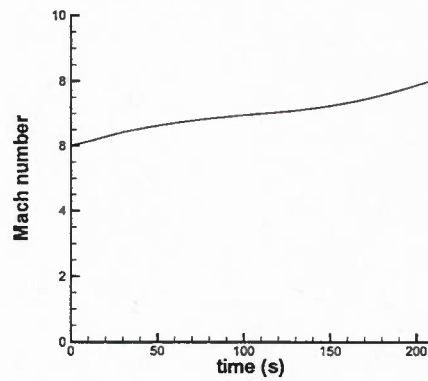
The computational time to finish this UPTOP run is approximately 10 minutes for sample SEM.



(a) Altitude



(b) AoA



(c) Mach number

Figure 8.4.2 SEM trajectory of Design Cycle 1

Listing 8.4.1: Des.inp UPTOP Input File

```
DES INPUTS

Run Control
-9          Restart (0 - new run, 1- restart)
100         Maximum Generations
0           Convergence Criteria (# of generations without improvement)
-9          Stop when value reached

Input/Output Control
100         restart file write frequency (number of generations)
-9          screen output
1           file output (0 - off/external, 1 - only rec. improvements, 2 - all)
0           dvrec.out placement
10          dvrec.out flush increment

Optimization Control
0           Pareto Optimization (0 - single obj fcn, 1 - Pareto-front optimization)
0           random number seed (0 - fcn of date, else specify exact)
50          population size
0           Localization Switch
0.          diversity threshold
0.          diversity radius

DES Operator Parameters
1           number of differential terms (1-3)
-.7         crossover probability (<0, 0-1)
-.7         mutation intensity (<0, 0-1)
-1          coefficient of complex combination (<0, 0-1)

Supplemental Optimizer
2           optimizer switch (0- none, 1- DHC, 2- DOT)
10          call frequency (< 0 = CVR, > 0 = # of generations)
0           Maximum number of parallel calls

Mini Populations
0           Mini-Populations switch
0
```

Listing 8.4.2: Params.inp UPTOP Input File

```
CODE PARAMETERS FILE

SWITCHES
0           Atmosphere Model (0- 1976 US Standard, 1- NRL model)
0           Rotating Earth
1           Speed of Sound (1- actual, 0-constant (sos at sea level))
1           Keep mass constant (0- constant mass, 1- fuel expended)

TRAJECTORY PARAMETERS
.1          Time Step
1000.       Maximum Time

EARTH/ORBIT INFORMATION
1           Auxillary Calculation
1           Fully resolve states
1           Calculate Ranges
0           Calculate Orbital Parameters
0           Calculate Entry Parameters
0           Full Guidance Output

OPTIMIZATION PARAMETERS
0           optimization method
1           print progress (0 - no, 1 - debug single run, -1 - debug optimization)

MAPSPACE PARAMETERS
3           number of discretization steps (0 - default=11)
1           DS value (0 - objective fcn value, 1 - true value)

OUTPUT PARAMETERS
0           screen output (0- off, 2- final output only, 1- all output)
1           record generation info (0-no, 1- record improvement,2-record all)
0           increment value for output file (0 - default=1000)
0           print input to file
1           Tecplot header

VEHICLE INFORMATION
0           vehicle model (1=h1-20, 2=F-4)
1           thrust vector alignment (0 - wind axis, 1 - vehicle nose)
```

```

CONSTANTS
9.80665  acceleration due to gravity (m/s)
6378.   radius of earth (km)
288.16  sea level temperature (K)
1.01325e5 sea level pressure (N/m^2)
1.225   sea level density (kg/m^3)

```

```

UNITS I/O
1  angles (0- radians, 1- degrees)

```

```

DEBUG
0
0
0
0

```

Listing 8.4.3: Trajct.dat UPTOP Output File that is used in TPSOPT and SMB

```

TRAJCT      100      10
0.0  6.0200  22328.  1.250
9.0  6.1200  22332.  1.250
18.0 6.2500  22375.  1.260
27.0 6.3800  22482.  1.260
36.0 6.4900  22645.  1.270
45.0 6.5800  22841.  1.270
54.0 6.6600  23063.  1.280
63.0 6.7300  23301.  1.280
72.0 6.7900  23547.  1.280
81.0 6.8500  23785.  1.290
90.0 6.9000  24003.  1.290
99.0 6.9500  24186.  1.300
108.0 6.9900  24325.  1.300
117.0 7.0300  24412.  1.310
126.0 7.0700  24451.  1.310
135.0 7.1200  24454.  1.310
144.0 7.1900  24439.  1.320
153.0 7.2600  24431.  1.320
162.0 7.3500  24457.  1.330
171.0 7.4500  24549.  1.330
180.0 7.5600  24732.  1.340
189.0 7.6900  25031.  1.340
198.0 7.8300  25460.  1.340
207.0 7.9800  26019.  1.350
208.0 8.0000  26089.  1.350
timesp 201      0.000  45.000  90.000 135.000 180.000 208.000
                                TECPLOT      1209.PLT

```

8.5 Run UCDA to Generate Mesh for TPSOPT and SMB

This section corresponds to the Step 2 in the Graphical User Interface (GUI). See Figure 8.5.1 below.

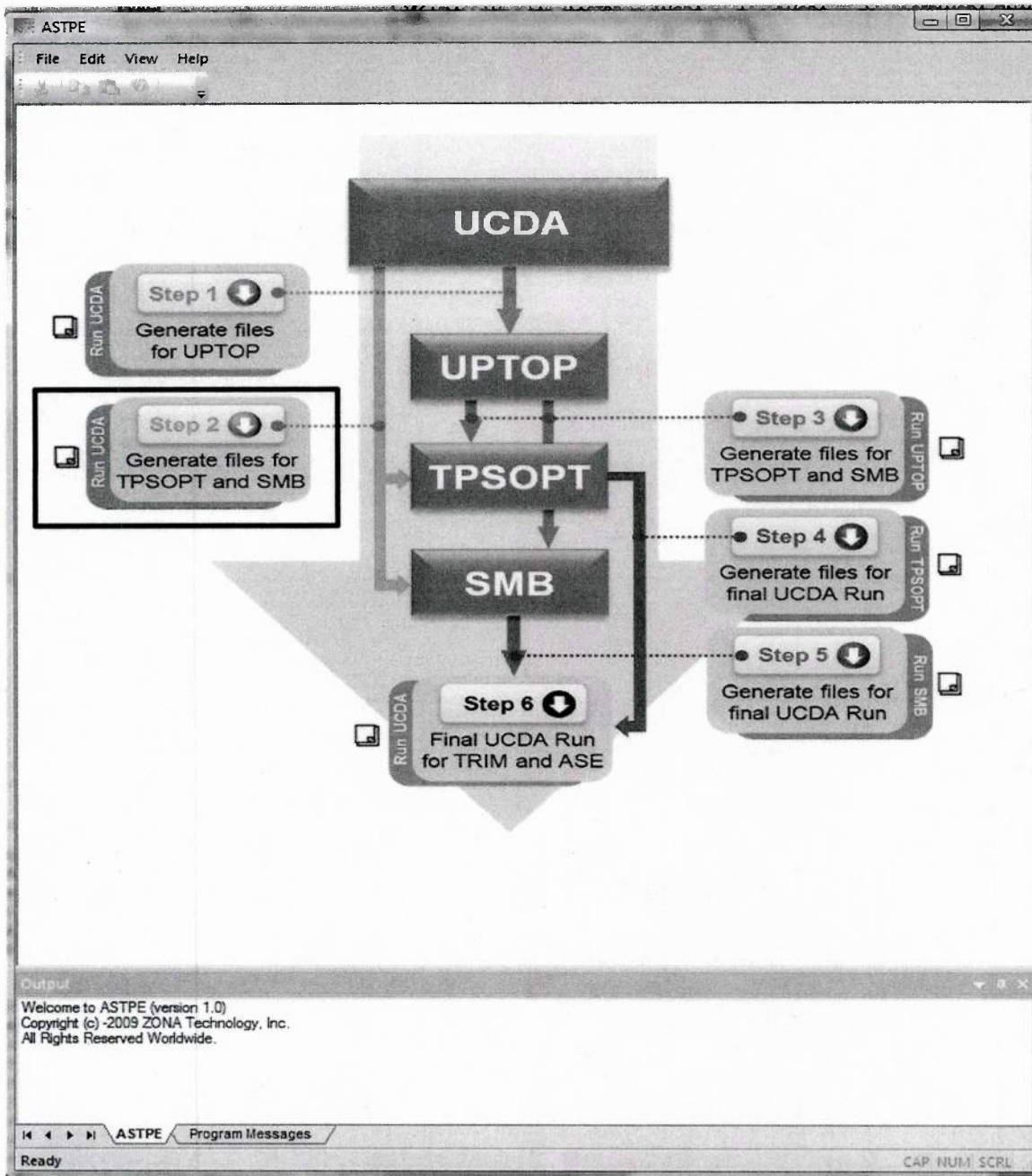


Figure 8.5.1 Section Corresponding to Step 2 of GUI

Input Files:

File Name	Type	Remarks	See Listing
vehicle.inp	Standard input file	Also look at Table 8.5.1	Shown in Listing 8.5.1
chem.bin	Engine chemistry information	Required	Shown in Listing 8.2.2

Output Files:

File Name	Type	Remarks	See Listing
geom_data.dat	unformatted	See Fig. 8.2.1	Not shown

Input File descriptions

vehicle.inp: See Listing 8.5.1 for the entire input file. The part of the input file that is used to command the code to generate mesh data for TPSOPT and SMB is shown in Table 8.5.1. It can be noted that **itps** is set to **1** in this case. This is the most important parameter to generate the mesh for TPSOPT and SMB. To run the code faster and only to output geometry information, **ideriv**, **ittrajectory**, **itrim** are all set to **0**.

chem.bin: This file remains the same for all UCDA runs. Please see Section 8.2 for description on this file.

Output File descriptions

geom_data.dat: This file is unformatted and thus it cannot be shown. It contains information such as grid points, panel ID, normal vector, area etc. The vehicle has been shown in Figure 8.2.1. This information is read into TPSOPT and SMB to compute heat flux and load respectively.

The computational run time for generating the geometry information is about a few seconds.

Table 8.5.1: Necessary Block on Vehicle.inp to Generate Geometry Information

TEST INPUT DECK: Note - this line must be here!

```
2 ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1 ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle
1 iunits - Output unit switch: SI (1) or English (2)
3 ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1 iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2 inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1 iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
0 itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0 icone - cone flow data: exact (0), curve-fit approximation (1)
1 imodel - Forebody type: WA (1), VWA (2), or VWA + cone flow (3)
0 itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0 nderiv - Calculate derivatives: no (0), yes (1)
1 itps - If itps is 1, then prepare for tps and smb. nderiv and itps cannot be 1 at one time
0 ifeedback - If 1, then gets weight and Cg information from SMB and TPSOPT
```

Listing 8.5.1: Vehicle.inp Input File for TPS and SMB Geometry File Generation**TEST INPUT DECK: Note - this line must be here!**

```
2 ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1 ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle
1 iunits - Output unit switch: SI (1) or English (2)
3 ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1 iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2 inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1 iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
0 itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0 icone - cone flow data: exact (0), curve-fit approximation (1)
1 imodel - Forebody type: WA (1), VWA (2), or VWA + cone flow (3)
0 itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0 nderiv - Calculate derivatives: no (0), yes (1)
1 itps - If itps is 1, then prepare for tps and smb. nderiv and itps cannot be 1 at one time
0 ifeedback - If 1, then gets weight and Cg information from SMB and TPSOPT
```

OUTPUT FILE SWITCHES AND NAMES:

```
1 'plot.dat' VEHICLEFIG: off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23 1st # -> # of variables to read, others -> vars to plot
1 'metrics.dat' METRICS: off (0), on (1)
0 'cowlexit.dat' COWLEXIT: off (0), on (1)
0 'moc.dat' NOZFIG: off (0), P,T,M (1), all (2)
0 'offdesign.dat' AOA: off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0 'scramjet.dat' CKENGINE: off (0), on (1)
0 IPRINTINLET: off (0), all (1), results (2), all-real (3), results-real (4)
0 IPRINTENGINE: off (0), on (1)
0 IDEBUG: off (0), on (1) (print debugging info)
```

ZONE DATA AND GRID SIZES:

```
16 NUMBER OF ZONES
'forebody : top' 31 31
'keel : top' 101 6
'aftbody : top' 101 31
'forebody : bot' 31 31
'ramps : bot' 55 6
'comb : bot' 101 6
'cowl : top' 101 6
'nozzle : bot' 31 6
'ramp walls : inside' 35 6
'comb wall : inside' 101 7
'nozzle wall : inside' 21 7
'aftbody : bot' 101 31
'cowl : bot' 101 6
'ramp walls : outside' 35 6
'comb wall : outside' 101 7
'nozzle wall : outside' 21 7
```

INPUT DATA: (0 = degrees, 1 = m, 2 = ft, 3 = atm, 4 = dimensionless, K or kg, 5 = psf)

x1	x	xu	unit	res name
22500.	26000.	30000.	1	2500. 'altitude' - altitude (if required)
2000.	2200.	2400.0	5	200. 'q0' - dynamic pressure (if required)
.50	1.099	1.0	4	.250 'equiv' - equivalence ratio
1.	1.	0.0	4	-.05 'throttle' - engine throttle (if required)
6.0	6.00	8.00	4	.5 'm0' - Mach number
-2.0	-1.0	3.00	0	.5 'AOA' - angle of attack
6.0	4			'Mdes' - design Mach number
1.0	0			'AOAdes' - design angle of attack
21800.	1			'Zdes' - design altitude
4.2672	1			'lvehicle' - vehicle length

6.0000	0	'thforclu'	- forebody upper surface angle
5.2797	0	'thforcil'	- forebody ramp angle
0.5873	1	'lcontrol'	- control surface length
7.73	0	'th_control'	- control surface deflection angle
0.9920	0	'th_expn'	- nozzle initial expansion angle
10.8958	0	'th_exit'	- nozzle exit angle
0.0	4	'p_nozpoly'	- % diff between nozzle designs [DON'T USE-defaulted to 1.]
1.901	1	'lcowl'	- cowl length (isolator/combustor)
.3	1	'lcowlxt'	- cowl extension length (internal nozzle)
0.545	4	'p_iso'	- percent of lcowl that is isolator
.3238	1	'height'	- height of vehicle (if required)
20.0	1	'linlet'	- inlet length of vehicle (if required)
.26	1	'wengine'	- width of the engine (currently defaulted to unit width)
3.00	4	'iramps'	- number of inlet ramps in addition to the forebody
6.4012	0	'th_ramp1'	- inlet ramp 1 angle
5.2383	0	'th_ramp2'	- inlet ramp 2 angle
5.5	0	'th_ramp3'	- inlet ramp 3 angle
0.0	0	'th_ramp4'	- inlet ramp 4 angle
0.0	0	'th_ramp5'	- inlet ramp 5 angle
3.09	0	'th_div1'	- first combustor expansion angle
0.2	0	'th_div2'	- second combustor expansion angle
0.01	1	'Xinjs'	- beginning of injectors (m)
0.02	1	'Xinje'	- end of injectors (m)
0.01	1	'Lmix'	- fuel mixing length (m)
1.00	4	'eta_mix'	- fuel mixing and burning efficiency
3000.	4	'Tlimit'	- maximum engine temperature (K)
90.	0	'Thetainj'	- injector angle (degrees) [90 deg. is normal to flow]
1200.	4	'Tw'	- adiabatic wall temperature (K)
0.1527	4	'nfor'	- forebody exponent n
2.0	2	'wfor'	- forebody width
1.5	2	'lfor'	- forebody length
0.2427	4	'mfor'	- forebody exponent m
5.797	0	'thforle'	- forebody leading edge angle
21.519	0	'th_le'	- leading edge attachment angle
0.0000	4	'p_kl'	- keel-line height percentage
0.25	4	'fuelfrac'	- vehicle fuel volume fraction
0.0104	2	't_plate'	- shell plate thickness (Tungsten)
0.0	4	'mass_smb'	- mass due to Structural Modal Base (SMB) analysis
0.0	4	'mass_tps'	- mass due to Thermal Protection System (TPS) analysis
0.0	4	'mass_nose'	- lumped mass at the nose to manipulate CG

8.6 Run TPSOPT for Optimizing the Thermal Protection System

Input Files:

File Name	Type	Remarks	See Listing
sem_tpsopt.inp	Standard input file	Required	Shown in listing 8.6.1
traject.dat	Trajectory data generated by UPTOP	Inserted into the Standard input file sem_tpsopt.INP by the INCLUDE bulk data card	Shown in Listing 8.4.3
geom_data.dat	Aerodynamic mesh generated by UCDA	Imported by the ASSIGN AEROBASE executive control command	Not Shown

Output Files:

File Name	Type	Remarks	See Listing
sem_tpsopt.out	Standard output file	Print out results	Shown in Listing 8.6.2
AERO.PLT	TECPLOT file of aerodynamic mesh.	Generated by the PLTAERO bulk data card with ID=1	Not Shown
SEM_TPS3.PLT	TECPLOT file containing the TPS thickness of each layers on the aerodynamic panel model	Generated by the PLTTPS bulk data card with ID=103	Not Shown
SEM_TPS4.PLT	TECPLOT file containing the total TPS thickness on each aerodynamic panel model	Generated by the PLTTPS bulk data card with ID=-104	Not Shown
1209.PLT	TECPLOT file containing the heat flux at the last time step of the trajectory.	Generated by the TRAJECT bulk data card	Not shown
mass_tps.dat	Mass of the optimized TPS	Input file for UCDA to update the change of weight due to TPS	Shown in Listing 8.6.3

8.6.1 Descriptions of the Input File: sem_tpsopt.inp (Shown in Listing 8.6.1)

General description of Executive Control Section, Case Control Section and Bulk Data Section of TPSOPT input is given in the Users Manual (Sections 5.3 and 5.4). For sample SEM, the TPSOPT input is described here.

The aerodynamic mesh of the SEM configuration generated by UCDA is stored in the file “geom_data.dat” and imported into the TPSOPT module by the following executive control command:

```
ASSIGN AEROBASE = geom_data.dat
```

There is only one subcase defined in the case control command shown as follows:

```
TPSDES = 100
```

This case control command refers to a **TPSDES** bulk data card with ID = 100 in the Bulk Data Section. The interrelationship of all bulk data cards in the Bulk Data Section is presented in Figure 8.6.1.

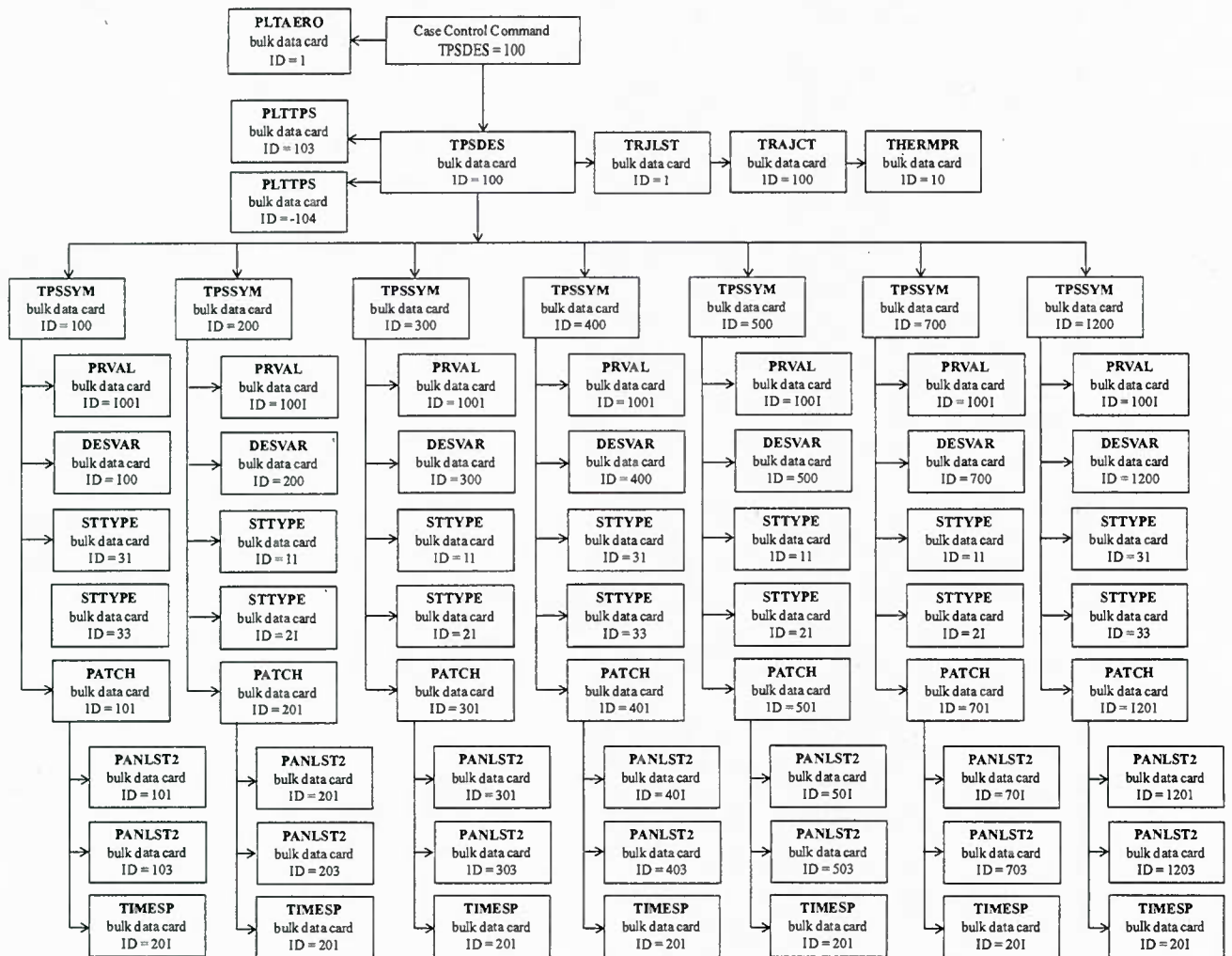


Figure 8.6.1 Interrelationship of All Bulk Data Cards for Optimizing the TPS for SEM

The aerodynamic mesh generated by UCDA and imported by the ASSIGN AEROBASE = geom_data.dat executive control command can be visualized using the TECPLOT file "AERO.PLT" that is generated by a **PLTAERO** bulk data card with ID = 1. This aerodynamic mesh is shown in Figure 8.6.2.

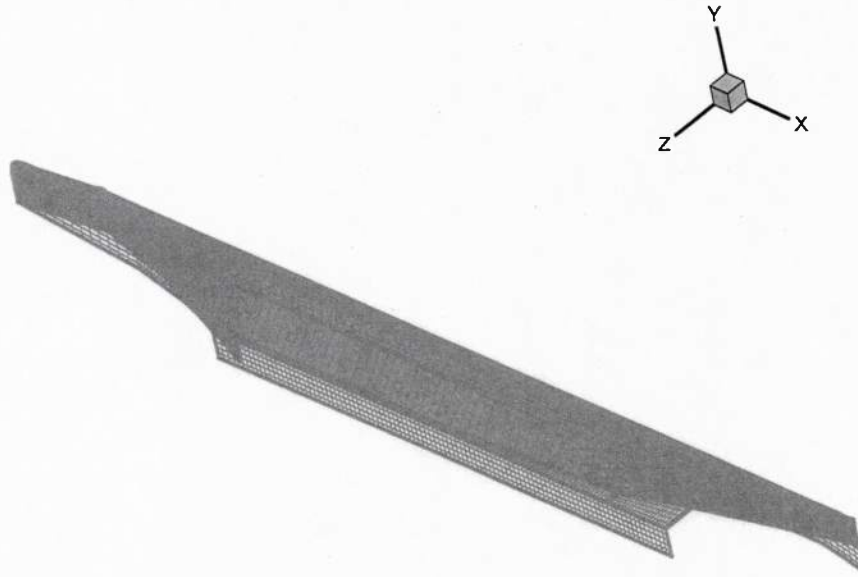


Figure 8.6.2 Visualization of Aerodynamic Mesh Using the PLTAERO bulk data card

There are 16 patches in the aerodynamic mesh but among them, only 7 patches with panel ID starting from 100001, 200001, 300001, 400001, 500001, 700001, and 1200001, respectively, are the outer surfaces and require the thermal protection system (TPS). Thus, the purpose of TPSOPT is to design the TPS system on those 7 patches for minimum TPS weight while satisfying the temperature constraints of each TPS layer as well as the load-carried structure. These temperature constraints are computed by integrating the heat flux on the outer surfaces along the trajectory generated by UPTOP. This trajectory is provided in the file "traject.dat" in which a **TRAJCT** bulk data card with ID = 100 and a **TIMESP** bulk data card with ID = 201 are stored. These two bulk data cards are automatically inserted into the bulk data section by the **INCLUDE** bulk data card shown as follows:

```
INCLUDE  traject.dat
```

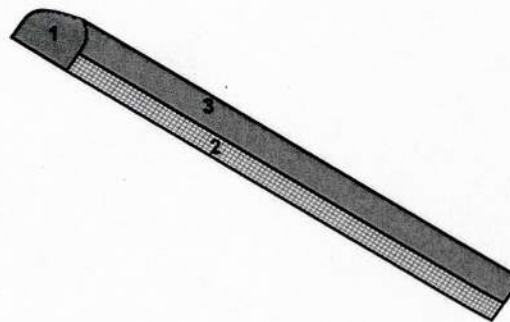
Note that the **TRAJCT** bulk data card with ID = 100 is referred to by a **TRJLST** bulk data card with ID = 1 that is activated by the **TPSDES** bulk data card with ID = 100. The parameters for computing the heat flux by the aeroheating analysis are defined in a **THERMPR** bulk data card with ID = 10 that is referred to by the **TRAJCT** bulk data card with ID = 100.

In order to design the minimum TPS weight on those 7 patches, 7 **TPSSYM** bulk data cards with ID = 100, 200, 300, 400, 500, 700, and 1200 are specified that are all referred to by the **TPSDES** bulk data card with ID = 100. Each **TPSSYM** bulk data card refers to a **PRVAL** bulk data card, a **DESVAR** bulk data card, a **PATCH** bulk data card and two **PANLST2** bulk data cards. The **PRVAL** bulk data card with ID = 1001 that is referred to by all the 7 **TPSSYM** bulk data cards defines the parameters for the transient thermal analysis. The **PATCH** bulk data card first refers to a **PANLST2** bulk data card to list the identification numbers of the panels that belong to a patch in the aerodynamic mesh. Then it refers to another **PANLST2** bulk data card to define a set of so-called “hot panels” on which the temperature constraints of the TPS is imposed by listing the identification numbers of those hot panels. Note that those hot panels must be a subset of the panels of the patch.

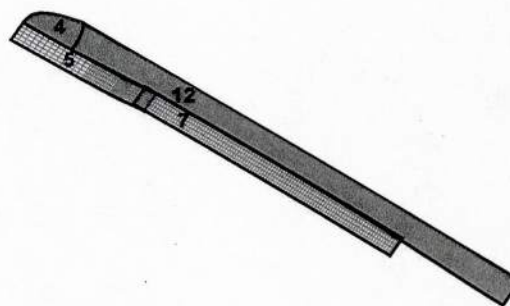
The temperature constraints are evaluated at all layers of the TPS located on those hot panels and are computed at a set of time steps defined by the **TIMESP** bulk data card with ID = 201. Thus, the total number of the temperature constraints is product of the number of layers of the TPS, the number of the hot panels, and the number of time steps listed in the **TIMESP** bulk data card. This is the reason why only 6 time steps in the **TIMESP** are selected from those 25 time steps in the **TRAJCT** bulk data card. Otherwise, if all those 25 time steps listed in the **TRAJCT** bulk data card are used to evaluate the temperature constraints, the number of temperature constraints would be too many and might require the amount of computer memory beyond the available memory in the computer.

Seven **PATCH** bulk data cards with ID = 101, 201, 301, 401, 501, 701, and 1201 that are referred to by those 7 **TPSSYM** bulk data cards respectively, are used to define the panels on

those 7 outer surface patches in the aerodynamic mesh by specifying 7 **PANLST2** bulk data cards with ID = 101, 201, 301, 401, 501, 701 and 1201. The hot panels on those 7 patches are defined by another 7 **PANLST2** bulk data cards with ID = 103, 203, 303, 403, 503, 703, and 1203. The identification numbers of those panels on the 7 patches are presented in Figure 8.6.3.



(a)



(b)

Figure 8.6.3 Panel Identification Numbers on the 7 Patches with TPS

The correspondences between 7 patches and the zones shown in Figure 8.2.1 are:

patch 1: forebody top

patch 2: keel top

patch 3: aftbody top

patch 4: forebody bottom

patch 5: ramp bottom

patch 7: cowl top

patch 12: aftbody bottom

Patches 1, 4 and 12 with panel ID starting from 100001, 400001 and 1200001, respectively, are potentially exposed to the high aeroheating environment. This suggests that in order to achieve a minimum weight design of the TPS, different TPS concepts and materials from the rest of the patches be employed for those 3 patches. This TPS consists of two TPS layers and is defined in the **TPSSYM** bulk data cards with ID = 100, 400 and 1200 in which the top layer is defined by a **STTYPE** bulk data card with ID = 31 and the bottom layer is defined by a **STTYPE** bulk data card with ID = 33. The **STTYPE** bulk data card with ID = 31 defines a Slab TPS structure made by ZIRCONIA FIBERS with initial thickness = 0.1 m whereas the **STTYPE** bulk data card with ID = 33 defines a Slab structure made by a HEAT SINK with thickness = 0.2 m. This HEAT SINK is a virtual material with a very high heat capacity to represent an active cooling concept that absorbs the heat by circling the fuel. The thickness of the ZIRCONIA FIBERS is subjected to the design for minimum weight with the design variable being defined by a **DESVAR** bulk data card whereas the thickness of the HEAT SINK is kept to be constant at 0.2 m. Three **DESVAR** bulk data cards with ID = 100, 400, and 1200 are specified that are referred to by the entry **DESVAR1** of the three **TPSSYM** bulk data cards with ID = 100, 400 and 1200, respectively. A minimum and maximum thickness of 0.0002 m and 10.0 m for the ZIRCONIA FIBERS is also specified in these **TPSSYM** bulk data cards. Note that the entry **DESVAR2** of these three **TPSSYM** bulk data cards is blank to indicate that the bottom layer; i.e. the thickness

of the HEAT SINK, is not subjected to design and remains unaltered. The purpose of the **DESVAR** bulk data card is to define a curvilinear coordinates over the patch on which a set of shape functions can be formulated to represent the thickness distribution of the ZIRCORNIA FIBERS on this patch. Thus, the actual design variables controlled by the optimizer are the unknown coefficients of those shape functions and are not the thickness of the ZIRCORNIA FIBERS on each panel. Using these shape functions, the number of design variables can be greatly reduced and the thickness distribution of the optimized TPS is ensured to be smooth for the ease of fabrication. This curvilinear coordinates is defined by selecting a set of M by N panels on the patch. A 2 by 2 panels is defines by the **DESVAR** bulk data cards with ID = 100 and 400 and a 3 by 3 panels is defined by the **DESVAR** bulk data card with ID = 1200. (Please refer to Users Manual Section 5.4, TPSOPT Bulk Data Section, for more information about DESVAR bulk data card.)

The TPS on the rest of 4 patches defined by the four **TPSSYM** bulk data cards with ID = 200, 300, 500 and 700 is also a two-layer TPS. The top layer is a Slab structure made by CRI-II and is defined by a **STTYPE** bulk data card with ID = 11 whereas the bottom layer is a thin skin made by RTV-560 and is defined by a **STTYPE** bulk data card with ID = 21. The top layer is subjected to design with initial thickness of 0.1 m and minimum thickness and maximum thickness of 0.002 m and 10.0 m, respectively, and the bottom layer is kept to be 2.45×10^{-5} m. Four **DESVAR** bulk data cards with ID = 200, 300, 500 and 700 that are referred by the **TPSSYM** bulk data cards with ID = 200, 300, 500 and 700, respectively, are specified to select an M by N panels for defining the curvilinear coordinates on their respective patches. A set of 2 by 3 panels is defined by the **DESVAR** bulk data cards with ID = 200, 500 and 700 and a set of 3 by 3 panels by the **DESVAR** bulk data card with ID = 300. (Please refer to Users Manual Section 5.4, TPSOPT Bulk Data Section, for more information about DESVAR bulk data card.)

In order to visualize to optimized TPS thickness distribution, two **PLTTPS** bulk data cards with ID = 103 and = -104 are employed that generate two TECPLOT files called “SEM_TPS3.PLT” and “SEM_TPS4.PLT”, respectively where the first contains the thickness of each TPS layer and the maximum temperature on each panel and the latter contains the total thickness of the TPS. In addition, the heat flux at a time step in the trajectory can be also outputted in a TECPLOT file by

specifying a file name in the **TRAJCT** bulk data card. A **TECPLOT** file called “1209.PLT” is generated to display the heat flux at the last time step of the trajectory.

The final optimized averaged TPS thickness of each layer of patched 100, 200, 300, 400, 500, 700, and 1200 are shown in Figures 8.6.4, 8.6.5, 8.6.6, 8.6.7, 8.6.8, 8.6.9 and 8.6.10. The masses of those 7 TPS are 3.07170152E-03, 1.65916653E+00, 3.89700886E+00, 1.46587057E-03, 7.15747357E-01, 2.09356866E+00, and 1.85629520E-02 KG, respectively; giving a total mass of the entire TPS of 15.66 KG (both sides). This total mass along with the sum of the product of TPS mass on each panel and the location of the panel is stored in a file called “mass_tps.dat” that is shown in Listing 8.6.3. This file will be an input file of UCDA to include the TPS weight in the total vehicle weight for the next design cycle.

OPTIMAL STRUCTURES OF TPS FOR PATCH = 100 (WITH AVERAGE THICKNESS)			
=====			
ZIRCONIA FIBERS	slab	0.00066 FT	2278.6 F
=====			
HEAT SINK	slab	0.65617 FT	2177.0 F
=====			

Figure 8.6.4 Optimized Averaged TPS Thickness of Patch 100

OPTIMAL STRUCTURES OF TPS FOR PATCH = 200 (WITH AVERAGE THICKNESS)			
=====			
CRI-I 2.0	slab	0.05911 FT	2117.2 F
=====			
RTV-560	thin skin	0.00066 FT	548.5 F
=====			

Figure 8.6.5 Optimized Averaged TPS Thickness of Patch 200

OPTIMAL STRUCTURES OF TPS FOR PATCH = 300 (WITH AVERAGE THICKNESS)			
=====			
CRI-I 2.0	slab	0.07074 FT	2290.3 F
=====			
RTV-560	thin skin	0.00066 FT	546.0 F
=====			

Figure 8.6.6 Optimized Averaged TPS Thickness of Patch 300

OPTIMAL STRUCTURES OF TPS FOR PATCH = 400 (WITH AVERAGE THICKNESS)			
=====			
ZIRCONIA FIBERS	slab	0.00066 FT	2406.5 F
=====			
HEAT SINK	slab	0.65617 FT	2299.5 F
=====			

Figure 8.6.7 Optimized Averaged TPS Thickness of Patch 400

OPTIMAL STRUCTURES OF TPS FOR PATCH = 500 (WITH AVERAGE THICKNESS)			
=====			
ZIRCONIA FIBERS	slab	0.12422 FT	2670.4 F
=====			
RTV-560	thin skin	0.00066 FT	548.0 F
=====			

Figure 8.6.8 Optimized Averaged TPS Thickness of Patch 500

OPTIMAL STRUCTURES OF TPS FOR PATCH = 700 (WITH AVERAGE THICKNESS)			
=====			
CRI-I 2.0	slab	0.076302 FT	2128.3 F
=====			
RTV-560	thin skin	0.00066 FT	548.0 F
=====			

Figure 8.6.9 Optimized Averaged TPS Thickness of Patch 700

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1200 (WITH AVERAGE THICKNESS)			
=====			
ZIRCONIA FIBERS	slab	0.00066 FT	2743.2 F
=====			
HEAT SINK	slab	0.65617 FT	2613.3 F
=====			

Figure 8.6.10 Optimized averaged TPS thickness of patch 1200

Using the file "SEM_TPS4.PLT", the total thickness contour of the TPS and the maximum temperature distribution are depicted in Figures 8.6.11 and 8.6.12, respectively. The heat flux at the last time step of the trajectory is shown in Figure 8.6.13.

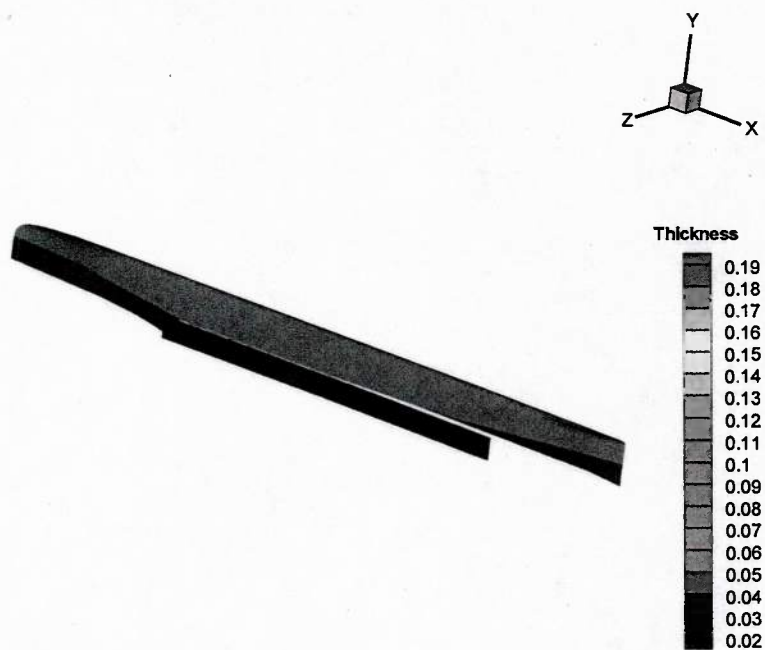


Figure 8.6.11 Thickness Contour of the Optimized TPS

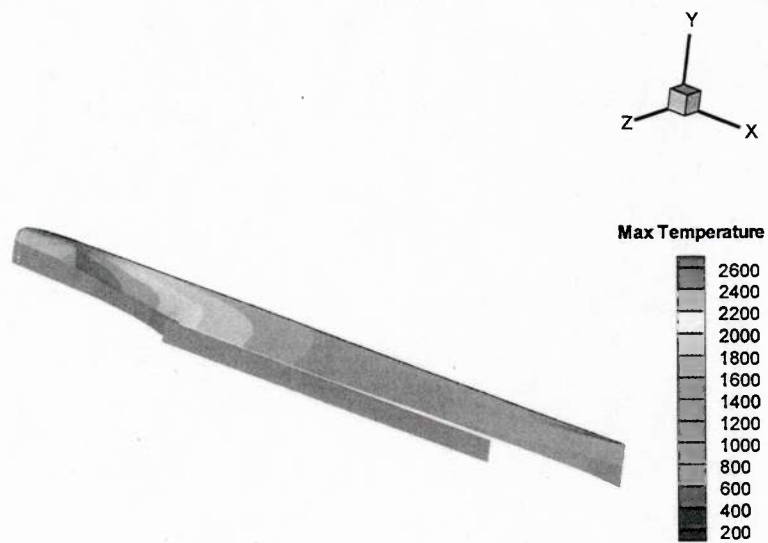


Figure 8.6.12 Temperature Contour of the Optimized TPS

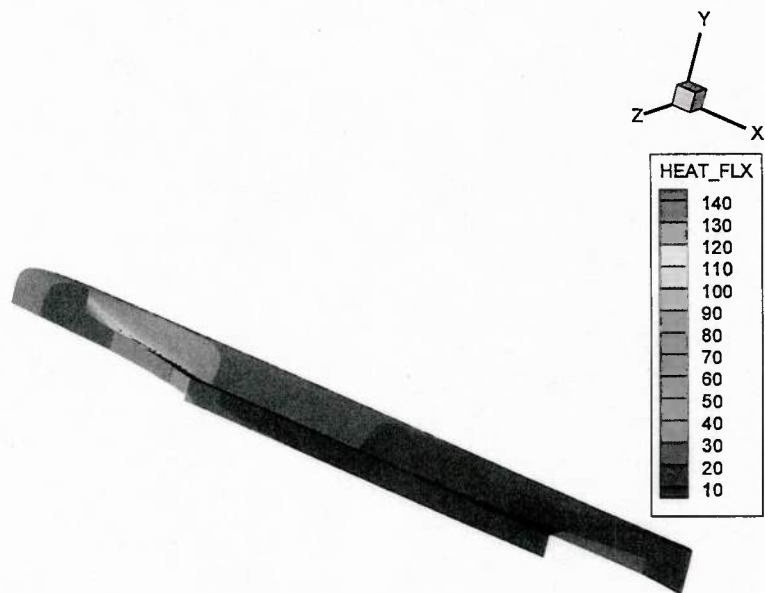


Figure 8.6.13 Heat Flux at the Last Time Step of the Trajectory

Listing 8.6.1 Sample Input File: sem_tpsopt.inp

[illegible]

```

700001 700100
700201 700300
700401 700500
$234567812345678123456781234567812345678123456781234567812345678
$234567812345678123456781234567812345678123456781234567812345678
TP55YM 1200 1201 2 1001
1200 31 .0002 10.
33 .0002 90.
PATCH 1201 1201 1203 NO 201
PANLST2 1201 1200001 1200001 thru 1203000
PANLST2 1203 1200001 1200001 1200025 1200050 1200075 1200100 1201501
1201525 1201550 1201575 1201600 1202901 1202925 1202950 1202975
1203000
$PANLST2 1203 1200001 1200001 1200050 1200075 1200100 1201501 1201550
$ 1201575 1201600 1202901 1202950 1203000
DESVAR 1200 3 3
1200001 1201501 1202901
1200050 1201550 1202950
1200100 1201600 1203000
$234567812345678123456781234567812345678123456781234567812345678
$. .1. . .2. . .3. . .4. . .5. . .6. . .7. . .8. . .9. . .10. .
PRVAL 1001 90000000
0
STTYPE 11 1 315
0.100
STTYPE 21 6 245
2.45e-5
STTYPE 31 1 251
0.100
STTYPE 41 1 221
0.100
STTYPE 2 1 266
0.001
STTYPE 3 1 260
0.001
STTYPE 4 1 266
0.001
STTYPE 5 1 245
0.001
STTYPE 6 1 101
0.010
STTYPE 33 1 701
0.200
STTYPE 34 1 501
0.200
STTYPE 35 1 502
0.200
STTYPE 36 1 309
0.200
$234567812345678123456781234567812345678123456781234567812345678
ENDDATA

```

Listing 8.6.2 Sample Output File: sem_tpsopt.out

EXECUTIVE CONTROL SUMMARY

```

|. .1. . .2. . .3. . .4. . .5. . .6. . .7. . .8. . .9. . .10. .

```

```

ASSIGN AEROBASE=geom_data.dat,PRINT=1

```

```

CEND

```

CASE CONTROL SUMMARY

S I N G L E P R E C I S I O N C O M P U T A T I O N

M A X I M U M A L L O C A B L E M E M O R Y = 8 0 0 M E G A B Y T E S

|...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10...|

TITLE=SEM CONFIGURATION

ECHO=SORT

SUBCASE =1

TPSDES=100

BEGIN BULK

S O R T E D B U L K D A T A E C H O

CARD

COUNT |...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10...|

1 -	DESVAR	100	2	2
2 -		100001	100030	
3 -		100871	100900	
4 -	DESVAR	200	2	3
5 -		200001	200100	
6 -		200201	200300	
7 -		200401	200500	
8 -	DESVAR	300	3	3
9 -		300001	301501	302901
10 -		300050	301550	302950
11 -		300100	301600	303000
12 -	DESVAR	400	2	2
13 -		400001	400030	
14 -		400871	400900	
15 -	DESVAR	500	2	3
16 -		500001	500054	
17 -		500109	500162	

18 -		500217	500270					
19 -	DESVAR	700	2	3				
20 -		700001	700100					
21 -		700201	700300					
22 -		700401	700500					
23 -	DESVAR	1200	3	3				
24 -		1200001	1201501	1202901				
25 -		1200050	1201550	1202950				
26 -		1200100	1201600	1203000				
27 -	PANLST2	101	100001	100001	THRU	100900		
28 -	PANLST2	103	100001	100001	100030	100871	100900	
29 -	PANLST2	201	200001	200001	THRU	200500		
30 -	PANLST2	203	200001	200001	200100	200201	200300	200401 200500
31 -	PANLST2	301	300001	300001	THRU	303000		
32 -	PANLST2	302	300001	300001	301501	302901	300050 301550	302950
33 -		300100	301600	303000				
34 -	PANLST2	303	300001	300001	300025	300050	300075	300100 301501
35 -		301525	301550	301575	301600	302901	302925	302950 302975
36 -		303000						
37 -	PANLST2	401	400001	400001	THRU	400900		
38 -	PANLST2	403	400001	400001	400030	400871	400900	
39 -	PANLST2	501	500001	500001	THRU	500270		
40 -	PANLST2	503	500001	500001	500054	500109	500162	500217 500270
41 -	PANLST2	701	700001	700001	THRU	700500		
42 -	PANLST2	703	700001	700001	700100	700201	700300	700401 700500
43 -	PANLST2	1201	1200001	1200001	THRU	1203000		
44 -	PANLST2	1203	1200001	1200001	1200025	1200050	1200075	1200100 1201501
45 -		1201525	1201550	1201575	1201600	1202901	1202925	1202950 1202975
46 -		1203000						
47 -	PATCH	101	101	103	NO	201		
48 -	PATCH	201	201	203	NO	201		
49 -	PATCH	301	301	303	NO	201		
50 -	PATCH	401	401	403	NO	201		
51 -	PATCH	501	501	503	NO	201		
52 -	PATCH	701	701	703	NO	201		
53 -	PATCH	1201	1201	1203	NO	201		

54 -	PLTAERO	1							TECPLOT AERO.PLT
56 -	PLTTPS	-104	100	ALL	TECPLOT SEM_T	PS4.PLT	-30.00		
57 -	PLTTPS	103	100	ALL	TECPLOT SEM_T	PS3.PLT	-30.00		
58 -	PRVAL	1001			90000000				
59 -					0				
60 -	STTYPE	2	1		266				
61 -		0.001							
62 -	STTYPE	3	1		260				
63 -		0.001							
64 -	STTYPE	4	1		266				
65 -		0.001							
66 -	STTYPE	5	1		245				
67 -		0.001							
68 -	STTYPE	6	1		101				
69 -		0.010							
70 -	STTYPE	11	1		315				
71 -		0.100							
72 -	STTYPE	21	6		245				
73 -		2.45E-5							
74 -	STTYPE	31	1		251				
75 -		0.100							
76 -	STTYPE	33	1		701				
77 -		0.200							
78 -	STTYPE	34	1		501				
79 -		0.200							
80 -	STTYPE	35	1		502				
81 -		0.200							
82 -	STTYPE	36	1		309				
83 -		0.200							
84 -	STTYPE	41	1		221				
85 -		0.100							
86 -	THERMPR	10	100.F	YES	2	0	0.8		
87 -	TIMESP	201	0.000	45.000	90.000	135.000	180.000	208.000	
88 -	TPSDES	100	1	1					
89 -		100	200	300	400	500	700	1200	
90 -	TPSSYM	100	101	2	1001				

91 -		100	31	.0002	10.
92 -			33	.0002	90.
93 -	TPSSYM	200	201	2	1001
94 -		200	11	.0002	10.
95 -			21	.0002	10.
96 -	TPSSYM	300	301	2	1001
97 -		300	11	.0002	10.
98 -			21	.0002	10.
99 -	TPSSYM	400	401	2	1001
100 -		400	31	.0002	10.
101 -			33	.0002	90.
102 -	TPSSYM	500	501	2	1001
103 -		500	31	.0002	10.
104 -			21	.0002	10.
105 -	TPSSYM	700	701	2	1001
106 -		700	11	.0002	10.
107 -			21	.0002	10.
108 -	TPSSYM	1200	1201	2	1001
109 -		1200	31	.0002	10.
110 -			33	.0002	90.
111 -	TRAJCT	100	10		
112 -		0.0	6.0200	22328.	1.250
113 -		9.0	6.1200	22332.	1.250
114 -		18.0	6.2500	22375.	1.260
115 -		27.0	6.3800	22482.	1.260
116 -		36.0	6.4900	22645.	1.270
117 -		45.0	6.5800	22841.	1.270
118 -		54.0	6.6600	23063.	1.280
119 -		63.0	6.7300	23301.	1.280
120 -		72.0	6.7900	23547.	1.280
121 -		81.0	6.8500	23785.	1.290
122 -		90.0	6.9000	24003.	1.290
123 -		99.0	6.9500	24186.	1.300
124 -		108.0	6.9900	24325.	1.300
125 -		117.0	7.0300	24412.	1.310
126 -		126.0	7.0700	24451.	1.310

127 -	135.0	7.1200	24454.	1.310		
128 -	144.0	7.1900	24439.	1.320		
129 -	153.0	7.2600	24431.	1.320		
130 -	162.0	7.3500	24457.	1.330		
131 -	171.0	7.4500	24549.	1.330		
132 -	180.0	7.5600	24732.	1.340		
133 -	189.0	7.6900	25031.	1.340		
134 -	198.0	7.8300	25460.	1.340		
135 -	207.0	7.9800	26019.	1.350		
136 -	208.0	8.0000	26089.	1.350	TECPLOT	1209.PLT
137 -	TRJLST	1				
138 -		100				
139 -	ENDDATA					

```

*****
*                                     *
*      SUBCASE      =      1      *
*      DISCIPLINE   = TPSDES      *
*      BULK ENTRY ID =      100   *
*                                     *
*****

```

OPTIMIZATION SYSTEM FOR TPSSYM = 100

TOTAL NUMBER OF DESIGN VARIABLES = 4

TOTAL NUMBER OF CONSTRAINS = 1840

TOTAL NUMBER OF TEMP. CONSTRAINS = 48

TOTAL NUMBER OF TEMP. PRINTOUTS = 6

MAXIMUM TEMPERATURE OF EACH LAYER VS OUTPUT TIMES

X 0.2279E+04

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.0020000

THE TOTAL OPTIMAL WEIGHT = 3.07170152E-03

OPTIMAL STRUCTURES OF TPS FOR PATCH = 100

(WITH AVERAGE THICKNESS)

```
=====
i
ZIRCONIA FIBERS      slab      0.00066 FT  2278.6 F
i
=====
i
HEAT SINK            slab      0.65617 FT  2177.0 F
i
=====
```

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 100

PANEL	LAYER01		LAYER02	
100001	0.00020	2278.59	0.20000	2176.96
100002	0.00020	2266.32	0.20000	2215.62
.....				
.....				
.....				
100899	0.00020	100.00	0.20000	100.00
100900	0.00020	100.00	0.20000	100.00

OPTIMIZATION SYSTEM FOR TPSSYM = 200

TOTAL NUMBER OF DESIGN VARIABLES = 6

TOTAL NUMBER OF CONSTRAINS = 1060

TOTAL NUMBER OF TEMP. CONSTRAINS = 72

WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

X 0.2117E+04



LAYER:	1	2
Tmax:	2400.33	550.33
Optv:	2117.20	548.45

VALUES OF DESIGN VARIABLES :

LAYER	DEV01	DEV02	DEV03	DEV04	DEV05	DEV06
1	0.02243	0.01363	0.02241	0.01362	0.02240	0.01361

THE ORIGINAL OBJECTIVE FUNCTION = 1742.1259766

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.1799643

THE TOTAL OPTIMAL WEIGHT = 1.65916653E+00

OPTIMAL STRUCTURES OF TPS FOR PATCH = 200

(WITH AVERAGE THICKNESS)

Material	Thickness (in)	Material	Thickness (in)	Weight (lb)	Area (sq ft)
CRI-I	2.0	slab	0.05911	2117.2	0.05911
RTV-560		thin skin	0.00066	548.5	0.00066

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 200

PANEL	LAYER01	LAYER02	Thickness (in)	Temperature (°F)
200001	0.02243	2116.93	0.00002	550.33
200002	0.02234	2108.23	0.00002	550.33
200499	0.01370	1270.89	0.00002	550.33
200500	0.01361	1261.99	0.00002	550.33

OPTIMIZATION SYSTEM FOR TPSSYM = 300

LAYER:	1	2
Tmax:	2400.33	550.33
Optv:	2290.35	545.99

LAYER	DEV01	DEV02	DEV03	DEV04	DEV05	DEV06	DEV07	DEV08	DEV09
1	0.02132	0.02140	0.02248	0.02163	0.02165	0.02176	0.02116	0.02114	0.02116

THE TOTAL OPTIMAL WEIGHT = 3.89700886E+00

(WITH AVERAGE THICKNESS)

		i	
CRI-I 2.0	slab	0.07074 FT	2290.3 F
		i	
RTV-560	thin skin	0.00066 FT	546.0 F

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 300

PANEL	LAYER01		LAYER02	
300001	0.02132	2117.38	0.00002	550.33
300002	0.02133	2114.24	0.00002	550.33
.....				
.....				
.....				
302999	0.02117	1965.72	0.00002	550.33
303000	0.02116	1967.03	0.00002	550.33

```

TOTAL NUMBER OF DESIGN VARIABLES =      4
TOTAL NUMBER OF CONSTRAINS          = 1840
TOTAL NUMBER OF TEMP. CONSTRAINS =    48
TOTAL NUMBER OF TEMP. PRINTOUTS    =     6

```

X 0.2406E+04

8-58

TIME (X 1.733E+02)

MAXIMUM TEMPERATURE OF EVERY LAYER

LAYER: 1 2
Tmax: 3000.33 8540.33
Optv: 2406.49 2299.50

VALUES OF DESIGN VARIABLES :

LAYER	DEV01	DEV02	DEV03	DEV04
1	0.00020	0.00020	0.00020	0.00020

THE ORIGINAL OBJECTIVE FUNCTION = 1771.6535645

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.0020000

THE TOTAL OPTIMAL WEIGHT = 1.46587057E-03

OPTIMAL STRUCTURES OF TPS FOR PATCH = 400

(WITH AVERAGE THICKNESS)

```
-----  
i  
ZIRCONIA FIBERS        slab        0.00066 FT    2406.5 F  
i  
-----  
i  
HEAT SINK                slab        0.65617 FT    2299.5 F  
i  
-----
```

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 400

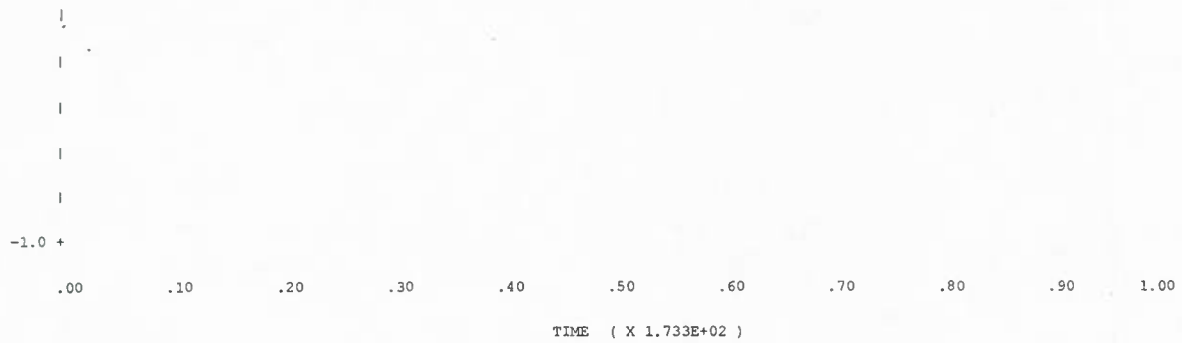
PANEL	LAYER01		LAYER02	
400001	0.00020	2406.49	0.20000	2352.99
400002	0.00020	2391.05	0.20000	2337.80

.....

```
TOTAL NUMBER OF DESIGN VARIABLES =      6
TOTAL NUMBER OF CONSTRAINS        =    600
TOTAL NUMBER OF TEMP. CONSTRAINS =     72
TOTAL NUMBER OF TEMP. PRINTOUTS   =      6
WARNING: MODIFICATION EXCEEDS ALLOWED VALUE
```

X 0.2670E+04

Concentration (x)	Observed Optical Density (y) for Series A	Observed Optical Density (y) for Series B
1	0.85	-
2	-	0.15
3	0.75	0.25
4	0.65	0.35
5	0.55	0.45
6	0.50	0.50
7	0.48	0.52
8	0.46	0.54
9	0.45	0.55
10	0.45	0.55



MAXIMUM TEMPERATURE OF EVERY LAYER

LAYER: 1 2
 Tmax: 3000.33 550.33
 Optv: 2670.36 547.98

VALUES OF DESIGN VARIABLES :

LAYER	DEV01	DEV02	DEV03	DEV04	DEV05	DEV06
1	0.03480	0.04058	0.03493	0.04081	0.03503	0.04102

THE ORIGINAL OBJECTIVE FUNCTION = 531.4960938

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.3848726

THE TOTAL OPTIMAL WEIGHT = 7.15747357E-01

OPTIMAL STRUCTURES OF TPS FOR PATCH = 500

(WITH AVERAGE THICKNESS)

		THICKNESS	TEMPERATURE
ZIRCONIA FIBERS	slab	0.12422 FT	2670.4 F
RTV-560	thin skin	0.00066 FT	548.0 F

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 500

PANEL	LAYER01	LAYER02
500001	0.03480 2106.05	0.00002 550.33
500002	0.03502 2127.22	0.00002 550.33

500269	0.04091 2660.05	0.00002 550.33
500270	0.04102 2670.36	0.00002 550.33

OPTIMIZATION SYSTEM FOR TPSSYM = 700

TOTAL NUMBER OF DESIGN VARIABLES = 6

TOTAL NUMBER OF CONSTRAINS = 1060

TOTAL NUMBER OF TEMP. CONSTRAINS = 72

TOTAL NUMBER OF TEMP. PRINTOUTS = 6

WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

MAXIMUM TEMPERATURE OF EACH LAYER VS OUTPUT TIMES

X 0.2128E+04

1.0 A	A	A	A
I	A	A	A
I			
I			
I			
I			
I			
B			
I	B		
I		B	B


```

=====
RTV-560          thin skin      0.00066 FT   540.8 F
=====

```

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 700

PANEL	LAYER01	LAYER02
700001	0.02128 2128.29	0.00002 550.33
700002	0.02124 2123.60	0.00002 550.33

.....

.....

.....

700499	0.01728 1655.68	0.00002 550.33
700500	0.01725 1651.83	0.00002 550.33

OPTIMIZATION SYSTEM FOR TPSSYM = 1200

TOTAL NUMBER OF DESIGN VARIABLES = 9

TOTAL NUMBER OF CONSTRAINS = 6162

TOTAL NUMBER OF TEMP. CONSTRAINS = 180

TOTAL NUMBER OF TEMP. PRINTOUTS = 6

MAXIMUM TEMPERATURE OF EACH LAYER VS OUTPUT TIMES

X 0.2743E+04

1.0 B	A
	B A
	B B A
	B B


```

i
ZIRCONIA FIBERS      slab      0.00066 FT  2743.2 F
i
=====
i
HEAT SINK            slab      0.65617 FT  2613.3 F
i
=====

```

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 1200

PANEL	LAYER01	LAYER02
1200001	0.00020 2008.14	0.20000 1962.09
1200002	0.00020 1997.29	0.20000 1951.04
.....		
.....		
.....		
1202999	0.00020 691.81	0.20000 642.59
1203000	0.00020 677.43	0.20000 628.26

TOTAL MASS OF BOTH SIDES : 0.15660E+02 (KG), C. G. FROM X=0. IS : 0.21950E+01 (M)

```

*****
***                                     ***
*** T P S O P T   T E R M I N A T E D ***
***                                     ***
***           N O R M A L L Y           ***
***                                     ***
***      18:25:40      08/17/2009      ***
***                                     ***
*****

```

Listing 8.6.3 Output of Mass change due to TPS: mass_tps.dat

15.65999 34.37291

8.7 Run SMB for Structural Design

Input Files:

File Name	Type	Remarks	See Listing
smb_run.inp	Standard input file	Required	Shown in listing 8.7.1
traject.dat	Trajectory data generated by UPTOP	Inserted into the Standard input file smb_run.inp by the INCLUDE bulk data card	Shown in Listing 8.4.3
geom_data.dat	Aerodynamic mesh generated by UCDA	Imported by the ASSIGN AEROBASE executive control command	Not Shown

Output Files:

File Name	Type	Remarks	See Listing
smb_run.out	Standard output file	Print out results	Shown in Listing 8.7.2
RDOF_EIGEN.FREE	Eigenvalues and Eigenvectors of the beam model	Input file for TRIM and ASE analysis	Shown in Listing 8.7.3
masschnng.dat	Mass of the structural skin designed by SMB	Input file for UCDA to update the change of weight due to structure	Shown in Listing 8.7.4

8.7.1 Descriptions of the Input File: SMB_RUN.INP (Shown in Listing 8.7.1)

The aerodynamic mesh of the SEM configuration generated by UCDA is stored in the file “geom_data.dat” and imported into the SMB module by the executive control command shown as follows:

```
ASSIGN AEROBASE=geom_data.dat
```

Based on this aerodynamic mesh, SMB computes the width and height at 20 axial stations to approximate the cross section of the SEM configuration as rectangular boxes. Then, the SMB module constructs a beam finite element model with 20 grid points and 19 beam elements along the x axis of the vehicle. The area moment of inertias of each beam element is calculated based on the size of the rectangular box at each axial station with the optimum skin thickness that is to be designed by the fully stressed design method. Meanwhile, the vehicle weight calculated by UCDA and stored in the file “geom_data.dat” is distributed at each grid points of the beam model to represent the non-structural weight of the SEM configuration.

There is only one subcase defined by the case control command shown as follows:

```
BEAM=100
```

This case control command refers to a **BEAMFSD** bulk data card with ID = 100 in the bulk data section. In this **BEAMFSD** bulk data card, the material properties of the Aluminum along with a failure stress = 1.5×10^6 is specified. It also defines an initial and minimum skin thickness as 0.00001 and 0.000001, respectively, as well as a load factor of 1.5. The minimum skin thickness serves as a lower bound of thickness used by the Fully Stressed Design method. The load factor is used as a multiplication factor to the computed aerodynamic loads along on the trajectory. It should be noted that since the units of length and mass defined by UCDA for the SEM

configuration are in Meter and KG, respectively, the units of length and mass involved in the BEAMFSD input entries must be consistent with that of UCDA.

The trajectory is computed by UPTOP which is stored on the file "trajct.dat" that consists of one **TRAJCT** bulk data card with ID = 100 and one **TIMESP** bulk data card. The **TRAJCT** bulk data card is referred to by the **TRJLST** bulk data card with ID = 1. The **TIMESP** bulk data card is used only by the **TPSOPT** module and is not used by the **SMB** module. This trajectory file "trajct.dat" is automatically inserted into the bulk data section by the **INCLUDE** bulk data card shown as follows:

```
INCLUDE  trajct.dat
```

8.7.2 Descriptions of the Standard Output File: smb_run.lut (Shown in Listing 8.7.2)

The standard output file first prints out the input bulk data cards in an alphabetic order. Then it shows the 20 grid point locations and the non-structural masses at each grid points. The total non-structural mass is 572.7 KG that serves as the initial mass distribution of the beam model. The stiffness of the 19 beam elements with the initial skin thickness (0.00001) in term of EI and GJ is printed next.

After the Fully Stressed design computation is completed, **SMB** prints out the optimum thickness and the mass distribution of the beam model. This optimum thickness along with the initial thickness of the 19 beam element is shown in Figure 8.7.1. The total mass of the optimized structural model is 610.0 KG which shows a 37.3 KG increase of mass due to the structural skin.

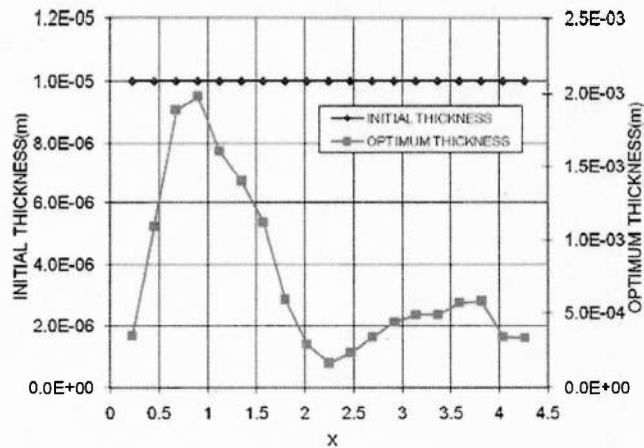


Figure 8.7.1 Optimum Thickness of the SEM configuration

Next, the EI and GJ distribution followed by the natural frequencies of the optimized beam model are printed out. These EI and GJ distributions are depicted in Figure 8.7.2 and the natural frequencies of the first 5 elastic modes are shown in Table 8.7.2.

Finally, an NASTRAN input file of the optimized beam model is printed in the standard file that allows the user to use NASTRAN to verify the SMB solution.

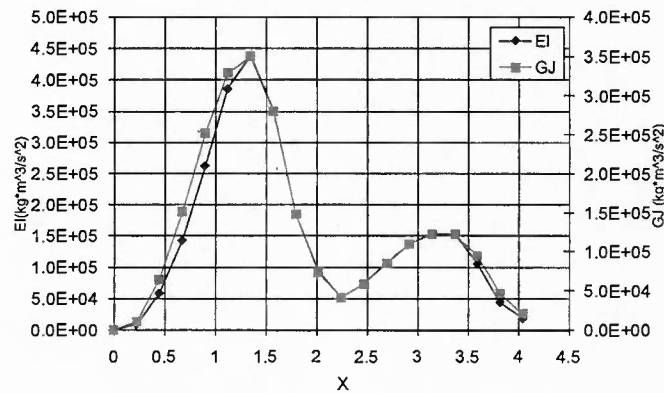


Figure 8.7.2 EI and GJ of the Optimized Beam Model for the SEM Configuration

Table 8.7.2 Natural Frequencies of the First Elastic Modes

BENDING MODE NO.	NATURAL FREQUENCY(Hz)
1	6.30E+00
2	2.04E+01
3	3.53E+01
4	5.16E+01
5	7.22E+01

8.7.3 Other Output Files: RDOF_EIGEN.FREE (Shown in Listing 8.7.3) and masschg.dat (Shown in Listing 8.7.4)

The file “RDOF_EIGEN.FREE” contains the natural frequencies and generalized masses of the first 20 modes. Note that the first 3 modes are corresponding to the fore-aft, plunge, and pitch rigid body modes. The first 3 elastic modes of the optimized beam model are depicted in Figure 8.7.3

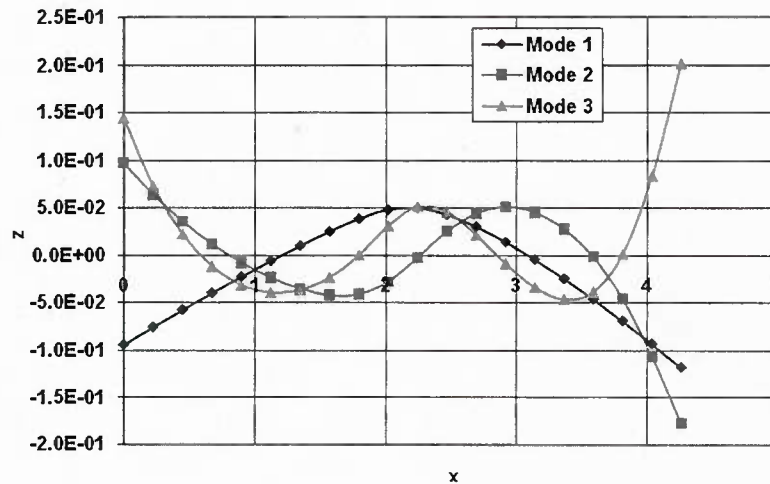


Figure 8.7.3 The First 3 Elastic Modes of the Optimized Beam Model

The file “masschg.dat” contains the locations of the 20 grid points and the incremental masses due to the structural skin at those 20 grid points. This file will be imported back to UCDA for

the next design cycle to include the impact of the structural skin weight on the weight and center of gravity of the whole vehicle.

Listing 8.7.1 Standard Input File: smb_run.inp

```

assign aerobase=geom_data.dat,print=1
cend
title= SEM Beam Model
echo=sort
subcase =1
    Beam=100
begin bulk
$
include 'trajct.dat'
$
beamfsd 100    1      6.895E092.592E09 .33    .00001 1.50    1.5E6
        .5      .01    .000001 6750.    .0001
trjlst  1
        100
enddata

```

Listing 8.7.2 Standard Output File: smb_run.out

```

EXECUTIVE CONTROL SUMMARY

|...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10...|

assign aerobase=geom_data.dat,print=1
cend

CASE CONTROL SUMMARY

SINGLE PRECISION COMPUTATION

MAXIMUM ALLOCABLE MEMORY = 800 MEGABYTES

|...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10...|

```

title= SEM Beam Model

echo=sort

subcase =1

Beam=100

begin bulk

SORTED BULK DATA ECHO

CARD

COUNT |...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10...|

1 -	BEAMFSD	100	1	6.895E09	2.592E09	33	.00001	1.50	1.5E6
2 -		.5	.01	.000001	6750.	.0001			
3 -	TIMESP	201	0.000	45.000	90.000	135.000	180.000	208.000	
4 -	TRAJCT	100	10						
5 -		9.0	6.1200	22332.	1.250				
6 -		18.0	6.2500	22375.	1.260				
7 -		27.0	6.3800	22482.	1.260				
8 -		36.0	6.4900	22645.	1.270				
9 -		45.0	6.5800	22841.	1.270				
10 -		54.0	6.6600	23063.	1.280				
11 -		63.0	6.7300	23301.	1.280				
12 -		72.0	6.7900	23547.	1.280				
13 -		81.0	6.8500	23785.	1.290				
14 -		90.0	6.9000	24003.	1.290				
15 -		99.0	6.9500	24186.	1.300				
16 -		108.0	6.9900	24325.	1.300				
17 -		117.0	7.0300	24412.	1.310				
18 -		126.0	7.0700	24451.	1.310				
19 -		135.0	7.1200	24454.	1.310				
20 -		144.0	7.1900	24439.	1.320				
21 -		153.0	7.2600	24431.	1.320				
22 -		162.0	7.3500	24457.	1.330				
23 -		171.0	7.4500	24549.	1.330				
24 -		180.0	7.5600	24732.	1.340				


```

25 -          189.0   7.6900  25031.  1.340
26 -          198.0   7.8300  25460.  1.340
27 -          207.0   7.9800  26019.  1.350
28 -          208.0   8.0000  26089.  1.350          TECPLOT          1209.PLT
29 -  TRJLST  1
30 -          100
31 -  ENDDATA

```

```

*****
*
*
*   SUBCASE      =      1   *
*
*   DISCIPLINE   =  BEAM    *
*
*   BULK ENTRY ID =      100  *
*
*
*****

```

FINITE ELEMENT MODEL DESCRIPTION

GRID ID	COORDINATE			CONCENTATED MASS
	X	Y	Z	
1	0.000	0.000	0.000	4.639
2	0.225	0.000	0.000	14.949
3	0.449	0.000	0.000	17.948
4	0.674	0.000	0.000	22.341
5	0.898	0.000	0.000	29.908
6	1.123	0.000	0.000	37.558
7	1.348	0.000	0.000	38.891
8	1.572	0.000	0.000	38.889
9	1.797	0.000	0.000	38.889

10	2.021	0.000	0.000	38.896
11	2.246	0.000	0.000	38.904
12	2.470	0.000	0.000	38.913
13	2.695	0.000	0.000	38.926
14	2.920	0.000	0.000	38.918
15	3.144	0.000	0.000	38.870
16	3.369	0.000	0.000	36.775
17	3.593	0.000	0.000	23.666
18	3.818	0.000	0.000	18.136
19	4.043	0.000	0.000	14.431
20	4.267	0.000	0.000	2.224

*TOTAL MASS = 0.57267133E+03

ELEMENT	CROSS SECTION(BOX)			MOMENT OF INERTIA			STIFFNESS	
ID	WIDTH	HEIGHT	THICKNESS	Izz	Iyy	J	BENDING(EI)	TORSION(GJ)
1	0.57E+0	0.11E+0	0.10E-4	0.48E-6	0.36E-7	0.11E-6	0.25038E+03	0.29666E+03
2	0.60E+0	0.15E+0	0.10E-4	0.65E-6	0.77E-7	0.23E-6	0.53007E+03	0.58614E+03
3	0.61E+0	0.18E+0	0.10E-4	0.71E-6	0.11E-6	0.30E-6	0.74271E+03	0.78581E+03
4	0.61E+0	0.23E+0	0.10E-4	0.81E-6	0.19E-6	0.48E-6	0.13039E+04	0.12551E+04
5	0.61E+0	0.31E+0	0.10E-4	0.95E-6	0.34E-6	0.78E-6	0.23698E+04	0.20184E+04
6	0.61E+0	0.35E+0	0.10E-4	0.10E-5	0.45E-6	0.96E-6	0.31047E+04	0.24820E+04
7	0.61E+0	0.35E+0	0.10E-4	0.10E-5	0.45E-6	0.96E-6	0.31272E+04	0.24956E+04
8	0.61E+0	0.35E+0	0.10E-4	0.10E-5	0.45E-6	0.96E-6	0.31229E+04	0.24930E+04
9	0.61E+0	0.35E+0	0.10E-4	0.10E-5	0.45E-6	0.96E-6	0.31242E+04	0.24938E+04
10	0.61E+0	0.35E+0	0.10E-4	0.10E-5	0.45E-6	0.96E-6	0.31255E+04	0.24946E+04
11	0.61E+0	0.35E+0	0.10E-4	0.10E-5	0.45E-6	0.96E-6	0.31268E+04	0.24954E+04
12	0.61E+0	0.35E+0	0.10E-4	0.10E-5	0.45E-6	0.96E-6	0.31290E+04	0.24967E+04
13	0.61E+0	0.35E+0	0.10E-4	0.10E-5	0.45E-6	0.96E-6	0.31303E+04	0.24974E+04
14	0.61E+0	0.35E+0	0.10E-4	0.10E-5	0.45E-6	0.96E-6	0.31243E+04	0.24938E+04
15	0.61E+0	0.35E+0	0.10E-4	0.10E-5	0.45E-6	0.96E-6	0.31196E+04	0.24910E+04
16	0.61E+0	0.28E+0	0.10E-4	0.89E-6	0.27E-6	0.64E-6	0.18531E+04	0.16646E+04
17	0.61E+0	0.18E+0	0.10E-4	0.71E-6	0.11E-6	0.31E-6	0.75761E+03	0.79915E+03
18	0.61E+0	0.15E+0	0.10E-4	0.66E-6	0.79E-7	0.23E-6	0.54205E+03	0.59991E+03
19	0.33E+0	0.11E+0	0.10E-4	0.12E-6	0.20E-7	0.55E-7	0.13884E+03	0.14278E+03

FULLY STRESSED DESIGN RESULT

DESIGN VARIABLE : THICKNESS OF CROSS SECTION(BOX)

MINIMUM THICKNESS : 0.1000000E-03

ELEMENTS ID	INITIAL THICKNESS	OPTIMUM THICKNESS	INCREMENTS
1	0.99999997E-05	0.35148129E-03	0.34148130E-03
2	0.99999997E-05	0.10882088E-02	0.10782088E-02
3	0.99999997E-05	0.18891594E-02	0.18791595E-02
4	0.99999997E-05	0.19792626E-02	0.19692625E-02
5	0.99999997E-05	0.16131498E-02	0.16031498E-02
6	0.99999997E-05	0.13999925E-02	0.13899925E-02
7	0.99999997E-05	0.11146659E-02	0.11046659E-02
8	0.99999997E-05	0.59418526E-03	0.58418524E-03
9	0.99999997E-05	0.29307799E-03	0.28307800E-03
10	0.99999997E-05	0.16511255E-03	0.15511255E-03
11	0.99999997E-05	0.23398212E-03	0.22398212E-03
12	0.99999997E-05	0.33900252E-03	0.32900253E-03
13	0.99999997E-05	0.44028691E-03	0.43028692E-03
14	0.99999997E-05	0.48912334E-03	0.47912335E-03
15	0.99999997E-05	0.48940675E-03	0.47940676E-03
16	0.99999997E-05	0.56959159E-03	0.55959157E-03
17	0.99999997E-05	0.58346102E-03	0.57346100E-03
18	0.99999997E-05	0.34013751E-03	0.33013753E-03
19	0.99999997E-05	0.33359733E-03	0.32359734E-03

GRID ID	COORDINATE			CONCENTATED MASS
	X	Y	Z	
1	0.000	0.000	0.000	4.990
2	0.225	0.000	0.000	16.541
3	0.449	0.000	0.000	21.447
4	0.674	0.000	0.000	27.131
5	0.898	0.000	0.000	34.684
6	1.123	0.000	0.000	41.834

7	1.348	0.000	0.000	42.539
8	1.572	0.000	0.000	41.359
9	1.797	0.000	0.000	40.156
10	2.021	0.000	0.000	39.536
11	2.246	0.000	0.000	39.457
12	2.470	0.000	0.000	39.720
13	2.695	0.000	0.000	40.035
14	2.920	0.000	0.000	40.247
15	3.144	0.000	0.000	40.270
16	3.369	0.000	0.000	38.228
17	3.593	0.000	0.000	25.107
18	3.818	0.000	0.000	19.207
19	4.043	0.000	0.000	15.026
20	4.267	0.000	0.000	2.437

*TOTAL MASS = 0.60995239E+03

ELEMENT	CROSS SECTION (BOX)			MOMENT OF INERTIA			STIFFNESS	
ID	WIDTH	HEIGHT	THICKNESS	I _{zz}	I _{yy}	J	BENDING (EI)	TORSION (GJ)
1	0.57E+0	0.11E+0	0.35E-3	0.17E-4	0.13E-5	0.40E-5	0.88621E+04	0.10494E+05
2	0.60E+0	0.15E+0	0.11E-2	0.71E-4	0.85E-5	0.25E-4	0.58627E+05	0.64732E+05
3	0.61E+0	0.18E+0	0.19E-2	0.14E-3	0.21E-4	0.59E-4	0.14381E+06	0.15179E+06
4	0.61E+0	0.23E+0	0.20E-2	0.16E-3	0.38E-4	0.98E-4	0.26345E+06	0.25306E+06
5	0.61E+0	0.31E+0	0.16E-2	0.16E-3	0.56E-4	0.13E-3	0.38741E+06	0.32955E+06
6	0.61E+0	0.35E+0	0.14E-2	0.15E-3	0.64E-4	0.14E-3	0.43922E+06	0.35081E+06
7	0.61E+0	0.35E+0	0.11E-2	0.12E-3	0.51E-4	0.11E-3	0.35147E+06	0.28029E+06
8	0.61E+0	0.35E+0	0.59E-3	0.62E-4	0.27E-4	0.57E-4	0.18637E+06	0.14873E+06
9	0.61E+0	0.35E+0	0.29E-3	0.30E-4	0.13E-4	0.28E-4	0.91759E+05	0.73230E+05
10	0.61E+0	0.35E+0	0.17E-3	0.17E-4	0.75E-5	0.16E-4	0.51666E+05	0.41232E+05
11	0.61E+0	0.35E+0	0.23E-3	0.24E-4	0.11E-4	0.23E-4	0.73285E+05	0.58477E+05
12	0.61E+0	0.35E+0	0.34E-3	0.35E-4	0.15E-4	0.33E-4	0.10634E+06	0.84829E+05
13	0.61E+0	0.35E+0	0.44E-3	0.46E-4	0.20E-4	0.43E-4	0.13827E+06	0.11028E+06
14	0.61E+0	0.35E+0	0.49E-3	0.51E-4	0.22E-4	0.47E-4	0.15337E+06	0.12238E+06
15	0.61E+0	0.35E+0	0.49E-3	0.51E-4	0.22E-4	0.47E-4	0.15323E+06	0.12231E+06
16	0.61E+0	0.28E+0	0.57E-3	0.51E-4	0.15E-4	0.37E-4	0.10609E+06	0.95252E+05
17	0.61E+0	0.18E+0	0.58E-3	0.42E-4	0.65E-5	0.18E-4	0.44535E+05	0.46943E+05
18	0.61E+0	0.15E+0	0.34E-3	0.23E-4	0.27E-5	0.79E-5	0.18528E+05	0.20497E+05

19 0.33E+0 0.11E+0 0.33E-3 0.39E-5 0.68E-6 0.18E-5 0.46657E+04 0.47946E+04

MAXIMUM STRESS AFTER FULLY STRESSED DESIGN

LOAD CASE NUMBER	ELEMENT ID	STRESS
1	10	0.30549E+07
2	2	0.27570E+07
3	2	0.27413E+07
4	2	0.29748E+07
5	2	0.27805E+07

REAL EIGENVALUES OF OPTIMUM SYSTEM

MODE NO.	EXTRACTION ORDER	EIGENVALUE	RADIANS	CYCLES	GENERALIZED MASS	GENERALIZED STIFFNESS
1	1	0.328012E-02	0.572723E-01	0.911518E-02	0.100000E+01	0.328012E-02
2	2	0.763687E-01	0.276349E+00	0.439823E-01	0.100000E+01	0.763687E-01
3	3	0.362413E+00	0.602008E+00	0.958125E-01	0.100000E+01	0.362413E+00
4	4	0.156646E+04	0.395785E+02	0.629912E+01	0.100000E+01	0.156646E+04
5	5	0.164186E+05	0.128135E+03	0.203934E+02	0.100000E+01	0.164186E+05
6	6	0.211866E+05	0.145556E+03	0.231660E+02	0.100000E+01	0.211866E+05
7	7	0.490913E+05	0.221566E+03	0.352633E+02	0.100000E+01	0.490913E+05
8	8	0.105222E+06	0.324380E+03	0.516267E+02	0.100000E+01	0.105222E+06
9	9	0.136950E+06	0.370068E+03	0.588981E+02	0.100000E+01	0.136950E+06
10	10	0.206066E+06	0.453945E+03	0.722476E+02	0.100000E+01	0.206066E+06
11	11	0.284621E+06	0.533499E+03	0.849090E+02	0.100000E+01	0.284621E+06
12	12	0.354590E+06	0.595475E+03	0.947727E+02	0.100000E+01	0.354590E+06
13	13	0.443067E+06	0.665633E+03	0.105939E+03	0.100000E+01	0.443067E+06
14	14	0.547201E+06	0.739730E+03	0.117732E+03	0.100000E+01	0.547201E+06
15	15	0.653282E+06	0.808259E+03	0.128638E+03	0.100000E+01	0.653282E+06
16	16	0.817484E+06	0.904148E+03	0.143900E+03	0.100000E+01	0.817484E+06
17	17	0.824236E+06	0.907875E+03	0.144493E+03	0.100000E+01	0.824236E+06
18	18	0.107971E+07	0.103909E+04	0.165376E+03	0.100000E+01	0.107971E+07
19	19	0.121719E+07	0.110326E+04	0.175590E+03	0.100000E+01	0.121719E+07

20	20	0.135788E+07	0.116528E+04	0.185460E+03	0.100000E+01	0.135788E+07
21	21	0.152273E+07	0.123399E+04	0.196396E+03	0.100000E+01	0.152273E+07
22	22	0.176706E+07	0.132931E+04	0.211566E+03	0.100000E+01	0.176706E+07
23	23	0.204883E+07	0.143137E+04	0.227810E+03	0.100000E+01	0.204883E+07
24	24	0.210969E+07	0.145248E+04	0.231169E+03	0.100000E+01	0.210969E+07
25	25	0.256708E+07	0.160221E+04	0.255000E+03	0.100000E+01	0.256708E+07
26	26	0.257644E+07	0.160513E+04	0.255464E+03	0.100000E+01	0.257644E+07
27	27	0.319019E+07	0.178611E+04	0.284268E+03	0.100000E+01	0.319019E+07
28	28	0.369745E+07	0.192288E+04	0.306035E+03	0.100000E+01	0.369745E+07
29	29	0.386050E+07	0.196482E+04	0.312710E+03	0.100000E+01	0.386050E+07
30	30	0.446682E+07	0.211349E+04	0.336372E+03	0.100000E+01	0.446682E+07
31	31	0.458788E+07	0.214193E+04	0.340899E+03	0.100000E+01	0.458788E+07
32	32	0.492742E+07	0.221978E+04	0.353289E+03	0.100000E+01	0.492742E+07
33	33	0.596267E+07	0.244186E+04	0.388634E+03	0.100000E+01	0.596267E+07
34	34	0.685215E+07	0.261766E+04	0.416614E+03	0.100000E+01	0.685215E+07
35	35	0.804543E+07	0.283645E+04	0.451435E+03	0.100000E+01	0.804543E+07
36	36	0.839791E+07	0.289791E+04	0.461217E+03	0.100000E+01	0.839791E+07
37	37	0.116353E+08	0.341106E+04	0.542886E+03	0.100000E+01	0.116353E+08
38	38	0.122275E+08	0.349678E+04	0.556530E+03	0.100000E+01	0.122275E+08
39	39	0.153337E+08	0.391582E+04	0.623223E+03	0.100000E+01	0.153337E+08
40	40	0.286732E+08	0.535474E+04	0.852233E+03	0.100000E+01	0.286732E+08
41	41	0.210351E+11	0.145035E+06	0.230830E+05	0.100000E+01	0.210351E+11
42	42	0.295906E+11	0.172019E+06	0.273777E+05	0.100000E+01	0.295906E+11
43	43	0.371050E+11	0.192626E+06	0.306575E+05	0.100000E+01	0.371050E+11
44	44	0.401755E+11	0.200438E+06	0.319008E+05	0.100000E+01	0.401755E+11
45	45	0.530688E+11	0.230367E+06	0.366640E+05	0.100000E+01	0.530688E+11
46	46	0.587319E+11	0.242347E+06	0.385707E+05	0.100000E+01	0.587319E+11
47	47	0.659566E+11	0.256820E+06	0.408742E+05	0.100000E+01	0.659566E+11
48	48	0.691115E+11	0.262891E+06	0.418404E+05	0.100000E+01	0.691115E+11
49	49	0.786366E+11	0.280422E+06	0.446306E+05	0.100000E+01	0.786366E+11
50	50	0.983478E+11	0.313604E+06	0.499117E+05	0.100000E+01	0.983478E+11
51	51	0.113244E+12	0.336517E+06	0.535584E+05	0.100000E+01	0.113244E+12
52	52	0.122690E+12	0.350272E+06	0.557475E+05	0.100000E+01	0.122690E+12
53	53	0.144016E+12	0.379494E+06	0.603983E+05	0.100000E+01	0.144016E+12
54	54	0.150538E+12	0.387992E+06	0.617508E+05	0.100000E+01	0.150538E+12
55	55	0.182569E+12	0.427280E+06	0.680038E+05	0.100000E+01	0.182569E+12

56	56	0.185401E+12	0.430582E+06	0.685293E+05	0.100000E+01	0.185401E+12
57	57	0.226531E+12	0.475953E+06	0.757503E+05	0.100000E+01	0.226531E+12
58	58	0.292183E+12	0.540539E+06	0.860295E+05	0.100000E+01	0.292183E+12
59	59	0.381235E+12	0.617442E+06	0.982690E+05	0.100000E+01	0.381235E+12
60	60	0.484582E+12	0.696119E+06	0.110791E+06	0.100000E+01	0.484582E+12

N A S T R A N I N P U T D E C K

SOL 101

CEND

SUBCASE = 1

LOAD = 1

DISP = ALL

STRESS = ALL

SUBCASE = 2

LOAD = 2

DISP = ALL

STRESS = ALL

SUBCASE = 3

LOAD = 3

DISP = ALL

STRESS = ALL

SUBCASE = 4

LOAD = 4

DISP = ALL

STRESS = ALL

SUBCASE = 5

LOAD = 5

DISP = ALL

STRESS = ALL

BEGIN BULK

PARAM, INREL, -1

PARAM, GRDPNT, 1

SUPPORT,1,123456

GRID	1	0.000	0.000	0.000
GRID	2	0.225	0.000	0.000
GRID	3	0.449	0.000	0.000
GRID	4	0.674	0.000	0.000
GRID	5	0.898	0.000	0.000
GRID	6	1.123	0.000	0.000
GRID	7	1.348	0.000	0.000
GRID	8	1.572	0.000	0.000
GRID	9	1.797	0.000	0.000
GRID	10	2.021	0.000	0.000
GRID	11	2.246	0.000	0.000
GRID	12	2.470	0.000	0.000
GRID	13	2.695	0.000	0.000
GRID	14	2.920	0.000	0.000
GRID	15	3.144	0.000	0.000
GRID	16	3.369	0.000	0.000
GRID	17	3.593	0.000	0.000
GRID	18	3.818	0.000	0.000
GRID	19	4.043	0.000	0.000
GRID	20	4.267	0.000	0.000

CBAR	1	1	1	2	1.000	1.000	0.000
CBAR	2	2	2	3	1.000	1.000	0.000
CBAR	3	3	3	4	1.000	1.000	0.000
CBAR	4	4	4	5	1.000	1.000	0.000
CBAR	5	5	5	6	1.000	1.000	0.000
CBAR	6	6	6	7	1.000	1.000	0.000
CBAR	7	7	7	8	1.000	1.000	0.000
CBAR	8	8	8	9	1.000	1.000	0.000
CBAR	9	9	9	10	1.000	1.000	0.000
CBAR	10	10	10	11	1.000	1.000	0.000
CBAR	11	11	11	12	1.000	1.000	0.000
CBAR	12	12	12	13	1.000	1.000	0.000
CBAR	13	13	13	14	1.000	1.000	0.000
CBAR	14	14	14	15	1.000	1.000	0.000
CBAR	15	15	15	16	1.000	1.000	0.000

CBAR	16	16	16	17	1.000	1.000	0.000
CBAR	17	17	17	18	1.000	1.000	0.000
CBAR	18	18	18	19	1.000	1.000	0.000
CBAR	19	19	19	20	1.000	1.000	0.000
FORCE	1	1	0	0.12E+3	0.000	0.000	1.000
FORCE	1	2	0	0.30E+3	0.000	0.000	1.000
FORCE	1	3	0	-0.17E+3	0.000	0.000	1.000
FORCE	1	4	0	-0.11E+4	0.000	0.000	1.000
FORCE	1	5	0	-0.15E+4	0.000	0.000	1.000
FORCE	1	6	0	-0.21E+4	0.000	0.000	1.000
FORCE	1	7	0	-0.13E+4	0.000	0.000	1.000
FORCE	1	8	0	0.47E+3	0.000	0.000	1.000
FORCE	1	9	0	0.48E+3	0.000	0.000	1.000
FORCE	1	10	0	0.47E+3	0.000	0.000	1.000
FORCE	1	11	0	0.51E+3	0.000	0.000	1.000
FORCE	1	12	0	0.50E+3	0.000	0.000	1.000
FORCE	1	13	0	0.57E+3	0.000	0.000	1.000
FORCE	1	14	0	0.57E+3	0.000	0.000	1.000
FORCE	1	15	0	0.57E+3	0.000	0.000	1.000
FORCE	1	16	0	0.72E+3	0.000	0.000	1.000
FORCE	1	17	0	0.85E+3	0.000	0.000	1.000
FORCE	1	18	0	0.89E+3	0.000	0.000	1.000
FORCE	1	19	0	0.73E+3	0.000	0.000	1.000
FORCE	1	20	0	0.28E+3	0.000	0.000	1.000
FORCE	2	1	0	0.11E+3	0.000	0.000	1.000
FORCE	2	2	0	0.27E+3	0.000	0.000	1.000
FORCE	2	3	0	-0.16E+3	0.000	0.000	1.000
FORCE	2	4	0	-0.98E+3	0.000	0.000	1.000
FORCE	2	5	0	-0.14E+4	0.000	0.000	1.000
FORCE	2	6	0	-0.20E+4	0.000	0.000	1.000
FORCE	2	7	0	-0.12E+4	0.000	0.000	1.000
FORCE	2	8	0	0.42E+3	0.000	0.000	1.000
FORCE	2	9	0	0.43E+3	0.000	0.000	1.000
FORCE	2	10	0	0.42E+3	0.000	0.000	1.000
FORCE	2	11	0	0.46E+3	0.000	0.000	1.000
FORCE	2	12	0	0.45E+3	0.000	0.000	1.000

FORCE	2	13	0 0.51E+3	0.000	0.000	1.000
FORCE	2	14	0 0.52E+3	0.000	0.000	1.000
FORCE	2	15	0 0.51E+3	0.000	0.000	1.000
FORCE	2	16	0 0.64E+3	0.000	0.000	1.000
FORCE	2	17	0 0.76E+3	0.000	0.000	1.000
FORCE	2	18	0 0.80E+3	0.000	0.000	1.000
FORCE	2	19	0 0.65E+3	0.000	0.000	1.000
FORCE	2	20	0 0.25E+3	0.000	0.000	1.000
FORCE	3	1	0 0.11E+3	0.000	0.000	1.000
FORCE	3	2	0 0.27E+3	0.000	0.000	1.000
FORCE	3	3	0-0.17E+3	0.000	0.000	1.000
FORCE	3	4	0-0.98E+3	0.000	0.000	1.000
FORCE	3	5	0-0.14E+4	0.000	0.000	1.000
FORCE	3	6	0-0.20E+4	0.000	0.000	1.000
FORCE	3	7	0-0.13E+4	0.000	0.000	1.000
FORCE	3	8	0 0.42E+3	0.000	0.000	1.000
FORCE	3	9	0 0.43E+3	0.000	0.000	1.000
FORCE	3	10	0 0.42E+3	0.000	0.000	1.000
FORCE	3	11	0 0.45E+3	0.000	0.000	1.000
FORCE	3	12	0 0.45E+3	0.000	0.000	1.000
FORCE	3	13	0 0.50E+3	0.000	0.000	1.000
FORCE	3	14	0 0.51E+3	0.000	0.000	1.000
FORCE	3	15	0 0.51E+3	0.000	0.000	1.000
FORCE	3	16	0 0.63E+3	0.000	0.000	1.000
FORCE	3	17	0 0.74E+3	0.000	0.000	1.000
FORCE	3	18	0 0.78E+3	0.000	0.000	1.000
FORCE	3	19	0 0.64E+3	0.000	0.000	1.000
FORCE	3	20	0 0.25E+3	0.000	0.000	1.000
FORCE	4	1	0 0.12E+3	0.000	0.000	1.000
FORCE	4	2	0 0.29E+3	0.000	0.000	1.000
FORCE	4	3	0-0.20E+3	0.000	0.000	1.000
FORCE	4	4	0-0.11E+4	0.000	0.000	1.000
FORCE	4	5	0-0.15E+4	0.000	0.000	1.000
FORCE	4	6	0-0.22E+4	0.000	0.000	1.000
FORCE	4	7	0-0.14E+4	0.000	0.000	1.000
FORCE	4	8	0 0.44E+3	0.000	0.000	1.000

FORCE	4	9	0 0.45E+3	0.000	0.000	1.000
FORCE	4	10	0 0.44E+3	0.000	0.000	1.000
FORCE	4	11	0 0.48E+3	0.000	0.000	1.000
FORCE	4	12	0 0.47E+3	0.000	0.000	1.000
FORCE	4	13	0 0.53E+3	0.000	0.000	1.000
FORCE	4	14	0 0.54E+3	0.000	0.000	1.000
FORCE	4	15	0 0.54E+3	0.000	0.000	1.000
FORCE	4	16	0 0.66E+3	0.000	0.000	1.000
FORCE	4	17	0 0.78E+3	0.000	0.000	1.000
FORCE	4	18	0 0.81E+3	0.000	0.000	1.000
FORCE	4	19	0 0.67E+3	0.000	0.000	1.000
FORCE	4	20	0 0.26E+3	0.000	0.000	1.000
FORCE	5	1	0 0.11E+3	0.000	0.000	1.000
FORCE	5	2	0 0.27E+3	0.000	0.000	1.000
FORCE	5	3	0-0.19E+3	0.000	0.000	1.000
FORCE	5	4	0-0.10E+4	0.000	0.000	1.000
FORCE	5	5	0-0.14E+4	0.000	0.000	1.000
FORCE	5	6	0-0.21E+4	0.000	0.000	1.000
FORCE	5	7	0-0.13E+4	0.000	0.000	1.000
FORCE	5	8	0 0.40E+3	0.000	0.000	1.000
FORCE	5	9	0 0.41E+3	0.000	0.000	1.000
FORCE	5	10	0 0.41E+3	0.000	0.000	1.000
FORCE	5	11	0 0.44E+3	0.000	0.000	1.000
FORCE	5	12	0 0.43E+3	0.000	0.000	1.000
FORCE	5	13	0 0.49E+3	0.000	0.000	1.000
FORCE	5	14	0 0.49E+3	0.000	0.000	1.000
FORCE	5	15	0 0.49E+3	0.000	0.000	1.000
FORCE	5	16	0 0.60E+3	0.000	0.000	1.000
FORCE	5	17	0 0.71E+3	0.000	0.000	1.000
FORCE	5	18	0 0.73E+3	0.000	0.000	1.000
FORCE	5	19	0 0.60E+3	0.000	0.000	1.000
FORCE	5	20	0 0.23E+3	0.000	0.000	1.000
PBAR	1	1.477E-03.171E-04.129E-05.405E-05				
		-.28E+000.55E-010.28E+000.55E-010.28E+00-.55E-01-.28E+00-.55E-01				
PBAR	2	1.165E-02.709E-04.850E-05.250E-04				
		-.30E+000.77E-010.30E+000.77E-010.30E+00-.77E-01-.30E+00-.77E-01				

PBAR	3	1.300E-02.136E-03.209E-04.586E-04
		-.30E+000.90E-010.30E+000.90E-010.30E+00-.90E-01-.30E+00-.90E-01
PBAR	4	1.336E-02.163E-03.382E-04.976E-04
		-.30E+000.12E+000.30E+000.12E+000.30E+00-.12E+00-.30E+00-.12E+00
PBAR	5	1.298E-02.155E-03.562E-04.127E-03
		-.30E+000.16E+000.30E+000.16E+000.30E+00-.16E+00-.30E+00-.16E+00
PBAR	6	1.270E-02.146E-03.637E-04.135E-03
		-.30E+000.18E+000.30E+000.18E+000.30E+00-.18E+00-.30E+00-.18E+00
PBAR	7	1.215E-02.116E-03.510E-04.108E-03
		-.30E+000.18E+000.30E+000.18E+000.30E+00-.18E+00-.30E+00-.18E+00
PBAR	8	1.115E-02.616E-04.270E-04.574E-04
		-.30E+000.18E+000.30E+000.18E+000.30E+00-.18E+00-.30E+00-.18E+00
PBAR	9	1.565E-03.303E-04.133E-04.283E-04
		-.30E+000.18E+000.30E+000.18E+000.30E+00-.18E+00-.30E+00-.18E+00
PBAR	10	1.318E-03.171E-04.749E-05.159E-04
		-.30E+000.18E+000.30E+000.18E+000.30E+00-.18E+00-.30E+00-.18E+00
PBAR	11	1.451E-03.242E-04.106E-04.226E-04
		-.30E+000.18E+000.30E+000.18E+000.30E+00-.18E+00-.30E+00-.18E+00
PBAR	12	1.653E-03.351E-04.154E-04.327E-04
		-.30E+000.18E+000.30E+000.18E+000.30E+00-.18E+00-.30E+00-.18E+00
PBAR	13	1.849E-03.456E-04.201E-04.425E-04
		-.30E+000.18E+000.30E+000.18E+000.30E+00-.18E+00-.30E+00-.18E+00
PBAR	14	1.943E-03.507E-04.222E-04.472E-04
		-.30E+000.18E+000.30E+000.18E+000.30E+00-.18E+00-.30E+00-.18E+00
PBAR	15	1.943E-03.507E-04.222E-04.472E-04
		-.30E+000.18E+000.30E+000.18E+000.30E+00-.18E+00-.30E+00-.18E+00
PBAR	16	1.101E-02.510E-04.154E-04.367E-04
		-.30E+000.14E+000.30E+000.14E+000.30E+00-.14E+00-.30E+00-.14E+00
PBAR	17	1.924E-03.418E-04.646E-05.181E-04
		-.30E+000.91E-010.30E+000.91E-010.30E+00-.91E-01-.30E+00-.91E-01
PBAR	18	1.520E-03.226E-04.269E-05.791E-05
		-.30E+000.77E-010.30E+000.77E-010.30E+00-.77E-01-.30E+00-.77E-01
PBAR	19	1.290E-03.387E-05.677E-06.185E-05
		-.16E+000.53E-010.16E+000.53E-010.16E+00-.53E-01-.16E+00-.53E-01
CONM2	21	1 0.50E+1
		1.E-6 1.E-6 1.E-6

CONM2	22	2	0.17E+2	
	1.E-6	1.E-6		1.E-6
CONM2	23	3	0.21E+2	
	1.E-6	1.E-6		1.E-6
CONM2	24	4	0.27E+2	
	1.E-6	1.E-6		1.E-6
CONM2	25	5	0.35E+2	
	1.E-6	1.E-6		1.E-6
CONM2	26	6	0.42E+2	
	1.E-6	1.E-6		1.E-6
CONM2	27	7	0.43E+2	
	1.E-6	1.E-6		1.E-6
CONM2	28	8	0.41E+2	
	1.E-6	1.E-6		1.E-6
CONM2	29	9	0.40E+2	
	1.E-6	1.E-6		1.E-6
CONM2	30	10	0.40E+2	
	1.E-6	1.E-6		1.E-6
CONM2	31	11	0.39E+2	
	1.E-6	1.E-6		1.E-6
CONM2	32	12	0.40E+2	
	1.E-6	1.E-6		1.E-6
CONM2	33	13	0.40E+2	
	1.E-6	1.E-6		1.E-6
CONM2	34	14	0.40E+2	
	1.E-6	1.E-6		1.E-6
CONM2	35	15	0.40E+2	
	1.E-6	1.E-6		1.E-6
CONM2	36	16	0.38E+2	
	1.E-6	1.E-6		1.E-6
CONM2	37	17	0.25E+2	
	1.E-6	1.E-6		1.E-6
CONM2	38	18	0.19E+2	
	1.E-6	1.E-6		1.E-6
CONM2	39	19	0.15E+2	
	1.E-6	1.E-6		1.E-6

```

CONM2      40      20      0.24E+1

      1.E-6      1.E-6      1.E-6

MAT1      1 0.7E+10 0.3E+10 0.33E+0

ENDDATA

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***                                     ***

*** S   M   B   T E R M I N A T E D ***

***                                     ***

***           N O R M A L L Y           ***

***                                     ***

***      18:28:09      08/17/2009      ***

***                                     ***

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Listing 8.7.3 Eigenvalues and Eigenvectors of the Beam Model: RDOF_EIGEN.FREE

20	20					
1	0.00000000E+00	0.00000000E+00	0.00000000E+00			
2	0.22458947E+00	0.00000000E+00	0.00000000E+00			
3	0.44917893E+00	0.00000000E+00	0.00000000E+00			
4	0.67376840E+00	0.00000000E+00	0.00000000E+00			
5	0.89835787E+00	0.00000000E+00	0.00000000E+00			
6	0.11229473E+01	0.00000000E+00	0.00000000E+00			
7	0.13475368E+01	0.00000000E+00	0.00000000E+00			
8	0.15721263E+01	0.00000000E+00	0.00000000E+00			
9	0.17967157E+01	0.00000000E+00	0.00000000E+00			
10	0.20213053E+01	0.00000000E+00	0.00000000E+00			
11	0.22458947E+01	0.00000000E+00	0.00000000E+00			
12	0.24704843E+01	0.00000000E+00	0.00000000E+00			
13	0.26950736E+01	0.00000000E+00	0.00000000E+00			
14	0.29196632E+01	0.00000000E+00	0.00000000E+00			
15	0.31442525E+01	0.00000000E+00	0.00000000E+00			
16	0.33688421E+01	0.00000000E+00	0.00000000E+00			
17	0.35934315E+01	0.00000000E+00	0.00000000E+00			
18	0.38180211E+01	0.00000000E+00	0.00000000E+00			
19	0.40426106E+01	0.00000000E+00	0.00000000E+00			
20	0.42672000E+01	0.00000000E+00	0.00000000E+00			
\$MODE 1						
0.57272335E-01 0.10000000E+01						
1	-0.404903816E-01	0.00000000E+00	-0.489255126E-06	0.00000000E+00	-0.380781555E-06	0.00000000E+00
2	-0.404903815E-01	0.00000000E+00	-0.403735601E-06	0.00000000E+00	-0.380781507E-06	0.00000000E+00
3	-0.404903807E-01	0.00000000E+00	-0.318216072E-06	0.00000000E+00	-0.380781732E-06	0.00000000E+00
4	-0.404903819E-01	0.00000000E+00	-0.232696502E-06	0.00000000E+00	-0.380781703E-06	0.00000000E+00
5	-0.404903830E-01	0.00000000E+00	-0.147176944E-06	0.00000000E+00	-0.380781740E-06	0.00000000E+00
6	-0.404903877E-01	0.00000000E+00	-0.616573504E-07	0.00000000E+00	-0.380782007E-06	0.00000000E+00
7	-0.404903890E-01	0.00000000E+00	0.238623523E-07	0.00000000E+00	-0.380782773E-06	0.00000000E+00
8	-0.404903904E-01	0.00000000E+00	0.109382364E-06	0.00000000E+00	-0.380784766E-06	0.00000000E+00
9	-0.404903930E-01	0.00000000E+00	0.194903123E-06	0.00000000E+00	-0.380789353E-06	0.00000000E+00
10	-0.404903979E-01	0.00000000E+00	0.280425505E-06	0.00000000E+00	-0.380798871E-06	0.00000000E+00
11	-0.404904020E-01	0.00000000E+00	0.365950743E-06	0.00000000E+00	-0.380815229E-06	0.00000000E+00
12	-0.404904045E-01	0.00000000E+00	0.451479058E-06	0.00000000E+00	-0.380825553E-06	0.00000000E+00
13	-0.404904080E-01	0.00000000E+00	0.537009134E-06	0.00000000E+00	-0.380831768E-06	0.00000000E+00
14	-0.404904105E-01	0.00000000E+00	0.622540525E-06	0.00000000E+00	-0.380836751E-06	0.00000000E+00
15	-0.404904097E-01	0.00000000E+00	0.708073128E-06	0.00000000E+00	-0.380844026E-06	0.00000000E+00
16	-0.404904088E-01	0.00000000E+00	0.793608045E-06	0.00000000E+00	-0.380856754E-06	0.00000000E+00
17	-0.404904077E-01	0.00000000E+00	0.879146456E-06	0.00000000E+00	-0.380872712E-06	0.00000000E+00
18	-0.404904036E-01	0.00000000E+00	0.964687688E-06	0.00000000E+00	-0.380877538E-06	0.00000000E+00
19	-0.404904012E-01	0.00000000E+00	0.105022596E-05	0.00000000E+00	-0.380854355E-06	0.00000000E+00
20	-0.404904013E-01	0.00000000E+00	0.113575690E-05	0.00000000E+00	-0.380821590E-06	0.00000000E+00

```

$MODE 2
0.27634893E+00 0.10000000E+01
1 0.50445597E-06 0.00000000E+00 -0.365263016E-01 0.00000000E+00 -0.297418193E-01 0.00000000E+00
2 0.50445595E-06 0.00000000E+00 -0.298466060E-01 0.00000000E+00 -0.297417714E-01 0.00000000E+00
3 0.50445593E-06 0.00000000E+00 -0.231669195E-01 0.00000000E+00 -0.297417532E-01 0.00000000E+00
4 0.50445593E-06 0.00000000E+00 -0.164872382E-01 0.00000000E+00 -0.297417146E-01 0.00000000E+00
5 0.50445591E-06 0.00000000E+00 -0.980756673E-02 0.00000000E+00 -0.297416760E-01 0.00000000E+00
6 0.50445593E-06 0.00000000E+00 -0.312790199E-02 0.00000000E+00 -0.297416534E-01 0.00000000E+00
7 0.50445588E-06 0.00000000E+00 0.355175883E-02 0.00000000E+00 -0.297416471E-01 0.00000000E+00
8 0.50445579E-06 0.00000000E+00 0.102314239E-01 0.00000000E+00 -0.297416901E-01 0.00000000E+00
9 0.50445558E-06 0.00000000E+00 0.169111047E-01 0.00000000E+00 -0.297417751E-01 0.00000000E+00
10 0.50445507E-06 0.00000000E+00 0.235908069E-01 0.00000000E+00 -0.297418451E-01 0.00000000E+00
11 0.50445395E-06 0.00000000E+00 0.302705049E-01 0.00000000E+00 -0.297417698E-01 0.00000000E+00
12 0.50445305E-06 0.00000000E+00 0.369501751E-01 0.00000000E+00 -0.297415578E-01 0.00000000E+00
13 0.50445237E-06 0.00000000E+00 0.436297890E-01 0.00000000E+00 -0.297413471E-01 0.00000000E+00
14 0.50445180E-06 0.00000000E+00 0.503093730E-01 0.00000000E+00 -0.297412592E-01 0.00000000E+00
15 0.50445194E-06 0.00000000E+00 0.569889385E-01 0.00000000E+00 -0.297412056E-01 0.00000000E+00
16 0.50445407E-06 0.00000000E+00 0.636685025E-01 0.00000000E+00 -0.297412410E-01 0.00000000E+00
17 0.50445444E-06 0.00000000E+00 0.703480494E-01 0.00000000E+00 -0.297414756E-01 0.00000000E+00
18 0.50445389E-06 0.00000000E+00 0.770277678E-01 0.00000000E+00 -0.297418286E-01 0.00000000E+00
19 0.50445383E-06 0.00000000E+00 0.837074998E-01 0.00000000E+00 -0.297420186E-01 0.00000000E+00
20 0.50445659E-06 0.00000000E+00 0.903872522E-01 0.00000000E+00 -0.297420940E-01 0.00000000E+00

$MODE 3
0.60200765E+00 0.10000000E+01
1 0.164771606E-07 0.00000000E+00 -0.841103576E-01 0.00000000E+00 -0.252457161E-01 0.00000000E+00
2 0.164771586E-07 0.00000000E+00 -0.784404688E-01 0.00000000E+00 -0.252452761E-01 0.00000000E+00
3 0.164771558E-07 0.00000000E+00 -0.727706762E-01 0.00000000E+00 -0.252449368E-01 0.00000000E+00
4 0.164771535E-07 0.00000000E+00 -0.671009721E-01 0.00000000E+00 -0.252447555E-01 0.00000000E+00
5 0.164771500E-07 0.00000000E+00 -0.614313851E-01 0.00000000E+00 -0.252439153E-01 0.00000000E+00
6 0.164771451E-07 0.00000000E+00 -0.557619279E-01 0.00000000E+00 -0.252433584E-01 0.00000000E+00
7 0.164771351E-07 0.00000000E+00 -0.500925957E-01 0.00000000E+00 -0.252428250E-01 0.00000000E+00
8 0.164771187E-07 0.00000000E+00 -0.44233890E-01 0.00000000E+00 -0.252422622E-01 0.00000000E+00
9 0.164770810E-07 0.00000000E+00 -0.387543284E-01 0.00000000E+00 -0.252415784E-01 0.00000000E+00
10 0.164769906E-07 0.00000000E+00 -0.330854128E-01 0.00000000E+00 -0.252409723E-01 0.00000000E+00
11 0.164768044E-07 0.00000000E+00 -0.274165823E-01 0.00000000E+00 -0.252409208E-01 0.00000000E+00
12 0.16476655E-07 0.00000000E+00 -0.217476885E-01 0.00000000E+00 -0.252413924E-01 0.00000000E+00
13 0.164765423E-07 0.00000000E+00 -0.160786861E-01 0.00000000E+00 -0.252418976E-01 0.00000000E+00
14 0.164764459E-07 0.00000000E+00 -0.104095712E-01 0.00000000E+00 -0.252423144E-01 0.00000000E+00
15 0.164762429E-07 0.00000000E+00 -0.474037818E-02 0.00000000E+00 -0.252426472E-01 0.00000000E+00
16 0.164762467E-07 0.00000000E+00 0.92888684E-03 0.00000000E+00 -0.252429085E-01 0.00000000E+00
17 0.164764318E-07 0.00000000E+00 0.659820563E-02 0.00000000E+00 -0.252431427E-01 0.00000000E+00
18 0.164765001E-07 0.00000000E+00 0.122675886E-01 0.00000000E+00 -0.252434223E-01 0.00000000E+00
19 0.164767725E-07 0.00000000E+00 0.179370280E-01 0.00000000E+00 -0.252436324E-01 0.00000000E+00
20 0.164769397E-07 0.00000000E+00 0.236064944E-01 0.00000000E+00 -0.252437320E-01 0.00000000E+00

$MODE 4
0.39578528E+02 0.10000000E+01
1 -0.196674606E-10 0.00000000E+00 -0.940948699E-01 0.00000000E+00 -0.832574359E-01 0.00000000E+00
2 -0.196659404E-10 0.00000000E+00 -0.755528337E-01 0.00000000E+00 -0.811642040E-01 0.00000000E+00
3 -0.196438776E-10 0.00000000E+00 -0.574820026E-01 0.00000000E+00 -0.793728618E-01 0.00000000E+00
4 -0.196294909E-10 0.00000000E+00 -0.398514493E-01 0.00000000E+00 -0.773592962E-01 0.00000000E+00
5 -0.196085515E-10 0.00000000E+00 -0.226957854E-01 0.00000000E+00 -0.752126464E-01 0.00000000E+00
6 -0.195733115E-10 0.00000000E+00 -0.605072729E-02 0.00000000E+00 -0.728500250E-01 0.00000000E+00
7 -0.195189745E-10 0.00000000E+00 0.999375657E-02 0.00000000E+00 -0.698762023E-01 0.00000000E+00
8 -0.194310574E-10 0.00000000E+00 0.251667634E-01 0.00000000E+00 -0.650673511E-01 0.00000000E+00
9 -0.192301126E-10 0.00000000E+00 0.385939436E-01 0.00000000E+00 -0.542486112E-01 0.00000000E+00
10 -0.187527067E-10 0.00000000E+00 0.480692442E-01 0.00000000E+00 -0.298348384E-01 0.00000000E+00
11 -0.177861315E-10 0.00000000E+00 0.497151583E-01 0.00000000E+00 0.152179565E-01 0.00000000E+00
12 -0.170248216E-10 0.00000000E+00 0.427938434E-01 0.00000000E+00 0.460931255E-01 0.00000000E+00
13 -0.164654489E-10 0.00000000E+00 0.302250297E-01 0.00000000E+00 0.654000418E-01 0.00000000E+00
14 -0.159615643E-10 0.00000000E+00 0.140827433E-01 0.00000000E+00 0.779001962E-01 0.00000000E+00
15 -0.154475418E-10 0.00000000E+00 -0.444011542E-02 0.00000000E+00 0.865950757E-01 0.00000000E+00
16 -0.163457478E-10 0.00000000E+00 -0.246143926E-01 0.00000000E+00 0.926210651E-01 0.00000000E+00
17 -0.171261139E-10 0.00000000E+00 -0.460640822E-01 0.00000000E+00 0.978749675E-01 0.00000000E+00
18 -0.172077810E-10 0.00000000E+00 -0.688371904E-01 0.00000000E+00 0.104034124E+00 0.00000000E+00
19 -0.181612898E-10 0.00000000E+00 -0.928766367E-01 0.00000000E+00 0.108844570E+00 0.00000000E+00
20 -0.196211395E-10 0.00000000E+00 -0.117685609E+00 0.00000000E+00 0.111273269E+00 0.00000000E+00

$MODE 5
0.12813527E+03 0.10000000E+01
1 -0.907625115E-11 0.00000000E+00 0.968081569E-01 0.00000000E+00 0.154702951E+00 0.00000000E+00
2 -0.902546662E-11 0.00000000E+00 0.637533673E-01 0.00000000E+00 0.132130422E+00 0.00000000E+00
3 -0.896248902E-11 0.00000000E+00 0.356576338E-01 0.00000000E+00 0.114445856E+00 0.00000000E+00
4 -0.889342793E-11 0.00000000E+00 0.117573540E-01 0.00000000E+00 0.961796104E-01 0.00000000E+00
5 -0.879336765E-11 0.00000000E+00 -0.800905964E-02 0.00000000E+00 0.784696414E-01 0.00000000E+00
6 -0.862584956E-11 0.00000000E+00 -0.237779420E-01 0.00000000E+00 0.611194221E-01 0.00000000E+00
7 -0.836958113E-11 0.00000000E+00 -0.354428711E-01 0.00000000E+00 0.423344610E-01 0.00000000E+00
8 -0.795937497E-11 0.00000000E+00 -0.421502193E-01 0.00000000E+00 0.174577267E-01 0.00000000E+00
9 -0.703515013E-11 0.00000000E+00 -0.411588404E-01 0.00000000E+00 -0.248775430E-01 0.00000000E+00
10 -0.489271123E-11 0.00000000E+00 -0.280802414E-01 0.00000000E+00 -0.862419990E-01 0.00000000E+00
11 -0.763923281E-12 0.00000000E+00 -0.247116908E-02 0.00000000E+00 -0.129348192E+00 0.00000000E+00
12 0.218468815E-11 0.00000000E+00 0.250173782E-01 0.00000000E+00 -0.106471342E+00 0.00000000E+00
13 0.414824446E-11 0.00000000E+00 0.439779910E-01 0.00000000E+00 -0.574837101E-01 0.00000000E+00
14 0.555510239E-11 0.00000000E+00 0.509400078E-01 0.00000000E+00 -0.250947652E-02 0.00000000E+00
15 0.731153851E-11 0.00000000E+00 0.453378353E-01 0.00000000E+00 0.523596798E-01 0.00000000E+00
16 0.785238307E-11 0.00000000E+00 0.278018923E-01 0.00000000E+00 0.102117540E+00 0.00000000E+00
17 0.680811381E-11 0.00000000E+00 -0.152755457E-02 0.00000000E+00 0.155252362E+00 0.00000000E+00
18 0.606017142E-11 0.00000000E+00 -0.455361758E-01 0.00000000E+00 0.227685935E+00 0.00000000E+00
19 0.399300425E-11 0.00000000E+00 -0.105588135E+00 0.00000000E+00 0.292053314E+00 0.00000000E+00
20 0.400560848E-11 0.00000000E+00 -0.176909860E+00 0.00000000E+00 0.330321022E+00 0.00000000E+00

$MODE 6
0.14555613E+03 0.10000000E+01
1 0.451430537E-01 0.00000000E+00 0.171072781E-10 0.00000000E+00 0.297528981E-10 0.00000000E+00
2 0.448173724E-01 0.00000000E+00 0.108209352E-10 0.00000000E+00 0.245027895E-10 0.00000000E+00

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3	0.444136522E-01	0.000000000E+00	0.567243532E-11	0.000000000E+00	0.205285354E-10	0.000000000E+00
4	0.439714936E-01	0.000000000E+00	0.145821895E-11	0.000000000E+00	0.165205034E-10	0.000000000E+00
5	0.433317349E-01	0.000000000E+00	-0.184936250E-11	0.000000000E+00	0.126643738E-10	0.000000000E+00
6	0.422625703E-01	0.000000000E+00	-0.429691255E-11	0.000000000E+00	0.899235455E-11	0.000000000E+00
7	0.406312203E-01	0.000000000E+00	-0.588341524E-11	0.000000000E+00	0.510569235E-11	0.000000000E+00
8	0.380291022E-01	0.000000000E+00	-0.646906729E-11	0.000000000E+00	0.194212983E-12	0.000000000E+00
9	0.321934718E-01	0.000000000E+00	-0.560822502E-11	0.000000000E+00	-0.748326601E-11	0.000000000E+00
10	0.187755529E-01	0.000000000E+00	-0.270906965E-11	0.000000000E+00	-0.171380536E-10	0.000000000E+00
11	-0.665706935E-02	0.000000000E+00	0.177167264E-11	0.000000000E+00	-0.202400097E-10	0.000000000E+00
12	-0.241979568E-01	0.000000000E+00	0.560384421E-11	0.000000000E+00	-0.122958849E-10	0.000000000E+00
13	-0.352853940E-01	0.000000000E+00	0.720589387E-11	0.000000000E+00	-0.123345619E-11	0.000000000E+00
14	-0.426711595E-01	0.000000000E+00	0.628238916E-11	0.000000000E+00	0.966177707E-11	0.000000000E+00
15	-0.480636256E-01	0.000000000E+00	0.327043821E-11	0.000000000E+00	0.157369928E-10	0.000000000E+00
16	-0.520377694E-01	0.000000000E+00	-0.211675587E-12	0.000000000E+00	0.141509428E-10	0.000000000E+00
17	-0.543863935E-01	0.000000000E+00	-0.300581664E-11	0.000000000E+00	0.125765849E-10	0.000000000E+00
18	-0.559362173E-01	0.000000000E+00	-0.776624123E-11	0.000000000E+00	0.337369389E-10	0.000000000E+00
19	-0.572642995E-01	0.000000000E+00	-0.223937838E-10	0.000000000E+00	0.884017371E-10	0.000000000E+00
20	-0.575988237E-01	0.000000000E+00	-0.512510924E-10	0.000000000E+00	0.148533026E-09	0.000000000E+00
SMODE 7						
0.22156564E+03 0.10000000E+01						
1	0.105529715E-14	0.000000000E+00	0.144094958E+00	0.000000000E+00	0.352565888E+00	0.000000000E+00
2	0.100825832E-14	0.000000000E+00	0.724331088E-01	0.000000000E+00	0.252107231E+00	0.000000000E+00
3	0.987348019E-15	0.000000000E+00	0.222540393E-01	0.000000000E+00	0.181248553E+00	0.000000000E+00
4	0.978906718E-15	0.000000000E+00	-0.118119057E-01	0.000000000E+00	0.115241909E+00	0.000000000E+00
5	0.944105450E-15	0.000000000E+00	-0.316546124E-01	0.000000000E+00	0.582112286E-01	0.000000000E+00
6	0.867099109E-15	0.000000000E+00	-0.393952927E-01	0.000000000E+00	0.968076160E-02	0.000000000E+00
7	0.815321115E-15	0.000000000E+00	-0.365954005E-01	0.000000000E+00	-0.339828277E-01	0.000000000E+00
8	0.673628673E-15	0.000000000E+00	-0.236894835E-01	0.000000000E+00	-0.783292633E-01	0.000000000E+00
9	0.390123055E-15	0.000000000E+00	0.355444777E-04	0.000000000E+00	-0.125840845E+00	0.000000000E+00
10	-0.210060355E-15	0.000000000E+00	0.310339712E-01	0.000000000E+00	-0.135780412E+00	0.000000000E+00
11	-0.122642120E-14	0.000000000E+00	0.513290906E-01	0.000000000E+00	-0.291346465E-01	0.000000000E+00
12	-0.185659297E-14	0.000000000E+00	0.457303381E-01	0.000000000E+00	0.787371921E-01	0.000000000E+00
13	-0.214504745E-14	0.000000000E+00	0.213803976E-01	0.000000000E+00	0.130876959E+00	0.000000000E+00
14	-0.203549769E-14	0.000000000E+00	-0.882217712E-02	0.000000000E+00	0.129969208E+00	0.000000000E+00
15	-0.222338059E-12	0.000000000E+00	-0.340284099E-01	0.000000000E+00	0.881382271E-01	0.000000000E+00
16	0.338429084E-12	0.000000000E+00	-0.463775385E-01	0.000000000E+00	0.191597160E-01	0.000000000E+00
17	0.185986768E-11	0.000000000E+00	-0.388748241E-01	0.000000000E+00	-0.829358340E-01	0.000000000E+00
18	0.332671874E-11	0.000000000E+00	0.969905202E-03	0.000000000E+00	-0.25608418E+00	0.000000000E+00
19	0.583168591E-11	0.000000000E+00	0.831077422E-01	0.000000000E+00	-0.437127873E+00	0.000000000E+00
20	0.552204634E-11	0.000000000E+00	0.200719362E+00	0.000000000E+00	-0.566947930E+00	0.000000000E+00
SMODE 8						
0.32437990E+03 0.10000000E+01						
1	-0.274452591E-11	0.000000000E+00	0.170489903E+00	0.000000000E+00	0.600580929E+00	0.000000000E+00
2	-0.264617816E-11	0.000000000E+00	0.546787659E-01	0.000000000E+00	0.345813255E+00	0.000000000E+00
3	-0.252697307E-11	0.000000000E+00	-0.839010176E-02	0.000000000E+00	0.189340616E+00	0.000000000E+00
4	-0.239919124E-11	0.000000000E+00	-0.379375658E-01	0.000000000E+00	0.640941693E-01	0.000000000E+00
5	-0.221871777E-11	0.000000000E+00	-0.424614541E-01	0.000000000E+00	-0.256415183E-01	0.000000000E+00
6	-0.192680862E-11	0.000000000E+00	-0.299052979E-01	0.000000000E+00	-0.840567635E-01	0.000000000E+00
7	-0.150246680E-11	0.000000000E+00	-0.685489228E-02	0.000000000E+00	-0.116824254E+00	0.000000000E+00
8	-0.868040358E-12	0.000000000E+00	0.207385568E-01	0.000000000E+00	-0.122684350E+00	0.000000000E+00
9	0.431218622E-12	0.000000000E+00	0.438667933E-01	0.000000000E+00	-0.756264803E-01	0.000000000E+00
10	0.296161078E-11	0.000000000E+00	0.452087283E-01	0.000000000E+00	0.622317833E-01	0.000000000E+00
11	0.619203075E-11	0.000000000E+00	0.120519714E-01	0.000000000E+00	0.199866715E+00	0.000000000E+00
12	0.661352904E-11	0.000000000E+00	-0.293139741E-01	0.000000000E+00	0.139379474E+00	0.000000000E+00
13	0.552616883E-11	0.000000000E+00	-0.468416274E-01	0.000000000E+00	0.632153351E-02	0.000000000E+00
14	0.379564776E-11	0.000000000E+00	-0.349804918E-01	0.000000000E+00	-0.107935727E+00	0.000000000E+00
15	0.138401288E-11	0.000000000E+00	-0.302604868E-02	0.000000000E+00	-0.164887165E+00	0.000000000E+00
16	-0.151928966E-11	0.000000000E+00	0.336535070E-01	0.000000000E+00	-0.149298812E+00	0.000000000E+00
17	-0.379103660E-11	0.000000000E+00	0.569688628E-01	0.000000000E+00	-0.510727269E-01	0.000000000E+00
18	-0.603180998E-11	0.000000000E+00	0.388398153E-01	0.000000000E+00	0.201387571E+00	0.000000000E+00
19	-0.890446773E-11	0.000000000E+00	-0.515167512E-01	0.000000000E+00	0.540890429E+00	0.000000000E+00
20	-0.909177014E-11	0.000000000E+00	-0.218308118E+00	0.000000000E+00	0.843532877E+00	0.000000000E+00
SMODE 9						
0.37006768E+03 0.10000000E+01						
1	0.317735637E-01	0.000000000E+00	0.221003542E-10	0.000000000E+00	0.891505283E-10	0.000000000E+00
2	0.302918333E-01	0.000000000E+00	0.530017290E-11	0.000000000E+00	0.461424932E-10	0.000000000E+00
3	0.285109922E-01	0.000000000E+00	-0.273169516E-11	0.000000000E+00	0.214955162E-10	0.000000000E+00
4	0.266179926E-01	0.000000000E+00	-0.564361684E-11	0.000000000E+00	0.331849635E-11	0.000000000E+00
5	0.239693391E-01	0.000000000E+00	-0.508231692E-11	0.000000000E+00	-0.826121762E-11	0.000000000E+00
6	0.197394300E-01	0.000000000E+00	-0.247991394E-11	0.000000000E+00	-0.143542954E-10	0.000000000E+00
7	0.137088399E-01	0.000000000E+00	0.100357210E-11	0.000000000E+00	-0.159236328E-10	0.000000000E+00
8	0.493006627E-02	0.000000000E+00	0.429628035E-11	0.000000000E+00	-0.126065806E-10	0.000000000E+00
9	-0.123543351E-01	0.000000000E+00	0.582803388E-11	0.000000000E+00	-0.600062888E-12	0.000000000E+00
10	-0.434962968E-01	0.000000000E+00	0.341260380E-11	0.000000000E+00	0.200483262E-10	0.000000000E+00
11	-0.746613963E-01	0.000000000E+00	-0.245406606E-11	0.000000000E+00	0.254799325E-10	0.000000000E+00
12	-0.674934639E-01	0.000000000E+00	-0.628904900E-11	0.000000000E+00	0.545211515E-11	0.000000000E+00
13	-0.442414719E-01	0.000000000E+00	-0.532422023E-11	0.000000000E+00	-0.135358040E-10	0.000000000E+00
14	-0.170334578E-01	0.000000000E+00	-0.126672077E-11	0.000000000E+00	-0.203549750E-10	0.000000000E+00
15	0.107076965E-01	0.000000000E+00	0.286784457E-11	0.000000000E+00	-0.144729598E-10	0.000000000E+00
16	0.363999161E-01	0.000000000E+00	0.452426992E-11	0.000000000E+00	0.898729746E-12	0.000000000E+00
17	0.542222882E-01	0.000000000E+00	0.178216409E-11	0.000000000E+00	0.212085114E-10	0.000000000E+00
18	0.671496092E-01	0.000000000E+00	-0.496150288E-11	0.000000000E+00	0.317103159E-10	0.000000000E+00
19	0.790560605E-01	0.000000000E+00	-0.902175209E-11	0.000000000E+00	0.386288438E-11	0.000000000E+00
20	0.821397348E-01	0.000000000E+00	-0.109410916E-11	0.000000000E+00	-0.548792730E-10	0.000000000E+00
SMODE 10						
0.45394492E+03 0.10000000E+01						
1	0.306839988E-11	0.000000000E+00	-0.177769261E+00	0.000000000E+00	-0.889759293E+00	0.000000000E+00
2	0.285312586E-11	0.000000000E+00	-0.168866163E-01	0.000000000E+00	-0.369516074E+00	0.000000000E+00
3	0.259918118E-11	0.000000000E+00	0.407000026E-01	0.000000000E+00	-0.108834632E+00	0.000000000E+00
4	0.233420688E-11	0.000000000E+00	0.476818082E-01	0.000000000E+00	0.501964151E-01	0.000000000E+00
5	0.197115731E-11	0.000000000E+00	0.274866983E-01	0.000000000E+00	0.123067335E+00	0.000000000E+00
6	0.140794920E-11	0.000000000E+00	-0.224915930E-02	0.000000000E+00	0.132999361E+00	0.000000000E+00

7	0.640215607E-12	0.000000000E+00	-0.288603924E-01	0.000000000E+00	0.966436029E-01	0.000000000E+00
8	-0.408407031E-12	0.000000000E+00	-0.416770861E-01	0.000000000E+00	0.143773606E-01	0.000000000E+00
9	-0.227912612E-11	0.000000000E+00	-0.277862092E-01	0.000000000E+00	-0.127927180E+00	0.000000000E+00
10	-0.498594270E-11	0.000000000E+00	0.170955196E-01	0.000000000E+00	-0.230068698E+00	0.000000000E+00
11	-0.563071325E-11	0.000000000E+00	0.526619157E-01	0.000000000E+00	-0.352910307E-01	0.000000000E+00
12	-0.277721210E-11	0.000000000E+00	0.358668932E-01	0.000000000E+00	0.171946570E+00	0.000000000E+00
13	0.325002956E-12	0.000000000E+00	-0.858189396E-02	0.000000000E+00	0.191771938E+00	0.000000000E+00
14	0.260980914E-11	0.000000000E+00	-0.404677356E-01	0.000000000E+00	0.717904155E-01	0.000000000E+00
15	0.349405421E-11	0.000000000E+00	-0.382571294E-01	0.000000000E+00	-0.914575797E-01	0.000000000E+00
16	0.388797339E-11	0.000000000E+00	-0.329032651E-02	0.000000000E+00	-0.202489911E+00	0.000000000E+00
17	0.481390904E-11	0.000000000E+00	0.455931817E-01	0.000000000E+00	-0.205587429E+00	0.000000000E+00
18	0.488319736E-11	0.000000000E+00	0.661636912E-01	0.000000000E+00	0.427611300E-01	0.000000000E+00
19	0.439678713E-11	0.000000000E+00	-0.112608933E-01	0.000000000E+00	0.576830200E+00	0.000000000E+00
20	0.411328889E-11	0.000000000E+00	-0.237253460E+00	0.000000000E+00	0.122096404E+01	0.000000000E+00
SMODE 11						
0.53349915E+03 0.10000000E+01						
1	-0.520987930E-01	0.000000000E+00	-0.717624578E-11	0.000000000E+00	-0.427623856E-10	0.000000000E+00
2	-0.470494357E-01	0.000000000E+00	0.268427593E-12	0.000000000E+00	-0.138335596E-10	0.000000000E+00
3	-0.412239337E-01	0.000000000E+00	0.210575458E-11	0.000000000E+00	-0.123724094E-11	0.000000000E+00
4	-0.352739743E-01	0.000000000E+00	0.168186330E-11	0.000000000E+00	0.478409202E-11	0.000000000E+00
5	-0.273221947E-01	0.000000000E+00	0.407360712E-12	0.000000000E+00	0.603236544E-11	0.000000000E+00
6	-0.154114742E-01	0.000000000E+00	-0.816809439E-12	0.000000000E+00	0.442230375E-11	0.000000000E+00
7	-0.581571644E-04	0.000000000E+00	-0.146843263E-11	0.000000000E+00	0.116881070E-11	0.000000000E+00
8	0.192237676E-01	0.000000000E+00	-0.121940200E-11	0.000000000E+00	-0.323256721E-11	0.000000000E+00
9	0.490069645E-01	0.000000000E+00	0.120748096E-12	0.000000000E+00	-0.776468237E-11	0.000000000E+00
10	0.771073026E-01	0.000000000E+00	0.183667626E-11	0.000000000E+00	-0.570353425E-11	0.000000000E+00
11	0.381197682E-01	0.000000000E+00	0.165354768E-11	0.000000000E+00	0.719571145E-11	0.000000000E+00
12	-0.203233791E-01	0.000000000E+00	-0.446340291E-12	0.000000000E+00	0.925824642E-11	0.000000000E+00
13	-0.491915537E-01	0.000000000E+00	-0.190938023E-11	0.000000000E+00	0.265663269E-11	0.000000000E+00
14	-0.498990072E-01	0.000000000E+00	-0.175664917E-11	0.000000000E+00	-0.348692424E-11	0.000000000E+00
15	-0.307837636E-01	0.000000000E+00	-0.525151547E-12	0.000000000E+00	-0.742674091E-11	0.000000000E+00
16	0.513839656E-03	0.000000000E+00	0.128075586E-11	0.000000000E+00	-0.737346979E-11	0.000000000E+00
17	0.295238227E-01	0.000000000E+00	0.213354145E-11	0.000000000E+00	0.582662825E-12	0.000000000E+00
18	0.538264207E-01	0.000000000E+00	-0.307549983E-12	0.000000000E+00	0.190692553E-10	0.000000000E+00
19	0.785773236E-01	0.000000000E+00	-0.648043904E-11	0.000000000E+00	0.295822210E-10	0.000000000E+00
20	0.852269510E-01	0.000000000E+00	-0.106159918E-10	0.000000000E+00	0.128297674E-10	0.000000000E+00
SMODE 12						
0.59547469E+03 0.10000000E+01						
1	0.218712018E-12	0.000000000E+00	-0.178223671E+00	0.000000000E+00	-0.120264339E+01	0.000000000E+00
2	0.192315334E-12	0.000000000E+00	0.246844734E-01	0.000000000E+00	-0.305127524E+00	0.000000000E+00
3	0.162466513E-12	0.000000000E+00	0.572494700E-01	0.000000000E+00	0.395917729E-01	0.000000000E+00
4	0.132555620E-12	0.000000000E+00	0.326940434E-01	0.000000000E+00	0.163598248E+00	0.000000000E+00
5	0.934926522E-13	0.000000000E+00	-0.465121283E-02	0.000000000E+00	0.150479997E+00	0.000000000E+00
6	0.368956526E-13	0.000000000E+00	-0.306658213E-01	0.000000000E+00	0.698535271E-01	0.000000000E+00
7	-0.321556576E-13	0.000000000E+00	-0.347124026E-01	0.000000000E+00	-0.351050571E-01	0.000000000E+00
8	-0.111449079E-12	0.000000000E+00	-0.140093081E-01	0.000000000E+00	-0.138343166E+00	0.000000000E+00
9	-0.213934597E-12	0.000000000E+00	0.252841779E-01	0.000000000E+00	-0.181718215E+00	0.000000000E+00
10	-0.246124043E-12	0.000000000E+00	0.493518835E-01	0.000000000E+00	-0.495737920E-02	0.000000000E+00
11	0.500788439E-13	0.000000000E+00	0.129242551E-01	0.000000000E+00	0.265881828E+00	0.000000000E+00
12	0.208491790E-12	0.000000000E+00	-0.384483544E-01	0.000000000E+00	0.126108986E+00	0.000000000E+00
13	0.171458914E-12	0.000000000E+00	-0.402267525E-01	0.000000000E+00	-0.112594255E+00	0.000000000E+00
14	0.495388250E-13	0.000000000E+00	-0.112021232E-02	0.000000000E+00	-0.202719195E+00	0.000000000E+00
15	-0.158618655E-12	0.000000000E+00	0.366635157E-01	0.000000000E+00	-0.103181285E+00	0.000000000E+00
16	-0.155860286E-11	0.000000000E+00	0.379202394E-01	0.000000000E+00	0.938637631E-01	0.000000000E+00
17	-0.402682046E-11	0.000000000E+00	-0.748981508E-02	0.000000000E+00	0.272493862E+00	0.000000000E+00
18	-0.562766128E-11	0.000000000E+00	-0.684391488E-01	0.000000000E+00	0.192271767E+00	0.000000000E+00
19	-0.669693418E-11	0.000000000E+00	-0.322020555E-01	0.000000000E+00	-0.490958021E+00	0.000000000E+00
20	-0.668051788E-11	0.000000000E+00	0.259764053E+00	0.000000000E+00	-0.170453825E+01	0.000000000E+00
SMODE 13						
0.66563269E+03 0.10000000E+01						
1	-0.598871174E-01	0.000000000E+00	0.325063432E-11	0.000000000E+00	0.248494458E-10	0.000000000E+00
2	-0.508517948E-01	0.000000000E+00	-0.806805706E-12	0.000000000E+00	0.447729039E-11	0.000000000E+00
3	-0.408944693E-01	0.000000000E+00	-0.107337265E-11	0.000000000E+00	-0.227408106E-11	0.000000000E+00
4	-0.311759842E-01	0.000000000E+00	-0.345763140E-12	0.000000000E+00	-0.370211709E-11	0.000000000E+00
5	-0.188684246E-01	0.000000000E+00	0.376325134E-12	0.000000000E+00	-0.233332761E-11	0.000000000E+00
6	-0.182756833E-02	0.000000000E+00	0.666308826E-12	0.000000000E+00	-0.108354547E-12	0.000000000E+00
7	0.173802587E-01	0.000000000E+00	0.445140041E-12	0.000000000E+00	0.196393178E-11	0.000000000E+00
8	0.365296267E-01	0.000000000E+00	-0.166526807E-12	0.000000000E+00	0.313330280E-11	0.000000000E+00
9	0.534611827E-01	0.000000000E+00	-0.785764187E-12	0.000000000E+00	0.185192766E-11	0.000000000E+00
10	0.329297519E-01	0.000000000E+00	-0.616884416E-12	0.000000000E+00	-0.313512125E-11	0.000000000E+00
11	-0.626062167E-01	0.000000000E+00	0.465776331E-12	0.000000000E+00	-0.434018273E-11	0.000000000E+00
12	-0.509136270E-01	0.000000000E+00	0.884792383E-12	0.000000000E+00	0.120668784E-11	0.000000000E+00
13	0.183053797E-02	0.000000000E+00	0.228443197E-12	0.000000000E+00	0.379522872E-11	0.000000000E+00
14	0.411837514E-01	0.000000000E+00	-0.438849308E-12	0.000000000E+00	0.126986168E-11	0.000000000E+00
15	0.512379403E-01	0.000000000E+00	-0.452221602E-12	0.000000000E+00	-0.306167175E-13	0.000000000E+00
16	0.297080371E-01	0.000000000E+00	-0.617265464E-12	0.000000000E+00	0.125589293E-11	0.000000000E+00
17	-0.658405777E-02	0.000000000E+00	-0.776625335E-12	0.000000000E+00	-0.806311182E-12	0.000000000E+00
18	-0.437091415E-01	0.000000000E+00	0.719711117E-12	0.000000000E+00	-0.124193987E-10	0.000000000E+00
19	-0.863757044E-01	0.000000000E+00	0.499024591E-11	0.000000000E+00	-0.185246592E-10	0.000000000E+00
20	-0.983169796E-01	0.000000000E+00	0.465124614E-11	0.000000000E+00	0.115265702E-10	0.000000000E+00
SMODE 14						
0.73973021E+03 0.10000000E+01						
1	0.623401668E-12	0.000000000E+00	0.164577292E+00	0.000000000E+00	0.142421921E+01	0.000000000E+00
2	0.507233060E-12	0.000000000E+00	-0.595328874E-01	0.000000000E+00	0.145208740E+00	0.000000000E+00
3	0.383134119E-12	0.000000000E+00	-0.516053639E-01	0.000000000E+00	-0.202978188E+00	0.000000000E+00
4	0.265812957E-12	0.000000000E+00	-0.966555370E-03	0.000000000E+00	-0.207334911E+00	0.000000000E+00
5	0.12829983E-12	0.000000000E+00	0.333090928E-01	0.000000000E+00	-0.752565081E-01	0.000000000E+00
6	-0.637992816E-13	0.000000000E+00	0.345619965E-01	0.000000000E+00	0.657758413E-01	0.000000000E+00
7	-0.252057428E-12	0.000000000E+00	0.839109571E-02	0.000000000E+00	0.153615086E+00	0.000000000E+00
8	-0.399537675E-12	0.000000000E+00	-0.277984675E-01	0.000000000E+00	0.146910241E+00	0.000000000E+00
9	-0.419344359E-12	0.000000000E+00	-0.427184099E-01	0.000000000E+00	-0.266811368E-01	0.000000000E+00
10	0.720323078E-13	0.000000000E+00	-0.203744862E-02	0.000000000E+00	-0.275253366E+00	0.000000000E+00

11	0.784909708E-12	0.000000000E+00	0.475775318E-01	0.000000000E+00	-0.522492914E-01	0.000000000E+00
12	0.631339152E-13	0.000000000E+00	0.228672363E-01	0.000000000E+00	0.235059036E+00	0.000000000E+00
13	-0.503440936E-12	0.000000000E+00	-0.289238623E-01	0.000000000E+00	0.161189857E+00	0.000000000E+00
14	-0.516379796E-12	0.000000000E+00	-0.393486823E-01	0.000000000E+00	-0.797856801E-01	0.000000000E+00
15	-0.745226224E-12	0.000000000E+00	-0.191635831E-02	0.000000000E+00	-0.216358182E+00	0.000000000E+00
16	-0.158749913E-11	0.000000000E+00	0.406007987E-01	0.000000000E+00	-0.122715154E+00	0.000000000E+00
17	-0.222856100E-11	0.000000000E+00	0.360176800E-01	0.000000000E+00	0.153346499E+00	0.000000000E+00
18	-0.216965467E-11	0.000000000E+00	-0.376722469E-01	0.000000000E+00	0.385209535E+00	0.000000000E+00
19	-0.966811998E-12	0.000000000E+00	-0.683162434E-01	0.000000000E+00	-0.215492605E+00	0.000000000E+00
20	-0.885400042E-12	0.000000000E+00	0.250686029E+00	0.000000000E+00	-0.202285634E+01	0.000000000E+00
SMODE 15						
0.80825867E+03 0.100000000E+01						
1	-0.715220944E-01	0.000000000E+00	-0.203287182E-11	0.000000000E+00	-0.195501042E-10	0.000000000E+00
2	-0.556116635E-01	0.000000000E+00	0.943692989E-12	0.000000000E+00	-0.673811517E-12	0.000000000E+00
3	-0.391683053E-01	0.000000000E+00	0.568648917E-12	0.000000000E+00	0.349558960E-11	0.000000000E+00
4	-0.241300421E-01	0.000000000E+00	-0.188989158E-12	0.000000000E+00	0.259059524E-11	0.000000000E+00
5	-0.656240701E-02	0.000000000E+00	-0.530050051E-12	0.000000000E+00	0.201623777E-12	0.000000000E+00
6	0.148617360E-01	0.000000000E+00	-0.356735893E-12	0.000000000E+00	-0.165213863E-11	0.000000000E+00
7	0.335969301E-01	0.000000000E+00	0.116883910E-12	0.000000000E+00	-0.229519899E-11	0.000000000E+00
8	0.429760429E-01	0.000000000E+00	0.540183612E-12	0.000000000E+00	-0.120196258E-11	0.000000000E+00
9	0.275680182E-01	0.000000000E+00	0.434800159E-12	0.000000000E+00	0.202028472E-11	0.000000000E+00
10	-0.454121438E-01	0.000000000E+00	-0.367643493E-12	0.000000000E+00	0.382239253E-11	0.000000000E+00
11	-0.548368695E-01	0.000000000E+00	-0.647957217E-12	0.000000000E+00	-0.208227143E-11	0.000000000E+00
12	0.406625591E-01	0.000000000E+00	0.157960394E-12	0.000000000E+00	-0.36877457E-11	0.000000000E+00
13	0.539444140E-01	0.000000000E+00	0.650783894E-12	0.000000000E+00	-0.668956012E-13	0.000000000E+00
14	0.100174861E-01	0.000000000E+00	0.345962473E-12	0.000000000E+00	0.209784213E-11	0.000000000E+00
15	-0.386338661E-01	0.000000000E+00	0.127602826E-12	0.000000000E+00	-0.132526649E-11	0.000000000E+00
16	-0.521594097E-01	0.000000000E+00	0.966321412E-12	0.000000000E+00	-0.506979531E-11	0.000000000E+00
17	-0.228054840E-01	0.000000000E+00	0.183423832E-11	0.000000000E+00	-0.104623117E-11	0.000000000E+00
18	0.224958651E-01	0.000000000E+00	-0.789321163E-13	0.000000000E+00	0.170679651E-10	0.000000000E+00
19	0.853075621E-01	0.000000000E+00	-0.511639509E-11	0.000000000E+00	0.149864981E-10	0.000000000E+00
20	0.103917364E+00	0.000000000E+00	0.355462486E-11	0.000000000E+00	-0.654069940E-10	0.000000000E+00
SMODE 16						
0.90414831E+03 0.100000000E+01						
1	-0.332944307E-10	0.000000000E+00	0.125334885E-01	0.000000000E+00	0.137791649E+01	0.000000000E+00
2	-0.240262867E-10	0.000000000E+00	-0.751856645E-01	0.000000000E+00	-0.772672124E-01	0.000000000E+00
3	-0.149440037E-10	0.000000000E+00	-0.247078657E-01	0.000000000E+00	-0.299777496E+00	0.000000000E+00
4	-0.708482188E-11	0.000000000E+00	0.305297149E-01	0.000000000E+00	-0.137255026E+00	0.000000000E+00
5	0.145218351E-11	0.000000000E+00	0.394298929E-01	0.000000000E+00	0.663402445E-01	0.000000000E+00
6	0.106229116E-10	0.000000000E+00	0.112463986E-01	0.000000000E+00	0.166051094E+00	0.000000000E+00
7	0.163575296E-10	0.000000000E+00	-0.250646439E-01	0.000000000E+00	0.133547977E+00	0.000000000E+00
8	0.149425062E-10	0.000000000E+00	-0.385109017E-01	0.000000000E+00	-0.226453139E-01	0.000000000E+00
9	-0.208459461E-11	0.000000000E+00	-0.418034624E-02	0.000000000E+00	-0.241008580E+00	0.000000000E+00
10	-0.326763381E-10	0.000000000E+00	0.489559192E-01	0.000000000E+00	-0.134165841E+00	0.000000000E+00
11	0.211887308E-10	0.000000000E+00	0.178658069E-01	0.000000000E+00	0.327640327E+00	0.000000000E+00
12	0.980059780E-11	0.000000000E+00	-0.444205781E-01	0.000000000E+00	0.102133020E+00	0.000000000E+00
13	-0.139245277E-10	0.000000000E+00	-0.271860198E-01	0.000000000E+00	-0.227653646E+00	0.000000000E+00
14	-0.146958078E-10	0.000000000E+00	0.282008192E-01	0.000000000E+00	-0.189976249E+00	0.000000000E+00
15	0.178835967E-11	0.000000000E+00	0.402077470E-01	0.000000000E+00	0.100347843E+00	0.000000000E+00
16	0.163109447E-10	0.000000000E+00	-0.837042620E-02	0.000000000E+00	0.276936692E+00	0.000000000E+00
17	0.129854541E-10	0.000000000E+00	-0.590080070E-01	0.000000000E+00	0.114842015E+00	0.000000000E+00
18	0.147995331E-12	0.000000000E+00	-0.136596665E-01	0.000000000E+00	-0.430978297E+00	0.000000000E+00
19	-0.229438739E-10	0.000000000E+00	0.902409263E-01	0.000000000E+00	-0.186169207E+00	0.000000000E+00
20	-0.293099927E-10	0.000000000E+00	-0.215538698E+00	0.000000000E+00	0.213539382E+01	0.000000000E+00
SMODE 17						
0.90787455E+03 0.100000000E+01						
1	-0.839427312E-01	0.000000000E+00	-0.487014235E-10	0.000000000E+00	-0.538048128E-09	0.000000000E+00
2	-0.603827062E-01	0.000000000E+00	0.294652298E-10	0.000000000E+00	0.319860534E-10	0.000000000E+00
3	-0.373469083E-01	0.000000000E+00	0.941265880E-11	0.000000000E+00	0.117703360E-09	0.000000000E+00
4	-0.174605900E-01	0.000000000E+00	-0.121466584E-10	0.000000000E+00	0.527814891E-10	0.000000000E+00
5	0.407151877E-02	0.000000000E+00	-0.153762259E-10	0.000000000E+00	-0.271013874E-10	0.000000000E+00
6	0.270648429E-01	0.000000000E+00	-0.415730028E-11	0.000000000E+00	-0.653667577E-10	0.000000000E+00
7	0.411731231E-01	0.000000000E+00	0.100020659E-10	0.000000000E+00	-0.514371128E-10	0.000000000E+00
8	0.370229784E-01	0.000000000E+00	0.149561566E-10	0.000000000E+00	0.105479229E-10	0.000000000E+00
9	-0.666907253E-02	0.000000000E+00	0.120607713E-11	0.000000000E+00	0.949928022E-10	0.000000000E+00
10	-0.825642535E-01	0.000000000E+00	-0.192917000E-10	0.000000000E+00	0.495532968E-10	0.000000000E+00
11	0.582848864E-01	0.000000000E+00	-0.642647038E-11	0.000000000E+00	-0.129319550E-09	0.000000000E+00
12	0.206726952E-01	0.000000000E+00	0.176203169E-10	0.000000000E+00	-0.363410119E-10	0.000000000E+00
13	-0.390250305E-01	0.000000000E+00	0.100602082E-10	0.000000000E+00	0.914963215E-10	0.000000000E+00
14	-0.355515062E-01	0.000000000E+00	-0.117699431E-10	0.000000000E+00	0.734857253E-10	0.000000000E+00
15	0.832947839E-02	0.000000000E+00	-0.161650620E-10	0.000000000E+00	-0.403681420E-10	0.000000000E+00
16	0.426456286E-01	0.000000000E+00	0.288529800E-11	0.000000000E+00	-0.107700692E-09	0.000000000E+00
17	0.313579682E-01	0.000000000E+00	0.224189865E-10	0.000000000E+00	-0.436450115E-10	0.000000000E+00
18	-0.386646183E-02	0.000000000E+00	0.490568016E-11	0.000000000E+00	0.164188125E-09	0.000000000E+00
19	-0.626188342E-01	0.000000000E+00	-0.335867572E-10	0.000000000E+00	0.637454968E-10	0.000000000E+00
20	-0.808972379E-01	0.000000000E+00	0.843949901E-10	0.000000000E+00	-0.819875750E-09	0.000000000E+00
SMODE 18						
0.10390886E+04 0.100000000E+01						
1	-0.381985599E-01	0.000000000E+00	0.206093278E-11	0.000000000E+00	0.268169994E-10	0.000000000E+00
2	-0.241544852E-01	0.000000000E+00	-0.161152125E-11	0.000000000E+00	-0.466944237E-11	0.000000000E+00
3	-0.115928496E-01	0.000000000E+00	-0.587344645E-13	0.000000000E+00	-0.662633733E-11	0.000000000E+00
4	-0.174435744E-02	0.000000000E+00	0.918430663E-12	0.000000000E+00	-0.960592167E-12	0.000000000E+00
5	0.753874281E-02	0.000000000E+00	0.631698247E-12	0.000000000E+00	0.326165856E-11	0.000000000E+00
6	0.149135160E-01	0.000000000E+00	-0.215683181E-12	0.000000000E+00	0.360250477E-11	0.000000000E+00
7	0.149233153E-01	0.000000000E+00	-0.752101605E-12	0.000000000E+00	0.793126296E-12	0.000000000E+00
8	0.455726230E-02	0.000000000E+00	-0.436520411E-12	0.000000000E+00	-0.327788358E-11	0.000000000E+00
9	-0.207025921E-01	0.000000000E+00	0.621918407E-12	0.000000000E+00	-0.466472245E-11	0.000000000E+00
10	-0.201563243E-01	0.000000000E+00	0.853956422E-12	0.000000000E+00	0.314067350E-11	0.000000000E+00
11	0.689462681E-01	0.000000000E+00	-0.642683344E-12	0.000000000E+00	0.525152168E-11	0.000000000E+00
12	-0.804541950E-01	0.000000000E+00	-0.747726558E-12	0.000000000E+00	-0.461205783E-11	0.000000000E+00
13	-0.114965471E-01	0.000000000E+00	0.603157420E-12	0.000000000E+00	-0.513190701E-11	0.000000000E+00
14	0.606565325E-01	0.000000000E+00	0.118607804E-11	0.000000000E+00	0.350004943E-13	0.000000000E+00

```

15 0.345365473E-01 0.000000000E+00 0.757972175E-12 0.000000000E+00 0.321694225E-11 0.000000000E+00
16 -0.434486336E-01 0.000000000E+00 0.375793938E-13 0.000000000E+00 0.244101256E-11 0.000000000E+00
17 -0.584030717E-01 0.000000000E+00 0.337831592E-14 0.000000000E+00 -0.220428652E-11 0.000000000E+00
18 -0.189565641E-01 0.000000000E+00 0.107177610E-11 0.000000000E+00 -0.414191065E-11 0.000000000E+00
19 0.757526774E-01 0.000000000E+00 0.387038388E-12 0.000000000E+00 0.823502993E-11 0.000000000E+00
20 0.107599730E+00 0.000000000E+00 -0.335980676E-11 0.000000000E+00 0.209078366E-10 0.000000000E+00
SMODE 19
0.11032624E+04 0.10000000E+01
1 0.231211682E-12 0.000000000E+00 0.955760030E-01 0.000000000E+00 0.134573620E+01 0.000000000E+00
2 0.135399733E-12 0.000000000E+00 -0.829591652E-01 0.000000000E+00 -0.306548544E+00 0.000000000E+00
3 0.539950522E-13 0.000000000E+00 0.688180292E-02 0.000000000E+00 -0.337237007E+00 0.000000000E+00
4 -0.629919366E-14 0.000000000E+00 0.506164822E-01 0.000000000E+00 0.974114842E-03 0.000000000E+00
5 -0.580289599E-13 0.000000000E+00 0.253397063E-01 0.000000000E+00 0.199820841E+00 0.000000000E+00
6 -0.895068062E-13 0.000000000E+00 -0.202311116E-01 0.000000000E+00 0.166256378E+00 0.000000000E+00
7 -0.693306731E-13 0.000000000E+00 -0.389942460E-01 0.000000000E+00 -0.145004327E-01 0.000000000E+00
8 0.104095474E-13 0.000000000E+00 -0.104605988E-01 0.000000000E+00 -0.210462537E+00 0.000000000E+00
9 0.145254918E-12 0.000000000E+00 0.421222417E-01 0.000000000E+00 -0.179101250E+00 0.000000000E+00
10 0.920426641E-14 0.000000000E+00 0.278094353E-01 0.000000000E+00 0.277772123E+00 0.000000000E+00
11 -0.277893206E-12 0.000000000E+00 -0.480746086E-01 0.000000000E+00 0.129108787E+00 0.000000000E+00
12 0.483905712E-12 0.000000000E+00 -0.183507940E-01 0.000000000E+00 -0.318504844E+00 0.000000000E+00
13 -0.156943665E-12 0.000000000E+00 0.429295671E-01 0.000000000E+00 -0.105169157E+00 0.000000000E+00
14 -0.356772071E-12 0.000000000E+00 0.239952885E-01 0.000000000E+00 0.240439694E+00 0.000000000E+00
15 0.457798936E-12 0.000000000E+00 -0.336434941E-01 0.000000000E+00 0.178349585E+00 0.000000000E+00
16 0.16826442E-11 0.000000000E+00 -0.339347162E-01 0.000000000E+00 -0.179859601E+00 0.000000000E+00
17 0.144648389E-11 0.000000000E+00 0.397806947E-01 0.000000000E+00 -0.357390382E+00 0.000000000E+00
18 -0.200890190E-12 0.000000000E+00 0.596419683E-01 0.000000000E+00 0.234987673E+00 0.000000000E+00
19 -0.222667632E-11 0.000000000E+00 -0.844376389E-01 0.000000000E+00 0.546335919E+00 0.000000000E+00
20 -0.312059235E-11 0.000000000E+00 0.147829284E+00 0.000000000E+00 -0.182451038E+01 0.000000000E+00
SMODE 20
0.11652801E+04 0.10000000E+01
1 -0.146457417E+00 0.000000000E+00 -0.624763938E-13 0.000000000E+00 -0.938426738E-12 0.000000000E+00
2 -0.787380343E-01 0.000000000E+00 0.591268408E-13 0.000000000E+00 0.257904317E-12 0.000000000E+00
3 -0.243096006E-01 0.000000000E+00 -0.111525907E-13 0.000000000E+00 0.238046205E-12 0.000000000E+00
4 0.134127659E-01 0.000000000E+00 -0.380860091E-13 0.000000000E+00 -0.283874536E-13 0.000000000E+00
5 0.422759773E-01 0.000000000E+00 -0.130277374E-13 0.000000000E+00 -0.166543964E-12 0.000000000E+00
6 0.530324532E-01 0.000000000E+00 0.211087303E-13 0.000000000E+00 -0.106343014E-12 0.000000000E+00
7 0.285583765E-01 0.000000000E+00 0.272411104E-13 0.000000000E+00 0.571505744E-13 0.000000000E+00
8 -0.271388138E-01 0.000000000E+00 -0.190537348E-14 0.000000000E+00 0.175331166E-12 0.000000000E+00
9 -0.884122641E-01 0.000000000E+00 -0.353360425E-13 0.000000000E+00 0.700803373E-13 0.000000000E+00
10 0.654305809E-01 0.000000000E+00 -0.691537205E-14 0.000000000E+00 -0.250980406E-12 0.000000000E+00
11 -0.212432452E-01 0.000000000E+00 0.375848807E-13 0.000000000E+00 0.312064551E-13 0.000000000E+00
12 -0.141823831E-03 0.000000000E+00 -0.807011430E-14 0.000000000E+00 0.256806514E-12 0.000000000E+00
13 0.147990499E-01 0.000000000E+00 -0.465389780E-13 0.000000000E+00 0.445513738E-13 0.000000000E+00
14 -0.457838050E-02 0.000000000E+00 -0.490059475E-13 0.000000000E+00 0.787511121E-13 0.000000000E+00
15 -0.133786661E-01 0.000000000E+00 -0.727860018E-13 0.000000000E+00 0.382708969E-14 0.000000000E+00
16 0.309569574E-02 0.000000000E+00 -0.374566597E-13 0.000000000E+00 -0.249723139E-12 0.000000000E+00
17 0.132833304E-01 0.000000000E+00 -0.480976695E-14 0.000000000E+00 0.669040944E-13 0.000000000E+00
18 0.846620429E-02 0.000000000E+00 -0.137900314E-12 0.000000000E+00 0.851814958E-12 0.000000000E+00
19 -0.139220296E-01 0.000000000E+00 -0.229202915E-12 0.000000000E+00 -0.462501861E-12 0.000000000E+00
20 -0.221770246E-01 0.000000000E+00 0.641007742E-12 0.000000000E+00 -0.558205150E-11 0.000000000E+00

```

Listing 8.7.4 Output of Mass change due to Structure: masschg.dat

```

0.00000000 0.35151434E+00
0.22458947 0.15923738E+01
0.44917893 0.34992027E+01
0.67376840 0.47900314E+01
0.89835787 0.47755566E+01
1.12294734 0.42759323E+01
1.34753680 0.36480141E+01
1.57212627 0.24694061E+01
1.79671574 0.12667809E+01
2.02130532 0.63976669E+00
2.24589467 0.55348587E+00
2.47048426 0.80759811E+00
2.69507360 0.11092186E+01
2.91966319 0.13285332E+01
3.14425254 0.13999634E+01
3.36884212 0.14529495E+01
3.59343147 0.14412441E+01
3.81802106 0.10710030E+01
4.04261065 0.59553242E+00
4.26719999 0.21292615E+00

```


8.8 Run UCDA to get TRIM and ASE Solution

This section corresponds to the Step 6 in the Graphical User Interface (GUI). See Figure 8.8.1 below.

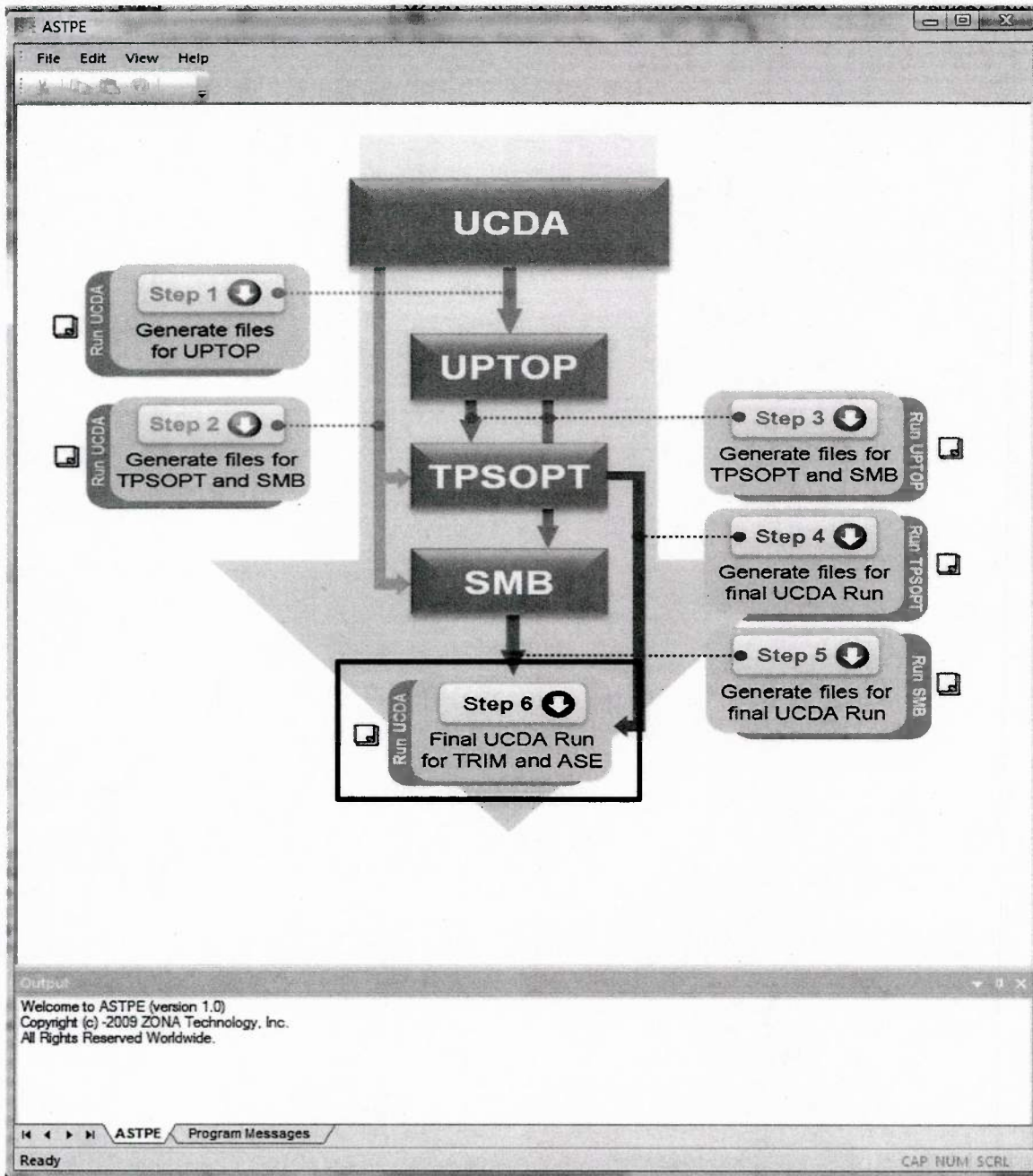


Figure 8.8.1 Section Corresponding to Step 6 of GUI

Input Files:

File Name	Type	Remarks	See Listing
vehicle.inp	Standard input file	Also look at Table 8.8.1	Shown in Listing 8.8.1
chem.bin	Engine chemistry information	Required	Shown in Listing 8.2.2
mass_tps.dat	Generated by TPSOPT	iffeedback needs to be 1	Shown in Listing 8.8.2
masschg.dat	Generated by SMB	iffeedback needs to be 1	Shown in Listing 8.8.3
RDOF_EIGEN.FREE	Generated by SMB	iffeedback needs to be 1	Shown in Listing 8.8.4

Output Files:

File Name	Type	Remarks	See Listing
trim_output.dat	Trim results by UCDA	See Fig. 8.8.2	Shown in Listing 8.8.5
Prep_ASE.dat	ASE results by UCDA	See Tables 8.8.2-8.8.3	Shown in Listing 8.8.6

Input File Descriptions

vehicle.inp: See Listing 8.8.1 for the entire input file. Also, Table 8.8.1 shows the necessary block and change in input parameters therein. The user should turn on **itrim** so that UCDA includes control surface in its calculation. **ideriv** is the input switch parameter that is to be set to **1** for running TRIM and ASE. **itps** should be turned back to **0** so that TPS geometry information is not created and in the process that saves some computational run time. Finally, **iffeedback** should be turned on to include the mass update from TPS and SMB. The user should note at this point that before this step, **iffeedback** was always set to **0**. That is because before this step, TPSOPT and SMB was never run (look at Figure 8.8.1). This step finishes one design cycle. After this step, for all the subsequent design cycles, this **iffeedback** parameter should ALWAYS be set to **1**. The code internally keeps track of the mass for each design cycle and that needs **iffeedback** to be set to **1**. If **iffeedback** value is set to **0** by mistake, the mass information is not going to be right.

Table 8.8.1: Showing Necessary Block on Vehicle.inp to Compute TRIM and ASE

TEST INPUT DECK: Note - this line must be here!

```
2 ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1 ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle
1 iunits - Output unit switch: SI (1) or English (2)
3 ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1 iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2 inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1 iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
0 itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0 iconc - cone flow data: exact (0), curve-fit approximation (1)
1 imodel - Forebody type: WA (1), VWA (2), or VWA + cone flow (3)
1 itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
1 nderiv - Calculate derivatives: no (0), yes (1)
0 itps - If itps is 1, then prepare for tps and smb. nderiv and itps cannot be 1 at one time
1 ifeedback - If 1, then gets weight and Cg information from SMB and TPSOPT
```

chem.bin: This file does not change for any UCDA run. Please see Section 8.2 for description on this file.

mass_tps.dat: This file is shown in Listing 8.8.2. It is generated by TPSOPT run. More on this can be found in Section 6.

masschng.dat: This file is shown in Listing 8.8.3 and it is generated by SMB run. When UCDA was run to generate the geometry for TPSOPT and SMB that were described in Section 8.5, the structure was approximated by a finite number of discrete points. masschng.dat outputs the additional mass due to skin thickness at each of those points. More on this can be found in Section 8.7.

RDOF_EIGEN.DAT: This file is shown in Listing 8.8.4. It is also generated by SMB run. Natural frequencies and generalized masses of the first 20 modes are recorded in the file. More on this can be found in Section 8.7.

Output File descriptions

Trim_output.dat: This file is shown in Listing 8.8.5. It outputs the summary of information related to trim iterations. Geometric information such as C.G., reference area, reference chord and aerodynamic information such as Coefficients of lift, drag and moment due to change in angle of attack and control surface deflection angle are some of the information. Also, trim variables angle of attack and control surface deflection angles are listed for each iteration.

The iteration history from trim_output.dat file is shown in Figure 8.8.2. It can be seen that this iterative process requires only less than 10 iterations to achieve a fully converged solution. In fact, the mean flow condition in terms of α_0 and δ_0 does not change significantly after 5 iterations. Meanwhile, the lift and moment at the fifth iteration have already nearly satisfied the lift-equal-weight and zero-pitch-moment conditions. From the fifth to the tenth iteration, the trim solution remains nearly the same; indicating that this iterative process is stable and provides a fast converging rate.

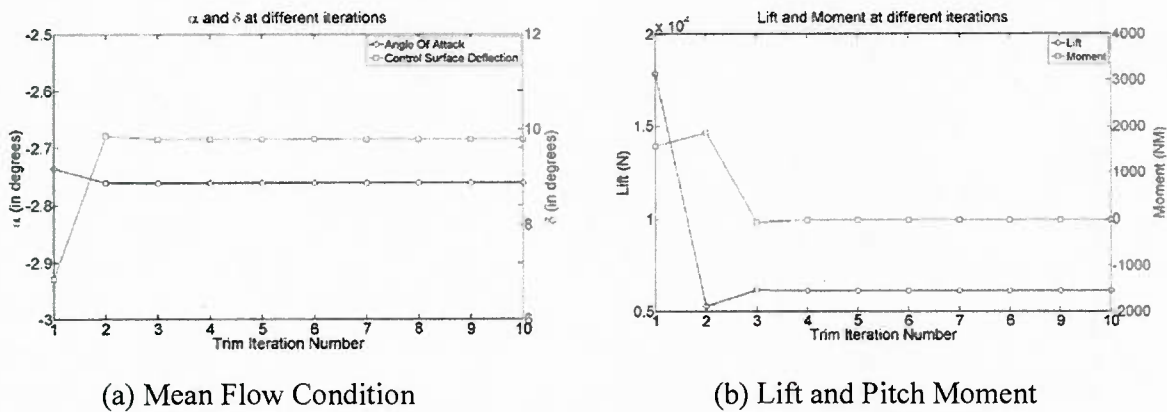


Figure 8.8.2 Iteration history of the iterative process for solving the nonlinear trim problem

Prep_ASE.dat: This file is shown in Listing 8.8.6. It outputs the summary of information related to ASE matrix preparation. As shown in the listing, A and B matrices are listed first. Then, the eigenvalues of matrix A is given. Frequency and damping ratio corresponding to the eigenvalues are then output. Finally, other aerodynamic information are written out so that the results can be compared with analytical expressions.

Validation of the ASE module

The validation of the ASE module can be achieved by first excluding the elastic modes then comparing the eigenvalues of the matrix $[A]$ to those of analytical flight dynamic equations shown in the following equations²:

For Phugoid mode:

$$\omega_{np} = \frac{\rho S U \sqrt{-C_{L_u} C_{L_o}}}{2m} \quad (8.8.1)$$

$$\zeta_p = \frac{-C_{x_u}}{2 \frac{mU}{Sq} \sqrt{-C_{L_u} C_{L_o}}} = \frac{-C_{D_u}}{2 \sqrt{-C_{L_u} C_{L_o}}} \quad (8.8.2)$$

For short period mode:

$$\omega = \left(\frac{\frac{c}{2U} C_{m_q} C_{L_\alpha} - \frac{mU}{Sq} C_{m_\alpha}}{\left(\frac{I_y}{Sqc} \right) \left(\frac{mU}{Sq} \right)} \right)^{1/2} \quad (8.8.3)$$

$$\zeta = -\frac{1}{4} \left(C_{m_q} + C_{m_\alpha} + \frac{2l_y}{mc^2} C_{L_\alpha} \right) \left(\frac{mc^2}{I_y \left(\frac{C_{m_q} C_{L_\alpha}}{2} - \frac{2mC_{m_\alpha}}{pSc} \right)} \right)^{1/2} \quad (8.8.4)$$

² Blakelock, J. H., "Automated Control of Aircraft and Missiles," Air Force Institute of Technology, 1981.

The aerodynamic stability derivatives are computed first on the selected scramjet flight vehicle at the trim condition of $\alpha = -2.76^\circ$, $\delta = 9.79^\circ$. These aerodynamic stability derivatives are shown in Table 8.8.2. Other parameters required by the analytical flight dynamic equations are: mass (m) = 625.6124, moment of inertia (I_y) = 3632.134, velocity (U) = 1777.383, surface area (S) = 1.777043, dynamic pressure (q) = 95729.13 and reference chord (c) = 4.267200 .

Table 8.8.2 Aerodynamic Stability Derivatives of a Scramjet Flight Vehicle

Airframe State	C_D	C_L	C_M
Mean Flow	8.6021081E-02	3.6066845E-02	-2.2896980E-05
Forward Velocity	1.2826486E-04	1.2870191E-04	-3.8179856E-05
Angle of Attack	-0.6494278	2.286335	6.1838981E-02
Pitch Rate	7.8784697E-02	-2.6101999E-02	2.4510620E-02

It can be seen in Table 8.8.2 that the pitch moment stability derivative of angle of attack (C_{m_α}) is positive; indicating a statically unstable flight vehicle.

Two sets of the ASE module of ASTPE are computed, one without the elastic mode (rigid body modes only) and the other with the first bending mode with natural frequency = 9.755 Hz, and compared to the analytical solution. This comparison is presented in Table 8.8.3 where an excellent agreement between the ASE module result without the elastic mode and the analytical solution can be seen. Meanwhile, the ASE module result with the first bending mode shows only a slight difference from that with only the rigid modes. This suggests that the structure designed by the SMB module provides sufficient stiffness by which the impact of aeroelastic effects on the flight dynamics is minimized.

Table 8.8.3 Validation of the ASE module with Analytical Solution

Longitudinal Dynamics	ASTPE				Analytical (Rigid)	
	+ Bending		Rigid			
	Damping	Frequency	Damping	Frequency	Damping	Frequency
Short Period	-1.0	0.3278 (Hz)	-1.0	0.343 (Hz)	-1.0	0.343 (Hz)
Phugoid	0.772	0.00079 (Hz)	0.729	0.00091(Hz)	0.734	0.00091(Hz)

Note that the negative damping of the short period mode is due to the unstable C_{m_z} , leading to a statically unstable flight vehicle that must be stabilized by a flight control system. A flight control system is designed for studied SEM and is given in Figure 8.8.3.

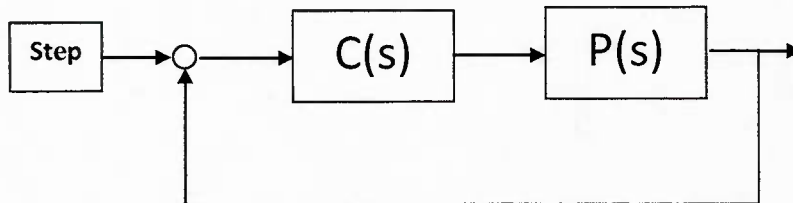


Figure 8.8.3 Block diagram of closed loop system

The compensator $C(s)$ takes the form:

$$C(s) = \frac{-1.489s^6 - 2.299s^5 - 5594s^4 - 8571s^3 - 2292s^2 - 19.15s - 0.07096}{0.001156s^7 + 0.03502s^6 + 5.345s^5 + 131.6s^4 + 3759s^3 + 31.87s^2 + 0.1198s}$$

Listing 8.8.1: Vehicle.inp Input File for TRIM and ASE

```

TEST INPUT DECK: Note - this line must be here!
2 ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1 ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle
1 iunits - Output unit switch: SI (1) or English (2)
3 ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1 iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2 inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1 iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
0 itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0 icone - cone flow data: exact (0), curve-fit approximation (1)
1 imodel - Forebody type: WA (1), VWA (2), or VWA + cone flow (3)
1 itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
1 ilderiv - Calculate derivatives: no (0), yes (1)
0 itps - If itps is 1, then prepare for tps and smb. ilderiv and itps cannot be 1 at one time
  
```

```

1         ifeedback - If 1, then gets weight and Cg information from SMB and TPSOPT

OUTPUT FILE SWITCHES AND NAMES:
1 'plot.dat'          VEHICLEFIG:      off (0), select (1), x,y,z (2), all (3)
1 1 2 3 8 18 23      1st # -> # of variables to read, others -> vars to plot
1 'metrics.dat'       METRICS:      off (0), on (1)
0 'cowlexit.dat'      COWLEXIT:      off (0), on (1)
0 'moc.dat'           NOZFIG:      off (0), P,T,M (1), all (2)
0 'offdesign.dat'     AOA:        off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0 'scramjet.dat'      CKENGINE:     off (0), on (1)
0 IPRINTINLET:        off (0), all (1), results (2), all-real (3), results-real (4)
0 IPRINTENGINE:       off (0), on (1)
0 IDEBUG:             off (0), on (1) [print debugging info]

ZONE DATA AND GRID SIZES:
16      NUMBER OF ZONES
'forebody : top'      31      31
'keel : top'          101      6
'aftbody : top'       101      31
'forebody : bot'      31      31
'ramps : bot'         55      6
'comb : bot'          101      6
'cowl : top'          101      6
'nozzle : bot'        31      6
'ramp walls : inside' 35      6
'comb wall : inside'  101      7
'nozzle wall : inside' 21      7
'aftbody : bot'       101      31
'cowl : bot'          101      6
'ramp walls : outside' 35      6
'comb wall : outside' 101      7
'nozzle wall : outside' 21      7

INPUT DATA: (0 = degrees, 1 = m, 2 = ft, 3 = atm, 4 = dimensionless, K or kg, 5 = psf)
xl      x      xu      unit      res name
22500.  26000.  30000.  1      2500.      'altitude' - altitude (if required)
2000.   2200.   2400.0  5      200.       'q0'       - dynamic pressure (if required)
.50     1.099  1.0      4      .250       'equiv'    - equivalence ratio
1.       1.      0.0      4      -.05       'throttle' - engine throttle (if required)
6.0     6.00   8.00     4      .5         'm0'       - Mach number
-2.0    -1.0   3.00     0      .5         'AOA'      - angle of attack
6.0     4      'Mdes'    - design Mach number
1.0     0      'AOAdeg'  - design angle of attack
21800.  1      'Zdes'    - design altitude
4.2672  1      'lvehicle' - vehicle length
6.0000  0      'thforclu' - forebody upper surface angle
5.2797  0      'thforcll' - forebody ramp angle
0.5873  1      'lcontrol' - control surface length
7.73    0      'th_control' - control surface deflection angle
0.9920  0      'th_expn'  - nozzle initial expansion angle
10.8958 0      'th_exit'  - nozzle exit angle
0.0     4      'p_nozpoly' - % diff between nozzle designs [DON'T USE-defaulted to 1.]
1.901   1      'lCowl'    - cowl length (isolator/combustor)
.3       1      'lcowlxt'  - cowl extension length (internal nozzle)
0.545   4      'p_iso'    - percent of lcowl that is isolator
.3238   1      'height'   - height of vehicle (if required)
20.0    1      'linlet'   - inlet length of vehicle (if required)
.26     1      'wengine'  - width of the engine (currently defaulted to unit width)
3.00    4      'iramps'   - number of inlet ramps in addition to the forebody
6.4012  0      'th_ramp1' - inlet ramp 1 angle
5.2383  0      'th_ramp2' - inlet ramp 2 angle
5.5     0      'th_ramp3' - inlet ramp 3 angle
0.0     0      'th_ramp4' - inlet ramp 4 angle
0.0     0      'th_ramp5' - inlet ramp 5 angle
3.09    0      'th_div1'  - first combustor expansion angle
0.2     0      'th_div2'  - second combustor expansion angle
0.01    1      'Xinj's'   - beginning of injectors (m)
0.02    1      'Xinje'   - end of injectors (m)
0.01    1      'Lmix'    - fuel mixing length (m)
1.00    4      'eta_mix'  - fuel mixing and burning efficiency
3000.   4      'Tlimit'   - maximum engine temperature (K)
90.     0      'Thetainj' - injector angle (degrees) [90 deg. is normal to flow]
1200.   4      'Tw'      - adiabatic wall temperature (K)
0.1527  4      'nfor'    - forebody exponent n
2.0     2      'wfor'    - forebody width
1.5     2      'lfor'    - forebody length
0.2427  4      'mfor'    - forebody exponent m
5.797   0      'thforle'  - forebody leading edge angle
21.519  0      'th_le'   - leading edge attachment angle
0.0000  4      'p_Kl'    - keel-line height percentage
0.25    4      'fuelfrac' - vehicle fuel volume fraction
0.0104  2      't_plate' - shell plate thickness (Tungsten)
0.0     4      'mass_smb' - mass due to Structural Modal Base (SMB) analysis
0.0     4      'mass_tps' - mass due to Thermal Protection System (TPS) analysis
0.0     4      'mass_nose' - lumped mass at the nose to manipulate CG

```

Listing 8.8.2 mass_tps.DAT

15.65999 34.37291

Listing 8.8.3 masschg.dat

0.00000000	0.35151434E+00
0.22458947	0.15923738E+01
0.44917893	0.34992027E+01
0.67376840	0.47900314E+01
0.89835787	0.47755566E+01
1.12294734	0.42759323E+01
1.34753680	0.36480141E+01
1.57212627	0.24694061E+01
1.79671574	0.12667809E+01
2.02130532	0.63976669E+00
2.24589467	0.55348587E+00
2.47048426	0.80759811E+00
2.69507360	0.11092186E+01
2.91966319	0.13285332E+01
3.14425254	0.13999634E+01
3.36884212	0.14529495E+01
3.59343147	0.14412441E+01
3.81802106	0.10710030E+01
4.04261065	0.59553242E+00
4.26719999	0.21292615E+00

Listing 8.8.4 Eigenvalues and Eigenvectors of the Beam Model: RDOF_EIGEN.FREE

20	20					
1	0.00000000E+00	0.00000000E+00	0.00000000E+00			
2	0.22458947E+00	0.00000000E+00	0.00000000E+00			
3	0.44917893E+00	0.00000000E+00	0.00000000E+00			
4	0.67376840E+00	0.00000000E+00	0.00000000E+00			
5	0.89835787E+00	0.00000000E+00	0.00000000E+00			
6	0.11229473E+01	0.00000000E+00	0.00000000E+00			
7	0.13475368E+01	0.00000000E+00	0.00000000E+00			
8	0.15721263E+01	0.00000000E+00	0.00000000E+00			
9	0.17967157E+01	0.00000000E+00	0.00000000E+00			
10	0.20213053E+01	0.00000000E+00	0.00000000E+00			
11	0.22458947E+01	0.00000000E+00	0.00000000E+00			
12	0.24704843E+01	0.00000000E+00	0.00000000E+00			
13	0.26950736E+01	0.00000000E+00	0.00000000E+00			
14	0.29196632E+01	0.00000000E+00	0.00000000E+00			
15	0.31442525E+01	0.00000000E+00	0.00000000E+00			
16	0.33688421E+01	0.00000000E+00	0.00000000E+00			
17	0.35934315E+01	0.00000000E+00	0.00000000E+00			
18	0.38180211E+01	0.00000000E+00	0.00000000E+00			
19	0.40426106E+01	0.00000000E+00	0.00000000E+00			
20	0.42672000E+01	0.00000000E+00	0.00000000E+00			
\$MODE	1					
0.57272335E-01	0.10000000E+01					
1	-0.40490381E-01	0.00000000E+00	-0.48925512E-06	0.00000000E+00	-0.38078155E-06	0.00000000E+00
2	-0.40490381E-01	0.00000000E+00	-0.40373560E-06	0.00000000E+00	-0.38078150E-06	0.00000000E+00
3	-0.40490380E-01	0.00000000E+00	-0.31821607E-06	0.00000000E+00	-0.38078173E-06	0.00000000E+00
4	-0.40490381E-01	0.00000000E+00	-0.23269650E-06	0.00000000E+00	-0.38078170E-06	0.00000000E+00
5	-0.40490383E-01	0.00000000E+00	-0.14717694E-06	0.00000000E+00	-0.38078174E-06	0.00000000E+00
6	-0.40490387E-01	0.00000000E+00	-0.61657350E-07	0.00000000E+00	-0.38078200E-06	0.00000000E+00
7	-0.40490389E-01	0.00000000E+00	0.23862352E-07	0.00000000E+00	-0.38078277E-06	0.00000000E+00
8	-0.40490390E-01	0.00000000E+00	0.10938236E-06	0.00000000E+00	-0.38078476E-06	0.00000000E+00
9	-0.40490393E-01	0.00000000E+00	0.19490312E-06	0.00000000E+00	-0.38078935E-06	0.00000000E+00
10	-0.40490397E-01	0.00000000E+00	0.28042550E-06	0.00000000E+00	-0.38079887E-06	0.00000000E+00
11	-0.40490402E-01	0.00000000E+00	0.36595074E-06	0.00000000E+00	-0.38081522E-06	0.00000000E+00
12	-0.40490404E-01	0.00000000E+00	0.45147905E-06	0.00000000E+00	-0.38082553E-06	0.00000000E+00
13	-0.40490408E-01	0.00000000E+00	0.53700913E-06	0.00000000E+00	-0.38083176E-06	0.00000000E+00
14	-0.40490410E-01	0.00000000E+00	0.62254052E-06	0.00000000E+00	-0.38083675E-06	0.00000000E+00
15	-0.40490409E-01	0.00000000E+00	0.70807312E-06	0.00000000E+00	-0.38084402E-06	0.00000000E+00
16	-0.40490408E-01	0.00000000E+00	0.79360804E-06	0.00000000E+00	-0.38085675E-06	0.00000000E+00
17	-0.40490407E-01	0.00000000E+00	0.87914645E-06	0.00000000E+00	-0.38087271E-06	0.00000000E+00
18	-0.40490403E-01	0.00000000E+00	0.96468768E-06	0.00000000E+00	-0.38087753E-06	0.00000000E+00
19	-0.40490401E-01	0.00000000E+00	0.10502259E-05	0.00000000E+00	-0.38088543E-06	0.00000000E+00
20	-0.40490401E-01	0.00000000E+00	0.11357569E-05	0.00000000E+00	-0.38082159E-06	0.00000000E+00
\$MODE	2					
0.27634893E+00	0.10000000E+01					
1	0.50445597E-06	0.00000000E+00	-0.36526301E-01	0.00000000E+00	-0.29741819E-01	0.00000000E+00

2	0.504455957E-06	0.000000000E+00	-0.298466060E-01	0.000000000E+00	-0.297417714E-01	0.000000000E+00
3	0.504455931E-06	0.000000000E+00	-0.231669195E-01	0.000000000E+00	-0.297417532E-01	0.000000000E+00
4	0.504455930E-06	0.000000000E+00	-0.164872382E-01	0.000000000E+00	-0.297417146E-01	0.000000000E+00
5	0.504455918E-06	0.000000000E+00	-0.980756673E-02	0.000000000E+00	-0.297416760E-01	0.000000000E+00
6	0.504455935E-06	0.000000000E+00	-0.312790199E-02	0.000000000E+00	-0.297416534E-01	0.000000000E+00
7	0.504455885E-06	0.000000000E+00	0.355175883E-02	0.000000000E+00	-0.297416471E-01	0.000000000E+00
8	0.504455797E-06	0.000000000E+00	0.102314239E-01	0.000000000E+00	-0.297416901E-01	0.000000000E+00
9	0.504455888E-06	0.000000000E+00	0.169111047E-01	0.000000000E+00	-0.297417751E-01	0.000000000E+00
10	0.504455073E-06	0.000000000E+00	0.235908069E-01	0.000000000E+00	-0.297418451E-01	0.000000000E+00
11	0.504453953E-06	0.000000000E+00	0.302705049E-01	0.000000000E+00	-0.297417698E-01	0.000000000E+00
12	0.504453502E-06	0.000000000E+00	0.369501751E-01	0.000000000E+00	-0.297415578E-01	0.000000000E+00
13	0.504452379E-06	0.000000000E+00	0.436297890E-01	0.000000000E+00	-0.297413471E-01	0.000000000E+00
14	0.504451802E-06	0.000000000E+00	0.503093730E-01	0.000000000E+00	-0.297412592E-01	0.000000000E+00
15	0.504451945E-06	0.000000000E+00	0.569889385E-01	0.000000000E+00	-0.297412056E-01	0.000000000E+00
16	0.504454070E-06	0.000000000E+00	0.636685025E-01	0.000000000E+00	-0.297412410E-01	0.000000000E+00
17	0.504454445E-06	0.000000000E+00	0.703480946E-01	0.000000000E+00	-0.297414756E-01	0.000000000E+00
18	0.504453899E-06	0.000000000E+00	0.770276778E-01	0.000000000E+00	-0.297418286E-01	0.000000000E+00
19	0.504453831E-06	0.000000000E+00	0.837074998E-01	0.000000000E+00	-0.297420186E-01	0.000000000E+00
20	0.504456598E-06	0.000000000E+00	0.903872522E-01	0.000000000E+00	-0.297420940E-01	0.000000000E+00
SMODE 3						
0.60200765E+00 0.10000000E+01						
1	0.164771606E-07	0.000000000E+00	-0.841103576E-01	0.000000000E+00	-0.252457161E-01	0.000000000E+00
2	0.164771586E-07	0.000000000E+00	-0.784404688E-01	0.000000000E+00	-0.252452761E-01	0.000000000E+00
3	0.164771558E-07	0.000000000E+00	-0.727706762E-01	0.000000000E+00	-0.252449368E-01	0.000000000E+00
4	0.164771535E-07	0.000000000E+00	-0.671009721E-01	0.000000000E+00	-0.252444755E-01	0.000000000E+00
5	0.164771500E-07	0.000000000E+00	-0.614313851E-01	0.000000000E+00	-0.252439153E-01	0.000000000E+00
6	0.164771451E-07	0.000000000E+00	-0.557619279E-01	0.000000000E+00	-0.252433584E-01	0.000000000E+00
7	0.164771351E-07	0.000000000E+00	-0.500925957E-01	0.000000000E+00	-0.252428250E-01	0.000000000E+00
8	0.164771187E-07	0.000000000E+00	-0.444233890E-01	0.000000000E+00	-0.252422622E-01	0.000000000E+00
9	0.164770810E-07	0.000000000E+00	-0.387543284E-01	0.000000000E+00	-0.252415784E-01	0.000000000E+00
10	0.164769906E-07	0.000000000E+00	-0.330854128E-01	0.000000000E+00	-0.252409723E-01	0.000000000E+00
11	0.164768044E-07	0.000000000E+00	-0.274165823E-01	0.000000000E+00	-0.252409208E-01	0.000000000E+00
12	0.164766558E-07	0.000000000E+00	-0.217476885E-01	0.000000000E+00	-0.252413924E-01	0.000000000E+00
13	0.164765423E-07	0.000000000E+00	-0.160786861E-01	0.000000000E+00	-0.252418976E-01	0.000000000E+00
14	0.164764459E-07	0.000000000E+00	-0.104095712E-01	0.000000000E+00	-0.252423144E-01	0.000000000E+00
15	0.164762429E-07	0.000000000E+00	-0.474037818E-02	0.000000000E+00	-0.252426472E-01	0.000000000E+00
16	0.164762467E-07	0.000000000E+00	0.928888684E-03	0.000000000E+00	-0.252429085E-01	0.000000000E+00
17	0.164764318E-07	0.000000000E+00	0.659820563E-02	0.000000000E+00	-0.252431427E-01	0.000000000E+00
18	0.164765001E-07	0.000000000E+00	0.122675886E-01	0.000000000E+00	-0.252434223E-01	0.000000000E+00
19	0.164767725E-07	0.000000000E+00	0.179370280E-01	0.000000000E+00	-0.252436324E-01	0.000000000E+00
20	0.164769397E-07	0.000000000E+00	0.236064944E-01	0.000000000E+00	-0.252437320E-01	0.000000000E+00
SMODE 4						
0.39578528E+02 0.10000000E+01						
1	-0.196674606E-10	0.000000000E+00	-0.940948699E-01	0.000000000E+00	-0.832574359E-01	0.000000000E+00
2	-0.196659404E-10	0.000000000E+00	-0.755528337E-01	0.000000000E+00	-0.811642040E-01	0.000000000E+00
3	-0.196643877E-10	0.000000000E+00	-0.574820026E-01	0.000000000E+00	-0.793728618E-01	0.000000000E+00
4	-0.196294909E-10	0.000000000E+00	-0.398514493E-01	0.000000000E+00	-0.773592962E-01	0.000000000E+00
5	-0.196085515E-10	0.000000000E+00	-0.226957854E-01	0.000000000E+00	-0.752126464E-01	0.000000000E+00
6	-0.195733115E-10	0.000000000E+00	-0.605072729E-02	0.000000000E+00	-0.728500250E-01	0.000000000E+00
7	-0.195189745E-10	0.000000000E+00	0.999375657E-02	0.000000000E+00	-0.698762023E-01	0.000000000E+00
8	-0.194310574E-10	0.000000000E+00	0.251667634E-01	0.000000000E+00	-0.650673511E-01	0.000000000E+00
9	-0.192301126E-10	0.000000000E+00	0.385939436E-01	0.000000000E+00	-0.542486112E-01	0.000000000E+00
10	-0.187527067E-10	0.000000000E+00	0.480692442E-01	0.000000000E+00	-0.298348384E-01	0.000000000E+00
11	-0.177861315E-10	0.000000000E+00	0.497151583E-01	0.000000000E+00	0.152179565E-01	0.000000000E+00
12	-0.170248216E-10	0.000000000E+00	0.427938434E-01	0.000000000E+00	0.460931255E-01	0.000000000E+00
13	-0.164465489E-10	0.000000000E+00	0.302250297E-01	0.000000000E+00	0.654000418E-01	0.000000000E+00
14	-0.159615643E-10	0.000000000E+00	0.140827433E-01	0.000000000E+00	0.779001962E-01	0.000000000E+00
15	-0.154475418E-10	0.000000000E+00	-0.444011542E-02	0.000000000E+00	0.865950757E-01	0.000000000E+00
16	-0.163457478E-10	0.000000000E+00	-0.246143926E-01	0.000000000E+00	0.926210651E-01	0.000000000E+00
17	-0.171261139E-10	0.000000000E+00	-0.460640822E-01	0.000000000E+00	0.978749675E-01	0.000000000E+00
18	-0.172077810E-10	0.000000000E+00	-0.688371904E-01	0.000000000E+00	0.104034124E+00	0.000000000E+00
19	-0.181612898E-10	0.000000000E+00	-0.928766367E-01	0.000000000E+00	0.108845700E+00	0.000000000E+00
20	-0.196211395E-10	0.000000000E+00	-0.117685609E+00	0.000000000E+00	0.111273269E+00	0.000000000E+00
SMODE 5						
0.12813527E+03 0.10000000E+01						
1	-0.907625115E-11	0.000000000E+00	0.968081569E-01	0.000000000E+00	0.154702951E+00	0.000000000E+00
2	-0.902546662E-11	0.000000000E+00	0.637533673E-01	0.000000000E+00	0.132130422E+00	0.000000000E+00
3	-0.896248902E-11	0.000000000E+00	0.356576338E-01	0.000000000E+00	0.114445856E+00	0.000000000E+00
4	-0.889342793E-11	0.000000000E+00	0.117573540E-01	0.000000000E+00	0.961796104E-01	0.000000000E+00
5	-0.879336765E-11	0.000000000E+00	-0.800905964E-02	0.000000000E+00	0.784696414E-01	0.000000000E+00
6	-0.862584956E-11	0.000000000E+00	-0.237779420E-01	0.000000000E+00	0.611194221E-01	0.000000000E+00
7	-0.836958113E-11	0.000000000E+00	-0.354428711E-01	0.000000000E+00	0.423344610E-01	0.000000000E+00
8	-0.795937497E-11	0.000000000E+00	-0.421502193E-01	0.000000000E+00	0.174577267E-01	0.000000000E+00
9	-0.703515013E-11	0.000000000E+00	-0.411588404E-01	0.000000000E+00	-0.248775430E-01	0.000000000E+00
10	-0.489271123E-11	0.000000000E+00	-0.280802414E-01	0.000000000E+00	-0.862419990E-01	0.000000000E+00
11	-0.763923281E-12	0.000000000E+00	-0.247116908E-02	0.000000000E+00	-0.129348192E+00	0.000000000E+00
12	0.218468815E-11	0.000000000E+00	0.250173782E-01	0.000000000E+00	-0.106471342E+00	0.000000000E+00
13	0.414824446E-11	0.000000000E+00	0.439779910E-01	0.000000000E+00	-0.574837101E-01	0.000000000E+00
14	0.555510239E-11	0.000000000E+00	0.509400078E-01	0.000000000E+00	-0.250947652E-02	0.000000000E+00
15	0.731153851E-11	0.000000000E+00	0.453378353E-01	0.000000000E+00	0.523596798E-01	0.000000000E+00
16	0.785238307E-11	0.000000000E+00	0.278018923E-01	0.000000000E+00	0.102117540E+00	0.000000000E+00
17	0.680811381E-11	0.000000000E+00	-0.152755457E-02	0.000000000E+00	0.155252362E+00	0.000000000E+00
18	0.606017142E-11	0.000000000E+00	-0.455361758E-01	0.000000000E+00	0.227685935E+00	0.000000000E+00
19	0.399300425E-11	0.000000000E+00	-0.105588135E+00	0.000000000E+00	0.292053314E+00	0.000000000E+00
20	0.400560848E-11	0.000000000E+00	-0.176909860E+00	0.000000000E+00	0.330321022E+00	0.000000000E+00
SMODE 6						
0.14555613E+03 0.10000000E+01						
1	0.451430537E-01	0.000000000E+00	0.171072781E-10	0.000000000E+00	0.297528981E-10	0.000000000E+00
2	0.448173724E-01	0.000000000E+00	0.108209352E-10	0.000000000E+00	0.245027895E-10	0.000000000E+00
3	0.444136522E-01	0.000000000E+00	0.567243532E-11	0.000000000E+00	0.205285354E-10	0.000000000E+00
4	0.439714936E-01	0.000000000E+00	0.145821895E-11	0.000000000E+00	0.165205034E-10	0.000000000E+00
5	0.433317349E-01	0.000000000E+00	-0.184936250E-11	0.000000000E+00	0.126643738E-10	0.000000000E+00

6	0.422625703E-01	0.000000000E+00	-0.429691255E-11	0.000000000E+00	0.899235455E-11	0.000000000E+00
7	0.406312203E-01	0.000000000E+00	-0.588341524E-11	0.000000000E+00	0.510569235E-11	0.000000000E+00
8	0.380291022E-01	0.000000000E+00	-0.646906729E-11	0.000000000E+00	0.194212983E-12	0.000000000E+00
9	0.321934718E-01	0.000000000E+00	-0.560822502E-11	0.000000000E+00	-0.748326601E-11	0.000000000E+00
10	0.187755529E-01	0.000000000E+00	-0.270906965E-11	0.000000000E+00	-0.171380536E-10	0.000000000E+00
11	-0.665706935E-02	0.000000000E+00	0.177167264E-11	0.000000000E+00	-0.202400097E-10	0.000000000E+00
12	-0.241979568E-01	0.000000000E+00	0.560384421E-11	0.000000000E+00	-0.122958849E-10	0.000000000E+00
13	-0.352853940E-01	0.000000000E+00	0.720589387E-11	0.000000000E+00	-0.123345619E-11	0.000000000E+00
14	-0.426711595E-01	0.000000000E+00	0.628238916E-11	0.000000000E+00	0.966177707E-11	0.000000000E+00
15	-0.480636256E-01	0.000000000E+00	0.327043821E-11	0.000000000E+00	0.157369928E-10	0.000000000E+00
16	-0.520377694E-01	0.000000000E+00	-0.211675587E-12	0.000000000E+00	0.141509428E-10	0.000000000E+00
17	-0.543863935E-01	0.000000000E+00	-0.300581664E-11	0.000000000E+00	0.125765849E-10	0.000000000E+00
18	-0.559362173E-01	0.000000000E+00	-0.776624123E-11	0.000000000E+00	0.337369389E-10	0.000000000E+00
19	-0.572642995E-01	0.000000000E+00	-0.223937838E-10	0.000000000E+00	0.884017371E-10	0.000000000E+00
20	-0.575988237E-01	0.000000000E+00	-0.512510924E-10	0.000000000E+00	0.148533026E-09	0.000000000E+00
SMODE 7						
0.22156564E+03 0.10000000E+01						
1	0.105529715E-14	0.000000000E+00	0.144094958E+00	0.000000000E+00	0.352565888E+00	0.000000000E+00
2	0.100825832E-14	0.000000000E+00	0.724331088E-01	0.000000000E+00	0.252107231E+00	0.000000000E+00
3	0.987348019E-15	0.000000000E+00	0.222540393E-01	0.000000000E+00	0.181248553E+00	0.000000000E+00
4	0.978906718E-15	0.000000000E+00	-0.118119057E-01	0.000000000E+00	0.115241909E+00	0.000000000E+00
5	0.944105450E-15	0.000000000E+00	-0.316546124E-01	0.000000000E+00	0.582112286E-01	0.000000000E+00
6	0.867099109E-15	0.000000000E+00	-0.393952927E-01	0.000000000E+00	0.968071610E-02	0.000000000E+00
7	0.815321115E-15	0.000000000E+00	-0.365954005E-01	0.000000000E+00	-0.339828277E-01	0.000000000E+00
8	0.673628673E-15	0.000000000E+00	-0.236894835E-01	0.000000000E+00	-0.783292633E-01	0.000000000E+00
9	0.390123055E-15	0.000000000E+00	0.355444777E-04	0.000000000E+00	-0.125840845E+00	0.000000000E+00
10	-0.210060355E-15	0.000000000E+00	0.310339712E-01	0.000000000E+00	-0.135780412E+00	0.000000000E+00
11	-0.122642120E-14	0.000000000E+00	0.513290906E-01	0.000000000E+00	-0.291346465E-01	0.000000000E+00
12	-0.185659297E-14	0.000000000E+00	0.457303381E-01	0.000000000E+00	0.787371921E-01	0.000000000E+00
13	-0.214504745E-14	0.000000000E+00	0.213803976E-01	0.000000000E+00	0.130876959E+00	0.000000000E+00
14	-0.203549769E-14	0.000000000E+00	-0.882217712E-02	0.000000000E+00	0.129969208E+00	0.000000000E+00
15	-0.222338059E-12	0.000000000E+00	-0.340284099E-01	0.000000000E+00	0.881382271E-01	0.000000000E+00
16	0.338429084E-12	0.000000000E+00	-0.463775385E-01	0.000000000E+00	0.191597160E-01	0.000000000E+00
17	0.185986768E-11	0.000000000E+00	-0.388748241E-01	0.000000000E+00	-0.829358340E-01	0.000000000E+00
18	0.332671874E-11	0.000000000E+00	0.969905202E-03	0.000000000E+00	-0.255608418E+00	0.000000000E+00
19	0.583168591E-11	0.000000000E+00	0.831077422E-01	0.000000000E+00	-0.437127873E+00	0.000000000E+00
20	0.552204634E-11	0.000000000E+00	0.200719362E+00	0.000000000E+00	-0.566947930E+00	0.000000000E+00
SMODE 8						
0.32437990E+03 0.10000000E+01						
1	-0.274452591E-11	0.000000000E+00	0.170489903E+00	0.000000000E+00	0.600580929E+00	0.000000000E+00
2	-0.264617816E-11	0.000000000E+00	0.546787659E-01	0.000000000E+00	0.345813255E+00	0.000000000E+00
3	-0.252697307E-11	0.000000000E+00	-0.839010176E-02	0.000000000E+00	0.189340616E+00	0.000000000E+00
4	-0.239919124E-11	0.000000000E+00	-0.379375658E-01	0.000000000E+00	0.640941693E-01	0.000000000E+00
5	-0.221871777E-11	0.000000000E+00	-0.424614541E-01	0.000000000E+00	-0.256415183E-01	0.000000000E+00
6	-0.192680862E-11	0.000000000E+00	-0.299052979E-01	0.000000000E+00	-0.840567635E-01	0.000000000E+00
7	-0.150246680E-11	0.000000000E+00	-0.685489228E-02	0.000000000E+00	-0.116824254E+00	0.000000000E+00
8	-0.868040358E-12	0.000000000E+00	0.207385568E-01	0.000000000E+00	-0.122684350E+00	0.000000000E+00
9	0.431218622E-12	0.000000000E+00	0.438667933E-01	0.000000000E+00	-0.756264803E-01	0.000000000E+00
10	0.296161078E-11	0.000000000E+00	0.452087283E-01	0.000000000E+00	0.622317833E-01	0.000000000E+00
11	0.619203075E-11	0.000000000E+00	0.120519714E-01	0.000000000E+00	0.199866715E+00	0.000000000E+00
12	0.661352904E-11	0.000000000E+00	-0.293139741E-01	0.000000000E+00	0.139379474E+00	0.000000000E+00
13	0.552616883E-11	0.000000000E+00	-0.468416274E-01	0.000000000E+00	0.632153351E-02	0.000000000E+00
14	0.379564776E-11	0.000000000E+00	-0.349804918E-01	0.000000000E+00	-0.107935727E+00	0.000000000E+00
15	0.138401288E-11	0.000000000E+00	-0.302604868E-02	0.000000000E+00	-0.164887165E+00	0.000000000E+00
16	-0.151928966E-11	0.000000000E+00	0.336535070E-01	0.000000000E+00	-0.149298812E+00	0.000000000E+00
17	-0.379103660E-11	0.000000000E+00	0.569688628E-01	0.000000000E+00	-0.510727269E-01	0.000000000E+00
18	-0.603180998E-11	0.000000000E+00	0.388398153E-01	0.000000000E+00	0.201387571E+00	0.000000000E+00
19	-0.890446773E-11	0.000000000E+00	-0.515167512E-01	0.000000000E+00	0.540890429E+00	0.000000000E+00
20	-0.909177014E-11	0.000000000E+00	-0.218308118E+00	0.000000000E+00	0.843532877E+00	0.000000000E+00
SMODE 9						
0.37006768E+03 0.10000000E+01						
1	0.317735637E-01	0.000000000E+00	0.221003542E-10	0.000000000E+00	0.891505283E-10	0.000000000E+00
2	0.302918333E-01	0.000000000E+00	0.530017290E-11	0.000000000E+00	0.461424932E-10	0.000000000E+00
3	0.285109922E-01	0.000000000E+00	-0.273169516E-11	0.000000000E+00	0.214955162E-10	0.000000000E+00
4	0.266179926E-01	0.000000000E+00	-0.564361684E-11	0.000000000E+00	0.331849635E-11	0.000000000E+00
5	0.239693391E-01	0.000000000E+00	-0.508231692E-11	0.000000000E+00	-0.826121762E-11	0.000000000E+00
6	0.197394300E-01	0.000000000E+00	-0.247991394E-11	0.000000000E+00	-0.143542954E-10	0.000000000E+00
7	0.137088399E-01	0.000000000E+00	0.100357210E-11	0.000000000E+00	-0.159236328E-10	0.000000000E+00
8	0.493006627E-02	0.000000000E+00	0.429628035E-11	0.000000000E+00	-0.126065806E-10	0.000000000E+00
9	-0.123543351E-01	0.000000000E+00	0.582803388E-11	0.000000000E+00	-0.600062888E-12	0.000000000E+00
10	-0.434962968E-01	0.000000000E+00	0.341260380E-11	0.000000000E+00	0.200483262E-10	0.000000000E+00
11	-0.746613963E-01	0.000000000E+00	-0.245406606E-11	0.000000000E+00	0.254799325E-10	0.000000000E+00
12	-0.674934639E-01	0.000000000E+00	-0.628904900E-11	0.000000000E+00	0.545211515E-11	0.000000000E+00
13	-0.442414719E-01	0.000000000E+00	-0.532422023E-11	0.000000000E+00	-0.135358040E-10	0.000000000E+00
14	-0.170334578E-01	0.000000000E+00	-0.126672077E-11	0.000000000E+00	-0.203549750E-10	0.000000000E+00
15	0.107076965E-01	0.000000000E+00	0.286784457E-11	0.000000000E+00	-0.144729598E-10	0.000000000E+00
16	0.363999161E-01	0.000000000E+00	0.452426992E-11	0.000000000E+00	0.898729746E-12	0.000000000E+00
17	0.542222882E-01	0.000000000E+00	0.178216409E-11	0.000000000E+00	0.212085114E-10	0.000000000E+00
18	0.671496092E-01	0.000000000E+00	-0.496150288E-11	0.000000000E+00	0.317103159E-10	0.000000000E+00
19	0.790560605E-01	0.000000000E+00	-0.902175209E-11	0.000000000E+00	0.386288438E-11	0.000000000E+00
20	0.821397348E-01	0.000000000E+00	-0.109410916E-11	0.000000000E+00	-0.548792730E-10	0.000000000E+00
SMODE 10						
0.45394492E+03 0.10000000E+01						
1	0.306839988E-11	0.000000000E+00	-0.177769261E+00	0.000000000E+00	-0.889759293E+00	0.000000000E+00
2	0.285312586E-11	0.000000000E+00	-0.168866163E-01	0.000000000E+00	-0.369516074E+00	0.000000000E+00
3	0.259918118E-11	0.000000000E+00	0.407000026E-01	0.000000000E+00	-0.108834632E+00	0.000000000E+00
4	0.233420688E-11	0.000000000E+00	0.476818082E-01	0.000000000E+00	0.501964151E-01	0.000000000E+00
5	0.197115731E-11	0.000000000E+00	0.274866983E-01	0.000000000E+00	0.123067335E+00	0.000000000E+00
6	0.140794920E-11	0.000000000E+00	-0.224915930E-02	0.000000000E+00	0.132999361E+00	0.000000000E+00
7	0.640215607E-12	0.000000000E+00	-0.288603924E-01	0.000000000E+00	0.966436029E-01	0.000000000E+00
8	-0.40847031E-12	0.000000000E+00	-0.416770861E-01	0.000000000E+00	0.143773606E-01	0.000000000E+00
9	-0.227912612E-11	0.000000000E+00	-0.277862092E-01	0.000000000E+00	-0.127927180E+00	0.000000000E+00

10	-0.498594270E-11	0.000000000E+00	0.170955196E-01	0.000000000E+00	-0.230068698E+00	0.000000000E+00
11	-0.563071325E-11	0.000000000E+00	0.526619157E-01	0.000000000E+00	-0.352910307E-01	0.000000000E+00
12	-0.277721210E-11	0.000000000E+00	0.358668932E-01	0.000000000E+00	0.171946570E+00	0.000000000E+00
13	0.325002956E-12	0.000000000E+00	-0.858189396E-02	0.000000000E+00	0.191771938E+00	0.000000000E+00
14	0.260980914E-11	0.000000000E+00	-0.404677356E-01	0.000000000E+00	0.717904155E-01	0.000000000E+00
15	0.349405421E-11	0.000000000E+00	-0.382571294E-01	0.000000000E+00	-0.914575797E-01	0.000000000E+00
16	0.388797339E-11	0.000000000E+00	-0.329032651E-02	0.000000000E+00	-0.202489911E+00	0.000000000E+00
17	0.481930904E-11	0.000000000E+00	0.455931817E-01	0.000000000E+00	-0.205587429E+00	0.000000000E+00
18	0.488319736E-11	0.000000000E+00	0.661636912E-01	0.000000000E+00	0.427611300E-01	0.000000000E+00
19	0.439678713E-11	0.000000000E+00	-0.112608933E-01	0.000000000E+00	0.576830200E+00	0.000000000E+00
20	0.411328889E-11	0.000000000E+00	-0.237253460E+00	0.000000000E+00	0.122096404E+01	0.000000000E+00
\$MODE 11						
0.53349915E+03 0.10000000E+01						
1	-0.520987930E-01	0.000000000E+00	-0.717624578E-11	0.000000000E+00	-0.427623856E-10	0.000000000E+00
2	-0.470494357E-01	0.000000000E+00	0.268427593E-12	0.000000000E+00	-0.138335596E-10	0.000000000E+00
3	-0.412239337E-01	0.000000000E+00	0.210575458E-11	0.000000000E+00	-0.123724094E-11	0.000000000E+00
4	-0.352739743E-01	0.000000000E+00	0.168186330E-11	0.000000000E+00	0.478409202E-11	0.000000000E+00
5	-0.273221947E-01	0.000000000E+00	0.407360712E-12	0.000000000E+00	0.603236544E-11	0.000000000E+00
6	-0.154114742E-01	0.000000000E+00	-0.816809439E-12	0.000000000E+00	0.442230375E-11	0.000000000E+00
7	-0.581571644E-04	0.000000000E+00	-0.146843263E-11	0.000000000E+00	0.116881070E-11	0.000000000E+00
8	0.192237676E-01	0.000000000E+00	-0.121940200E-11	0.000000000E+00	-0.323256721E-11	0.000000000E+00
9	0.490069645E-01	0.000000000E+00	0.120748096E-12	0.000000000E+00	-0.776468237E-11	0.000000000E+00
10	0.771073026E-01	0.000000000E+00	0.183667626E-11	0.000000000E+00	-0.570353425E-11	0.000000000E+00
11	0.381197682E-01	0.000000000E+00	0.165354768E-11	0.000000000E+00	0.719571145E-11	0.000000000E+00
12	-0.203233791E-01	0.000000000E+00	-0.446340291E-12	0.000000000E+00	0.925824642E-11	0.000000000E+00
13	-0.491915537E-01	0.000000000E+00	-0.190938023E-11	0.000000000E+00	0.265663269E-11	0.000000000E+00
14	-0.498990072E-01	0.000000000E+00	-0.175664917E-11	0.000000000E+00	-0.348692424E-11	0.000000000E+00
15	-0.307837636E-01	0.000000000E+00	-0.525151547E-12	0.000000000E+00	-0.742674091E-11	0.000000000E+00
16	0.513839656E-03	0.000000000E+00	0.128075586E-11	0.000000000E+00	-0.737346979E-11	0.000000000E+00
17	0.295238227E-01	0.000000000E+00	0.213354145E-11	0.000000000E+00	0.582662825E-12	0.000000000E+00
18	0.538264207E-01	0.000000000E+00	-0.307549983E-12	0.000000000E+00	0.190692553E-10	0.000000000E+00
19	0.785773236E-01	0.000000000E+00	-0.648043904E-11	0.000000000E+00	0.295822210E-10	0.000000000E+00
20	0.852269510E-01	0.000000000E+00	-0.106159918E-10	0.000000000E+00	0.128297674E-10	0.000000000E+00
\$MODE 12						
0.59547469E+03 0.10000000E+01						
1	0.218712018E-12	0.000000000E+00	-0.178223671E+00	0.000000000E+00	-0.120264339E+01	0.000000000E+00
2	0.192315334E-12	0.000000000E+00	0.246844734E-01	0.000000000E+00	-0.305127524E+00	0.000000000E+00
3	0.162466513E-12	0.000000000E+00	0.572494700E-01	0.000000000E+00	0.395917729E-01	0.000000000E+00
4	0.132555620E-12	0.000000000E+00	0.326940434E-01	0.000000000E+00	0.163598248E+00	0.000000000E+00
5	0.934926522E-13	0.000000000E+00	-0.465121283E-02	0.000000000E+00	0.150479997E+00	0.000000000E+00
6	0.368956526E-13	0.000000000E+00	-0.306658213E-01	0.000000000E+00	0.698535271E-01	0.000000000E+00
7	-0.321556576E-13	0.000000000E+00	-0.347124026E-01	0.000000000E+00	-0.351050571E-01	0.000000000E+00
8	-0.111449079E-12	0.000000000E+00	-0.140093081E-01	0.000000000E+00	-0.138343166E+00	0.000000000E+00
9	-0.213934597E-12	0.000000000E+00	0.252841779E-01	0.000000000E+00	-0.181718215E+00	0.000000000E+00
10	-0.246124043E-12	0.000000000E+00	0.493518835E-01	0.000000000E+00	-0.495737920E-02	0.000000000E+00
11	0.500788439E-13	0.000000000E+00	0.129242551E-01	0.000000000E+00	0.265881828E+00	0.000000000E+00
12	0.208491790E-12	0.000000000E+00	-0.384483544E-01	0.000000000E+00	0.126108986E+00	0.000000000E+00
13	0.171458914E-12	0.000000000E+00	-0.402267525E-01	0.000000000E+00	-0.112594255E+00	0.000000000E+00
14	0.495389250E-13	0.000000000E+00	-0.112021232E-02	0.000000000E+00	-0.202719195E+00	0.000000000E+00
15	-0.158618655E-12	0.000000000E+00	0.366635157E-01	0.000000000E+00	-0.103181285E+00	0.000000000E+00
16	-0.155860286E-11	0.000000000E+00	0.379202394E-01	0.000000000E+00	0.938637631E-01	0.000000000E+00
17	-0.402682046E-11	0.000000000E+00	-0.748981508E-02	0.000000000E+00	0.272493862E+00	0.000000000E+00
18	-0.562766128E-11	0.000000000E+00	-0.684391488E-01	0.000000000E+00	0.192271767E+00	0.000000000E+00
19	-0.669693418E-11	0.000000000E+00	-0.322020555E-01	0.000000000E+00	-0.490958021E+00	0.000000000E+00
20	-0.668051788E-11	0.000000000E+00	0.259764053E+00	0.000000000E+00	-0.170453825E+01	0.000000000E+00
\$MODE 13						
0.66563269E+03 0.10000000E+01						
1	-0.598871174E-01	0.000000000E+00	0.325063432E-11	0.000000000E+00	0.248494458E-10	0.000000000E+00
2	-0.508517948E-01	0.000000000E+00	-0.806805706E-12	0.000000000E+00	0.447729039E-11	0.000000000E+00
3	-0.408944693E-01	0.000000000E+00	-0.107337265E-11	0.000000000E+00	-0.227408106E-11	0.000000000E+00
4	-0.311759842E-01	0.000000000E+00	-0.345763140E-12	0.000000000E+00	-0.370211709E-11	0.000000000E+00
5	-0.188684246E-01	0.000000000E+00	0.376325134E-12	0.000000000E+00	-0.233332761E-11	0.000000000E+00
6	-0.182756833E-02	0.000000000E+00	0.666308826E-12	0.000000000E+00	-0.108354547E-12	0.000000000E+00
7	0.173802587E-01	0.000000000E+00	0.445140041E-12	0.000000000E+00	0.196393178E-11	0.000000000E+00
8	0.365296267E-01	0.000000000E+00	-0.166526807E-12	0.000000000E+00	0.313330280E-11	0.000000000E+00
9	0.534611827E-01	0.000000000E+00	-0.785764187E-12	0.000000000E+00	0.185192766E-11	0.000000000E+00
10	0.329297519E-01	0.000000000E+00	-0.616884416E-12	0.000000000E+00	-0.313512125E-11	0.000000000E+00
11	-0.626062167E-01	0.000000000E+00	0.465776331E-12	0.000000000E+00	-0.434018273E-11	0.000000000E+00
12	-0.509136270E-01	0.000000000E+00	0.884792383E-12	0.000000000E+00	0.120668784E-11	0.000000000E+00
13	0.183053797E-02	0.000000000E+00	0.228443197E-12	0.000000000E+00	0.379522872E-11	0.000000000E+00
14	0.411837514E-01	0.000000000E+00	-0.438849308E-12	0.000000000E+00	0.126986168E-11	0.000000000E+00
15	0.512379403E-01	0.000000000E+00	-0.45221602E-12	0.000000000E+00	-0.306167175E-13	0.000000000E+00
16	0.297080371E-01	0.000000000E+00	-0.617265464E-12	0.000000000E+00	0.125589293E-11	0.000000000E+00
17	-0.658405777E-02	0.000000000E+00	-0.776625335E-12	0.000000000E+00	-0.806311182E-12	0.000000000E+00
18	-0.437091415E-01	0.000000000E+00	0.719711117E-12	0.000000000E+00	-0.124193987E-10	0.000000000E+00
19	-0.863757044E-01	0.000000000E+00	0.499024591E-11	0.000000000E+00	-0.185246592E-10	0.000000000E+00
20	-0.983169796E-01	0.000000000E+00	0.465124614E-11	0.000000000E+00	0.115265702E-10	0.000000000E+00
\$MODE 14						
0.73973021E+03 0.10000000E+01						
1	0.623401668E-12	0.000000000E+00	0.164577292E+00	0.000000000E+00	0.142421921E+01	0.000000000E+00
2	0.507233060E-12	0.000000000E+00	-0.595328874E-01	0.000000000E+00	0.145208740E+00	0.000000000E+00
3	0.383134119E-12	0.000000000E+00	-0.516053639E-01	0.000000000E+00	-0.202978188E+00	0.000000000E+00
4	0.265812957E-12	0.000000000E+00	-0.966555370E-03	0.000000000E+00	-0.207334911E+00	0.000000000E+00
5	0.122829983E-12	0.000000000E+00	0.333090928E-01	0.000000000E+00	-0.752565081E-01	0.000000000E+00
6	-0.637992816E-13	0.000000000E+00	0.345619965E-01	0.000000000E+00	0.657758413E-01	0.000000000E+00
7	-0.252057428E-12	0.000000000E+00	0.839109571E-02	0.000000000E+00	0.153615086E+00	0.000000000E+00
8	-0.399537675E-12	0.000000000E+00	-0.277984675E-01	0.000000000E+00	0.146910241E+00	0.000000000E+00
9	-0.419344359E-12	0.000000000E+00	-0.427184099E-01	0.000000000E+00	-0.266811368E-01	0.000000000E+00
10	0.720323078E-13	0.000000000E+00	-0.203744862E-02	0.000000000E+00	-0.275253366E+00	0.000000000E+00
11	0.784909708E-12	0.000000000E+00	0.475775318E-01	0.000000000E+00	-0.522492914E-01	0.000000000E+00
12	0.631339152E-13	0.000000000E+00	0.228672363E-01	0.000000000E+00	0.235059036E+00	0.000000000E+00
13	-0.503440936E-12	0.000000000E+00	-0.289238623E-01	0.000000000E+00	0.161189857E+00	0.000000000E+00

14	-0.516379796E-12	0.000000000E+00	-0.393486823E-01	0.000000000E+00	-0.797856801E-01	0.000000000E+00
15	-0.745226224E-12	0.000000000E+00	-0.191635831E-02	0.000000000E+00	-0.216358182E+00	0.000000000E+00
16	-0.158749913E-11	0.000000000E+00	0.406007987E-01	0.000000000E+00	-0.122715154E+00	0.000000000E+00
17	-0.222856100E-11	0.000000000E+00	0.360176800E-01	0.000000000E+00	0.153346499E+00	0.000000000E+00
18	-0.216965467E-11	0.000000000E+00	-0.376722469E-01	0.000000000E+00	0.385209535E+00	0.000000000E+00
19	-0.966811998E-12	0.000000000E+00	-0.683162434E-01	0.000000000E+00	-0.215492605E+00	0.000000000E+00
20	-0.885400042E-12	0.000000000E+00	0.250686029E+00	0.000000000E+00	-0.202285634E+01	0.000000000E+00
SMODE 15						
0.80825867E+03 0.10000000E+01						
1	-0.715220944E-01	0.000000000E+00	-0.203287182E-11	0.000000000E+00	-0.195501042E-10	0.000000000E+00
2	-0.556116635E-01	0.000000000E+00	0.943692989E-12	0.000000000E+00	-0.673811517E-12	0.000000000E+00
3	-0.391683053E-01	0.000000000E+00	0.568648917E-12	0.000000000E+00	0.349558960E-11	0.000000000E+00
4	-0.241300421E-01	0.000000000E+00	-0.188989158E-12	0.000000000E+00	0.259059524E-11	0.000000000E+00
5	-0.656240701E-02	0.000000000E+00	-0.530050051E-12	0.000000000E+00	0.201623777E-12	0.000000000E+00
6	0.148617360E-01	0.000000000E+00	-0.356735893E-12	0.000000000E+00	-0.165213863E-11	0.000000000E+00
7	0.335969301E-01	0.000000000E+00	0.116883910E-12	0.000000000E+00	-0.229519899E-11	0.000000000E+00
8	0.429760429E-01	0.000000000E+00	0.540183612E-12	0.000000000E+00	-0.120196258E-11	0.000000000E+00
9	0.275680182E-01	0.000000000E+00	0.434800159E-12	0.000000000E+00	0.202028472E-11	0.000000000E+00
10	-0.454121438E-01	0.000000000E+00	-0.367643493E-12	0.000000000E+00	0.382239253E-11	0.000000000E+00
11	-0.548368695E-01	0.000000000E+00	-0.647957217E-12	0.000000000E+00	-0.208227143E-11	0.000000000E+00
12	0.406625591E-01	0.000000000E+00	0.157960394E-12	0.000000000E+00	-0.368777457E-11	0.000000000E+00
13	0.539444140E-01	0.000000000E+00	0.650783894E-12	0.000000000E+00	-0.668956012E-13	0.000000000E+00
14	0.100174861E-01	0.000000000E+00	0.345962473E-12	0.000000000E+00	0.209784213E-11	0.000000000E+00
15	-0.386338661E-01	0.000000000E+00	0.127602826E-12	0.000000000E+00	-0.132526649E-11	0.000000000E+00
16	-0.521594097E-01	0.000000000E+00	0.966321412E-12	0.000000000E+00	-0.506979531E-11	0.000000000E+00
17	-0.228054840E-01	0.000000000E+00	0.183423832E-11	0.000000000E+00	-0.104623117E-11	0.000000000E+00
18	0.224958651E-01	0.000000000E+00	-0.789321163E-13	0.000000000E+00	0.170679651E-10	0.000000000E+00
19	0.853075621E-01	0.000000000E+00	-0.511639509E-11	0.000000000E+00	0.149864981E-10	0.000000000E+00
20	0.103917364E+00	0.000000000E+00	0.355462486E-11	0.000000000E+00	-0.654069940E-10	0.000000000E+00
SMODE 16						
0.90414831E+03 0.10000000E+01						
1	-0.332944307E-10	0.000000000E+00	0.125334885E+00	0.000000000E+00	0.137791649E+01	0.000000000E+00
2	-0.240262867E-10	0.000000000E+00	-0.751856645E-01	0.000000000E+00	-0.772672124E-01	0.000000000E+00
3	-0.149440037E-10	0.000000000E+00	-0.247078657E-01	0.000000000E+00	-0.299777496E+00	0.000000000E+00
4	-0.708482188E-11	0.000000000E+00	0.305297149E-01	0.000000000E+00	-0.137255026E+00	0.000000000E+00
5	0.145218351E-11	0.000000000E+00	0.394298929E-01	0.000000000E+00	0.663402445E-01	0.000000000E+00
6	0.106229116E-10	0.000000000E+00	0.112463986E-01	0.000000000E+00	0.166051094E+00	0.000000000E+00
7	0.163575296E-10	0.000000000E+00	-0.250646439E-01	0.000000000E+00	0.133547977E+00	0.000000000E+00
8	0.149425062E-10	0.000000000E+00	-0.385109017E-01	0.000000000E+00	-0.226453139E-01	0.000000000E+00
9	-0.208459461E-11	0.000000000E+00	-0.418034624E-02	0.000000000E+00	-0.241008580E+00	0.000000000E+00
10	-0.326763381E-10	0.000000000E+00	0.489559192E-01	0.000000000E+00	-0.134165841E+00	0.000000000E+00
11	0.211887308E-10	0.000000000E+00	0.178658069E-01	0.000000000E+00	0.327640327E+00	0.000000000E+00
12	0.980059780E-11	0.000000000E+00	-0.444205781E-01	0.000000000E+00	0.102133020E+00	0.000000000E+00
13	-0.139245277E-10	0.000000000E+00	-0.271860198E-01	0.000000000E+00	-0.227653646E+00	0.000000000E+00
14	-0.146958078E-10	0.000000000E+00	0.282008192E-01	0.000000000E+00	-0.189976249E+00	0.000000000E+00
15	0.178835967E-11	0.000000000E+00	0.402077470E-01	0.000000000E+00	0.100347843E+00	0.000000000E+00
16	0.163109447E-10	0.000000000E+00	-0.837042620E-02	0.000000000E+00	0.276936692E+00	0.000000000E+00
17	0.129854541E-10	0.000000000E+00	-0.590080070E-01	0.000000000E+00	0.114842015E+00	0.000000000E+00
18	0.147995331E-12	0.000000000E+00	-0.136596665E-01	0.000000000E+00	-0.430978297E+00	0.000000000E+00
19	-0.229438739E-10	0.000000000E+00	0.902409263E-01	0.000000000E+00	-0.186169207E+00	0.000000000E+00
20	-0.293099927E-10	0.000000000E+00	-0.215538698E+00	0.000000000E+00	0.213539382E+01	0.000000000E+00
SMODE 17						
0.90787455E+03 0.10000000E+01						
1	-0.839427312E-01	0.000000000E+00	-0.487014235E-10	0.000000000E+00	-0.538048128E-09	0.000000000E+00
2	-0.603827062E-01	0.000000000E+00	0.294652998E-10	0.000000000E+00	0.319860534E-10	0.000000000E+00
3	-0.373469083E-01	0.000000000E+00	0.941265880E-11	0.000000000E+00	0.117703360E-09	0.000000000E+00
4	-0.174605900E-01	0.000000000E+00	-0.121466584E-10	0.000000000E+00	0.527814891E-10	0.000000000E+00
5	0.407151877E-02	0.000000000E+00	-0.153762259E-10	0.000000000E+00	-0.271013874E-10	0.000000000E+00
6	0.270648429E-01	0.000000000E+00	-0.415730028E-11	0.000000000E+00	-0.653667577E-10	0.000000000E+00
7	0.411731231E-01	0.000000000E+00	0.100020659E-10	0.000000000E+00	-0.514371128E-10	0.000000000E+00
8	0.370229784E-01	0.000000000E+00	0.149561566E-10	0.000000000E+00	0.105479229E-10	0.000000000E+00
9	-0.666907253E-02	0.000000000E+00	0.120607713E-11	0.000000000E+00	0.949928022E-10	0.000000000E+00
10	-0.825642535E-01	0.000000000E+00	-0.192917000E-10	0.000000000E+00	0.495532968E-10	0.000000000E+00
11	0.582848864E-01	0.000000000E+00	-0.642647038E-11	0.000000000E+00	-0.129319550E-09	0.000000000E+00
12	0.206726952E-01	0.000000000E+00	0.176203169E-10	0.000000000E+00	-0.363410119E-10	0.000000000E+00
13	-0.390250305E-01	0.000000000E+00	0.100602082E-10	0.000000000E+00	0.914963215E-10	0.000000000E+00
14	-0.355515062E-01	0.000000000E+00	-0.117699431E-10	0.000000000E+00	0.734857253E-10	0.000000000E+00
15	0.832947839E-02	0.000000000E+00	-0.161650620E-10	0.000000000E+00	-0.403681420E-10	0.000000000E+00
16	0.426456286E-01	0.000000000E+00	0.288529800E-11	0.000000000E+00	-0.107700692E-09	0.000000000E+00
17	0.313579682E-01	0.000000000E+00	0.224189865E-10	0.000000000E+00	-0.436450115E-10	0.000000000E+00
18	-0.386646183E-02	0.000000000E+00	0.490568016E-11	0.000000000E+00	0.164188125E-09	0.000000000E+00
19	-0.626188342E-01	0.000000000E+00	-0.335867572E-10	0.000000000E+00	0.637454968E-10	0.000000000E+00
20	-0.808972379E-01	0.000000000E+00	0.843949901E-10	0.000000000E+00	-0.819875750E-09	0.000000000E+00
SMODE 18						
0.10390886E+04 0.10000000E+01						
1	-0.381985599E-01	0.000000000E+00	0.206093278E-11	0.000000000E+00	0.268169994E-10	0.000000000E+00
2	-0.241544852E-01	0.000000000E+00	-0.161152125E-11	0.000000000E+00	-0.466944237E-11	0.000000000E+00
3	-0.115928496E-01	0.000000000E+00	-0.587344645E-13	0.000000000E+00	-0.662633733E-11	0.000000000E+00
4	-0.174435744E-02	0.000000000E+00	0.918430663E-12	0.000000000E+00	-0.960592167E-12	0.000000000E+00
5	0.753874281E-02	0.000000000E+00	0.631698247E-12	0.000000000E+00	0.326165856E-11	0.000000000E+00
6	0.149135160E-01	0.000000000E+00	-0.215683181E-12	0.000000000E+00	0.360252047E-11	0.000000000E+00
7	0.149233153E-01	0.000000000E+00	-0.752101605E-12	0.000000000E+00	0.793126296E-12	0.000000000E+00
8	0.455726230E-02	0.000000000E+00	-0.436520411E-12	0.000000000E+00	-0.327788358E-11	0.000000000E+00
9	-0.207025921E-01	0.000000000E+00	0.621918407E-12	0.000000000E+00	-0.466472245E-11	0.000000000E+00
10	-0.201563243E-01	0.000000000E+00	0.853956422E-12	0.000000000E+00	0.314067350E-11	0.000000000E+00
11	0.689462681E-01	0.000000000E+00	-0.642683344E-12	0.000000000E+00	0.525152168E-11	0.000000000E+00
12	-0.804541950E-01	0.000000000E+00	-0.747726558E-12	0.000000000E+00	-0.461205783E-11	0.000000000E+00
13	-0.114965471E-01	0.000000000E+00	0.603157420E-12	0.000000000E+00	-0.513190701E-11	0.000000000E+00
14	0.606565325E-01	0.000000000E+00	0.118607804E-11	0.000000000E+00	0.350004943E-13	0.000000000E+00
15	0.345365473E-01	0.000000000E+00	0.757972175E-12	0.000000000E+00	0.321694225E-11	0.000000000E+00
16	-0.434486336E-01	0.000000000E+00	0.375793938E-13	0.000000000E+00	0.244101256E-11	0.000000000E+00
17	-0.584030717E-01	0.000000000E+00	0.337831592E-14	0.000000000E+00	-0.220428652E-11	0.000000000E+00

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18 -0.189565641E-01 0.000000000E+00 0.107177610E-11 0.000000000E+00 -0.414191065E-11 0.000000000E+00
19 0.757526774E-01 0.000000000E+00 0.387038388E-12 0.000000000E+00 0.823502993E-11 0.000000000E+00
20 0.107599730E+00 0.000000000E+00 -0.335980676E-11 0.000000000E+00 0.209078366E-10 0.000000000E+00
$MODE 19
0.11032624E+04 0.100000000E+01
1 0.231211682E-12 0.000000000E+00 0.955760030E-01 0.000000000E+00 0.134573620E+01 0.000000000E+00
2 0.135399733E-12 0.000000000E+00 -0.829591652E-01 0.000000000E+00 -0.306548544E+00 0.000000000E+00
3 0.539950522E-13 0.000000000E+00 0.688180292E-02 0.000000000E+00 -0.337237007E+00 0.000000000E+00
4 -0.629919366E-14 0.000000000E+00 0.506164822E-01 0.000000000E+00 0.974114842E-03 0.000000000E+00
5 -0.580289599E-13 0.000000000E+00 0.253397063E-01 0.000000000E+00 0.199820841E+00 0.000000000E+00
6 -0.895068062E-13 0.000000000E+00 -0.202311116E-01 0.000000000E+00 0.166256378E+00 0.000000000E+00
7 -0.693306731E-13 0.000000000E+00 -0.389942460E-01 0.000000000E+00 -0.145004327E-01 0.000000000E+00
8 0.104095474E-13 0.000000000E+00 -0.104605988E-01 0.000000000E+00 -0.210462537E+00 0.000000000E+00
9 0.145254918E-12 0.000000000E+00 0.421222417E-01 0.000000000E+00 -0.179101250E+00 0.000000000E+00
10 0.920426641E-14 0.000000000E+00 0.278094353E-01 0.000000000E+00 0.277772123E+00 0.000000000E+00
11 -0.277893206E-12 0.000000000E+00 -0.480746086E-01 0.000000000E+00 0.129108787E+00 0.000000000E+00
12 0.483905712E-12 0.000000000E+00 -0.183507940E-01 0.000000000E+00 -0.318504844E+00 0.000000000E+00
13 -0.156943665E-12 0.000000000E+00 0.429295671E-01 0.000000000E+00 -0.105169157E+00 0.000000000E+00
14 -0.356772071E-12 0.000000000E+00 0.239952885E-01 0.000000000E+00 0.240439694E+00 0.000000000E+00
15 0.457798936E-12 0.000000000E+00 -0.336434941E-01 0.000000000E+00 0.178349585E+00 0.000000000E+00
16 0.168264426E-11 0.000000000E+00 -0.339347162E-01 0.000000000E+00 -0.179859601E+00 0.000000000E+00
17 0.144648389E-11 0.000000000E+00 0.397806947E-01 0.000000000E+00 -0.357390382E+00 0.000000000E+00
18 -0.200890190E-12 0.000000000E+00 0.596419683E-01 0.000000000E+00 0.234987673E+00 0.000000000E+00
19 -0.222667632E-11 0.000000000E+00 -0.844376389E-01 0.000000000E+00 0.546335919E+00 0.000000000E+00
20 -0.312059235E-11 0.000000000E+00 0.147829284E+00 0.000000000E+00 -0.182451038E+01 0.000000000E+00
$MODE 20
0.11652801E+04 0.100000000E+01
1 -0.146457417E+00 0.000000000E+00 -0.624763938E-13 0.000000000E+00 -0.938426738E-12 0.000000000E+00
2 -0.787380349E-01 0.000000000E+00 0.591268408E-13 0.000000000E+00 0.257904317E-12 0.000000000E+00
3 -0.243096006E-01 0.000000000E+00 -0.111525907E-13 0.000000000E+00 0.238046205E-12 0.000000000E+00
4 0.134127659E-01 0.000000000E+00 -0.380860091E-13 0.000000000E+00 -0.283874536E-13 0.000000000E+00
5 0.422759773E-01 0.000000000E+00 -0.130277374E-13 0.000000000E+00 -0.166543964E-12 0.000000000E+00
6 0.530324532E-01 0.000000000E+00 0.211087303E-13 0.000000000E+00 -0.106343014E-12 0.000000000E+00
7 0.285583765E-01 0.000000000E+00 0.272411104E-13 0.000000000E+00 0.571505744E-13 0.000000000E+00
8 -0.271388138E-01 0.000000000E+00 -0.190537348E-14 0.000000000E+00 0.175331166E-12 0.000000000E+00
9 -0.884122641E-01 0.000000000E+00 -0.353360425E-13 0.000000000E+00 0.700803373E-13 0.000000000E+00
10 0.654305809E-01 0.000000000E+00 -0.691537205E-14 0.000000000E+00 -0.250980406E-12 0.000000000E+00
11 -0.212432452E-01 0.000000000E+00 0.375848807E-13 0.000000000E+00 0.312064551E-13 0.000000000E+00
12 -0.141823831E-03 0.000000000E+00 -0.807011430E-14 0.000000000E+00 0.256806514E-12 0.000000000E+00
13 0.147990499E-01 0.000000000E+00 -0.465389780E-13 0.000000000E+00 0.445513738E-13 0.000000000E+00
14 -0.457838050E-02 0.000000000E+00 -0.490059475E-13 0.000000000E+00 0.787511121E-13 0.000000000E+00
15 -0.133786661E-01 0.000000000E+00 -0.727860018E-13 0.000000000E+00 0.382708969E-14 0.000000000E+00
16 0.309569574E-02 0.000000000E+00 -0.374566597E-13 0.000000000E+00 -0.249723139E-12 0.000000000E+00
17 0.132833304E-01 0.000000000E+00 -0.480976695E-14 0.000000000E+00 0.669040944E-13 0.000000000E+00
18 0.846620429E-02 0.000000000E+00 -0.137900314E-12 0.000000000E+00 0.851814958E-12 0.000000000E+00
19 -0.139220296E-01 0.000000000E+00 -0.229202915E-12 0.000000000E+00 -0.462501861E-12 0.000000000E+00
20 -0.221770246E-01 0.000000000E+00 0.641007742E-12 0.000000000E+00 -0.558205150E-11 0.000000000E+00

```

Listing 8.8.5 trim_output.dat

TRIM ITERATION NUMBER : 1

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.600000E+01
 ALTITUDE IN METERS : 0.217924E+05
 DYNAMIC PRESSURE IN N/M^2 : 0.954531E+05
 ANGLE OF ATTACK IN DEGREES : -1.00000E+01
 CONTROL SURFACE DEFLECTION IN DEGREES : 0.773000E+01

TRIM VARIABLE: ALPHA =-0.173572E+01(DEG), DELTA =-0.876495E+00(DEG)

FINAL TRIM POSITION: ALPHA =-0.273572E+01(DEG), DELTA = 0.685351E+01(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
 REFERENCE AREA = 1.777327 REFERENCE CHORD = 4.267200
 X-CG = 2.101018 Z-CG = 6.9082335E-02
 TOTAL WEIGHT = 3067.581 NEWTON
 X AERODYNAMIC CENTER FROM X = 0 : 1.712372

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.6251E-01	0.6251E-01	0.1051E+00	0.1051E+00	0.2168E-02	0.2212E-02
ALPHA(/RAD)	-.9175E+00	-.9175E+00	0.2211E+01	0.2211E+01	0.1007E+00	0.1015E+00

DELTA(/RAD) 0.5636E-03 0.5636E-03 0.1313E+00 0.1313E+00 -.5641E-01 -.5642E-01

TRIM ITERATION NUMBER : 2

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.600000E+01
ALTITUDE IN METERS : 0.217924E+05
DYNAMIC PRESSURE IN N/M^2 : 0.957254E+05
ANGLE OF ATTACK IN DEGREES : -.273572E+01
CONTROL SURFACE DEFLECTION IN DEGREES : 0.685351E+01

TRIM VARIABLE: ALPHA =-0.251336E-01(DEG), DELTA = 0.300794E+01(DEG)

FINAL TRIM POSITION: ALPHA =-0.276085E+01(DEG), DELTA = 0.986144E+01(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.777042 REFERENCE CHORD = 4.267200
X-CG = 2.101018 Z-CG = 4.5984499E-02
TOTAL WEIGHT = 3067.581 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 1.867303

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.8570E-01	0.8570E-01	0.3100E-01	0.3100E-01	0.2562E-02	0.2588E-02
ALPHA(/RAD)	-.6475E+00	-.6475E+00	0.2289E+01	0.2289E+01	0.6268E-01	0.6324E-01
DELTA(/RAD)	0.5436E-03	0.5436E-03	0.1155E+00	0.1155E+00	-.4872E-01	-.4878E-01

TRIM ITERATION NUMBER : 3

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.600000E+01
ALTITUDE IN METERS : 0.217924E+05
DYNAMIC PRESSURE IN N/M^2 : 0.957290E+05
ANGLE OF ATTACK IN DEGREES : -.276085E+01
CONTROL SURFACE DEFLECTION IN DEGREES : 0.986144E+01

TRIM VARIABLE: ALPHA =-0.103209E-02(DEG), DELTA =-0.730282E-01(DEG)

FINAL TRIM POSITION: ALPHA =-0.276188E+01(DEG), DELTA = 0.978841E+01(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.777043 REFERENCE CHORD = 4.267200
X-CG = 2.101018 Z-CG = 4.5638017E-02
TOTAL WEIGHT = 3067.581 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 1.872830

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.8601E-01	0.8601E-01	0.3628E-01	0.3628E-01	-.9227E-04	-.7041E-04
ALPHA(/RAD)	-.6479E+00	-.6479E+00	0.2288E+01	0.2288E+01	0.6116E-01	0.6182E-01
DELTA(/RAD)	0.5386E-03	0.5386E-03	0.1331E+00	0.1331E+00	-.5604E-01	-.5611E-01

TRIM ITERATION NUMBER : 4

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.600000E+01
ALTITUDE IN METERS : 0.217924E+05
DYNAMIC PRESSURE IN N/M^2 : 0.957292E+05
ANGLE OF ATTACK IN DEGREES : -.276188E+01
CONTROL SURFACE DEFLECTION IN DEGREES : 0.978841E+01

TRIM VARIABLE: ALPHA =-0.492109E-05(DEG), DELTA =-0.670263E-03(DEG)

FINAL TRIM POSITION: ALPHA = -0.276189E+01(DEG), DELTA = 0.978774E+01(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.777044 REFERENCE CHORD = 4.267200
X-CG = 2.101018 Z-CG = 4.562375E-02
TOTAL WEIGHT = 3067.581 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 1.876536

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.8602E-01	0.8602E-01	0.3607E-01	0.3607E-01	-.2328E-04	-.6489E-06
ALPHA(/RAD)	-.6500E+00	-.6500E+00	0.2289E+01	0.2289E+01	0.6021E-01	0.6085E-01
DELTA(/RAD)	0.5389E-03	0.5389E-03	0.1326E+00	0.1326E+00	-.5585E-01	-.5592E-01

TRIM ITERATION NUMBER : 5

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.600000E+01
ALTITUDE IN METERS : 0.217924E+05
DYNAMIC PRESSURE IN N/M^2 : 0.957292E+05
ANGLE OF ATTACK IN DEGREES : -.276189E+01
CONTROL SURFACE DEFLECTION IN DEGREES : 0.978774E+01

TRIM VARIABLE: ALPHA = -0.114166E-04(DEG), DELTA = -0.211050E-03(DEG)

FINAL TRIM POSITION: ALPHA = -0.276190E+01(DEG), DELTA = 0.978753E+01(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.777043 REFERENCE CHORD = 4.267200
X-CG = 2.101018 Z-CG = 4.5623671E-02
TOTAL WEIGHT = 3067.581 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 1.872191

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.8602E-01	0.8602E-01	0.3607E-01	0.3607E-01	-.2294E-04	-.1936E-06
ALPHA(/RAD)	-.6463E+00	-.6463E+00	0.2288E+01	0.2288E+01	0.6134E-01	0.6200E-01
DELTA(/RAD)	0.5389E-03	0.5389E-03	0.1326E+00	0.1326E+00	-.5585E-01	-.5592E-01

TRIM ITERATION NUMBER : 6

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.600000E+01
ALTITUDE IN METERS : 0.217924E+05
DYNAMIC PRESSURE IN N/M^2 : 0.957292E+05
ANGLE OF ATTACK IN DEGREES : -.276190E+01
CONTROL SURFACE DEFLECTION IN DEGREES : 0.978753E+01

TRIM VARIABLE: ALPHA = 0.133668E-04(DEG), DELTA = 0.216527E-02(DEG)

FINAL TRIM POSITION: ALPHA = -0.276189E+01(DEG), DELTA = 0.978970E+01(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.777043 REFERENCE CHORD = 4.267200
X-CG = 2.101018 Z-CG = 4.5623533E-02
TOTAL WEIGHT = 3067.581 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 1.874963

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.8602E-01	0.8602E-01	0.3606E-01	0.3606E-01	-.2090E-04	0.2099E-05
ALPHA(/RAD)	-.6480E+00	-.6480E+00	0.2289E+01	0.2289E+01	0.6063E-01	0.6129E-01

DELTA(/RAD) 0.5389E-03 0.5389E-03 0.1326E+00 0.1326E+00 -.5585E-01 -.5591E-01

TRIM ITERATION NUMBER : 7

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.600000E+01
ALTITUDE IN METERS : 0.217924E+05
DYNAMIC PRESSURE IN N/M^2 : 0.957291E+05
ANGLE OF ATTACK IN DEGREES : -.276189E+01
CONTROL SURFACE DEFLECTION IN DEGREES : 0.978970E+01

TRIM VARIABLE: ALPHA =-0.117856E-05(DEG), DELTA =-0.131141E-02(DEG)

FINAL TRIM POSITION: ALPHA =-0.276189E+01(DEG), DELTA = 0.978839E+01(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.777043 REFERENCE CHORD = 4.267200
X-CG = 2.101018 Z-CG = 4.5623720E-02
TOTAL WEIGHT = 3067.581 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 1.876671

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.8602E-01	0.8602E-01	0.3607E-01	0.3607E-01	-.2394E-04	-.1279E-05
ALPHA(/RAD)	-.6488E+00	-.6488E+00	0.2290E+01	0.2290E+01	0.6019E-01	0.6084E-01
DELTA(/RAD)	0.5389E-03	0.5389E-03	0.1326E+00	0.1326E+00	-.5585E-01	-.5592E-01

TRIM ITERATION NUMBER : 8

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.600000E+01
ALTITUDE IN METERS : 0.217924E+05
DYNAMIC PRESSURE IN N/M^2 : 0.957291E+05
ANGLE OF ATTACK IN DEGREES : -.276189E+01
CONTROL SURFACE DEFLECTION IN DEGREES : 0.978839E+01

TRIM VARIABLE: ALPHA = 0.205561E-05(DEG), DELTA =-0.156982E-03(DEG)

FINAL TRIM POSITION: ALPHA =-0.276189E+01(DEG), DELTA = 0.978823E+01(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.777043 REFERENCE CHORD = 4.267200
X-CG = 2.101018 Z-CG = 4.5623697E-02
TOTAL WEIGHT = 3067.581 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 1.872713

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.8602E-01	0.8602E-01	0.3607E-01	0.3607E-01	-.2268E-04	-.1554E-06
ALPHA(/RAD)	-.6471E+00	-.6471E+00	0.2288E+01	0.2288E+01	0.6120E-01	0.6184E-01
DELTA(/RAD)	0.5389E-03	0.5389E-03	0.1326E+00	0.1326E+00	-.5585E-01	-.5592E-01

TRIM ITERATION NUMBER : 9

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.600000E+01
ALTITUDE IN METERS : 0.217924E+05
DYNAMIC PRESSURE IN N/M^2 : 0.957291E+05
ANGLE OF ATTACK IN DEGREES : -.276189E+01
CONTROL SURFACE DEFLECTION IN DEGREES : 0.978823E+01

TRIM VARIABLE: ALPHA =-0.458873E-05(DEG), DELTA = 0.643405E-03(DEG)

FINAL TRIM POSITION: ALPHA =-0.276189E+01(DEG), DELTA = 0.978887E+01(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.777044 REFERENCE CHORD = 4.267200
X-CG = 2.101018 Z-CG = 4.5623727E-02
TOTAL WEIGHT = 3067.581 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 1.879049

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.8602E-01	0.8602E-01	0.3606E-01	0.3606E-01	-.2225E-04	0.6328E-06
ALPHA(/RAD)	-.6509E+00	-.6509E+00	0.2290E+01	0.2290E+01	0.5955E-01	0.6021E-01
DELTA(/RAD)	0.5390E-03	0.5390E-03	0.1326E+00	0.1326E+00	-.5586E-01	-.5592E-01

TRIM ITERATION NUMBER : 10

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.600000E+01
ALTITUDE IN METERS : 0.217924E+05
DYNAMIC PRESSURE IN N/M^2 : 0.957290E+05
ANGLE OF ATTACK IN DEGREES : -.276189E+01
CONTROL SURFACE DEFLECTION IN DEGREES : 0.978887E+01

TRIM VARIABLE: ALPHA =-0.460579E-05(DEG), DELTA = 0.175394E-04(DEG)

FINAL TRIM POSITION: ALPHA =-0.276190E+01(DEG), DELTA = 0.978889E+01(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.777043 REFERENCE CHORD = 4.267200
X-CG = 2.101018 Z-CG = 4.5623649E-02
TOTAL WEIGHT = 3067.581 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 1.881174

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.8602E-01	0.8602E-01	0.3607E-01	0.3607E-01	-.2267E-04	0.2191E-07
ALPHA(/RAD)	-.6530E+00	-.6530E+00	0.2290E+01	0.2290E+01	0.5900E-01	0.5965E-01
DELTA(/RAD)	0.5389E-03	0.5389E-03	0.1326E+00	0.1326E+00	-.5585E-01	-.5592E-01

FINAL TRIM ANGLE OF ATTACK IN DEGREES = -0.276190E+01
FINAL TRIM DELTA IN DEGREES = 0.978889E+01

Listing 8.8.6 Prep_ASE.dat

A Matrix:

	1	2	3	4	5	6	7	8	9	10
1	0.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.0000E+00	-2.6360E-02	0.0000E+00	1.8640E+02	-9.8067E+00	-2.5716E-02	-1.9144E+00	-1.7635E+00	9.7859E-08	1.0687E-07
3	0.0000E+00	0.0000E+00	0.0000E+00	-1.7774E+03	1.7774E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	0.0000E+00	-6.2310E-06	0.0000E+00	-3.6294E-01	-1.9679E-08	1.0000E+00	3.3610E-13	4.1994E-13	-1.4502E-11	-4.2204E-11
5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6	0.0000E+00	-1.3736E-05	0.0000E+00	1.2359E+01	-5.1430E-07	5.5900E-03	5.5138E-03	-4.1750E-02	-1.9703E-07	-1.8099E-07
7	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000E+00	0.0000E+00
8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000E+00
9	0.0000E+00	-1.0008E-01	0.0000E+00	-1.2905E+03	2.5811E+03	1.4637E-01	-1.5665E+03	1.2274E-08	-7.9438E-03	-2.1889E-05
10	0.0000E+00	-1.3380E-01	0.0000E+00	9.2146E+02	-1.8429E+03	1.7026E-01	-9.5752E-09	-1.6419E+04	2.3872E-05	-2.5652E-02

B matrix:

0.000000E+00
-0.146517E+00
0.000000E+00
-0.202872E-01
0.000000E+00


```

-0.111612E+02
0.000000E+00
0.000000E+00
-0.895936E+03
-0.828795E+03

```

Eigenvalues of A:

```

(0.000000E+00,0.000000E+00)
(0.000000E+00,0.000000E+00)
(-1.283359E-02,128.1353)
(-1.283359E-02,-128.1353)
(-4.030227E-03,39.57858)
(-4.030227E-03,-39.57858)
(3.342636,0.000000E+00)
(-3.699774,0.000000E+00)
(-2.206570E-02,0.000000E+00)
(-4.372413E-03,0.000000E+00)

```

Damping Ratio (Zeta) and Frequency (Omega)

```

Zeta : -1.0015659E-04 Omega : 20.38516 Hz
Zeta : -1.0182850E-04 Omega : 6.296593 Hz
Zeta : 1.000000 Omega : 0.5317830 Hz
Zeta : -1.000000 Omega : 0.5886003 Hz
Zeta : -1.000000 Omega : 3.5104537E-03 Hz
Zeta : -1.000000 Omega : 6.9561129E-04 Hz

```

Output Prepared for Analytical Solution of Flight Dynamic Model

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-----
Mass (m) = 625.6124
Velocity (U) = 1777.383
Surface Area (S) = 1.777043
Dynamic Pressure (q) = 95729.13
Moment of Inertia (Iyy) = 3632.134
Reference Length (c) = 4.267200
Cd wrt u (Cdu) = 1.2826486E-04
Cm wrt u (Cmu) = -3.8179856E-05
Cl wrt u (Clu) = 1.2870191E-04

Cd wrt q (Cdq) = 7.8784697E-02
Cm wrt q (Cmq) = 2.4510620E-02
Cl wrt q (Clq) = -2.6101999E-02

Cd wrt alpha (Cd_alpha) = -0.6494278
Cm wrt alpha (Cm_alpha) = 6.1838981E-02
Cl wrt alpha (Cl_alpha) = 2.286335

Coefficient of drag (Cd) = 8.6021081E-02
Coefficient of moment (Cm) = -2.2896980E-05
Coefficient of lift (Cl) = 3.6066845E-02

```

8.9 Subsequent Design Cycles for Converged Configuration

The trim angle of attack obtained from the TRIM analysis may not agree with the initially guessed design angle of attack specified in the UCDA input file vehicle.inp with the parameter AOADES. In order to match these two angles of attack, it is required to perform multiple design cycles by repeating the entire cycle described in Sections 8.1 through 8.8. For each new design cycle, the parameter AOADES is updated by the trim angle of attack computed by the previous design cycle. This multiple design cycle process terminates when the variation between AOADES and trim angle of attack becomes small; leading to a converged configuration.

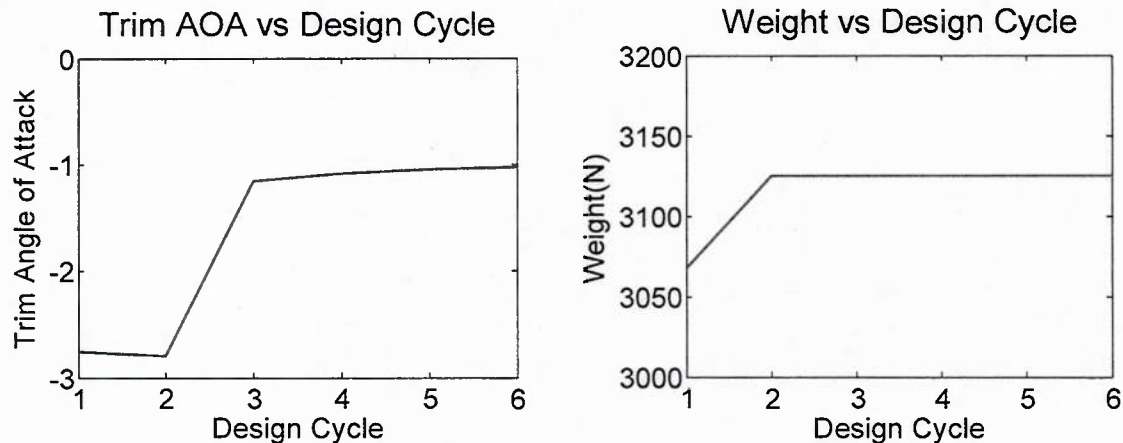


Figure 8.9.1 Convergence History of Angle of Attack and Weight for SEM Vehicle

For the present SEM configuration, it is found that this converged configuration is obtained after six design cycles. Figure 8.9.1 shows the trim angle of attack, control surface deflection angle and weight at each design cycle. It can be seen that at the sixth design cycle, the trim angle of attack is nearly converged at -1.029 degrees and the weight is nearly converged at 3125 Newton.

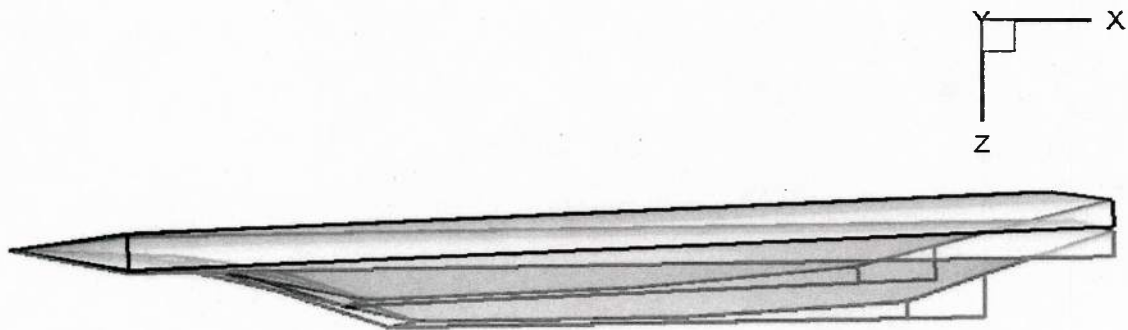


Figure. 8.9.2 Comparison of the SEM vehicle between first and final design cycles

Figure 8.9.2 shows the comparison of the vehicle geometry between first design cycle and the last design cycle. It can be seen that for the first design cycle, the vehicle had a higher negative trim angle of attack. That made the ramp angle narrower and thus in order to satisfy shock-on-lip condition, the inlet of the combustor was pushed forward by the design. On the other hand, for the final converged design, the trim angle of attack is smaller and thus the ramp angle is higher. Thus, to satisfy shock-on-lip condition, the inlet of the combustor is pushed backward.

The result of the SEM configuration suggests that this multiple design cycle process is a viable method to design such a vehicle even though there is not solid theoretical foundation to guarantee such a convergence at present.

Chapter 9 Case Study 2 - Single Engine Demo (SED)

9.1 Introduction

The second design study presented here is intended to “mimic” the Air Force’s X-51 Single Engine Demo, as shown in Figure 9.1.1. The caveat here is that the entire geometry, including scramjet flowpath, fuel-injection arrangement, and booster integration have been assumed (or approximated) since no details have been provided. Furthermore, the internal layout and structural design have been neglected. The sample SED model is shown in Figure 9.1.2. While the basic design construct is similar to the SEM from Chapter 1, the upper surface of the vehicle (forebody and afterbody) have been generated using the Superformula of the Superellipse. While not a perfect match to the X-51 the process could be easily repeated with detail.

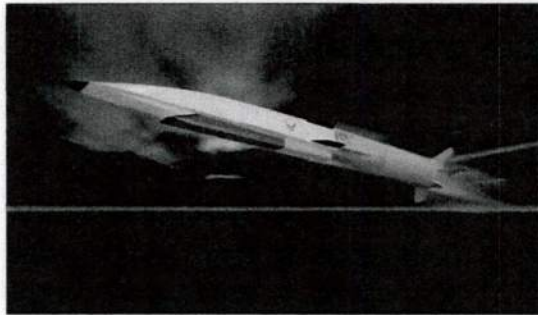


Figure 9.1.1 Air Force’s X-51 Single Engine Demo (SED) vehicle.



Figure 9.1.2 Approximated Single Engine Demo (SED) vehicle.

9.2 Run UCDA to Design the Vehicle

Input Files:

File Name	Type	Remarks	See Listing
vehicle.inp	Standard input file	Also look at Table 9.2.1a and 9.2.1b	Shown in Listing 9.2.1
chem.bin	Engine chemistry information	Required	Shown in Listing 9.2.2
SEDvehicle.inp	Standard input file for SED type vehicle	Also look at Table 9.2.2	Shown in Listing 9.2.3

Output Files:

File Name	Type	Remarks	See Listing
plot.dat	Standard Tecplot output file	See Fig. 9.2.1	Shown in Listing 9.2.4

Input File descriptions

vehicle.inp: This is a standard input file for UCDA. See listing 9.2.1 for the entire input file. The part that is used to generate the geometry of the vehicle is shown in Tables 9.2.1a and 9.2.1b. Table 9.2.1a shows different patches that are needed to generate the vehicle. There are 21 patches in this SED vehicle. Each patch should have a name of the patch, the number of grids in the x direction and the number of grids in the y direction. Table 9.2.1b shows the other necessary geometrical and engine input parameters necessary to design the vehicle. The details of the definitions and explanations can be found in the User's Manual.

chem.bin: This is a required input file for the engine chemistry of the vehicle. Chem.bin is generated using ChemKin Version 2 and for this case is a Jet-A reaction mechanism. Please see Listing 9.2.2.

SEDvehicle.inp: This is a supplementary input file to generate the SED-like vehicle configuration. The parameters in this file override the geometry features from vehicle.inp for the vehicle upper surface using the Super Formula of the Super Ellipse for both the forebody and the afterbody mesh generation. The detail of SEDvehicle.inp is given in Section 3.3.2 of User's Manual. Please find SEDvehicle.inp in Listing 9.2.3.

Output File descriptions

plot.dat: The output file is a Tecplot format file that can easily be plotted. The plot of the designed vehicle is shown in Figure 9.2.1. This output file is shown in Listing 9.2.4.

The computational run time for UCDA to design a vehicle is about a few seconds.

Table 9.2.1a: Different Zones of SED Vehicle (see Figure 9.2.2; forebody top, keel top and atbody top not used by SED)

ZONE DATA AND GRID SIZES:		
21	NUMBER OF ZONES	
'forebody : top'	3	3
'keel : top'	3	3
'aftbody : top'	3	3
'forebody : bot'	31	31
'ramps : bot'	55	6
'comb : bot'	101	6
'cowl : top'	101	6
'nozzle : bot'	31	6
'ramp walls : inside'	35	6
'comb wall : inside'	101	7
'nozzle wall : inside'	21	7
'aftbody : bot'	101	31
'cowl : bot'	101	6
'ramp walls : outside'	35	6
'comb wall : outside'	101	7
'nozzle wall : outside'	21	7
'SEDbody : top'	121	46
'Control_1 : top'	31	31 (Control surface dimensions must be the same)
'Control_1 : bottom'	31	31 (Control surface dimensions must be the same)
'Control_2 : top'	31	31 (Control surface dimensions must be the same)
'Control_2 : bottom'	31	31 (Control surface dimensions must be the same)

Table 9.2.1b: Geometrical and Engine Input Parameters of SED Vehicle

5.0	4	'Mdes' - design Mach number
-1.2	0	'AOA des' - design angle of attack
26000.	1	'Zdes' - design altitude
6.2672	1	'lvehicle' - vehicle length
5.5939	0	'thforclu' - forebody upper surface angle
3.8700	0	'thforcli' - forebody ramp angle
0.5873	1	'lcontrol' - control surface length
5.0	0	'th_control' - control surface deflection angle
0.9920	0	'th_expn' - nozzle initial expansion angle
10.8958	0	'th_exit' - nozzle exit angle
0.0	4	'p_nozpoly' - % diff between nozzle designs [DON'T USE-defaulted to 1.]
2.901	1	'lcowl' - cowl length (isolator/combustor)
.3	1	'lcowlxt' - cowl extension length (internal nozzle)
0.545	4	'p_iso' - percent of lcowl that is isolator
.3238	1	'height' - height of vehicle (if required)

20.0	1	'linlet' - inlet length of vehicle (if required)
.28	1	'wengine' - width of the engine (currently defaulted to unit width)
3.00	4	'iramps' - number of inlet ramps in addition to the forebody
4.4615	0	'th_ramp1' - inlet ramp 1 angle
5.1567	0	'th_ramp2' - inlet ramp 2 angle
5.9844	0	'th_ramp3' - inlet ramp 3 angle
0.0	0	'th_ramp4' - inlet ramp 4 angle
0.0	0	'th_ramp5' - inlet ramp 5 angle
3.09	0	'th_div1' - first combustor expansion angle
1.2	0	'th_div2' - second combustor expansion angle
0.01	1	'Xinjs' - beginning of injectors (m)
0.02	1	'Xinje' - end of injectors (m)
0.01	1	'Lmix' - fuel mixing length (m)
1.00	4	'eta_mix' - fuel mixing and burning efficiency
4000.	4	'Tlimit' - maximum engine temperature (K)
90.	0	'Thetainj' - injector angle (degrees) [90 deg. is normal to flow]
1200.	4	'Tw' - adiabatic wall temperature (K)
0.1527	4	'nfor' - forebody exponent n
2.0	2	'wfor' - forebody width
2.0	1	'lfor' - forebody length
0.2427	4	'mfor' - forebody exponent m
5.797	0	'thforle' - forebody leading edge angle
21.519	0	'th_le' - leading edge attachment angle
0.0000	4	'p_kl' - keel-line height percentage
0.25	4	'fuelfrac' - vehicle fuel volume fraction
0.0104	2	't_plate' - shell plate thickness (Tungsten)
0.00000	4	'mass_smb' - mass due to Structural Modal Base (SMB) analysis
0.00000	4	'mass_tps' - mass due to Thermal Protection System (TPS) analysis
0.00000	4	'mass_nose' - mass due to Thermal Protection System (TPS) analysis

Table 9.2.2: SEDvehicle.inp

1	type of fit for upper profile (1=linear fit, 2=quadratic fit)						
46	nphi - number of radial points [must be odd number]						
2	number of cross sections input						
read in cross section data (flag, naxi, n1, n2, n3, m, length, width, w/h ratio)							
- lengths are sequential, widths are absolute, ratio is width/height							
8	81	0.1	10.	10.	4.0	5.0	3.0 1.0
8	41	0.1	10.	10.	4.0	8.0	3.75 1.0

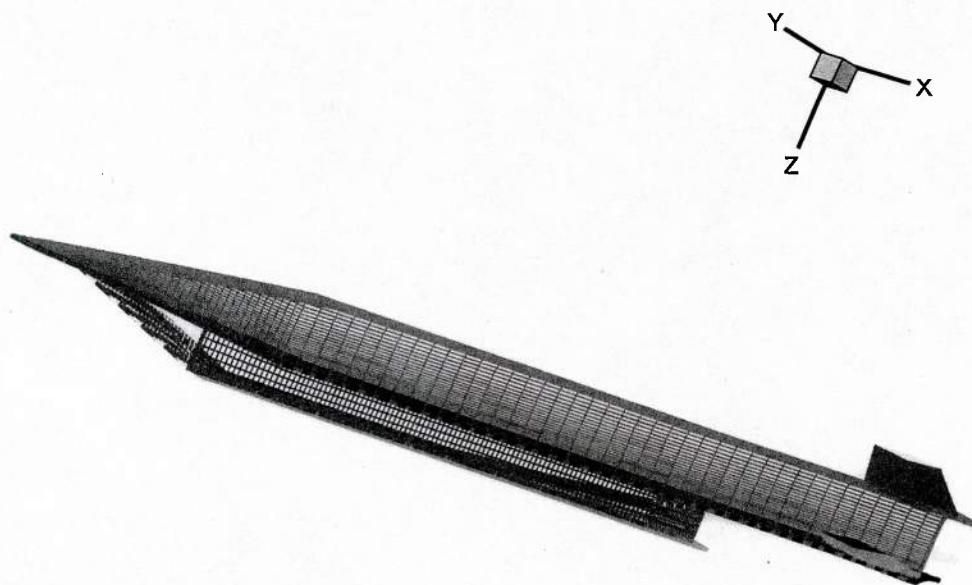
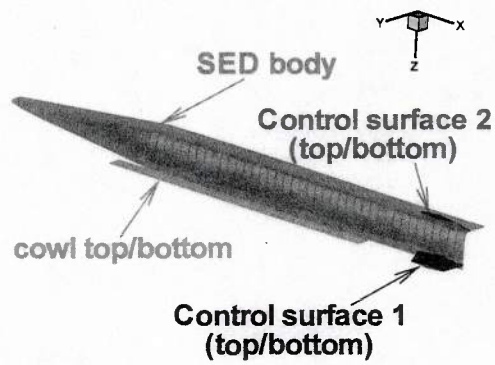
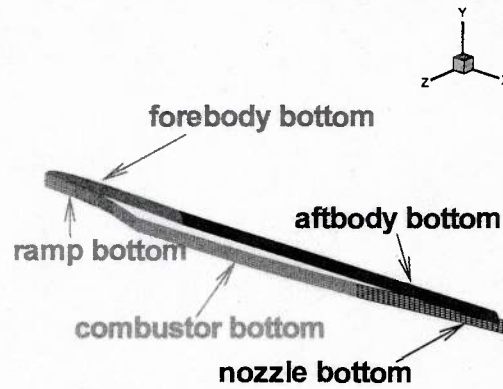


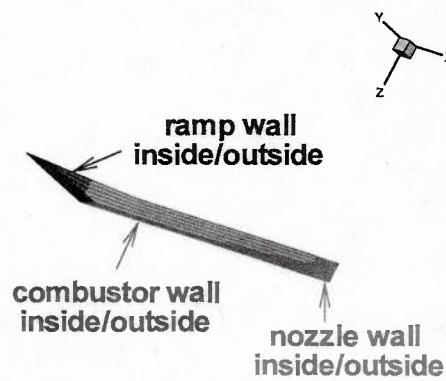
Figure 9.2.1 SED Vehicle Plot



(a) Selected Zones of SED Vehicle



(b) Selected Zones of SED Vehicle



(c) Selected Zones of SED Vehicle

Figure 9.2.2 Different Zones of SED Vehicle

Listing 9.2.1: Vehicle.inp Input File

```

TEST INPUT DECK: Note - this line must be here!
2      ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1      ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle, (2) max throttle
1      iunits - Output unit switch: SI (1) or English (2)
3      ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1      iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2      inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1      iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
0      itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0      icone - cone flow data: exact (0), curve-fit approximation (1)
4      imodel - Forebody type: WA (1), VWA (2), VWA + cone flow (3), or SED (4)
0      itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0      ilderiv - Calculate derivatives: no (0), yes (1)
0      itps - If itps is 1, then prepare for tps and smb. ilderiv and itps cannot be 1 at one time
1      ifeedback - If 1, then gets weight and Cg information from SMB and TPSOPT

OUTPUT FILE SWITCHES AND NAMES:
1      'plot.dat'          VEHICLEFIG:      off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23          1st # -> # of variables to read, others -> vars to plot
0      'metrics.dat'      METRICS:      off (0), on-real (1), on-cmplx (2)
0      'cowlexit.dat'     COWLEXIT:      off (0), on (1)
0      'moc.dat'          NOZFIG:      off (0), P,T,M (1), all (2)
0      'offdesign.dat'     AOA:          off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0      'scramjet.dat'     CKENGINE:      off (0), on (1)
0      IPRINTINLET:      off (0), all (1), results (2), all-real (3), results-real (4)
0      IPRINTENGINE:      off (0), on (1)
0      IDEBUG:            off (0), on (1) [print debugging info]

ZONE DATA AND GRID SIZES:
21      NUMBER OF ZONES
'forebody : top'          3          3
'keel : top'              3          3
'aftbody : top'           3          3
'forebody : bot'         31         31
'ramps : bot'            55          6
'comb : bot'             101          6
'cowl : top'             101          6
'nozzle : bot'           31          6
'ramp walls : inside'     35          6
'comb wall : inside'     101          7
'nozzle wall : inside'    21          7
'aftbody : bot'          101         31
'cowl : bot'             101          6
'ramp walls : outside'    35          6
'comb wall : outside'     101          7
'nozzle wall : outside'   21          7
'SEDbody : top'          121         46
'Control_1 : top'         31         31 (Control surface dimensions must be the same)
'Control_1 : bottom'      31         31 (Control surface dimensions must be the same)
'Control_2 : top'         31         31 (Control surface dimensions must be the same)
'Control_2 : bottom'      31         31 (Control surface dimensions must be the same)

INPUT DATA: (0 = degrees, 1 = m, 2 = ft, 3 = atm, 4 = dimensionless, K or kg, 5 = psf)
X1      x      xu      unit      res      name
22500.  26290.  30000.  1      2500.    'altitude' - altitude (if required)
1500.   1700.   2000.0  5      250.    'q0'       - dynamic pressure (if required)
.50     1.0299  1.0      4      .250    'equiv'    - equivalence ratio
1.      1.0      0.0      4      -.10    'throttle' - engine throttle (if required)
6.0     7.0     8.00     4      .5      'm0'       - Mach number
-2.00   0.0     3.00     0      .5      'AOA'      - angle of attack
5.0     4      'Mdes'    - design Mach number
0.2935  0      'AOAdeg'  - design angle of attack
26000.  1      'Zdes'    - design altitude
6.2672  1      'lvehicle' - vehicle length
5.5939  0      'thforclu' - forebody upper surface angle
3.8700  0      'thforcil' - forebody ramp angle
0.5873  1      'lcontrol' - control surface length
5.0     0      'th_control' - control surface deflection angle
0.9920  0      'th_expn'  - nozzle initial expansion angle
10.8958 0      'th_exit'  - nozzle exit angle
0.0     4      'p_nozpoly' - % diff between nozzle designs [DON'T USE-defaulted to 1.]
2.901   1      'lcowl'    - cowl length (isolator/combustor)
.3      1      'lcowlxt'  - cowl extension length (internal nozzle)
0.545   4      'p_iso'    - percent of lcowl that is isolator
.3238   1      'height'   - height of vehicle (if required)
20.0    1      'linlet'   - inlet length of vehicle (if required)
.28     1      'wengine'  - width of the engine (currently defaulted to unit width)
3.00    4      'iramps'   - number of inlet ramps in addition to the forebody
4.4615  0      'th_ramp1' - inlet ramp 1 angle
5.1567  0      'th_ramp2' - inlet ramp 2 angle
5.9844  0      'th_ramp3' - inlet ramp 3 angle
0.0     0      'th_ramp4' - inlet ramp 4 angle
0.0     0      'th_ramp5' - inlet ramp 5 angle
3.09    0      'th_div1'  - first combustor expansion angle
1.2     0      'th_div2'  - second combustor expansion angle
0.01    1      'XiNjs'    - beginning of injectors (m)
0.02    1      'XiNje'    - end of injectors (m)
0.01    1      'Lmix'     - fuel mixing length (m)
1.00    4      'eta_mix'  - fuel mixing and burning efficiency
4000.   4      'Tlimit'   - maximum engine temperature (K)
90.     0      'Thetainj' - injector angle (degrees) [90 deg. is normal to flow]
1200.   4      'Tw'       - adiabatic wall temperature (K)

```



```

0.1527 4      'nfor'   - forebody exponent n
2.0    2      'wfor'   - forebody width
2.0    1      'lfor'   - forebody length
0.2427 4      'mfor'   - forebody exponent m
5.797  0      'thforle' - forebody leading edge angle
21.519 0      'thle'   - leading edge attachment angle
0.0000 4      'p_kl'   - keel-line height percentage
0.25   4      'fuelfrac' - vehicle fuel volume fraction
0.0104 2      't_plate' - shell plate thickness (Tungsten)
0.00000 4     'mass_smb' - mass due to Structural Modal Base (SMB) analysis
0.00000 4     'mass_tps' - mass due to Thermal Protection System (TPS) analysis
0.00000 4     'mass_nose' - mass due to Thermal Protection System (TPS) analysis

```

Listing 9.2.2: Chem.bin Input File

```

"3.6      " "DOUBLE      " .F.
462 624 22 5 17 23 6 10 3 5 3 2 8 3 0 0 0 0 0 0 0 10 0.001000000005
"H      " 1.00796998
"O      " 15.9994001
"C      " 12.0111504
"N      " 14.0066996
"AR     " 39.9480019
"O2     " 0 2 0 0 0 0 0 31.9988003 3 300. 1000. 5000. 3.212936
0.001127486 -5.75615E-07 1.313877E-09 -8.768554E-13 -1005.249 6.034738
3.697578 0.0006135197 -1.258842E-07 1.775281E-11 -1.136435E-15 -1233.93
3.189166
"C12H23 " 23 0 12 0 0 0 0 167.317114 3 273. 1000. 5000.
2.0869217 0.13314965 -8.1157452E-05 2.9409286E-08 -6.5195213E-12 -35912.814
27.355289 24.880201 0.078250048 -3.1550973E-05 5.78789E-09 -3.9827968E-13
-43110.684 -93.655255
"H2     " 2 0 0 0 0 0 0 2.01593995 3 300. 1000. 5000. 3.298124
0.0008249442 -8.143015E-07 -9.475434E-11 4.134872E-13 -1012.521 -3.294094
2.991423 0.0007000644 -5.633829E-08 -9.231578E-12 1.582752E-15 -835.034
-1.35511
"H      " 1 0 0 0 0 0 0 1.00796998 3 300. 1000. 5000. 2.5 0.
0. 0. 0. 25471.63 -0.4601176 2.5 0. 0. 0. 0. 25471.63 -0.4601176
"O      " 0 1 0 0 0 0 0 15.9994001 3 300. 1000. 5000. 2.946429
-0.001638166 2.421032E-06 -1.602843E-09 3.890696E-13 29147.64 2.963995
2.54206 -2.755062E-05 -3.102803E-09 4.551067E-12 -4.368052E-16 29230.8
4.920308
"OH     " 1 1 0 0 0 0 0 17.0073701 3 300. 1000. 5000. 3.637266
0.000185091 -1.676165E-06 2.387203E-09 -8.431442E-13 3606.782 1.35886
2.88273 0.001013974 -2.276877E-07 2.174684E-11 -5.126305E-16 3886.888
5.595712
"H2O    " 1 2 0 0 0 0 0 33.0067703 3 300. 1000. 5000. 2.979963
0.004996697 -3.790997E-06 2.354192E-09 -8.089024E-13 176.2274 9.222724
4.072191 0.002131296 -5.308145E-07 6.112269E-11 -2.841165E-15 -157.9727
3.476029
"H2O    " 2 1 0 0 0 0 0 18.0153401 3 300. 1000. 5000. 3.386842
0.003474982 -6.354696E-06 6.968581E-09 -2.506588E-12 -30208.11 2.590233
2.672146 0.003056293 -8.73026E-07 1.200996E-10 -6.391618E-15 -29899.21
6.862817
"CH     " 1 0 1 0 0 0 0 13.0191203 3 300. 1000. 5000. 3.200202
0.002072876 -5.134431E-06 5.73389E-09 -1.955533E-12 70452.59 3.331588
2.196223 0.002340381 -7.058201E-07 9.007582E-11 -3.85504E-15 70867.23
9.178373
"CO2    " 0 2 1 0 0 0 0 44.0099506 3 300. 1000. 5000. 2.275725
0.009922072 -1.040911E-05 6.866687E-09 -2.11728E-12 -48373.14 10.18849
4.453623 0.003140169 -1.278411E-06 2.393997E-10 -1.669033E-14 -48966.96
-0.9553959
"CO     " 0 0 1 1 0 0 0 28.0105505 3 300. 1000. 5000. 3.262452
0.001511941 -3.881755E-06 5.581944E-09 -2.474951E-12 -14310.54 4.848897
3.025078 0.001442689 -5.630828E-07 1.018581E-10 -6.910952E-15 -14268.35
6.108218
"C2H2   " 2 0 2 0 0 0 0 26.0382407 3 300. 1000. 5000. 2.013562
0.01519045 -1.616319E-05 9.078992E-09 -1.912746E-12 26124.44 8.805378
4.43677 0.005376039 -1.912817E-06 3.286379E-10 -2.15671E-14 25667.66
-2.800338
"N      " 0 0 0 1 0 0 0 14.0066996 3 300. 1000. 5000. 2.503071
-2.180018E-05 5.420529E-08 -5.64756E-11 2.099904E-14 56098.9 4.167566
2.450268 0.0001066146 -7.465337E-08 1.879652E-11 -1.025984E-15 56116.04
4.448758
"NH     " 1 0 0 1 0 0 0 15.0146695 3 300. 1000. 5000. 3.339758
0.001253009 -3.491646E-06 4.218812E-09 -1.557618E-12 41850.47 2.507181
2.760249 0.001375346 -4.451914E-07 7.692792E-11 -5.017592E-15 42078.28
5.857199
"NO     " 0 0 1 0 1 0 0 30.0060997 3 300. 1000. 5000. 3.376542
0.001253063 -3.302751E-06 5.21781E-09 -2.446263E-12 9817.961 5.82959
3.245435 0.001269138 -5.01589E-07 9.169283E-11 -6.275419E-15 9800.84
6.417294
"AR     " 0 0 0 0 1 0 0 39.9480019 3 300. 1000. 5000. 2.5 0.
0. 0. 0. -745.375 4.366001 2.5 0. 0. 0. 0. -745.375 4.366001
"N2     " 0 0 0 2 0 0 0 28.0133991 3 300. 1000. 5000. 3.298677
0.00140824 -3.963222E-06 5.641515E-09 -2.444855E-12 -1020.9 3.950372
2.92664 0.001487977 -5.684761E-07 1.009704E-10 -6.753351E-15 -922.7977
5.980528
-5 2 4.35E+09 0. 15098.1385 -1 2 -1 17 0 0 12 9 11 4 1 17 5 3 1.E+15 0.
39255.16 -1 3 -1 17 -1 9 1 9 2 14 0 0 6 3 1.E+09 0.5 22093.6093 -1 5 -1 17
-1 7 2 15 1 4 1 5 4 2 3.E+13 1. 19124.3087 -1 3 -1 1 0 0 1 8 1 5 0 0 4 2

```



```

2.5E+15 0. 3019.62769 -1 3 -1 5 0 0 1 4 1 6 0 0 4 2 4.E+14 0. 9058.88307
-1 4 -1 1 0 0 1 5 1 6 0 0 4 2 1.E+18 0. 61519.3782 -1 17 -1 1 0 0 2 5 1 17 0
0 3 2 4.E+20 -1. 0. -1 3 -2 4 0 0 2 3 0 0 0 0 3 2 1.E+15 -1.15 0. -1 4 -1 1
0 0 1 7 0 0 0 0 4 2 1.E+13 0. 0. -1 6 -1 7 0 0 1 8 1 1 0 0 4 2 6.5E+13 0.
0. -1 4 -1 7 0 0 1 3 1 1 0 0 4 2 2.5E+13 0. 0. -1 5 -1 7 0 0 1 6 1 1 0 0 4
2 15100000. 1.28 -381.479632 -1 11 -1 6 0 0 1 10 1 4 0 0 4 2 1.5E+17 0.
-381.479632 -1 17 -2 9 0 0 1 12 1 17 0 0 4 2 3.E+15 0. 9562.15435 -1 12 -1 1
0 0 2 11 1 3 0 0 4 2 3.E+13 0. 3019.62769 -1 9 -1 6 0 0 1 11 1 3 0 0 4 2
3.E+12 0.6 0. -1 9 -1 5 0 0 1 11 1 4 0 0 4 2 1.E+11 0. 0. -1 9 -1 15 0 0
1 14 1 11 0 0 4 2 9.E+13 0. 37745.3461 -1 17 -1 5 0 0 1 13 1 15 0 0 4 2
6.3E+09 1. 3170.60907 -1 13 -1 1 0 0 1 15 1 5 0 0 4 2 1.E+12 0.
24157.0215 -1 15 -1 4 0 0 1 13 1 6 0 0 4 2 25000. 2.64 0. -1 14 -1 5 0 0 1
15 1 4 0 0 4 2 2.E+15 -0.8 0. -1 14 -1 15 0 0 1 17 1 6 0 0
2 1.95E+15 0. 0. 3 2.5E+10 0. 4026.17025 7 4.E+18 0. 0.

```

Listing 9.2.3: SEDvehicle.inp Input File

```

1      type of fit for upper profile (1=linear fit, 2=quadratic fit)
46     nphi - number of radial points [must be odd number]
2      number of cross sections input
read in cross section data (flag, naxi, n1, n2, n3, m, length, width, w/h ratio)
- lengths are sequential, widths are absolute, ratio is width/height
8  81 0.1 10. 10. 4.0 5.0 3.0 1.0
8  41 0.1 10. 10. 4.0 8.0 3.75 1.0

```

Listing 9.2.4: Plot.dat TECPLOT output file

```

variables =
"x"
"y"
"z"
"yz-area"
"xz-area"
"xy-area"
"SA"
"pn"
"tn"
"mn"
"viac-length"
"Dv-l/area"
"Dv-t/area"
"ave-x"
"ave-y"
"ave-z"
"yz-R-of-Curv"
"gamma"
"R"
"x-norm-vec"
"y-norm-vec"
"z-norm-vec"
"u-vel"
"v-vel"
"w-vel"
"phi"
"dphi"
"x0"
"y0"
"z0"
"r0"
"th0"
"qdot"
"psf"
""
zone f=block, t="forebody : bot", i= 31
,j= 31
0.1999999762E+01
0.1775430322E+01
0.1572604299E+01
0.1389763594E+01
0.1225263357E+01
0.1077568293E+01
0.9452453256E+00
0.8269558549E+00
0.7214568257E+00
0.6275903583E+00
0.5442843437E+00
0.4705444276E+00
0.4054505527E+00
0.3481531441E+00
0.2978700101E+00
0.2538813055E+00
0.2155252993E+00
0.1821971089E+00 .....

```

.....
.....
.....

0.000000000E+00
0.000000000E+00
0.000000000E+00
0.000000000E+00
0.000000000E+00
0.000000000E+00
0.000000000E+00
0.000000000E+00
0.000000000E+00
0.000000000E+00
0.000000000E+00
0.000000000E+00

9.3 Run UCDA to Generate Tables and Input Files for UPTOP

This section corresponds to the Step 1 in the Graphical User Interface (GUI). See Figure 9.3.1 below.

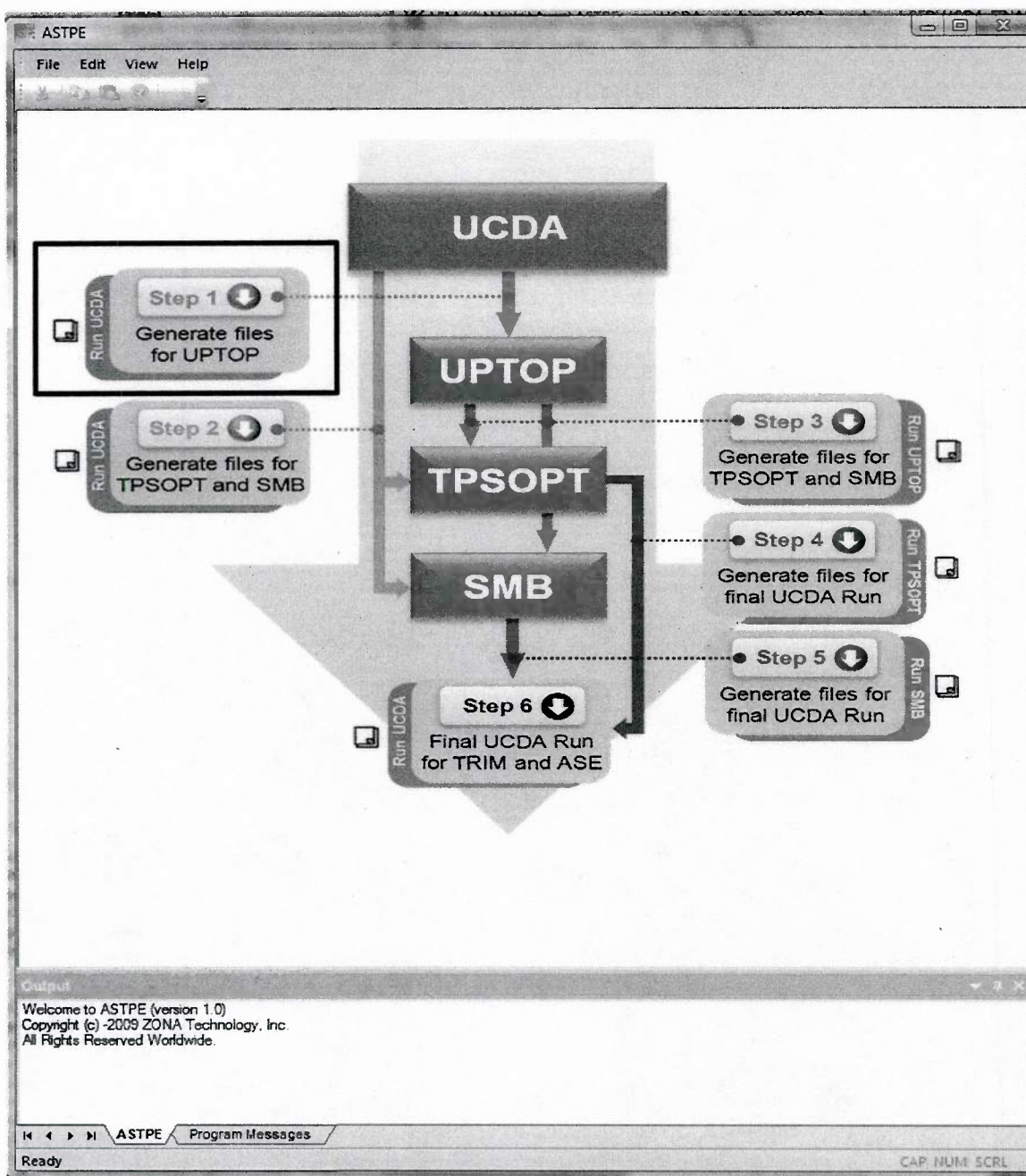


Figure 9.3.1 Section Corresponding to Step 1 of GUI

9.3.1 Generate Tab Files

Input Files:

File Name	Type	Remarks	See Listing
vehicle.inp	Standard input file	Also look at Table 9.3.1a 9.3.1.b	Shown in Listing 9.3.1
chem.bin	Engine chemistry information	Required	Shown in Listing 9.2.2
SEDvehicle.inp	Standard input file for SED type vehicle	Required	Shown in Listing 9.2.3

Output Files:

File Name	Type	Remarks	See Listing
lift.tab	Tabular format	Aerodynamic information for UPTOP	Shown in Listing 9.3.2
drag.tab	Tabular format	Aerodynamic information for UPTOP	Shown in Listing 9.3.3
fuel.tab	Tabular format	Aerodynamic information for UPTOP	Shown in Listing 9.3.4
thr.tab	Tabular format	Aerodynamic information for UPTOP	Shown in Listing 9.3.5

Input File descriptions

vehicle.inp: See Listing 9.3.1 for the entire input file. The parts of the input file that are used to generate the tables for UPTOP are displayed in Tables 9.3.1a and 9.3.1b. Table 9.3.1a shows the necessary parameters to control the creation of such tables and Table 9.3.1b shows a matrix of trajectory points. It can be noted that to generate tables for UPTOP, **itrajectory** has to be set to **2** and **offdesign.dat** switch has to be set to **2**. These are the only change needed from the earlier run of Section 9.2.

Different points on the trajectory are defined by the way shown in Table 9.3.1b. There are six lines in Table 9.3.1b. Each line has its own parameter such as altitude, dynamic pressure, throttle etc. Since **ialtdyn** is set to **2** (Table 9.3.1a), the code does not need to run corresponding to the altitude. Also, since **ithrottle** is set to **1**, the line with the Equivalence ratio is not used. More discussions on this can be found in the User's Manual. Thus, the code goes through the rest of the four variables. Each variable has got its lower bound and upper bound defined in the first and third number from the left. Also, the fifth variable is the value of its interval. For

example, for Mach number, the lower bound is 6.0, upper bound is 8.0 and interval is 0.5. Thus, the code will run through 5 points for Mach number. Similarly, each of these four parameters has such bounds and intervals. Thus, the code runs a combination of all possible points, which is a total of 3 dynamic pressure points x 11 throttle points x 5 mach number points x 11 angle of attack points = 1815 points.

chem.bin: This file remains the same for all UCDA runs. Please see Section 9.2 for description on this file.

SEDvehicle.inp: This file remains the same for all SED runs. Please see Section 9.2 for description on this file.

Table 9.3.1a Necessary Blocks Controlling TAB File Creation for UPTOP

TEST INPUT DECK: Note - this line must be here!	
2	ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1	ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle, (2) max throttle
1	iunits - Output unit switch: SI (1) or English (2)
3	ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1	iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2	inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1	iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
2	itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0	icone - cone flow data: exact (0), curve-fit approximation (1)
4	imodel - Forebody type: WA (1), VWA (2), VWA + cone flow (3), or SED (4)
0	itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0	ideriv - Calculate derivatives: no (0), yes (1)
0	itps - If itps is 1, then prepare for tps and smb. ideriv and itps cannot be 1 at one time
0	ifedback - If 1, then gets weight and Cg information from SMB and TPSOPT
OUTPUT FILE SWITCHES AND NAMES:	
0	'plot.dat' VEHICLEFIG: off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23	1st # -> # of variables to read, others -> vars to plot
0	'metrics.dat' METRICS: off (0), on-real (1), on-cmplx (2)
0	'cowlexit.dat' COWLEXIT: off (0), on (1)
0	'moc.dat' NOZFIG: off (0), P,T,M (1), all (2)
2	'offdesign.dat' AOA: off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0	'scramjet.dat' CKENGINE: off (0), on (1)
0	IPRINTINLET: off (0), all (1), results (2), all-real (3), results-real (4)
0	IPRINTENGINE: off (0), on (1)
0	IDEBUG: off (0), on (1) [print debugging info]

Table 9.3.1b Necessary Blocks to Run a Matrix of Points to Generate Table

INPUT DATA: (0 = degrees, 1 = m, 2 = ft, 3 = atm, 4 = dimensionless, K or kg, 5 = psf)					
xl	x	xu	unit	res	name
22500.	26290.	30000.	1	2500.	'altitude' - altitude (if required)

1500.	1700.	2000.0	5	250.	'q0' - dynamic pressure (if required)
.50	1.0299	1.0	4	.250	'equiv' - equivalence ratio
1.	1.0	0.0	4	-.10	'throttle' - engine throttle (if required)
6.0	7.0	8.00	4	.5	'm0' - Mach number
-2.00	0.0	3.00	0	.5	'AOA' - angle of attack

Output File Descriptions

lift.tab: For each of the points described above, lift is tabulated in this file. Please see Listing 9.3.2.

drag.tab: For each of the points described above, drag is tabulated in this file. Please see Listing 9.3.3.

fuel.tab: For each of the points described above, fuel is tabulated in this file. Please see Listing 9.3.4.

thr.tab: For each of the points described above, thrust is tabulated in this file. Please see Listing 9.3.5.

UPTOP requires these four tabulated results to find the optimized trajectory.

The computational run time to generate the *.tab files for UPTOP is approximately 30 minutes for sample SED.

9.3.2 Generate Input Files

Input Files:

File Name	Type	Remarks	See Listing
vehicle.inp	Standard input file	Also look at Table 9.3.2	Shown in Listing 9.3.6
chem.bin	Engine chemistry information	Required and does not change	Shown in Listing 9.2.2
SEDvehicle.inp	Standard input file for SED type vehicle	Require and does not change	Shown in Listing 9.2.3

Output Files:

File Name	Type	Remarks	See Listing
traj.inp	Standard input for UPTOP	Main input file for UPTOP	Shown in Listing 9.3.7
model.inp	Standard input for UPTOP	Information about model	Shown in Listing 9.3.8

Input File Descriptions

vehicle.inp: See Listing 9.3.6 for the entire input file. The part of the input file that is used to generate the input files model.inp and traj.inp for UPTOP is shown in Tables 9.3.2. It can be seen comparing Listings 9.3.1 and 9.3.6 that the only changes between these two vehicle.inps are in the parameters **itrajectory** and **offdesign.dat** file switch. For the generation of the *.tab files, **itrajectory** was set to 2. Here, as noted in Table 9.3.2, **itrajectory** is set to 0. The flag for **offdesign.dat** is changed to 3 from 2. These changes will generate model.inp and traj.inp.

Table 9.3.2: Changes in Input from Table 9.3.1a for Generating INP Files

TEST INPUT DECK: Note - this line must be here!	
2	ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1	ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle, (2) max throttle
1	iunits - Output unit switch: SI (1) or English (2)
3	ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1	iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2	inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1	iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
0	itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0	icone - cone flow data: exact (0), curve-fit approximation (1)
4	imodel - Forebody type: WA (1), VWA (2), VWA + cone flow (3), or SED (4)
0	itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0	ideriv - Calculate derivatives: no (0), yes (1)
0	itps - If itps is 1, then prepare for tps and smb. ideriv and itps cannot be 1 at one time

```
0 ifeedback - If 1, then gets weight and Cg information from SMB and TPSOPT
```

OUTPUT FILE SWITCHES AND NAMES:

```
0 'plot.dat'          VEHICLEFIG:    off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23      1st # -> # of variables to read, others -> vars to plot
0 'metrics.dat'      METRICS:      off (0), on-real (1), on-cmplx (2)
0 'cowlexit.dat'     COWLEXIT:     off (0), on (1)
0 'moc.dat'          NOZFIG:      off (0), P,T,M (1), all (2)
3 'offdesign.dat'    AOA:          off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0 'scramjet.dat'     CKENGINE:    off (0), on (1)
0                    IPRINTINLET: off (0), all (1), results (2), all-real (3), results-real (4)
0                    IPRINTENGINE: off (0), on (1)
0                    IDEBUG:      off (0), on (1) [print debugging info]
```

Output File descriptions

traj.inp: See Listing 9.3.7 for this output. This file is the main input file for UPTOP. It contains information about orientation parameters, optimization parameters, event parameters, engine throttle control etc. Please see Section 4.5.1 of User's Manual for detailed description.

model.inp: See Listing 9.3.8 for this output that is used by UPTOP as a standard input file. This file contains information about number of components, engine, fuel tank etc. The detailed explanation of this file can be found in Section 4.5.4 of User's Manual.

The computational run time to generate the input files for UPTOP is about a few seconds.

Listing 9.3.1: Vehicle.inp Input File for UPTOP Tab File Generation

```
TEST INPUT DECK: Note - this line must be here!
2 ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1 ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle, (2) max throttle
1 iunits - Output unit switch: SI (1) or English (2)
3 ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1 iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2 inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1 iheight - Height constrained vehicle: no (0) = linlet set, yes (1) = height set
2 itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0 icone - cone flow data: exact (0), curve-fit approximation (1)
4 imodel - Forebody type: WA (1), VWA (2), VWA + cone flow (3), or SED (4)
0 itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0 ideriv - Calculate derivatives: no (0), yes (1)
0 itps - If itps is 1, then prepare for tps and smb. ideriv and itps cannot be 1 at one time
1 ifeedback - If 1, then gets weight and Cg information from SMB and TPSOPT

OUTPUT FILE SWITCHES AND NAMES:
0 'plot.dat'          VEHICLEFIG:    off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23      1st # -> # of variables to read, others -> vars to plot
0 'metrics.dat'      METRICS:      off (0), on-real (1), on-cmplx (2)
0 'cowlexit.dat'     COWLEXIT:     off (0), on (1)
0 'moc.dat'          NOZFIG:      off (0), P,T,M (1), all (2)
2 'offdesign.dat'    AOA:          off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0 'scramjet.dat'     CKENGINE:    off (0), on (1)
0                    IPRINTINLET: off (0), all (1), results (2), all-real (3), results-real (4)
0                    IPRINTENGINE: off (0), on (1)
0                    IDEBUG:      off (0), on (1) [print debugging info]

ZONE DATA AND GRID SIZES:
```

```

21      NUMBER OF ZONES
'forebody : top'      3      3
'keel : top'          3      3
'aftbody : top'       3      3
'forebody : bot'      31     31
'ramps : bot'         55     6
'comb : bot'          101    6
'cowl : top'          101    6
'nozzle : bot'        31     6
'ramp walls : inside' 35     6
'comb wall : inside'  101    7
'nozzle wall : inside' 21     7
'aftbody : bot'       101    31
'cowl : bot'          101    6
'ramp walls : outside' 35     6
'comb wall : outside' 101    7
'nozzle wall : outside' 21     7
'SEDbody : top'       121    46
'Control_1 : top'      31     31 (Control surface dimensions must be the same)
'Control_1 : bottom'   31     31 (Control surface dimensions must be the same)
'Control_2 : top'      31     31 (Control surface dimensions must be the same)
'Control_2 : bottom'   31     31 (Control surface dimensions must be the same)

INPUT DATA: (0 = degrees, 1 = m, 2 = ft, 3 = atm, 4 = dimensionless, K or kg, 5 = psf)
X1      x      xu      unit      res      name
22500.  26290.  30000.  1      2500.    'altitude' - altitude (if required)
1500.   1700.   2000.0  5      250.    'q0'       - dynamic pressure (if required)
.50     1.0299  1.0      4      .250     'equiv'    - equivalence ratio
1.       1.0     0.0      4      -.10     'throttle' - engine throttle (if required)
6.0     7.0     8.00     4      .5       'm0'       - Mach number
-2.00   0.0     3.00     0      .5       'AOA'      - angle of attack
5.0     4      'Mdes'    - design Mach number
0.2935  0      'AOA des' - design angle of attack
26000.  1      'Zdes'    - design altitude
6.2672  1      'lvehicle' - vehicle length
5.5939  0      'thforclu' - forebody upper surface angle
3.8700  0      'thforc1l' - forebody ramp angle
0.5873  1      'lcontrol' - control surface length
5.0     0      'th_control' - control surface deflection angle
0.9920  0      'th_expn' - nozzle initial expansion angle
10.8958 0      'th_exit' - nozzle exit angle
0.0     4      'p_nozpoly' - % diff between nozzle designs [DON'T USE-defaulted to 1.]
2.901   1      'lcowl'    - cowl length (isolator/combustor)
.3      1      'lcowlex'  - cowl extension length (internal nozzle)
0.545   4      'p_iso'    - percent of lcowl that is isolator
.3238   1      'height'   - height of vehicle (if required)
20.0    1      'linlet'   - inlet length of vehicle (if required)
.28     1      'wengine'  - width of the engine (currently defaulted to unit width)
3.00    4      'iramps'   - number of inlet ramps in addition to the forebody
4.4615  0      'th_ramp1' - inlet ramp 1 angle
5.1567  0      'th_ramp2' - inlet ramp 2 angle
5.9844  0      'th_ramp3' - inlet ramp 3 angle
0.0     0      'th_ramp4' - inlet ramp 4 angle
0.0     0      'th_ramp5' - inlet ramp 5 angle
3.09    0      'th_div1'  - first combustor expansion angle
1.2     0      'th_div2'  - second combustor expansion angle
0.01    1      'Xinjs'    - beginning of injectors (m)
0.02    1      'Xinje'    - end of injectors (m)
0.01    1      'Lmix'     - fuel mixing length (m)
1.00    4      'eta_mix'  - fuel mixing and burning efficiency
4000.   4      'Tlimit'   - maximum engine temperature (K)
90.     0      'Thetainj' - injector angle (degrees) [90 deg. is normal to flow]
1200.   4      'Tw'       - adiabatic wall temperature (K)
0.1527  4      'nfor'     - forebody exponent n
2.0     2      'wfor'     - forebody width
2.0     1      'lfor'     - forebody length
0.2427  4      'mfor'     - forebody exponent m
5.797   0      'thforle'  - forebody leading edge angle
21.519  0      'th_le'    - leading edge attachment angle
0.0000  4      'p_k1'     - keel-line height percentage
0.25    4      'fuelfrac' - vehicle fuel volume fraction
0.0104  2      't_plate'  - shell plate thickness (Tungsten)
0.00000 4      'mass_smb' - mass due to Structural Modal Base (SMB) analysis
0.00000 4      'mass_tps' - mass due to Thermal Protection System (TPS) analysis
0.00000 4      'mass_nose' - mass due to Thermal Protection System (TPS) analysis

```

Listing 9.3.2: Lift.tab Output File From UCDA / Input File for UPTOP

```

1
      4
      3      10
      5      11
      11     30
      11     201
1 0
71820.38
83790.45

```

```

95760.52
6.000000
6.500000
7.000000
7.500000
8.000000
-2.000000
-1.500000
-1.000000
-0.500000
0.000000E+00
0.500000
1.000000
1.500000
2.000000
2.500000
3.000000
1.000000
0.900000
0.800000
0.700000
0.600000
0.500000
0.400000
0.300000
0.200000
9.9999987E-02
-1.4901161E-08
-8.5015129E-03
-8.8613592E-03
-9.2074331E-03
-8.9160744E-03
-9.3178777E-03
...
...
...
6.7598328E-02
6.5432645E-02
6.3360982E-02
6.2609807E-02
5.9198547E-02
8.1768841E-02
8.1367888E-02
7.8875162E-02
8.0384992E-02
7.8386605E-02
7.5742245E-02
7.3862076E-02
7.1785584E-02
7.0098795E-02
6.8872631E-02
6.6135794E-02
8.7031588E-02
8.6279862E-02
8.4007591E-02
8.5276090E-02
8.3665103E-02
8.1361860E-02
7.9045452E-02
7.7917948E-02
7.4844934E-02
7.4751720E-02
7.2875395E-02

```

Listing 9.3.3: Drag.tab Output File From UCDA / Input File for UPTOP

```

1
  4
  3      10
  5      11
 11      30
 11      201
1 0
71820.38
83790.45
95760.52
6.000000
6.500000
7.000000
7.500000
8.000000
-2.000000
-1.500000
-1.000000
-0.500000
0.000000E+00
0.500000
1.000000
1.500000
2.000000

```

```

2.500000
3.000000
1.000000
0.9000000
0.8000000
0.7000000
0.6000000
0.5000000
0.4000000
0.3000000
0.2000000
9.9999987E-02
-1.4901161E-08
4.1842587E-02
4.1646343E-02

```

```

-----

```

```

-----

```

```

-----

```

```

8.9965522E-02
8.6033843E-02
8.2398944E-02
7.9125471E-02
7.6165535E-02
7.3558360E-02
7.1296528E-02
6.9357380E-02
6.7708887E-02
0.1153808
0.1095439
0.1044403
9.9838257E-02
9.5641494E-02
9.1779627E-02
8.8255912E-02
8.5131563E-02
8.2363270E-02
7.9952553E-02
7.7863649E-02

```

Listing 9.3.4: Fuel.tab Output File From UCDA / Input File for UPTOP

```

1
      4
      3      10
      5      11
      11     30
      11     201
1 0
71820.38
83790.45
95760.52
6.000000
6.500000
7.000000
7.500000
8.000000
-2.000000
-1.500000
-1.000000
-0.500000
0.000000E+00
0.500000
1.000000
1.500000
2.000000
2.500000
3.000000
1.000000
0.9000000
0.8000000
0.7000000
0.6000000
0.5000000
0.4000000
0.3000000
0.2000000
9.9999987E-02
-1.4901161E-08
0.7388166
0.6649349
-----
-----
-----
0.4570374
0.3917464
0.3264553
0.2611642

```

```

0.1958732
0.1305821
6.5291047E-02
-9.7291259E-09
0.6349592
0.5714633
0.5079674
0.4444714
0.3809755
0.3174796
0.2539837
0.1904878
0.1269918
6.3495912E-02
-9.4616297E-09
0.5978621
0.5380759
0.4782897
0.4185035
0.3587173
0.2989311
0.2391448
0.1793586
0.1195724
5.9786201E-02
-8.9088399E-09

```

Listing 9.3.5: Thr.tab Output File From UCDA / Input File for UPTOP

```

1
      4
      3      10
      5      11
     11      30
     11      201
1 0
71820.38
83790.45
95760.52
6.000000
6.500000
7.000000
7.500000
8.000000
-2.000000
-1.500000
-1.000000
-0.500000
0.000000E+00
0.500000
1.000000
1.500000
2.000000
2.500000
3.000000
1.000000
0.900000
0.800000
0.700000
0.600000
0.500000
0.400000
0.300000
0.200000
9.9999987E-02
-1.4901161E-08
1.230211
1.218165

2.241872
2.116534
2.008070
1.903508
4.012670
3.756747
3.533950
3.335721
3.138714
2.954617
2.783321
2.624865
2.481252
2.353849
2.235506
4.541084
4.268238
4.019526
3.797655

```


3.585260
3.383832
3.194473
3.022392
2.860141
2.720629
2.591109

Listing 9.3.6: Vehicle.inp Input File for UPTOP Input (INP) File Generation

```

TEST INPUT DECK: Note - this line must be here!
2 ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1 ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle, (2) max throttle
1 iunits - Output unit switch: SI (1) or English (2)
3 ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1 iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2 inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1 iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
0 itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0 icone - cone flow data: exact (0), curve-fit approximation (1)
4 imodel - Forebody type: WA (1), VWA (2), VWA + cone flow (3), or SED (4)
0 itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0 nderiv - Calculate derivatives: no (0), yes (1)
0 itps - If itps is 1, then prepare for tps and smb. nderiv and itps cannot be 1 at one time
1 ifeedback - If 1, then gets weight and Cg information from SMB and TPSOPT

OUTPUT FILE SWITCHES AND NAMES:
0 'plot.dat' VEHICLEFIG: off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23 1st # -> # of variables to read, others -> vars to plot
0 'metrics.dat' METRICS: off (0), on-real (1), on-cmplx (2)
0 'cowlexit.dat' COWLEXIT: off (0), on (1)
0 'moc.dat' NOZFIG: off (0), P,T,M (1), all (2)
3 'offdesign.dat' AOA: off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0 'scramjet.dat' CKENGINE: off (0), on (1)
0 IPRINTINLET: off (0), all (1), results (2), all-real (3), results-real (4)
0 IPRINTENGINE: off (0), on (1)
0 IDEBUG: off (0), on (1) [print debugging info]

ZONE DATA AND GRID SIZES:
21 NUMBER OF ZONES
'forebody : top' 3 3
'keel : top' 3 3
'aftbody : top' 3 3
'forebody : bot' 31 31
'ramps : bot' 55 6
'comb : bot' 101 6
'cowl : top' 101 6
'nozzle : bot' 31 6
'ramp walls : inside' 35 6
'comb wall : inside' 101 7
'nozzle wall : inside' 21 7
'aftbody : bot' 101 31
'cowl : bot' 101 6
'ramp walls : outside' 35 6
'comb wall : outside' 101 7
'nozzle wall : outside' 21 7
'SEDbody : top' 121 46
'Control_1 : top' 31 31 (Control surface dimensions must be the same)
'Control_1 : bottom' 31 31 (Control surface dimensions must be the same)
'Control_2 : top' 31 31 (Control surface dimensions must be the same)
'Control_2 : bottom' 31 31 (Control surface dimensions must be the same)

INPUT DATA: (0 = degrees, 1 = m, 2 = ft, 3 = atm, 4 = dimensionless, K or kg, 5 = psf)
X1 x xu unit res name
22500. 26290. 30000. 1 2500. 'altitude' - altitude (if required)
1500. 1700. 2000.0 5 250. 'q0' - dynamic pressure (if required)
.50 1.0299 1.0 4 .250 'equiv' - equivalence ratio
1. 1.0 0.0 4 -.10 'throttle' - engine throttle (if required)
6.0 7.0 8.00 4 .5 'm0' - Mach number
-2.00 0.0 3.00 0 .5 'AOA' - angle of attack
5.0 4 'Mdes' - design Mach number
0.2935 0 'AOA des' - design angle of attack
26000. 1 'Zdes' - design altitude
6.2672 1 'lvehicle' - vehicle length
5.5939 0 'thforclu' - forebody upper surface angle
3.8700 0 'thforcll' - forebody ramp angle
0.5873 1 'lcontrol' - control surface length
5.0 0 'th_control' - control surface deflection angle
0.9920 0 'th_expn' - nozzle initial expansion angle
10.8958 0 'th_exit' - nozzle exit angle
0.0 4 'p_nozpoly' - % diff between nozzle designs [DON'T USE-defaulted to 1.]
2.901 1 'lcowl' - cowl length (isolator/combustor)
.3 1 'lcowl ext' - cowl extension length (internal nozzle)
0.545 4 'p_iso' - percent of lcowl that is isolator
.3238 1 'height' - height of vehicle (if required)
20.0 1 'linlet' - inlet length of vehicle (if required)
.28 1 'wengine' - width of the engine (currently defaulted to unit width)
3.00 4 'iramps' - number of inlet ramps in addition to the forebody
4.4615 0 'th_ramp1' - inlet ramp 1 angle
5.1567 0 'th_ramp2' - inlet ramp 2 angle
5.9844 0 'th_ramp3' - inlet ramp 3 angle
0.0 0 'th_ramp4' - inlet ramp 4 angle

```

0.0	0	'th_ramp5'	- inlet ramp 5 angle
3.09	0	'th_div1'	- first combustor expansion angle
1.2	0	'th_div2'	- second combustor expansion angle
0.01	1	'Xinjs'	- beginning of injectors (m)
0.02	1	'Xinje'	- end of injectors (m)
0.01	1	'Lmix'	- fuel mixing length (m)
1.00	4	'eta_mix'	- fuel mixing and burning efficiency
4000.	4	'Tlimit'	- maximum engine temperature (K)
90.	0	'Thetainj'	- injector angle (degrees) [90 deg. is normal to flow]
1200.	4	'Tw'	- adiabatic wall temperature (K)
0.1527	4	'nfor'	- forebody exponent n
2.0	2	'wfor'	- forebody width
2.0	1	'lfor'	- forebody length
0.2427	4	'mfor'	- forebody exponent m
5.797	0	'thforle'	- forebody leading edge angle
21.519	0	'th_le'	- leading edge attachment angle
0.0000	4	'p_kl'	- keel-line height percentage
0.25	4	'fuelfrac'	- vehicle fuel volume fraction
0.0104	2	't_plate'	- shell plate thickness (Tungsten)
0.00000	4	'mass_smb'	- mass due to Structural Modal Base (SMB) analysis
0.00000	4	'mass_tps'	- mass due to Thermal Protection System (TPS) analysis
0.00000	4	'mass_nose'	- mass due to Thermal Protection System (TPS) analysis

Listing 9.3.7: Traj.inp Output File From UCDA / Input File for UPTOP

RUN METHOD
10 (0-single case, 1-new GA, 2-restart, 3-mapspace)

INITIAL CONDITIONS

```

1 25230.2 22406.8 28053.7 initial altitude (m)
0 0.0 -10.0 10.0 initial gamma
1 -6.2 -8.0 -6.0 initial velocity (m/s)

```

ORIENTATION PARAMETERS

2 Mode (1 - rpy, 2 - aeroballistic angles)

```

30 angle 1 id
0 Variable Mode
1 Curve fit order
1 Independent Variable type
2 Number of Control Points
0 0 0.0 1.0 10.0
0 0 500.0 1.0 10.0
1 0 -1.5 -2.0 3.0
1 0 -1.0 -2.0 3.0

```

```

32 angle 1 id
2 Variable Mode
0 0 0 0

```

```

31 angle 1 id
2 Variable Mode
0 0 0 0

```

TRAJECTORY EVENTS
0 Number of Control Points

THROTTLE CONTROLS
1 Number of engine specifications

```

1 Engine Number
2 Specification Type
0 1 0 0

```

TERMINATION PARAMETERS

```

0 0 -551 1. 0 0

```

NAVIGATION PARAMETERS

```

0 0. 0. 10. mu
0 0. 0. 10. longitude
0 90. 0. 10. heading

```

THRUST

```

1
1
thr.tab
1
fuel.tab

```

VARIABLE TRACKING

```

1 Number of Variables to Track
2 6 0 0 0 -1

```

OPTIMIZATION AND CONSTRAINT PARAMETERS

```

-----
1 Number of Optimization Variables
58 1 .001 0 -1. 0.

2 Number of Constraint Variables
1001 1 1.00 0 -1.00 0 0.0000 1000.0000 0.0000
1001 -1 1.00 0 -1.00 0 0.0000 1000.0000 0.0000

IO FILES
1 number of output files
-----
3 5 output format, number of output variables
1 del(time) if >0; stride if <0
1 11 2 30 32 variable ids (from varlist.txt)
trajct.dat output filename

```

Listing 9.3.8: Model.inp Output File from UCDA / Input File for UPTOP

```

GENERAL INFORMATION
1 Number of vehicle components

Stage/Component Linking
#num no comps component numbers
1 1 1

Stage Reference Areas
0 3.658696 0. 0. stage(1)

Nose Radius
0 6.4000001E-06 0. 100.

VEHICLE COMPONENT PARAMETERS
***** Component 1 Information *****
0 1022.317 0. 0. Dry Vehicle Mass (kilograms)

Engine Information
1 Total Number of Engines groups
-----
1
0 0
0 9.8661505E-02 0 0 engine area

Fuel Tank Information
1 Total Number of Fuel Tanks
-----
1
0 254.6685 0. 0.

ENGINE/TANK LINKING
1 Total number of links
engine tank
1 1

```

9.4 Run UPTOP to Generate Optimized Trajectory for Use in TPSOPT and SMB

This section corresponds to the Step 3 in the Graphical User Interface (GUI). See Figure 9.4.1 below.

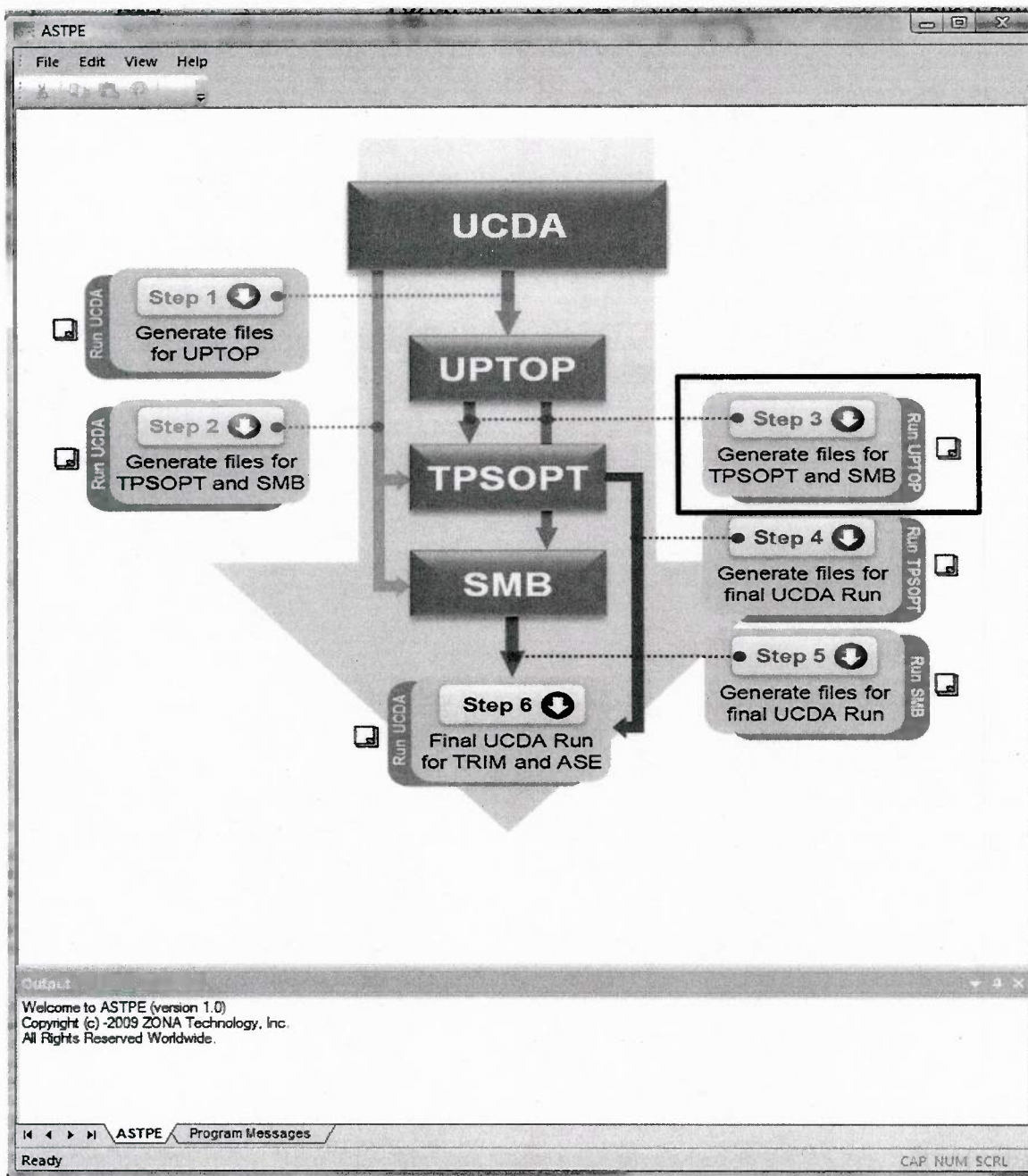


Figure 9.4.1 Section Corresponding to Step 3 of GUI

Input Files:

File Name	Type	Remarks	See Listing
des.inp	Standard input file	Required	Shown in Listing 9.4.1
params.inp	Standard input file	Required	Shown in Listing 9.4.2
traj.inp model.inp lift.tab drag.tab fuel.tab thr.tab	Input and Table files needed to generate optimized trajectory	Generated by UCDA (described in Section 9.3)	Shown in Listing 9.3.2-9.3.5,9.3.7-9.3.8

Output Files:

File Name	Type	Remarks	See Listing
trajct.dat	Optimized trajectory as input to TPSOPT and SMB	Time, Altitude, Angle of attack and Mach number information	Shown in Listing 9.4.3
output.dat	TECPLOT format	Plotted in Fig. 9.4.2	Not Shown

Input File descriptions

des.inp: See Listing 9.4.1 for des.inp input file to UPTOP. This file specifically caters to DES optimizer. If the optimization method is fixed, this input is fixed. Thus, this file is used for all the cases in ASTPE.

params.inp: See Listing 9.4.2 for params.inp input file to UPTOP. This file contains different necessary parameters about trajectory, earth/orbit, optimization etc.

The details on each of these files are listed in the User's Manual (Sections 4.5.2 and 4.5.3).

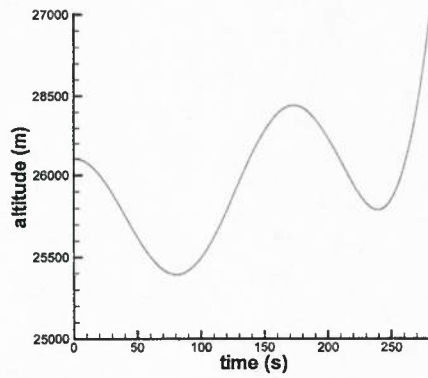
Output File descriptions

trajct.dat: See Listing 9.4.3 for this file. This file is a necessary input file for TPSOPT and SMB. Both TPSOPT and SMB need this file to compute heat flux and load respectively. The number

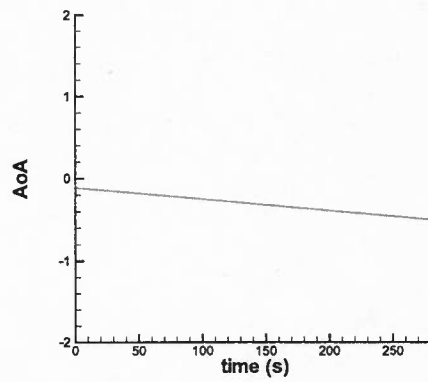
of points in `trajct.dat` is kept at 25 to maintain enough information about the trajectory without giving up computational efficiency.

output.dat: This is a TECPLOT format file and it contains optimized trajectory information. Figure 9.4.2 plots altitude, angle of attack and Mach number with respect to time using this file.

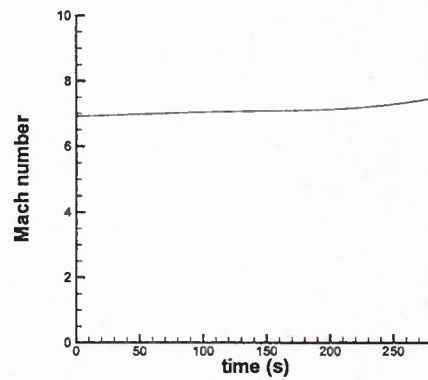
The computational time to finish this UPTOP run is approximately 60 minutes for sample SED.



(a) Altitude



(b) AoA



(c) Mach number

Figure 9.4.2 SED trajectory of Design Cycle 1

Listing 9.4.1: Des.inp UPTOP Input File

```
DES INPUTS
Run Control
-9          Restart (0 - new run, 1- restart)
100         Maximum Generations
0           Convergence Criteria (# of generations without improvement)
-9          Stop when value reached

Input/Output Control
100         restart file write frequency (number of generations)
-9          screen output
1           file output (0 - off/external, 1 - only rec. improvements, 2 - all)
10         dvrec.out flush increment

Optimization Control
0           Pareto Optimization (0 - single obj fcn, 1 - Pareto-front optimization)
0           random number seed (0 - fcn of date, else specify exact)
100        population size
0           Localization Switch
0.          diversity threshold
0.          diversity radius

DES Operator Parameters
1           number of differential terms (1-3)
-1          crossover probability (<0, 0-1)
-1          mutation intensity (<0, 0-1)
-1          coefficient of complex combination (<0, 0-1)

Supplemental Optimizer
2           optimizer switchb (0- none, 1- DHC, 2- DOT)
10          call frequency (< 0 = CVR, > 0 = # of generations)
0           Maximum number of parallel calls
```

Listing 9.4.2: Params.inp UPTOP Input File

```
CODE PARAMETERS FILE
MODEL
0           Atmosphere Model (0- 1976 US Standard, 1- NRL model)
0           Rotating Earth
1           Speed of Sound (1- actual, 0-constant (sos at sea level))
1           Keep mass constant (0- constant mass, 1- fuel expended)

TRAJECTORY PARAMETERS
.1          Time Step
1000.       Maximum Time

COMPUTATION MODULES
1           Auxillary Calculation
1           Calculate Ranges
0           Calculate Orbital Parameters
0           Calculate Entry Parameters
0           Full Guidance Output

OPTIMIZATION PARAMETERS
0           optimization method
1           print progress (0 - no, 1 - debug single run, -1 - debug optimization)

OUTPUT PARAMETERS
0           screen output (0- off, 2- final output only, 1- all output)
0           increment value for output file (0 - default=1000)
0           print input to file
1           Tecplot header

CONSTANTS
9.80665     acceleration due to gravity (m/s)
6378.       radius of earth (km)
288.16      sea level temperature (K)
1.01325e5   sea level pressure (N/m^2)
1.225       sea level density (kg/m^3)
```

Listing 9.4.3: Trajct.dat UPTOP Output File that is used in TPSOPT and SMB

```
TRAJCT      100      10
0.0  6.9200  26105.  -0.110
12.0  6.9300  26068.  -0.130
24.0  6.9400  25964.  -0.150
36.0  6.9600  25815.  -0.160
48.0  6.9700  25651.  -0.180
60.0  6.9900  25507.  -0.200
72.0  7.0100  25414.  -0.210
84.0  7.0200  25395.  -0.230
96.0  7.0300  25456.  -0.250
108.0  7.0400  25590.  -0.260
120.0  7.0500  25778.  -0.280
132.0  7.0600  25990.  -0.300
144.0  7.0700  26191.  -0.310
```

156.0	7.0700	26347.	-0.330						
168.0	7.0800	26430.	-0.350						
180.0	7.0900	26425.	-0.360						
192.0	7.1000	26335.	-0.380						
204.0	7.1200	26181.	-0.400						
216.0	7.1500	26001.	-0.410						
228.0	7.1900	25850.	-0.430						
240.0	7.2300	25789.	-0.450						
252.0	7.2900	25878.	-0.460						
264.0	7.3500	26167.	-0.480						
276.0	7.4300	26694.	-0.500						
282.0	7.4700	27056.	-0.510						
				TECPLOT		1283.PLT			
timesp	201	0.000	60.000	120.000	180.000	240.000	282.000		

9.5 Run UCDA to Generate Mesh for TPSOPT and SMB

This section corresponds to the Step 2 in the Graphical User Interface (GUI). See Figure 9.5.1 below.

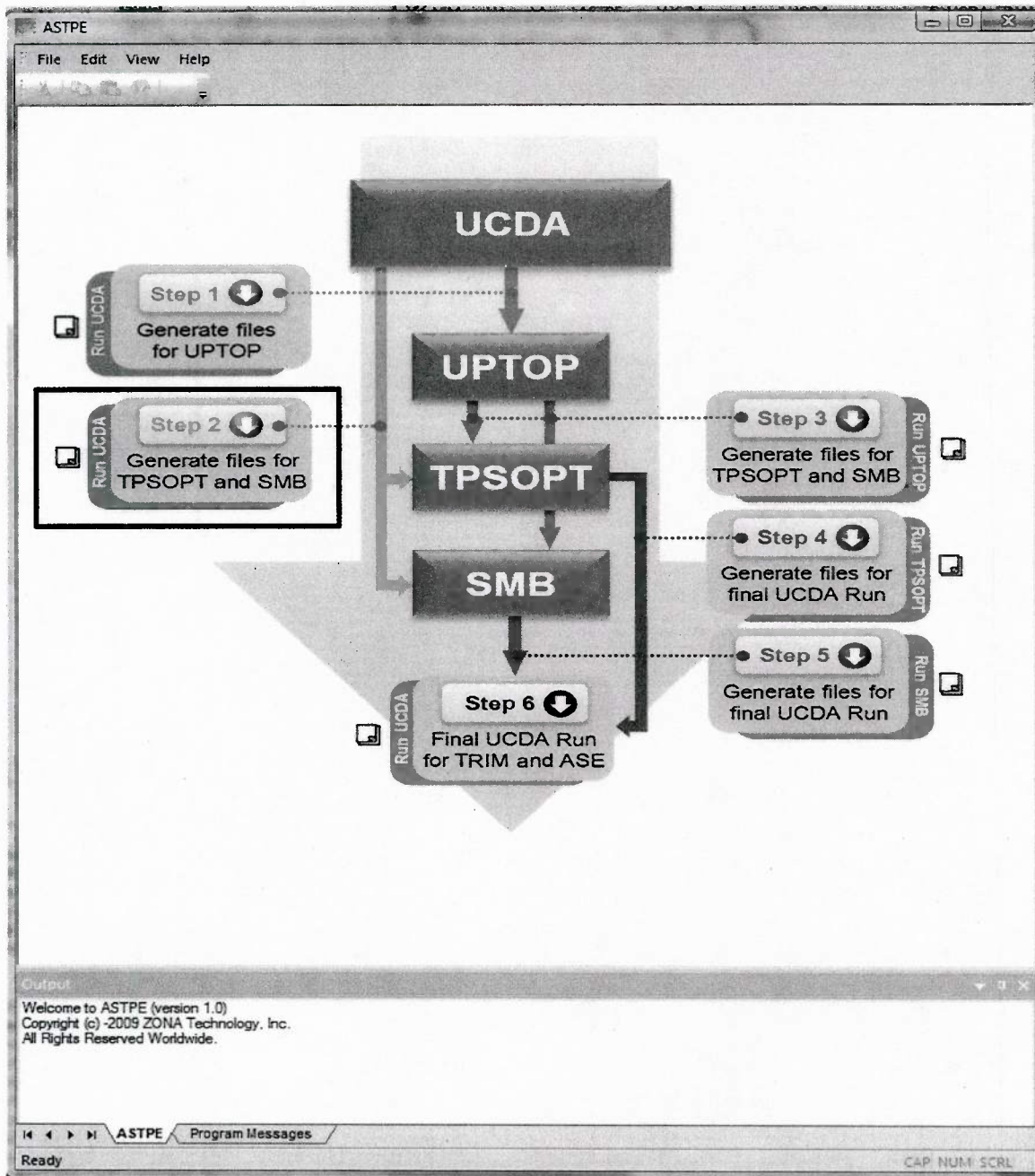


Figure 9.5.1 Section Corresponding to Step 2 of GUI

Input Files:

File Name	Type	Remarks	See Listing
vehicle.inp	Standard input file	Also look at Table 9.5.1	Shown in Listing 9.5.1
chem.bin	Engine chemistry information	Required	Shown in Listing 9.2.2
SEDvehicle.inp	Standard input file for SED type vehicle	Required	Shown in Listing 9.2.3

Output Files:

File Name	Type	Remarks	See Listing
geom_data.dat	unformatted	See Fig. 9.2.1	Not shown

Input File descriptions

vehicle.inp: See Listing 9.5.1 for the entire input file. The part of the input file that is used to command the code to generate mesh data for TPSOPT and SMB is shown in Table 9.5.1. It can be noted that **itps** is set to **1** in this case. This is the most important parameter to generate the mesh for TPSOPT and SMB. To run the code faster and only to output geometry information, **ideriv**, **itrajectory**, **itrim** are all set to **0**.

chem.bin: This file remains the same for all UCDA runs. Please see Section 9.2 for description on this file.

SEDvehicle.inp: This file remains the same for all SED runs. Please see Section 9.2 for description on this file.

Output File descriptions

geom_data.dat: This file is unformatted and thus it cannot be shown. It contains information such as grid points, panel ID, normal vector, area etc. The vehicle has been shown in Figure 9.2.1. This information is read into TPSOPT and SMB to compute heat flux and load respectively.

The computational run time for generating the geometry information is about a few seconds.

**Table 9.5.1: Necessary Block on Vehicle.inp to
Generate Geometry Information**

TEST INPUT DECK: Note - this line must be here!	
2	ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1	ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle, (2) max throttle
1	iunits - Output unit switch: SI (1) or English (2)
3	ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1	iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2	inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1	iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
0	itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0	icone - cone flow data: exact (0), curve-fit approximation (1)
4	imodel - Forebody type: WA (1), VWA (2), VWA + cone flow (3), or SED (4)
0	itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0	ideriv - Calculate derivatives: no (0), yes (1)
1	itps - If itps is 1, then prepare for tps and smb. nderiv and itps cannot be 1 at one time
0	ifedback - If 1, then gets weight and Cg information from SMB and TPSOPT

Listing 9.5.1: Vehicle.inp Input File for TPS and SMB Geometry File Generation

```

TEST INPUT DECK: Note - this line must be here!
2      ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1      ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle, (2) max throttle
1      iunits - Output unit switch: SI (1) or English (2)
3      ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1      iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2      inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1      iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
0      itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0      icone - cone flow data: exact (0), curve-fit approximation (1)
4      imodel - Forebody type: WA (1), VWA (2), VWA + cone flow (3), or SED (4)
0      itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
0      nderiv - Calculate derivatives: no (0), yes (1)
1      itps - If itps is 1, then prepare for tps and smb. nderiv and itps cannot be 1 at one time
1      ifedback - If 1, then gets weight and Cg information from SMB and TPSOPT

OUTPUT FILE SWITCHES AND NAMES:
0      'plot.dat'          VEHICLEFIG:      off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23          1st # -> # of variables to read, others -> vars to plot
0      'metrics.dat'      METRICS:      off (0), on-real (1), on-cmplx (2)
0      'cowlexit.dat'     COWLEXIT:      off (0), on (1)
0      'moc.dat'          NOZFIG:      off (0), P,T,M (1), all (2)
0      'offdesign.dat'     AOA:          off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0      'scramjet.dat'     CKENGINE:      off (0), on (1)
0      IPRINTINLET:      off (0), all (1), results (2), all-real (3), results-real (4)
0      IPRINTENGINE:      off (0), on (1)
0      IDEBUG:            off (0), on (1) [print debugging info]

ZONE DATA AND GRID SIZES:
21      NUMBER OF ZONES
'forebody : top'          3          3
'keel : top'              3          3
'aftbody : top'           3          3
'forebody : bot'         31         31
'ramps : bot'            55         6
'comb : bot'             101        6
'cowl : top'             101        6
'nozzle : bot'           31         6
'ramp walls : inside'     35         6
'comb wall : inside'     101        7
'nozzle wall : inside'    21         7
'aftbody : bot'          101        31
'cowl : bot'             101        6
'ramp walls : outside'    35         6
'comb wall : outside'     101        7
'nozzle wall : outside'   21         7
'SEDbody : top'          121        46
'Control_1 : top'         31         31 (Control surface dimensions must be the same)
'Control_1 : bottom'      31         31 (Control surface dimensions must be the same)
'Control_2 : top'         31         31 (Control surface dimensions must be the same)
'Control_2 : bottom'      31         31 (Control surface dimensions must be the same)

INPUT DATA:  (0 = degrees, 1 = m, 2 = ft, 3 = atm, 4 = dimensionless, K or kg, 5 = psf)

```


Xl	x	xu	unit	res	name
22500.	26290.	30000.	1	2500.	'altitude' - altitude (if required)
1500.	1700.	2000.0	5	250.	'q0' - dynamic pressure (if required)
.50	1.0299	1.0	4	.250	'equiv' - equivalence ratio
1.	1.0	0.0	4	-.10	'throttle' - engine throttle (if required)
6.0	7.0	8.00	4	.5	'm0' - Mach number
-2.00	0.0	3.00	0	.5	'AOA' - angle of attack
5.0	4	'Mdes'			- design Mach number
0.2935	0	'AOAdes'			- design angle of attack
26000.	1	'Zdes'			- design altitude
6.2672	1	'lvehicle'			- vehicle length
5.5939	0	'thforclu'			- forebody upper surface angle
3.8700	0	'thforcll'			- forebody ramp angle
0.5873	1	'lcontrol'			- control surface length
5.0	0	'th_control'			- control surface deflection angle
0.9920	0	'th_expn'			- nozzle initial expansion angle
10.8958	0	'th_exit'			- nozzle exit angle
0.0	4	'p_nozpoly'			- % diff between nozzle designs [DON'T USE-defaulted to 1.]
2.901	1	'lcowl'			- cowl length (isolator/combustor)
.3	1	'lcowltext'			- cowl extension length (internal nozzle)
0.545	4	'p_iso'			- percent of lcowl that is isolator
.3238	1	'height'			- height of vehicle (if required)
20.0	1	'linlet'			- inlet length of vehicle (if required)
.28	1	'wengine'			- width of the engine (currently defaulted to unit width)
3.00	4	'iramps'			- number of inlet ramps in addition to the forebody
4.4615	0	'th_ramp1'			- inlet ramp 1 angle
5.1567	0	'th_ramp2'			- inlet ramp 2 angle
5.9844	0	'th_ramp3'			- inlet ramp 3 angle
0.0	0	'th_ramp4'			- inlet ramp 4 angle
0.0	0	'th_ramp5'			- inlet ramp 5 angle
3.09	0	'th_div1'			- first combustor expansion angle
1.2	0	'th_div2'			- second combustor expansion angle
0.01	1	'Xinjs'			- beginning of injectors (m)
0.02	1	'Xinje'			- end of injectors (m)
0.01	1	'Lmix'			- fuel mixing length (m)
1.00	4	'eta_mix'			- fuel mixing and burning efficiency
4000.	4	'Tlimit'			- maximum engine temperature (K)
90.	0	'Thetainj'			- injector angle (degrees) [90 deg. is normal to flow]
1200.	4	'Tw'			- adiabatic wall temperature (K)
0.1527	4	'nfor'			- forebody exponent n
2.0	2	'wfor'			- forebody width
2.0	1	'lfor'			- forebody length
0.2427	4	'mfor'			- forebody exponent m
5.797	0	'thforle'			- forebody leading edge angle
21.519	0	'th_le'			- leading edge attachment angle
0.0000	4	'p_k1'			- keel-line height percentage
0.25	4	'fuelfrac'			- vehicle fuel volume fraction
0.0104	2	't_plate'			- shell plate thickness (Tungsten)
0.00000	4	'mass_smb'			- mass due to Structural Modal Base (SMB) analysis
0.00000	4	'mass_tps'			- mass due to Thermal Protection System (TPS) analysis
0.00000	4	'mass_nose'			- mass due to Thermal Protection System (TPS) analysis

9.6 Run TPSOPT for Optimizing the Thermal Protection System

Input Files:

File Name	Type	Remarks	See Listing
sed_tpsopt.inp	Standard input file	Required	Shown in listing 9.6.1
traject.dat	Trajectory data generated by UPTOP	Inserted into the Standard input file sed_tpsopt.INP by the INCLUDE bulk data card	Shown in Listing 9.4.3
geom_data.dat	Aerodynamic mesh generated by UCDA	Imported by the ASSIGN AEROBASE executive control command	Not Shown

Output Files:

File Name	Type	Remarks	See Listing
sed_tpsopt.out	Standard output file	Print out results	Shown in Listing 9.6.2
AERO.PLT	TECPLOT file of aerodynamic mesh.	Generated by the PLTAERO bulk data card with ID=1	Not Shown
SED_TPS3.PLT	TECPLOT file containing the TPS thickness of each layers on the aerodynamic panel model	Generated by the PLTTPS bulk data card with ID=103	Not Shown
SED_TPS4.PLT	TECPLOT file containing the total TPS thickness on each aerodynamic panel model	Generated by the PLTTPS bulk data card with ID=-104	Not Shown
1283.PLT	TECPLOT file containing the heat flux at the last time step of the trajectory.	Generated by the TRAJECT bulk data card	Not shown
mass_tps.dat	Mass of the optimized TPS	Input file for UCDA to update the change of weight due to TPS	Shown in Listing 9.6.3

9.6.1 Descriptions of the Input File: sed_tpsopt.inp (Shown in Listing 9.6.1)

General description of Executive Control Section, Case Control Section and Bulk Data Section of TPSOPT input is given in the Users Manual (Sections 5.3 and 5.4). For sample SED, the TPSOPT input is described here.

The aerodynamic mesh of the SED configuration generated by UCDA is stored in the file “geom_data.dat” and imported into the TPSOPT module by the following executive control command:

```
ASSIGN AEROBASE = geom_data.dat
```

There is only one subcase defined in the case control command shown as follows:

```
TPSDES = 100
```

This case control command refers to a **TPSDES** bulk data card with ID = 100 in the Bulk Data Section. The interrelationship of all bulk data cards in the Bulk Data Section is presented in Figure 9.6.1.

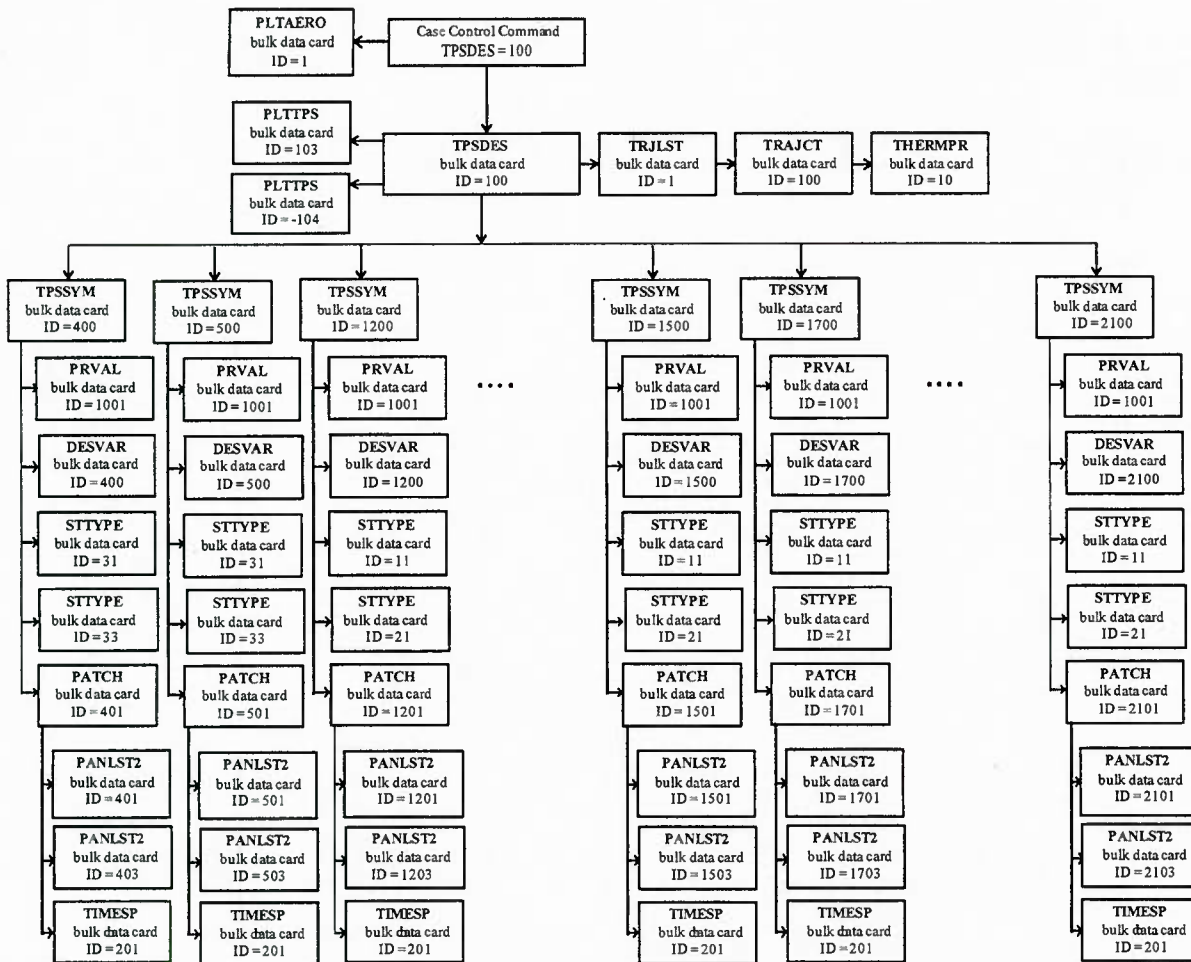


Figure 9.6.1 Interrelationship of All Bulk Data Cards for Optimizing the TPS for SED

The aerodynamic mesh generated by UCDA and imported by the ASSIGN AEROBASE = geom_data.dat executive control command can be visualized using the TECPLOT file "AERO.PLT" that is generated by a **PLTAERO** bulk data card with ID = 1. This aerodynamic mesh is shown in Figure 9.6.2.

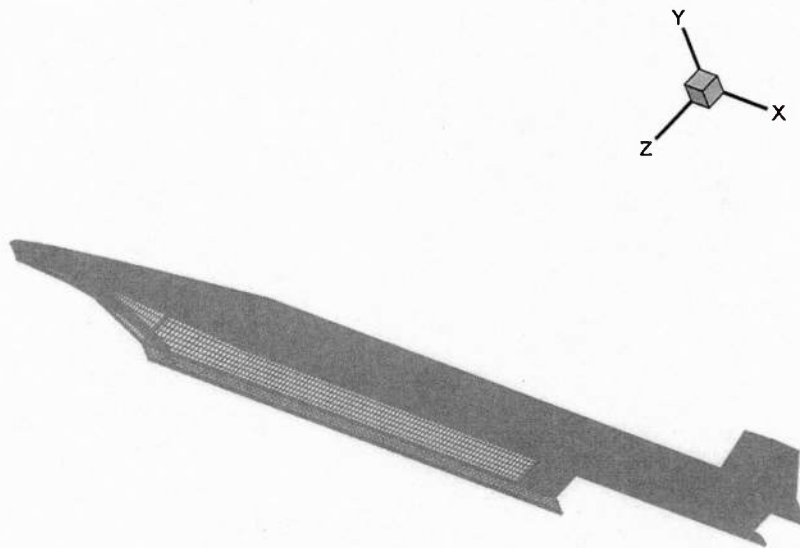


Figure 9.6.2 Visualization of Aerodynamic Mesh Using the PLTAERO bulk data card

There are 21 patches in the aerodynamic mesh but among them, only 8 patches with panel ID starting from 400001, 500001, 1200001, 1300001, 1400001, 1500001, 1700001, 1800001, 1900001, 2000001 and 2100001, respectively, are the outer surfaces and require the thermal protection system (TPS). Thus, the purpose of TPSOPT is to design the TPS system on those 11 patches for minimum TPS weight while satisfying the temperature constraints of each TPS layer as well as the load-carried structure. These temperature constraints are computed by integrating the heat flux on the outer surfaces along the trajectory generated by UPTOP. This trajectory is provided in the file "traject.dat" in which a **TRAJCT** bulk data card with ID = 100 and a **TIMESP** bulk data card with ID = 201 are stored. These two bulk data cards are automatically inserted into the bulk data section by the **INCLUDE** bulk data card shown as follows:

```
INCLUDE  traject.dat
```

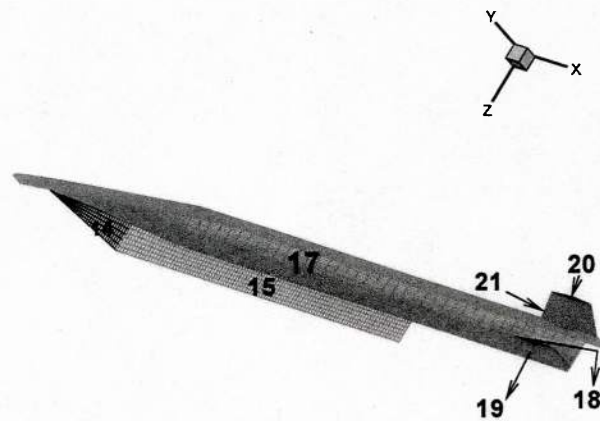
Note that the **TRAJCT** bulk data card with ID = 100 is referred to by a **TRJLST** bulk data card with ID = 1 that is activated by the **TPSDES** bulk data card with ID = 100. The parameters for computing the heat flux by the aeroheating analysis are defined in a **THERMPR** bulk data card with ID = 10 that is referred to by the **TRAJCT** bulk data card with ID = 100.

In order to design the minimum TPS weight on those 7 patches, 7 **TPSSYM** bulk data cards with ID = 400, 500, 1200, 1300, 1400, 1500, 1700, 1800, 1900, 2000, and 2100 are specified that are all referred to by the **TPSDES** bulk data card with ID = 100. Each **TPSSYM** bulk data card refers to a **PRVAL** bulk data card, a **DESVAR** bulk data card, a **PATCH** bulk data card and two **PANLST2** bulk data cards. The **PRVAL** bulk data card with ID = 1001 that is referred to by all the 11 **TPSSYM** bulk data cards defines the parameters for the transient thermal analysis. The **PATCH** bulk data card first refers to a **PANLST2** bulk data card to list the identification numbers of the panels that belong to a patch in the aerodynamic mesh. Then it refers to another **PANLST2** bulk data card to define a set of so-called “hot panels” on which the temperature constraints of the TPS is imposed by listing the identification numbers of those hot panels. Note that those hot panels must be a subset of the panels of the patch.

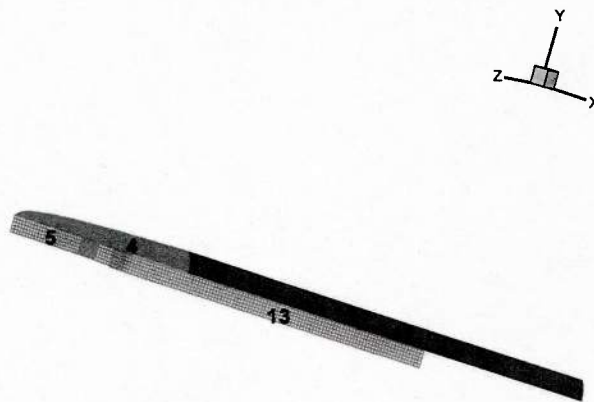
The temperature constraints are evaluated at all layers of the TPS located on those hot panels and are computed at a set of time steps defined by the **TIMESP** bulk data card with ID = 201. Thus, the total number of the temperature constraints is product of the number of layers of the TPS, the number of the hot panels, and the number of time steps listed in the **TIMESP** bulk data card. This is the reason why only 6 time steps in the **TIMESP** are selected from those 25 time steps in the **TRAJCT** bulk data card. Otherwise, if all those 25 time steps listed in the **TRAJCT** bulk data card are used to evaluate the temperature constraints, the number of temperature constraints would be too many and might require the amount of computer memory beyond the available memory in the computer.

Seven **PATCH** bulk data cards with ID = 401, 501, 1201, 1301, 1401, 1501, 1701, 1801, 1901, 2001, and 2101 that are referred to by those 11 **TPSSYM** bulk data cards respectively, are used to define the panels on those 11 outer surface patches in the aerodynamic mesh by specifying 11 **PANLST2** bulk data cards with ID = 401, 501, 1201, 1301, 1401, 1501, 1701, 1801, 1901, 2001,

and 2101. The hot panels on those 11 patches are defined by another 7 PANLST2 bulk data cards with ID = 403, 503, 1203, 1303, 1403, 1503, 1703, 1803, 1903, 2003, and 2103. The identification numbers of those panels on the 11 patches are presented in Figure 9.6.3.



(a)



(b)

Figure 9.6.3 Panel Identification Numbers on the 11 Patches with TPS

The correspondences between 11 patches and the zones shown in Figure 9.2.1 are:

patch 4: forebody bottom

patch 5: ramp bottom

patch 12: aftbody bottom

patch 13: cowl bottom

patch 14: ramp wall outside

patch 15: combustor wall outside

patch 17: SED body top

patch 18: control surface 1 top

patch 19: control surface 1 bottom

patch 20: control surface 2 top

patch 21: control surface 2 bottom

Patches 4 and 5 with panel ID starting from 400001 and 500001, respectively, are potentially exposed to the high aeroheating environment. This suggests that in order to achieve a minimum weight design of the TPS, different TPS concepts and materials from the rest of the patches be employed for those two patches. This TPS consists of two TPS layers and is defined in the **TPSSYM** bulk data cards with ID = 400 and 500 in which the top layer is defined by a **STTYPE** bulk data card with ID = 31 and the bottom layer is defined by a **STTYPE** bulk data card with ID = 33. The **STTYPE** bulk data card with ID = 31 defines a Slab TPS structure made by ZIRCONIA FIBERS with initial thickness = 0.1 m whereas the **STTYPE** bulk data card with ID = 33 defines a Slab structure made by a HEAT SINK with thickness = 0.2 m. This HEAT SINK is a virtual material with a very high heat capacity to represent an active cooling concept that absorbs the heat by circling the fuel. The thickness of the ZIRCONIA FIBERS is subjected to the design for minimum weight with the design variable being defined by a **DESVAR** bulk data card whereas the thickness of the HEAT SINK is kept to be constant at 0.2 m. Two **DESVAR** bulk data cards with ID = 400 and 500 are specified that are referred to by the entry **DESVAR1** of the **TPSSYM** bulk data cards with ID = 400 and 500, respectively. A minimum and maximum thickness of 0.0002 m and 10.0 m for the ZIRCONIA FIBERS is also specified in these **TPSSYM** bulk data cards. Note that the entry **DESVAR2** of these two **TPSSYM** bulk

data cards is blank to indicate that the bottom layer; i.e. the thickness of the HEAT SINK, is not subjected to design and remains unaltered. The purpose of the **DESVAR** bulk data card is to define a curvilinear coordinates over the patch on which a set of shape functions can be formulated to represent the thickness distribution of the ZIRCONIA FIBERS on this patch. Thus, the actual design variables controlled by the optimizer are the unknown coefficients of those shape functions and are not the thickness of the ZIRCONIA FIBERS on each panel. Using these shape functions, the number of design variables can be greatly reduced and the thickness distribution of the optimized TPS is ensured to be smooth for the ease of fabrication. This curvilinear coordinates is defined by selecting a set of M by N panels on the patch. A 2 by 2 panels is defines by the **DESVAR** bulk data cards with ID = 400 and a 2 by 3 panels is defined by the **DESVAR** bulk data card with ID = 500. (Please refer to Users Manual Section 5.4, TPSOPT Bulk Data Section, for more information about DESVAR bulk data card.)

The TPS on the rest of 9 patches defined by the four **TPSSYM** bulk data cards with ID = 1200, 1300, 1400, 1500, 1700, 1800, 1900, 2000 and 2100 is also a two-layer TPS. The top layer is a Slab structure made by CRI-II and is defined by a **STTYPE** bulk data card with ID = 11 whereas the bottom layer is a thin skin made by RTV-560 and is defined by a **STTYPE** bulk data card with ID = 21. The top layer is subjected to design with initial thickness of 0.1 m and minimum thickness and maximum thickness of 0.002 m and 10.0 m, respectively, and the bottom layer is kept to be 2.45×10^{-5} m. The **DESVAR** bulk data cards with ID = 1200, 1300, 1400, 1500, 1700, 1800, 1900, 2000 and 2100 that are referred by the **TPSSYM** bulk data cards with ID = 1200, 1300, 1400, 1500, 1700, 1800, 1900, 2000 and 2100, respectively, are specified to select an M by N panels for defining the curvilinear coordinates on their respective patches. A set of 2 by 2 panels is defined by the **DESVAR** bulk data cards with ID = 1700, 1800, 1900, 2000 and 2100 and a set of 3 by 3 panels by the **DESVAR** bulk data card with ID = 1200. The panels set are 3 by 2 and 2 by 3 for **DESVAR** bulk data card with ID = 1300 and 1400 respectively. (Please refer to Users Manual Section 5.4, TPSOPT Bulk Data Section, for more information about DESVAR bulk data card.)

In order to visualize to optimized TPS thickness distribution, two **PLTTPS** bulk data cards with ID = 103 and = -104 are employed that generate two TECPLOT files called “SED_TPS3.PLT”

and “SED_TPS4.PLT”, respectively where the first contains the thickness of each TPS layer and the maximum temperature on each panel and the latter contains the total thickness of the TPS. In addition, the heat flux at a time step in the trajectory can be also outputted in a TECPLOT file by specifying a file name in the **TRAJCT** bulk data card. A TECPLOT file called “1283.PLT” is generated to display the heat flux at the last time step of the trajectory.

The final optimized averaged TPS thickness of each layer of patched 400, 500, 1200, 1300, 1400, 1500, 1700, 1800, 1900, 2000 and 2100 are shown in Figures 2.6.4 to 2.6.14. The masses of those 11 TPS are 5.85777017E-03, 4.91326593E-03, 4.33150432E+00, 1.48797294E-01, 3.83791494E-02, 2.14508372E-01, 1.58559431E+01, 6.73263566E-01, 6.52450415E-01, 6.19316060E-01, and 6.61571832E-01 KG, respectively; giving a total mass of the entire TPS of 43.24 KG (both sides). This total mass along with the sum of the product of TPS mass on each panel and the location of the panel is stored in a file called “mass_tps.dat” that is shown in Listing 9.6.3. This file will be an input file of UCDA to include the TPS weight in the total vehicle weight for the next design cycle.

OPTIMAL STRUCTURES OF TPS FOR PATCH = 400 (WITH AVERAGE THICKNESS)			
=====			
ZIRCONIA FIBERS	slab	i	0.00066 FT 1840.8 F
=====			
HEAT SINK	slab	i	0.65617 FT 1771.5 F
=====			

Figure 9.6.4 Optimized Averaged TPS Thickness of Patch 400

OPTIMAL STRUCTURES OF TPS FOR PATCH = 500 (WITH AVERAGE THICKNESS)			
=====			
ZIRCONIA FIBERS	slab	i	0.00066 FT 2139.8 F
=====			
HEAT SINK	slab	i	0.65617 FT 2069.4 F
=====			

Figure 9.6.5 Optimized Averaged TPS Thickness of Patch 500

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1200
(WITH AVERAGE THICKNESS)

=====			i	
CRI-I	2.0	slab	0.09478 FT	1576.5 F
=====			i	
RTV-560		thin skin	0.00066 FT	494.6 F
=====				

Figure 9.6.6 Optimized Averaged TPS Thickness of Patch 1200

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1300
(WITH AVERAGE THICKNESS)

=====			i	
CRI-I	2.0	slab	0.00066 FT	100.0 F
=====			i	
RTV-560		thin skin	0.00066 FT	100.0 F
=====				

Figure 9.6.7 Optimized Averaged TPS Thickness of Patch 1300

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1400
(WITH AVERAGE THICKNESS)

=====			i	
CRI-I	2.0	slab	0.00066 FT	100.0 F
=====			i	
RTV-560		thin skin	0.00066 FT	100.0 F
=====				

Figure 9.6.8 Optimized Averaged TPS Thickness of Patch 1400

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1500
(WITH AVERAGE THICKNESS)

=====			i	
CRI-I	2.0	slab	0.00066 FT	100.0 F
=====			i	
RTV-560		thin skin	0.00066 FT	100.0 F
=====				

Figure 9.6.9 Optimized Averaged TPS Thickness of Patch 1500

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1700
(WITH AVERAGE THICKNESS)

=====			i	
CRI-I	2.0	slab	0.07724 FT	2173.7 F
=====			i	
RTV-560		thin skin	0.00066 FT	546.2 F
=====				

Figure 9.6.10 Optimized averaged TPS thickness of patch 1700

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1800
(WITH AVERAGE THICKNESS)

=====			i	
CRI-I	2.0	slab	0.07815 FT	1962.3 F
=====			i	

RTV-560	thin skin	0.00066 FT	546.0 F

Figure 9.6.11 Optimized averaged TPS thickness of patch 1800

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1900
(WITH AVERAGE THICKNESS)

CRI-I 2.0	slab	0.07589 FT	1962.3 F
RTV-560	thin skin	0.00066 FT	480.3 F

Figure 9.6.12 Optimized averaged TPS thickness of patch 1900

OPTIMAL STRUCTURES OF TPS FOR PATCH = 2000
(WITH AVERAGE THICKNESS)

CRI-I 2.0	slab	0.07154 FT	1922.1 F
RTV-560	thin skin	0.00066 FT	533.8 F

Figure 9.6.13 Optimized averaged TPS thickness of patch 2000

OPTIMAL STRUCTURES OF TPS FOR PATCH = 2100
(WITH AVERAGE THICKNESS)

CRI-I 2.0	slab	0.07714 FT	1922.0 F
RTV-560	thin skin	0.00066 FT	509.1 F

Figure 9.6.14 Optimized averaged TPS thickness of patch 2100

Using the file "SED_TPS4.PLT", the total thickness contour of the TPS and the maximum temperature distribution are depicted in Figures 9.6.15 and 9.6.16, respectively. The heat flux at the last time step of the trajectory is shown in Figure 9.6.17.

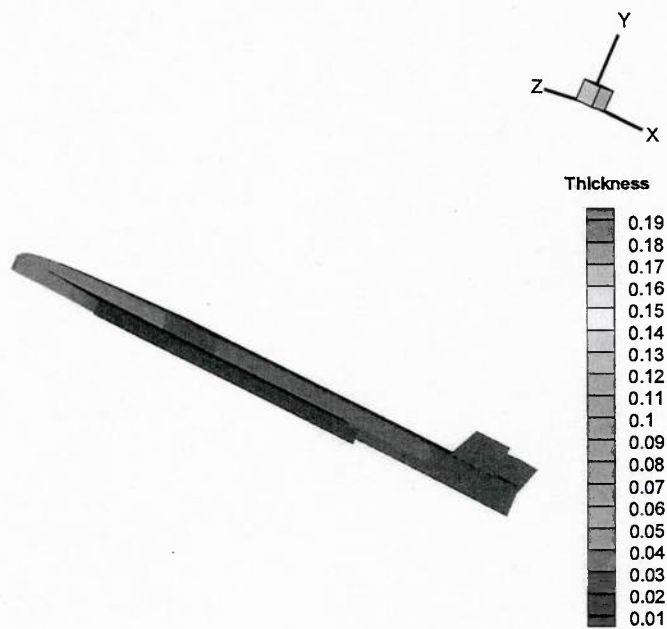


Figure 9.6.15 Thickness Contour of the Optimized TPS

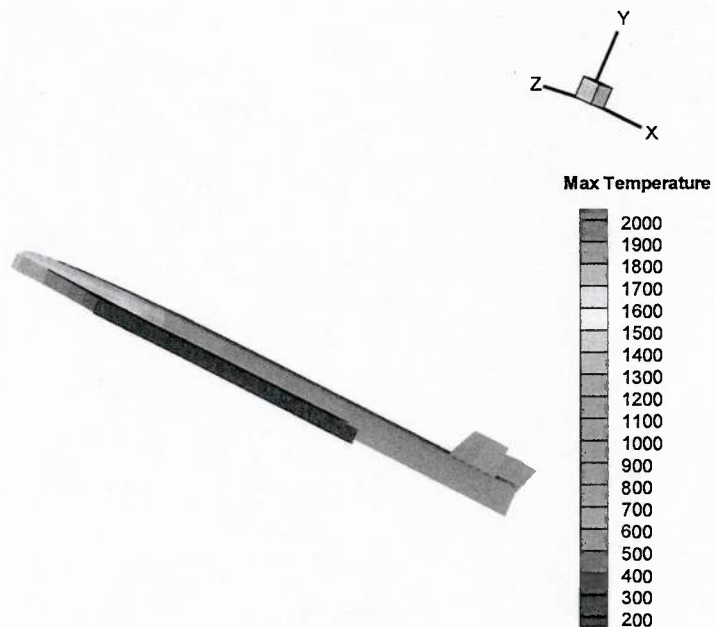


Figure 9.6.16 Temperature Contour of the Optimized TPS

[illegible]

```

1900    2000    2100

TRJLST  1

100

THERMPR 10    100.F  yes    2    0    0.8

$234567812345678123456781234567812345678123456781234567812345678

$forebody bottom

TPSSYM  400    401    2    1001

        400    31    .0002  10.

        33    .0002  10.

PATCH  401    401    403    NO    201

PANLST2 401    400001 400001 thru  400900

PANLST2 403    400001 400001 400030 400871 400900

DESVAR  400    2    2

        400001 400030

        400871 400900

$234567812345678123456781234567812345678123456781234567812345678

$ramp bottom

TPSSYM  500    501    2    1001

        500    31    .0002  10.

        33    .0002  10.

PATCH  501    501    503    NO    201

PANLST2 501    500001 500001 thru  500270

PANLST2 503    500001 500001 500054 500109 500162 500217 500270

DESVAR  500    2    3

        500001 500054

        500109 500162

        500217 500270

$234567812345678123456781234567812345678123456781234567812345678

$aftbody bottom

TPSSYM  1200   1201    2    1001

        1200   11    .0002  10.

        21    .0002  10.

PATCH  1201   1201   1203    NO    201

PANLST2 1201   1200001 1200001 thru  1203000

PANLST2 1203   1200001 1200001 1200025 1200050 1200075 1200100 1201501

        1201525 1201550 1201575 1201600 1202901 1202925 1202950 1202975

```

1203000

DESVAR 1200 3 3

1200001 1201501 1202901

1200050 1201550 1202950

1200100 1201600 1203000

\$234567812345678123456781234567812345678123456781234567812345678

\$cowl bottom

TPSSYM 1300 1301 2 1001

1300 11 .0002 10.

21 .0002 10.

PATCH 1301 1301 1303 NO 201

PANLST2 1301 1300001 1300001 thru 1300500

PANLST2 1303 1300001 1300001 1300050 1300100 1300401 1300450 1300500

DESVAR 1300 3 2

1300001 1300050 1300100

1300401 1300450 1300500

\$234567812345678123456781234567812345678123456781234567812345678

\$ramp wall outside

TPSSYM 1400 1401 2 1001

1400 11 .0002 10.

21 .0002 10.

PATCH 1401 1401 1403 NO 201

PANLST2 1401 1400001 1400001 thru 1400170

PANLST2 1403 1400001 1400001 1400017 1400034 1400137 1400153 1400170

DESVAR 1400 2 3

1400001 1400137

1400017 1400153

1400034 1400170

\$234567812345678123456781234567812345678123456781234567812345678

\$combustor wall outside

TPSSYM 1500 1501 2 1001

1500 11 .0002 10.

21 .0002 10.

PATCH 1501 1501 1503 NO 201

PANLST2 1501 1500001 1500001 thru 1500600

PANLST2 1503 1500001 1500001 1500050 1500100 1500501 1500550 1500600

DESVAR 1500 3 2

1500001 1500050 1500100

1500501 1500550 1500600

\$234567812345678123456781234567812345678123456781234567812345678

\$nozzle wall outside

TPSSYM 1600 1601 2 1001

1600 11 .0002 10.

21 .0002 10.

PATCH 1601 1601 1603 NO 201

PANLST2 1601 1600001 1600001 thru 1600600

PANLST2 1603 1600001 1600001 1600020 1600101 1600120

DESVAR 1600 2 2

1600001 1600020

1600101 1600120

\$234567812345678123456781234567812345678123456781234567812345678

\$SED body

TPSSYM 1700 1701 2 1001

1700 11 .0002 10.

21 .0002 10.

\$ 1700 41 .0002 10.

\$ 1700 31 .0002 10.

\$ 31 .0002 10.

PATCH 1701 1701 1703 NO 201

PANLST2 1701 1700001 1700001 thru 1705400

PANLST2 1703 1700001 1700001 1700120 1705281 1705400

DESVAR 1700 2 2

1700001 1700120

1705281 1705400

\$234567812345678123456781234567812345678123456781234567812345678

\$control surface 1 top

TPSSYM 1800 1801 2 1001

1800 11 .0002 10.

21 .0002 10.

PATCH 1801 1801 1803 NO 201

PANLST2 1801 1800001 1800001 thru 1800900

PANLST2 1803 1800001 1800001 1800030 1800871 1800900

```

DESVAR 1800 2 2
1800001 1800030
1800871 1800900
$234567812345678123456781234567812345678123456781234567812345678
$control surface 1 bottom
TPSSYM 1900 1901 2 1001
1900 11 .0002 10.
21 .0002 10.
PATCH 1901 1901 1903 NO 201
PANLST2 1901 1900001 1900001 thru 1900900
PANLST2 1903 1900001 1900001 1900030 1900871 1900900
DESVAR 1900 2 2
1900001 1900030
1900871 1900900
$234567812345678123456781234567812345678123456781234567812345678
$control surface 2 top
TPSSYM 2000 2001 2 1001
2000 11 .0002 10.
21 .0002 10.
PATCH 2001 2001 2003 NO 201
PANLST2 2001 2000001 2000001 thru 2000900
PANLST2 2003 2000001 2000001 2000030 2000871 2000900
DESVAR 2000 2 2
2000001 2000030
2000871 2000900
$234567812345678123456781234567812345678123456781234567812345678
$control surface 2 bottom
TPSSYM 2100 2101 2 1001
2100 11 .0002 10.
21 .0002 10.
PATCH 2101 2101 2103 NO 201
PANLST2 2101 2100001 2100001 thru 2100900
PANLST2 2103 2100001 2100001 2100030 2100871 2100900
DESVAR 2100 2 2
2100001 2100030
2100871 2100900

```


\$234567812345678123456781234567812345678123456781234567812345678

\$...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10...|

PRVAL 1001 99999000

0

STTYPE 11 1 315

0.100

STTYPE 21 6 245

2.45e-5

STTYPE 31 1 251

0.100

sttype 33 1 701

0.200

STTYPE 41 1 129

0.100

\$STTYPE 41 1 206

\$ 0.100

STTYPE 2 1 266

0.001

STTYPE 3 1 260

0.001

STTYPE 4 1 266

0.001

STTYPE 5 1 245

0.001

STTYPE 6 1 101

0.010

\$234567812345678123456781234567812345678123456781234567812345678

ENDDATA

Listing 9.6.2 Sample Output File: sed_tpsopt.out

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OF ZONA TECHNOLOGY, INC.

EXECUTIVE CONTROL SUMMARY

[...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10...|

ASSIGN AEROBASE=geom_data.DAT,print=1

CEND

CASE CONTROL SUMMARY

SINGLE PRECISION COMPUTATION

MAXIMUM ALLOCABLE MEMORY = 800 MEGABYTES

[...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10...|

TITLE=SED

ECHO=SORT

SUBCASE =1

TPSDES=100

BEGIN BULK

SORTED BULK DATA ECHO

CARD

COUNT |...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10...|

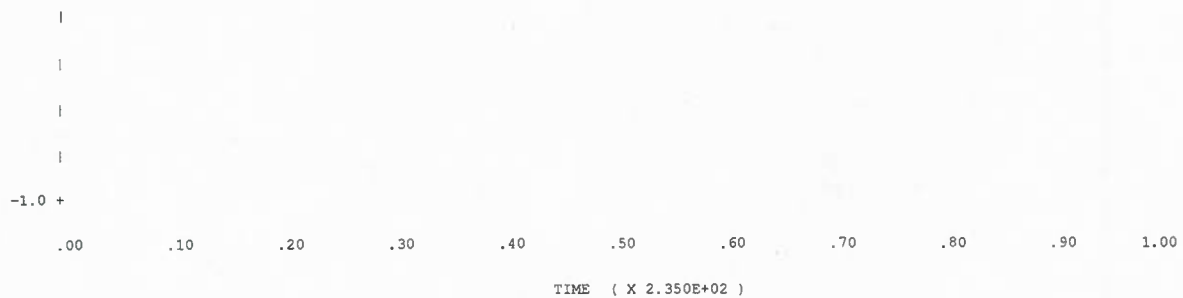
1 -	DESVAR	400	2	2
2 -		400001	400030	
3 -		400871	400900	
4 -	DESVAR	500	2	3
5 -		500001	500054	
6 -		500109	500162	
7 -		500217	500270	
8 -	DESVAR	1200	3	3
9 -		1200001	1201501	1202901
10 -		1200050	1201550	1202950
11 -		1200100	1201600	1203000
12 -	DESVAR	1300	3	2
13 -		1300001	1300050	1300100
14 -		1300401	1300450	1300500
15 -	DESVAR	1400	2	3
16 -		1400001	1400137	
17 -		1400017	1400153	
18 -		1400034	1400170	
19 -	DESVAR	1500	3	2
20 -		1500001	1500050	1500100
21 -		1500501	1500550	1500600
22 -	DESVAR	1600	2	2
23 -		1600001	1600020	
24 -		1600101	1600120	
25 -	DESVAR	1700	2	2
26 -		1700001	1700120	
27 -		1705281	1705400	
28 -	DESVAR	1800	2	2
29 -		1800001	1800030	
30 -		1800871	1800900	
31 -	DESVAR	1900	2	2
32 -		1900001	1900030	
33 -		1900871	1900900	

34 -	DESVAR	2000	2	2			
35 -		2000001	2000030				
36 -		2000871	2000900				
37 -	DESVAR	2100	2	2			
38 -		2100001	2100030				
39 -		2100871	2100900				
40 -	PANLST2	401	400001	400001	THRU	400900	
41 -	PANLST2	403	400001	400001	400030	400871	400900
42 -	PANLST2	501	500001	500001	THRU	500270	
43 -	PANLST2	503	500001	500001	500054	500109	500162 500217 500270
44 -	PANLST2	1201	1200001	1200001	THRU	1203000	
45 -	PANLST2	1203	1200001	1200001	1200025	1200050	1200075 1200100 1201501
46 -		1201525	1201550	1201575	1201600	1202901	1202925 1202950 1202975
47 -		1203000					
48 -	PANLST2	1301	1300001	1300001	THRU	1300500	
49 -	PANLST2	1303	1300001	1300001	1300050	1300100	1300401 1300450 1300500
50 -	PANLST2	1401	1400001	1400001	THRU	1400170	
51 -	PANLST2	1403	1400001	1400001	1400017	1400034	1400137 1400153 1400170
52 -	PANLST2	1501	1500001	1500001	THRU	1500600	
53 -	PANLST2	1503	1500001	1500001	1500050	1500100	1500501 1500550 1500600
54 -	PANLST2	1601	1600001	1600001	THRU	1600600	
55 -	PANLST2	1603	1600001	1600001	1600020	1600101	1600120
56 -	PANLST2	1701	1700001	1700001	THRU	1705400	
57 -	PANLST2	1703	1700001	1700001	1700120	1705281	1705400
58 -	PANLST2	1801	1800001	1800001	THRU	1800900	
59 -	PANLST2	1803	1800001	1800001	1800030	1800871	1800900
60 -	PANLST2	1901	1900001	1900001	THRU	1900900	
61 -	PANLST2	1903	1900001	1900001	1900030	1900871	1900900
62 -	PANLST2	2001	2000001	2000001	THRU	2000900	
63 -	PANLST2	2003	2000001	2000001	2000030	2000871	2000900
64 -	PANLST2	2101	2100001	2100001	THRU	2100900	
65 -	PANLST2	2103	2100001	2100001	2100030	2100871	2100900
66 -	PATCH	401	401	403	NO	201	
67 -	PATCH	501	501	503	NO	201	
68 -	PATCH	1201	1201	1203	NO	201	
69 -	PATCH	1301	1301	1303	NO	201	

70 -	PATCH	1401	1401	1403	NO	201
71 -	PATCH	1501	1501	1503	NO	201
72 -	PATCH	1601	1601	1603	NO	201
73 -	PATCH	1701	1701	1703	NO	201
74 -	PATCH	1801	1801	1803	NO	201
75 -	PATCH	1901	1901	1903	NO	201
76 -	PATCH	2001	2001	2003	NO	201
77 -	PATCH	2101	2101	2103	NO	201
78 -	PLTAERO	1			TECPLOT AERO.PLT	
79 -	PLTAERO	2			NASTRAN AERO1.PLT	
80 -	PLTTPS	-104	100	ALL	TECPLOT SED_T	PS4.PLT -30.00
81 -	PLTTPS	103	100	ALL	TECPLOT SED_T	PS3.PLT -30.00
82 -	PRVAL	1001		99999000		
83 -				0		
84 -	STTYPE	2	1	266		
85 -		0.001				
86 -	STTYPE	3	1	260		
87 -		0.001				
88 -	STTYPE	4	1	266		
89 -		0.001				
90 -	STTYPE	5	1	245		
91 -		0.001				
92 -	STTYPE	6	1	101		
93 -		0.010				
94 -	STTYPE	11	1	315		
95 -		0.100				
96 -	STTYPE	21	6	245		
97 -		2.45E-5				
98 -	STTYPE	31	1	251		
99 -		0.100				
100 -	STTYPE	33	1	701		
101 -		0.200				
102 -	STTYPE	41	1	129		
103 -		0.100				
104 -	THERMPR	10	100.F	YES	2	0 0.8
105 -	TIMESP	201	0.000	60.000	120.000	180.000 240.000 282.000

106 -	TPSDES	100	1	1					
107 -		400	500	1200	1300	1400	1500	1700	1800
108 -		1900	2000	2100					
109 -	TPSSYM	400	401	2	1001				
110 -		400	31	.0002	10.				
111 -			33	.0002	10.				
112 -	TPSSYM	500	501	2	1001				
113 -		500	31	.0002	10.				
114 -			33	.0002	10.				
115 -	TPSSYM	1200	1201	2	1001				
116 -		1200	11	.0002	10.				
117 -			21	.0002	10.				
118 -	TPSSYM	1300	1301	2	1001				
119 -		1300	11	.0002	10.				
120 -			21	.0002	10.				
121 -	TPSSYM	1400	1401	2	1001				
122 -		1400	11	.0002	10.				
123 -			21	.0002	10.				
124 -	TPSSYM	1500	1501	2	1001				
125 -		1500	11	.0002	10.				
126 -			21	.0002	10.				
127 -	TPSSYM	1600	1601	2	1001				
128 -		1600	11	.0002	10.				
129 -			21	.0002	10.				
130 -	TPSSYM	1700	1701	2	1001				
131 -		1700	11	.0002	10.				
132 -			21	.0002	10.				
133 -	TPSSYM	1800	1801	2	1001				
134 -		1800	11	.0002	10.				
135 -			21	.0002	10.				
136 -	TPSSYM	1900	1901	2	1001				
137 -		1900	11	.0002	10.				
138 -			21	.0002	10.				
139 -	TPSSYM	2000	2001	2	1001				
140 -		2000	11	.0002	10.				
141 -			21	.0002	10.				

142 -	TPSSYM	2100	2101	2	1001		
143 -		2100	11	.0002	10.		
144 -			21	.0002	10.		
145 -	TRAJCT	100	10				
146 -		0.0	6.9200	26105.	-0.110		
147 -		12.0	6.9300	26068.	-0.130		
148 -		24.0	6.9400	25964.	-0.150		
149 -		36.0	6.9600	25815.	-0.160		
150 -		48.0	6.9700	25651.	-0.180		
151 -		60.0	6.9900	25507.	-0.200		
152 -		72.0	7.0100	25414.	-0.210		
153 -		84.0	7.0200	25395.	-0.230		
154 -		96.0	7.0300	25456.	-0.250		
155 -		108.0	7.0400	25590.	-0.260		
156 -		120.0	7.0500	25778.	-0.280		
157 -		132.0	7.0600	25990.	-0.300		
158 -		144.0	7.0700	26191.	-0.310		
159 -		156.0	7.0700	26347.	-0.330		
160 -		168.0	7.0800	26430.	-0.350		
161 -		180.0	7.0900	26425.	-0.360		
162 -		192.0	7.1000	26335.	-0.380		
163 -		204.0	7.1200	26181.	-0.400		
164 -		216.0	7.1500	26001.	-0.410		
165 -		228.0	7.1900	25850.	-0.430		
166 -		240.0	7.2300	25789.	-0.450		
167 -		252.0	7.2900	25878.	-0.460		
168 -		264.0	7.3500	26167.	-0.480		
169 -		276.0	7.4300	26694.	-0.500		
170 -		282.0	7.4700	27056.	-0.510	TECPLOT	1283.PLT
171 -	TRJLST	1					
172 -		100					
173 -	ENDDATA						



MAXIMUM TEMPERATURE OF EVERY LAYER

LAYER: 1 2

Tmax: 3000.33 8540.33

Optv: 1840.80 1771.48

VALUES OF DESIGN VARIABLES :

LAYER	DEV01	DEV02	DEV03	DEV04
1	0.00020	0.00020	0.00020	0.00020

THE ORIGINAL OBJECTIVE FUNCTION = 1771.6535645

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.0020000

THE TOTAL OPTIMAL WEIGHT = 5.85777017E-03

OPTIMAL STRUCTURES OF TPS FOR PATCH = 400

(WITH AVERAGE THICKNESS)

		i	
ZIRCONIA FIBERS	slab	0.00066 FT	1840.8 F
		i	

		i	
HEAT SINK	slab	0.65617 FT	1771.5 F
		i	

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 400

PANEL	LAYER01	LAYER02
400001	0.00020 1840.80	0.20000 1771.48
400002	0.00020 1831.34	0.20000 1796.52
400003	0.00020 1821.88	0.20000 1786.89
400004	0.00020 1812.41	0.20000 1777.27
400005	0.00020 1802.95	0.20000 1767.64.....
.....		
.....		
400895	0.00020 1585.67	0.20000 1546.87
400896	0.00020 1585.67	0.20000 1546.87
400897	0.00020 1374.48	0.20000 1332.51
400898	0.00020 1366.32	0.20000 1324.23
400899	0.00020 1358.16	0.20000 1315.96
400900	0.00020 1350.01	0.20000 1265.35

OPTIMIZATION SYSTEM FOR TPSSYM = 500

TOTAL NUMBER OF DESIGN VARIABLES = 6

TOTAL NUMBER OF CONSTRAINS = 600

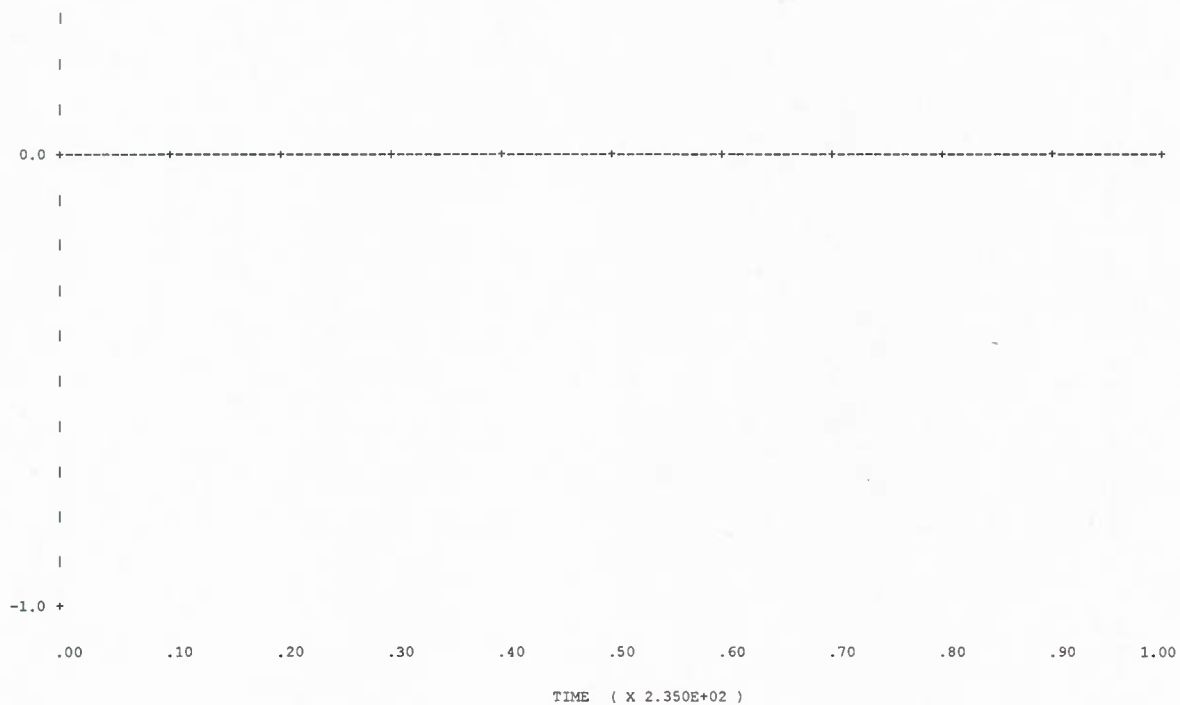
TOTAL NUMBER OF TEMP. CONSTRAINS = 72

TOTAL NUMBER OF TEMP. PRINTOUTS = 6

MAXIMUM TEMPERATURE OF EACH LAYER VS OUTPUT TIMES

X 0.2140E+04

1.0 B	A
	B B B A
	B



MAXIMUM TEMPERATURE OF EVERY LAYER

LAYER: 1 2
Tmax: 3000.33 8540.33
Optv: 2139.84 2069.40

VALUES OF DESIGN VARIABLES :

LAYER	DEV01	DEV02	DEV03	DEV04	DEV05	DEV06
1	0.00020	0.00020	0.00020	0.00020	0.00020	0.00020

THE ORIGINAL OBJECTIVE FUNCTION = 531.4960938

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.0020000

THE TOTAL OPTIMAL WEIGHT = 4.91326593E-03

OPTIMAL STRUCTURES OF TPS FOR PATCH = 500

(WITH AVERAGE THICKNESS)

=====

```

i
ZIRCONIA FIBERS      slab      0.00066 FT  2139.8 F
i
=====
i
HEAT SINK            slab      0.65617 FT  2069.4 F
i
=====

```

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 500

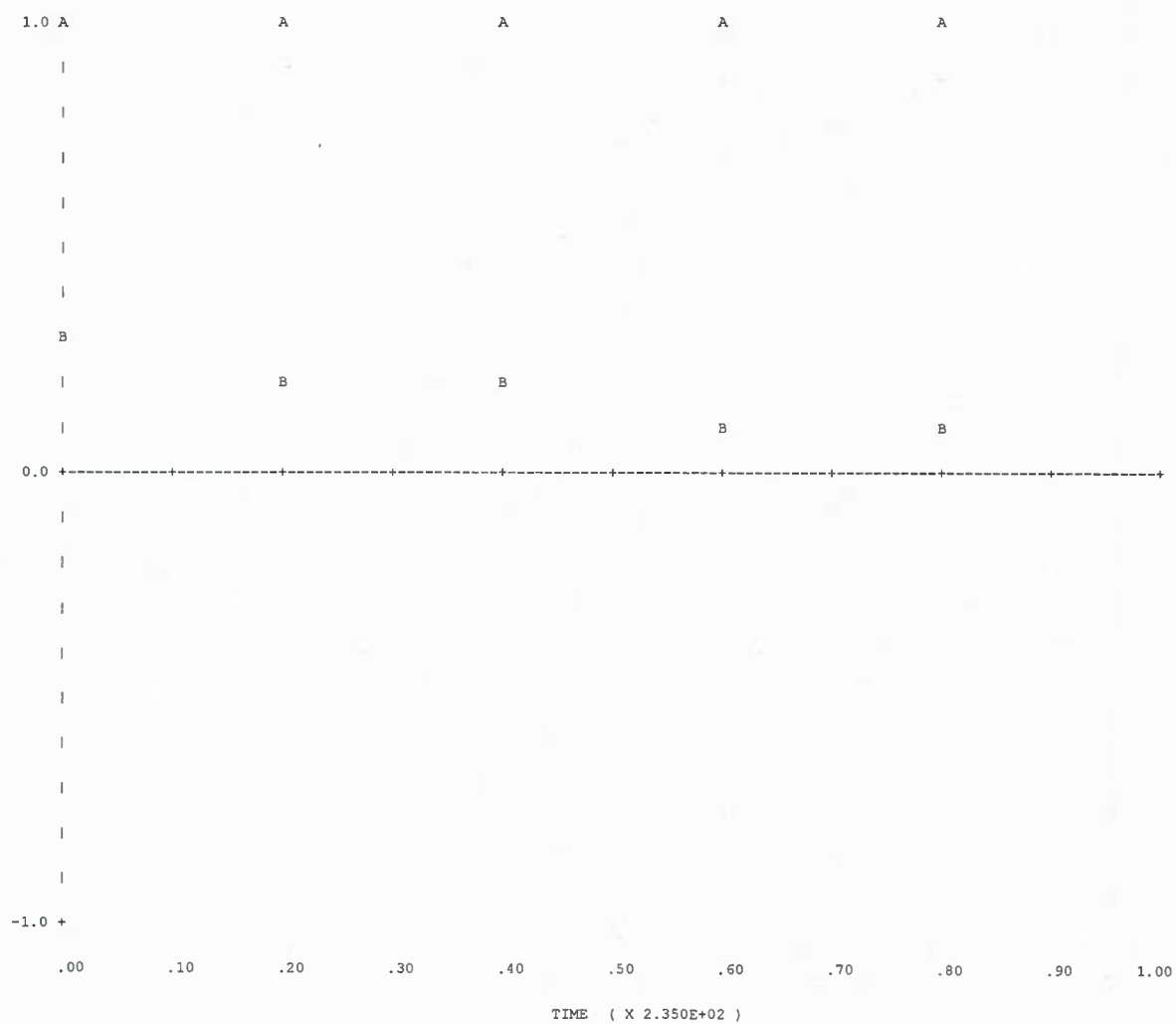
PANEL	LAYER01		LAYER02	
500001	0.00020	1713.02	0.20000	1676.61
500002	0.00020	1722.32	0.20000	1685.94
500003	0.00020	1731.62	0.20000	1695.26
500004	0.00020	1740.92	0.20000	1704.59
500005	0.00020	1750.22	0.20000	1713.91.....
.....				
.....				
500266	0.00020	2090.93	0.20000	2055.58
500267	0.00020	2103.16	0.20000	2067.84
500268	0.00020	2115.39	0.20000	2080.10
500269	0.00020	2127.62	0.20000	2092.36
500270	0.00020	2139.84	0.20000	2104.62

OPTIMIZATION SYSTEM FOR TPSSYM = 1200

TOTAL NUMBER OF DESIGN VARIABLES = 9
 TOTAL NUMBER OF CONSTRAINS = 6162
 TOTAL NUMBER OF TEMP. CONSTRAINS = 180
 TOTAL NUMBER OF TEMP. PRINTOUTS = 6
 WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

X 0.1576E+04



MAXIMUM TEMPERATURE OF EVERY LAYER

LAYER: 1 2
Tmax: 2400.33 550.33
Optv: 1576.49 494.62

VALUES OF DESIGN VARIABLES :

LAYER	DEV01	DEV02	DEV03	DEV04	DEV05	DEV06	DEV07	DEV08	DEV09
1	0.02205	0.02222	0.02235	0.03637	0.03652	0.03639	0.02058	0.02062	0.02064

THE ORIGINAL OBJECTIVE FUNCTION = 10452.7558594

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.3134504

THE TOTAL OPTIMAL WEIGHT = 4.33150432E+00

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1200

(WITH AVERAGE THICKNESS)

=====				-----
				i
CRI-I	2.0	slab	0.09478 FT	1576.5 F
				i
=====				-----
RTV-560		thin skin	0.00066 FT	494.6 F
=====				-----

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 1200

PANEL	LAYER01	LAYER02
1200001	0.02205 1576.34	0.00002 550.33
1200002	0.02264 1575.26	0.00002 550.33
1200003	0.02322 1574.19	0.00002 550.33
1200004	0.02378 1573.12	0.00002 550.33
1200005	0.02433 1572.07	0.00002 550.33.....
.....		

```

.....
1202995  0.02358  1510.20  0.00002  550.33
1202996  0.02302  1509.88  0.00002  550.33
1202997  0.02244  1509.57  0.00002  550.33
1202998  0.02185  1509.27  0.00002  550.33
1202999  0.02125  1508.98  0.00002  550.33
1203000  0.02064  1508.69  0.00002  550.33

```

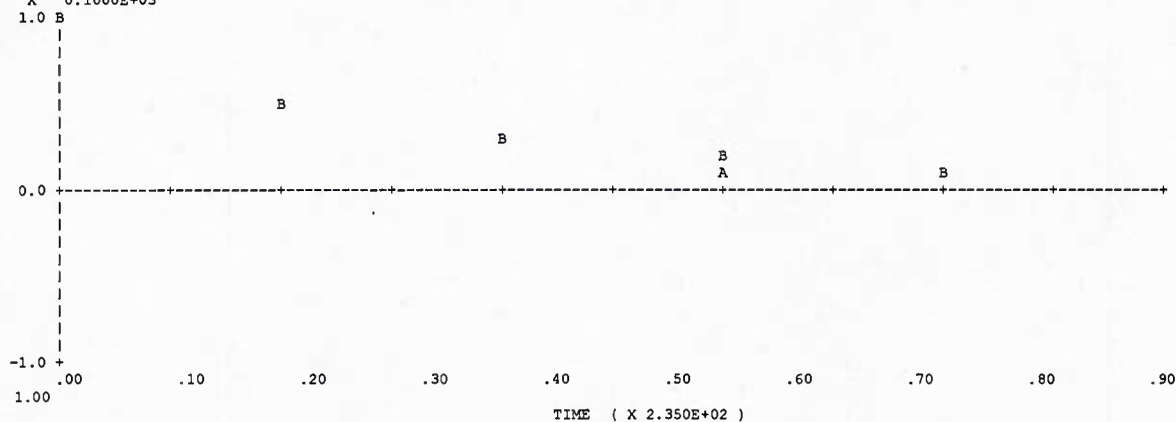
OPTIMIZATION SYSTEM FOR TPSSYM = 1300

```

TOTAL NUMBER OF DESIGN VARIABLES = 6
TOTAL NUMBER OF CONSTRAINS = 1060
TOTAL NUMBER OF TEMP. CONSTRAINS = 72
TOTAL NUMBER OF TEMP. PRINTOUTS = 6

```

MAXIMUM TEMPERATURE OF EACH LAYER VS OUTPUT TIMES
X 0.1000E+03



MAXIMUM TEMPERATURE OF EVERY LAYER
LAYER: 1 2
Tmax: 2400.33 550.33
Optv: 100.00 100.00

VALUES OF DESIGN VARIABLES :
LAYER DEV01 DEV02 DEV03 DEV04 DEV05 DEV06
1 0.00020 0.00020 0.00020 0.00020 0.00020 0.00020

THE ORIGINAL OBJECTIVE FUNCTION = 1742.1259766

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.0020000

THE TOTAL OPTIMAL WEIGHT = 1.48797294E-01

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1300
(WITH AVERAGE THICKNESS)

```

=====
                CRI-I  2.0          slab          0.00066 FT  100.0 F
                i
=====
                RTV-560          thin skin          0.00066 FT  100.0 F
                i
=====

```

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 1300

PANEL	LAYER01	LAYER02
1300001	0.00020 100.00	0.00002 100.00
1300002	0.00020 100.00	0.00002 100.00
1300003	0.00020 100.00	0.00002 100.00
1300004	0.00020 100.00	0.00002 100.00
1300005	0.00020 100.00	0.00002 100.00

```

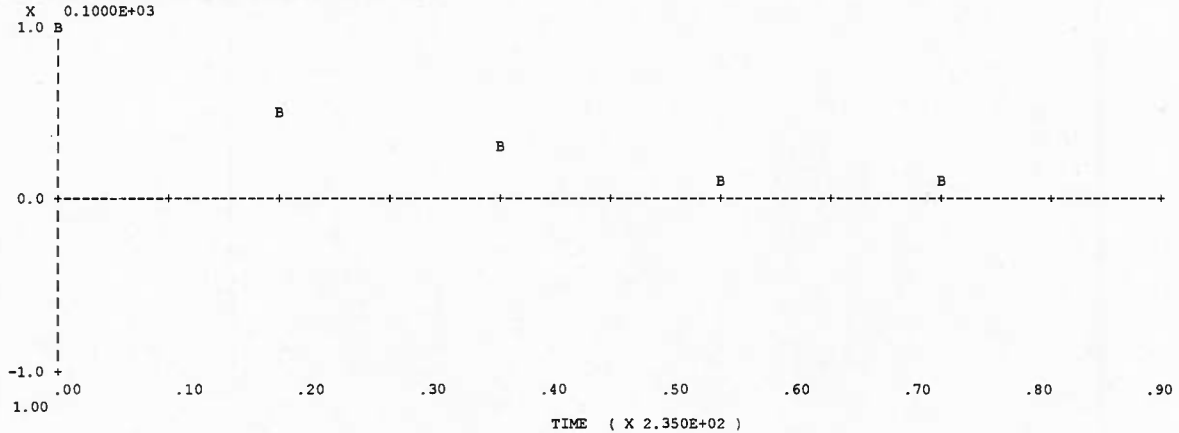
.....
1300495  0.00020  100.00  0.00002  100.00
1300496  0.00020  100.00  0.00002  100.00
1300497  0.00020  100.00  0.00002  100.00
1300498  0.00020  100.00  0.00002  100.00
1300499  0.00020  100.00  0.00002  100.00
1300500  0.00020  100.00  0.00002  100.00

```

OPTIMIZATION SYSTEM FOR TPSSYM = 1400

TOTAL NUMBER OF DESIGN VARIABLES = 6
 TOTAL NUMBER OF CONSTRAINS = 400
 TOTAL NUMBER OF TEMP. CONSTRAINS = 72
 TOTAL NUMBER OF TEMP. PRINTOUTS = 6

MAXIMUM TEMPERATURE OF EACH LAYER VS OUTPUT TIMES



MAXIMUM TEMPERATURE OF EVERY LAYER
 LAYER: 1 2
 Tmax: 2400.33 550.33
 Optv: 100.00 100.00

VALUES OF DESIGN VARIABLES :
 LAYER DEV01 DEV02 DEV03 DEV04 DEV05 DEV06
 1 0.00020 0.00020 0.00020 0.00020 0.00020 0.00020

THE ORIGINAL OBJECTIVE FUNCTION = 592.3228149

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.0020000

THE TOTAL OPTIMAL WEIGHT = 3.83791494E-02

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1400
 (WITH AVERAGE THICKNESS)

=====				i	
CRI-I	2.0	slab	0.00066 FT	100.0 F	
=====				i	
RTV-560		thin skin	0.00066 FT	100.0 F	
=====				-----	

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 1400

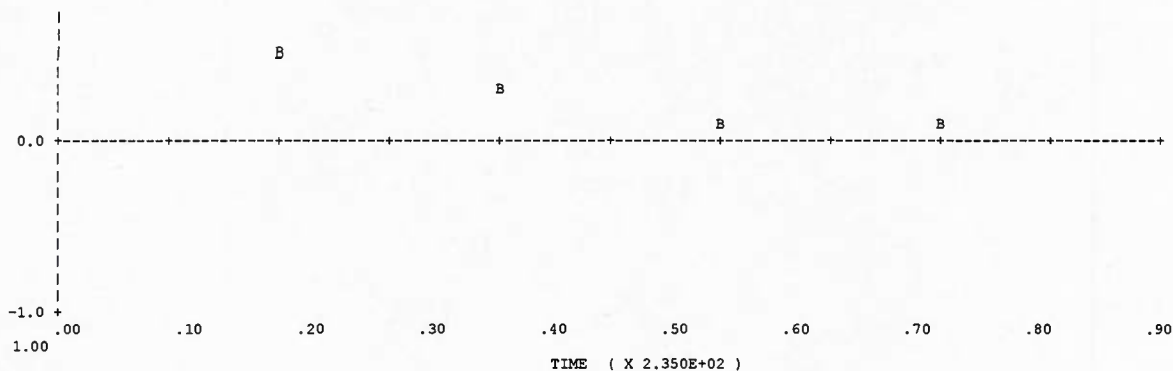
PANEL	LAYER01		LAYER02	
1400001	0.00020	100.00	0.00002	100.00
1400002	0.00020	100.00	0.00002	100.00
1400003	0.00020	100.00	0.00002	100.00
1400004	0.00020	100.00	0.00002	100.00
1400005	0.00020	100.00	0.00002	100.00
.....				
.....				
1400166	0.00020	100.00	0.00002	100.00
1400167	0.00020	100.00	0.00002	100.00
1400168	0.00020	100.00	0.00002	100.00
1400169	0.00020	100.00	0.00002	100.00
1400170	0.00020	100.00	0.00002	100.00

OPTIMIZATION SYSTEM FOR TPSSYM = 1500

TOTAL NUMBER OF DESIGN VARIABLES = 6
 TOTAL NUMBER OF CONSTRAINS = 1260
 TOTAL NUMBER OF TEMP. CONSTRAINS = 72
 TOTAL NUMBER OF TEMP. PRINTOUTS = 6

MAXIMUM TEMPERATURE OF EACH LAYER VS OUTPUT TIMES

X 0.1000E+03
 1.0 B
 |
 |



MAXIMUM TEMPERATURE OF EVERY LAYER
 LAYER: 1 2
 Tmax: 2400.33 550.33
 Optv: 100.00 100.00

VALUES OF DESIGN VARIABLES :
 LAYER DEV01 DEV02 DEV03 DEV04 DEV05 DEV06
 1 0.00020 0.00020 0.00020 0.00020 0.00020 0.00020

THE ORIGINAL OBJECTIVE FUNCTION = 2090.5512695

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.0020000

THE TOTAL OPTIMAL WEIGHT = 2.14508372E-01

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1500
 (WITH AVERAGE THICKNESS)

Material	Thickness (FT)	Temperature (F)
CRI-I 2.0 slab	0.00066	100.0
RTV-560 thin skin	0.00066	100.0

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 1500

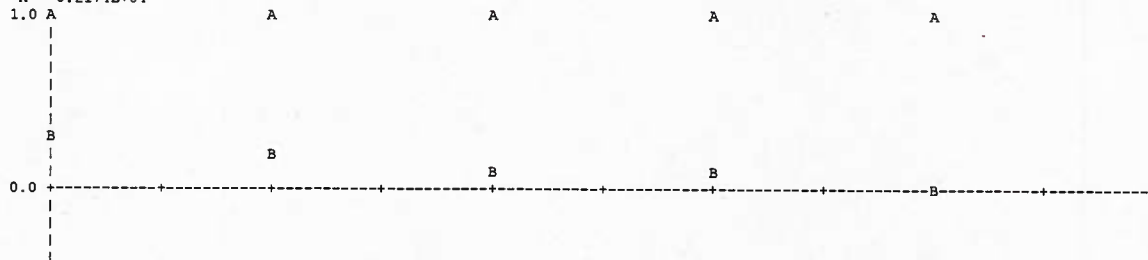
PANEL	LAYER01	LAYER02
1500001	0.00020	100.00
1500002	0.00020	100.00
1500003	0.00020	100.00
1500004	0.00020	100.00
1500005	0.00020	100.00

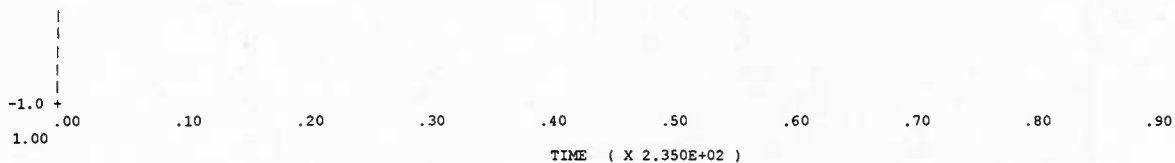
1500595	0.00020	100.00	0.00002	100.00
1500596	0.00020	100.00	0.00002	100.00
1500597	0.00020	100.00	0.00002	100.00
1500598	0.00020	100.00	0.00002	100.00
1500599	0.00020	100.00	0.00002	100.00
1500600	0.00020	100.00	0.00002	100.00

OPTIMIZATION SYSTEM FOR TPSSYM = 1700

TOTAL NUMBER OF DESIGN VARIABLES = 4
 TOTAL NUMBER OF CONSTRAINS = 10840
 TOTAL NUMBER OF TEMP. CONSTRAINS = 48
 TOTAL NUMBER OF TEMP. PRINTOUTS = 6

MAXIMUM TEMPERATURE OF EACH LAYER VS OUTPUT TIMES
 X 0.2174E+04





MAXIMUM TEMPERATURE OF EVERY LAYER
 LAYER: 1 2
 Tmax: 2400.33 550.33
 Optv: 2173.75 546.23

VALUES OF DESIGN VARIABLES :
 LAYER DEV01 DEV02 DEV03 DEV04
 1 0.02657 0.02222 0.02324 0.02214

THE ORIGINAL OBJECTIVE FUNCTION = 18814.9609375

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.2420817

THE TOTAL OPTIMAL WEIGHT = 1.58559431E+01

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1700
 (WITH AVERAGE THICKNESS)

=====				i
CRI-I	2.0	slab	0.07724 FT	2173.7 F
=====				i
RTV-560		thin skin	0.00066 FT	546.2 F
=====				

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 1700

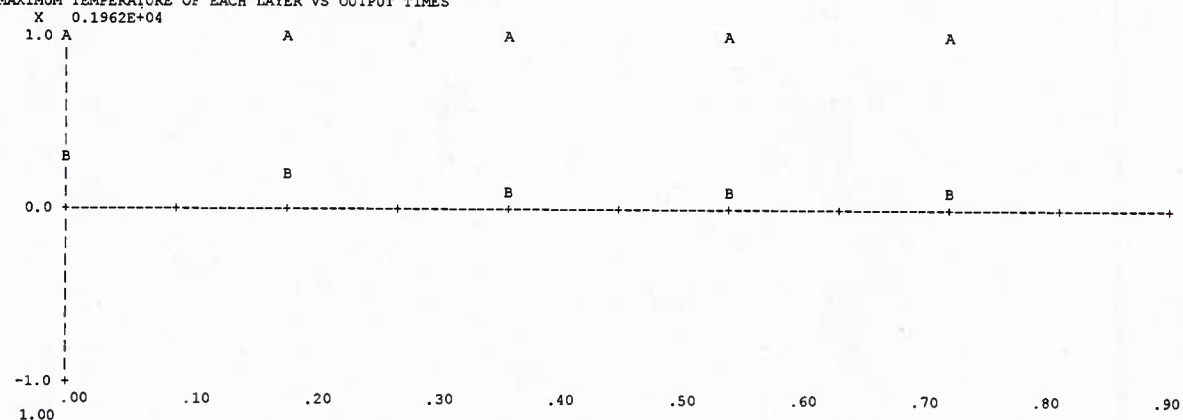
PANEL	LAYER01	LAYER02		
1700001	0.02657	2173.75	0.00002	550.33
1700002	0.02657	2173.51	0.00002	550.33
1700003	0.02656	2173.25	0.00002	550.33
1700004	0.02656	2173.00	0.00002	550.33
1700005	0.02656	2172.75	0.00002	550.33

1705395	0.02224	1618.14	0.00002	550.33
1705396	0.02222	1613.83	0.00002	550.33
1705397	0.02220	1609.53	0.00002	550.33
1705398	0.02218	1605.23	0.00002	550.33
1705399	0.02216	1600.93	0.00002	550.33
1705400	0.02214	1596.62	0.00002	550.33

OPTIMIZATION SYSTEM FOR TPSSYM = 1800

TOTAL NUMBER OF DESIGN VARIABLES = 4
 TOTAL NUMBER OF CONSTRAINS = 1840
 TOTAL NUMBER OF TEMP. CONSTRAINS = 48
 TOTAL NUMBER OF TEMP. PRINTOUTS = 6
 WARNING: MODIFICATION EXCEEDS ALLOWED VALUE
 WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

MAXIMUM TEMPERATURE OF EACH LAYER VS OUTPUT TIMES



TIME (X 2.350E+02)

MAXIMUM TEMPERATURE OF EVERY LAYER
LAYER: 1 2
Tmax: 2400.33 550.33
Optv: 1962.31 546.03

VALUES OF DESIGN VARIABLES :
LAYER DEV01 DEV02 DEV03 DEV04
1 0.03011 0.01984 0.02661 0.01872

THE ORIGINAL OBJECTIVE FUNCTION = 3135.8266602

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.2382071

THE TOTAL OPTIMAL WEIGHT = 6.73263566E-01

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1800
(WITH AVERAGE THICKNESS)

```
=====
CRI-I 2.0 slab 0.07815 FT 1962.3 F
i
RTV-560 thin skin 0.00066 FT 546.0 F
=====
```

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 1800

PANEL	LAYER01	LAYER02
1800001	0.03011 1962.31	0.00002 550.33
1800002	0.02975 1944.26	0.00002 550.33
1800003	0.02940 1926.21	0.00002 550.33
1800004	0.02904 1908.16	0.00002 550.33
1800005	0.02869 1890.11	0.00002 550.33

1800895	0.02008 1507.01	0.00002 550.33
1800896	0.01981 1493.37	0.00002 550.33
1800897	0.01954 1479.74	0.00002 550.33
1800898	0.01927 1466.10	0.00002 550.33
1800899	0.01900 1452.46	0.00002 550.33
1800900	0.01872 1438.83	0.00002 550.33

OPTIMIZATION SYSTEM FOR TPSSYM = 1900

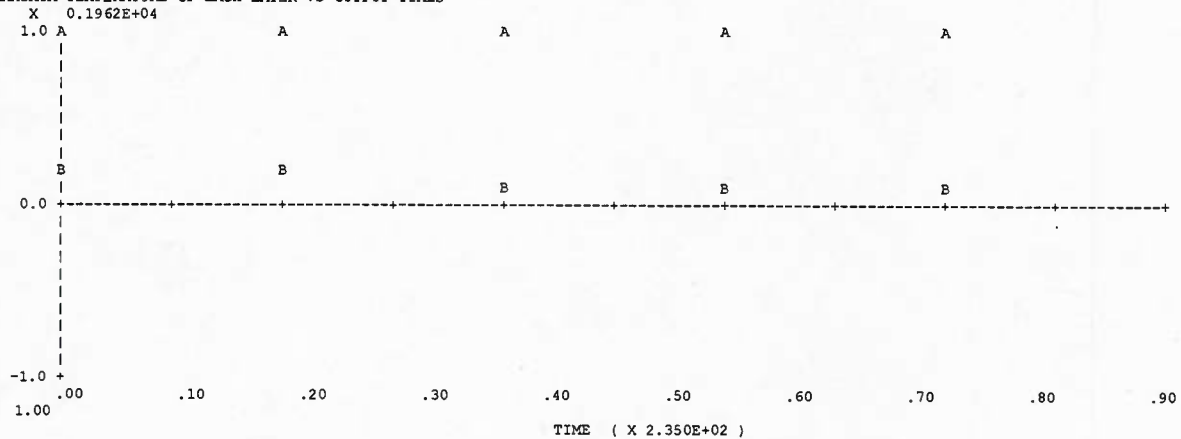
TOTAL NUMBER OF DESIGN VARIABLES = 4
TOTAL NUMBER OF CONSTRAINS = 1840
TOTAL NUMBER OF TEMP. CONSTRAINS = 48
TOTAL NUMBER OF TEMP. PRINTOUTS = 6
WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

MAXIMUM TEMPERATURE OF EACH LAYER VS OUTPUT TIMES



MAXIMUM TEMPERATURE OF EVERY LAYER

LAYER: 1 2
Tmax: 2400.33 550.33
Optv: 1962.29 480.34

VALUES OF DESIGN VARIABLES :
LAYER DEV01 DEV02 DEV03 DEV04
1 0.02748 0.01987 0.02544 0.01973

THE ORIGINAL OBJECTIVE FUNCTION = 3135.8266602
THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.2313011
THE TOTAL OPTIMAL WEIGHT = 6.52450415E-01

OPTIMAL STRUCTURES OF TPS FOR PATCH = 1900
(WITH AVERAGE THICKNESS)

Material	Thickness (FT)	Temperature (F)
CRI-I 2.0 slab	0.07589	1962.3
RTV-560 thin skin	0.00066	480.3

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 1900

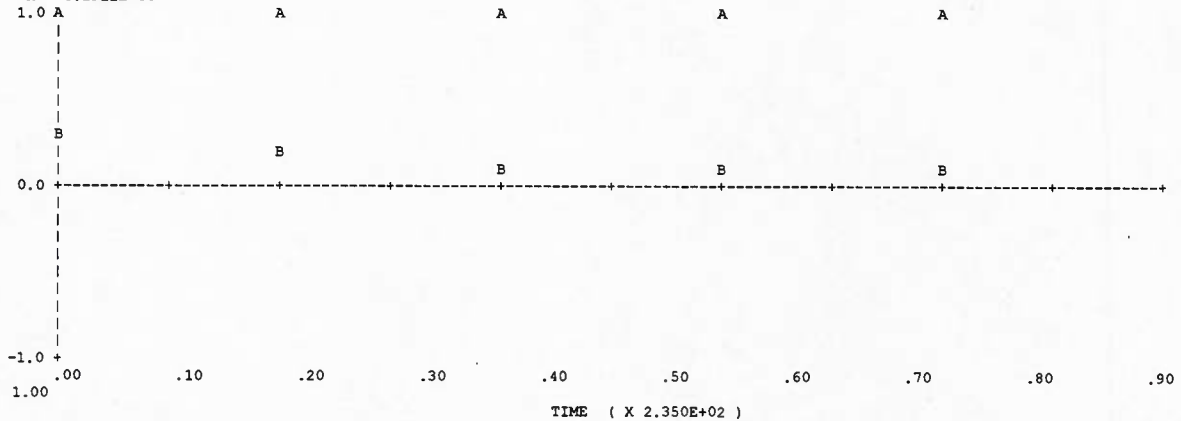
PANEL	LAYER01	LAYER02	Thickness	Temperature
1900001	0.02748	1962.29	0.00002	550.33
1900002	0.02721	1944.24	0.00002	550.33
1900003	0.02695	1926.19	0.00002	550.33
1900004	0.02669	1908.13	0.00002	550.33
1900005	0.02643	1890.08	0.00002	550.33

1900895	0.02072	1507.07	0.00002	550.33
1900896	0.02052	1493.43	0.00002	550.33
1900897	0.02032	1479.80	0.00002	550.33
1900898	0.02013	1466.17	0.00002	550.33
1900899	0.01993	1452.53	0.00002	550.33
1900900	0.01973	1438.90	0.00002	550.33

OPTIMIZATION SYSTEM FOR TPSSYM = 2000

TOTAL NUMBER OF DESIGN VARIABLES = 4
TOTAL NUMBER OF CONSTRAINS = 1840
TOTAL NUMBER OF TEMP. CONSTRAINS = 48
TOTAL NUMBER OF TEMP. PRINTOUTS = 6
WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

MAXIMUM TEMPERATURE OF EACH LAYER VS OUTPUT TIMES
X 0.1922E+04



MAXIMUM TEMPERATURE OF EVERY LAYER
LAYER: 1 2
Tmax: 2400.33 550.33
Optv: 1922.06 533.81

VALUES OF DESIGN VARIABLES :
LAYER DEV01 DEV02 DEV03 DEV04
1 0.02440 0.02047 0.02315 0.01919

THE ORIGINAL OBJECTIVE FUNCTION = 3135.8266602

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.2180511

THE TOTAL OPTIMAL WEIGHT = 6.19316060E-01

OPTIMAL STRUCTURES OF TPS FOR PATCH = 2000
(WITH AVERAGE THICKNESS)

```
=====
              CRI-I  2.0          slab          i
              0.07154 FT  1922.1 F          i
              -----
              RTV-560          thin skin        0.00066 FT  533.8 F
              =====
```

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 2000

PANEL	LAYER01		LAYER02	
2000001	0.02440	1922.06	0.00002	550.33
2000002	0.02427	1905.45	0.00002	550.33
2000003	0.02413	1888.84	0.00002	550.33
2000004	0.02400	1872.23	0.00002	550.33
2000005	0.02386	1855.62	0.00002	550.33

```
.....
2000895  0.01988  1501.67  0.00002  550.33
2000896  0.01974  1489.40  0.00002  550.33
2000897  0.01960  1477.14  0.00002  550.33
2000898  0.01947  1464.87  0.00002  550.33
2000899  0.01933  1452.61  0.00002  550.33
2000900  0.01919  1440.34  0.00002  550.33
```

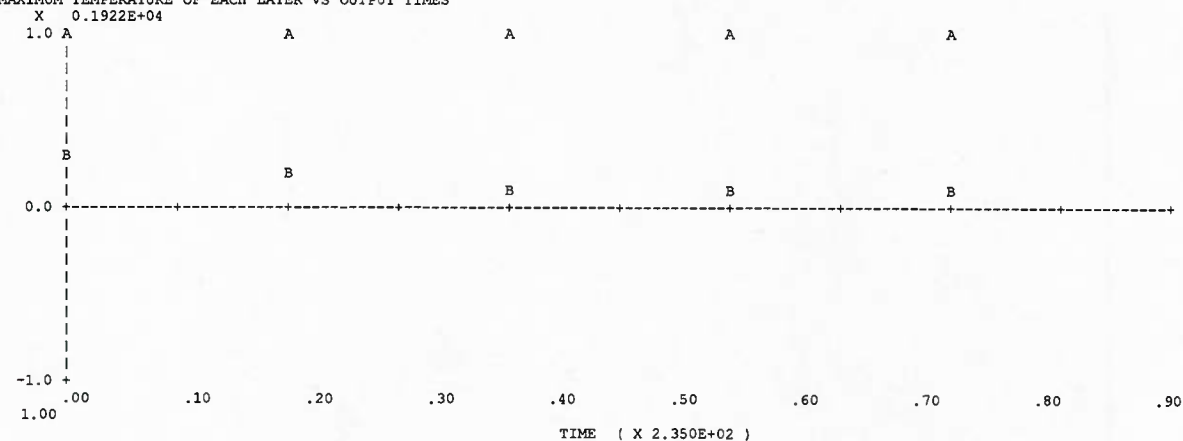
OPTIMIZATION SYSTEM FOR TPSSYM = 2100

TOTAL NUMBER OF DESIGN VARIABLES = 4
TOTAL NUMBER OF CONSTRAINS = 1840
TOTAL NUMBER OF TEMP. CONSTRAINS = 48
TOTAL NUMBER OF TEMP. PRINTOUTS = 6
WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

WARNING: MODIFICATION EXCEEDS ALLOWED VALUE

MAXIMUM TEMPERATURE OF EACH LAYER VS OUTPUT TIMES



MAXIMUM TEMPERATURE OF EVERY LAYER

LAYER:	1	2
Tmax:	2400.33	550.33
Optv:	1922.01	509.15

VALUES OF DESIGN VARIABLES :

LAYER	DEV01	DEV02	DEV03	DEV04
1	0.02870	0.02059	0.02349	0.02126

THE ORIGINAL OBJECTIVE FUNCTION = 3135.8266602

THE RATIO OF OPTIMAL OBJECTIVE FUNCTION = 0.2351092

THE TOTAL OPTIMAL WEIGHT = 6.61571832E-01

OPTIMAL STRUCTURES OF TPS FOR PATCH = 2100
(WITH AVERAGE THICKNESS)

-----		-----	
CRI-I	2.0	slab	i 0.07714 FT 1922.0 F
-----		-----	
RTV-560		thin skin	i 0.00066 FT 509.1 F
-----		-----	

THICKNESS AND TEMPERATURE OF LAYERS FOR PATCH = 2100

PANEL	LAYER01		LAYER02	
2100001	0.02870	1922.01	0.00002	550.33
2100002	0.02842	1905.40	0.00002	550.33
2100003	0.02814	1888.78	0.00002	550.33
2100004	0.02786	1872.17	0.00002	550.33
2100005	0.02758	1855.56	0.00002	550.33

2100895	0.02164	1501.66	0.00002	550.33
2100896	0.02157	1489.40	0.00002	550.33
2100897	0.02149	1477.13	0.00002	550.33
2100898	0.02141	1464.86	0.00002	550.33
2100899	0.02134	1452.59	0.00002	550.33
2100900	0.02126	1440.32	0.00002	550.33

TOTAL MASS OF BOTH SIDES : 0.43240E+02 (KG), C. G. FROM X=0. IS : 0.38270E+01 (M)

```

*****
***                                ***
*** T P S O P T   T E R M I N A T E D ***
***                                ***
***              N O R M A L L Y          ***
***                                ***
***      12:40:39      10/19/2009      ***
***                                ***
*****

```

Listing 9.6.3 Output of Mass change due to TPS: mass_tps.dat

43.24017

165.4823

9.7 Run SMB for Structural Design

Input Files:

File Name	Type	Remarks	See Listing
smb_run.inp	Standard input file	Required	Shown in listing 9.7.1
traject.dat	Trajectory data generated by UPTOP	Inserted into the Standard input file smb_run.inp by the INCLUDE bulk data card	Shown in Listing 9.4.3
geom_data.dat	Aerodynamic mesh generated by UCDA	Imported by the ASSIGN AEROBASE executive control command	Not Shown

Output Files:

File Name	Type	Remarks	See Listing
smb_run.out	Standard output file	Print out results	Shown in Listing 9.7.2
RDOF_EIGEN.FREE	Eigenvalues and Eigenvectors of the beam model	Input file for TRIM and ASE analysis	Shown in Listing 9.7.3
masschng.dat	Mass of the structural skin designed by SMB	Input file for UCDA to update the change of weight due to structure	Shown in Listing 9.7.4

9.7.1 Descriptions of the Input File: SMB_RUN.INP (Shown in Listing 9.7.1)

The aerodynamic mesh of the SED configuration generated by UCDA is stored in the file “geom_data.dat” and imported into the SMB module by the executive control command shown as follows:

```
ASSIGN AEROBASE=geom_data.dat
```

Based on this aerodynamic mesh, SMB computes the width and height at 20 axial stations to approximate the cross section of the SED configuration as rectangular boxes. Then, the SMB module constructs a beam finite element model with 20 grid points and 19 beam elements along the x axis of the vehicle. The area moment of inertias of each beam element is calculated based on the size of the rectangular box at each axial station with the optimum skin thickness that is to be designed by the fully stressed design method. Meanwhile, the vehicle weight calculated by UCDA and stored in the file “geom_data.dat” is distributed at each grid points of the beam model to represent the non-structural weight of the SED configuration.

There is only one subcase defined by the case control command shown as follows:

```
BEAM=100
```

This case control command refers to a **BEAMFSD** bulk data card with ID = 100 in the bulk data section. In this **BEAMFSD** bulk data card, the material properties of the Aluminum along with a failure stress = 1.5×10^6 is specified. It also defines an initial and minimum skin thickness as 0.00001 and 0.000001, respectively, as well as a load factor of 1.5. The minimum skin thickness serves as a lower bound of thickness used by the Fully Stressed Design method. The load factor is used as a multiplication factor to the computed aerodynamic loads along on the trajectory. It should be noted that since the units of length and mass defined by UCDA for the SED configuration are in Meter and KG, respectively, the units of length and mass involved in the BEAMFSD input entries must be consistent with that of UCDA.

The trajectory is computed by UPTOP which is stored on the file “traject.dat” that consists of one **TRAJCT** bulk data card with ID = 100 and one **TIMESP** bulk data card. The **TRAJCT** bulk data card is referred to by the **TRJLST** bulk data card with ID = 1. The **TIMESP** bulk data card is used only by the **TPSOPT** module and is not used by the **SMB** module. This trajectory file “traject.dat” is automatically inserted into the bulk data section by the **INCLUDE** bulk data card shown as follows:

```
INCLUDE  traject.dat
```

9.7.2 Descriptions of the Standard Output File: smb_run.lut (Shown in Listing 9.7.2)

The standard output file first prints out the input bulk data cards in an alphabetic order. Then it shows the 20 grid point locations and the non-structural masses at each grid points. The total non-structural mass is 1277.0 KG that serves as the initial mass distribution of the beam model. The stiffness of the 19 beam elements with the initial skin thickness (0.00001) in term of EI and GJ is printed next.

After the Fully Stressed design computation is completed, **SMB** prints out the optimum thickness and the mass distribution of the beam model. This optimum thickness along with the initial thickness of the 19 beam element is shown in Figure 9.7.1. The total mass of the optimized structural model is 1285.8 KG which shows a 8.8 KG increase of mass due to the structural skin.

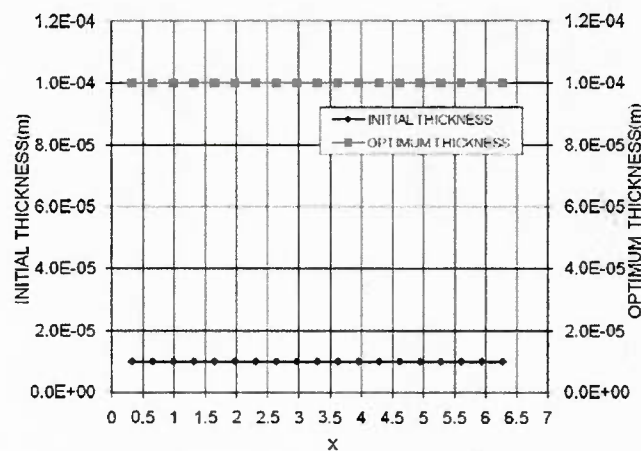


Figure 9.7.1 Optimum Thickness of the SED configuration

Next, the EI and GJ distribution followed by the natural frequencies of the optimized beam model are printed out. These EI and GJ distributions are depicted in Figure 9.7.2 and the natural frequencies of the first 5 elastic modes are shown in Table 9.7.2.

Finally, an NASTRAN input file of the optimized beam model is printed in the standard file that allows the user to use NASTRAN to verify the SMB solution.

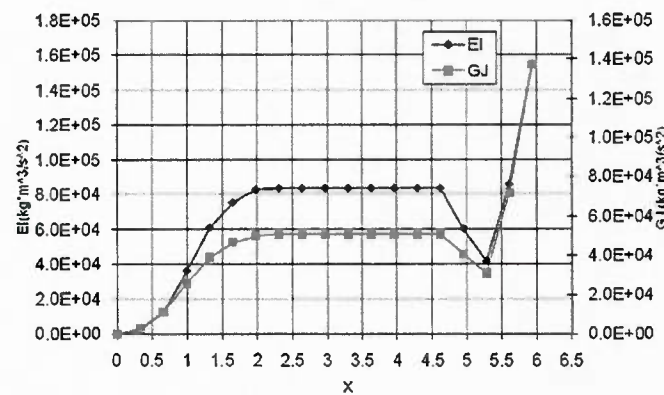


Figure 9.7.2 EI and GJ of the Optimized Beam Model for the SED Configuration

Table 9.7.2 Natural Frequencies of the First Elastic Modes

BENDING MODE NO.	NATURAL FREQUENCY(Hz)
1	1.91E+00
2	5.12E+00
3	9.64E+00
4	1.53E+01
5	2.91E+01

9.7.3 Other Output Files: RDOF_EIGEN.FREE (Shown in Listing 9.7.3) and masschng.dat (Shown in Listing 9.7.4)

The file “RDOF_EIGEN.FREE” contains the natural frequencies and generalized masses of the first 20 modes. Note that the first 3 modes are corresponding to the fore-aft, plunge, and pitch

rigid body modes. The first 3 elastic modes of the optimized beam model are depicted in Figure 9.7.3

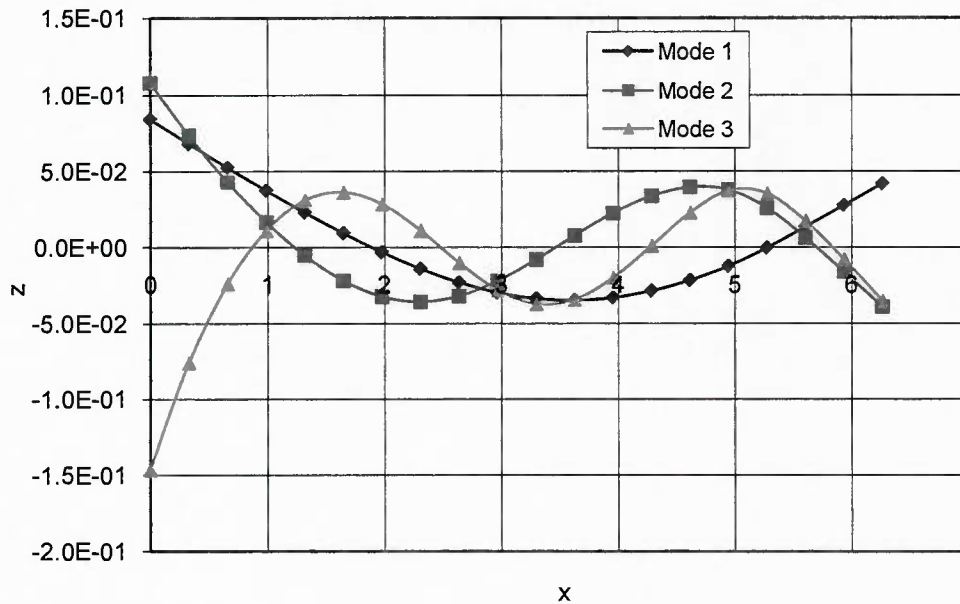


Figure 9.7.3 The First 3 Elastic Modes of the Optimized Beam Model

The file “masschng.dat” contains the locations of the 20 grid points and the incremental masses due to the structural skin at those 20 grid points. This file will be imported back to UCDA for the next design cycle to include the impact of the structural skin weight on the weight and center of gravity of the whole vehicle.

Listing 9.7.1 Standard Input File: smb_run.inp

```

assign aerobase=geom_data.dat,print=1
cend
title= SED Beam Model
echo=sort
subcase =1
    Beam=100
begin bulk
$
include 'trajct.dat'
$
beamfsd 100    1      6.895E09 2.592E09 .33    .00001 1.50    1.5E6
              .5      .05    .000005 6750.    .0001
trjlst 1

```

100
Enddata

Listing 9.7.2 Standard Output File: smb_run.out

```
EXECUTIVE CONTROL SUMMARY

|...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10...|

assign aerobase=geom_data.dat,print=1

cend

CASE CONTROL SUMMARY

SINGLE PRECISION COMPUTATION

MAXIMUM ALLOCABLE MEMORY = 800 MEGABYTES

|...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10...|

title= SED Beam Model

echo=sort

subcase =1

Beam=100

begin bulk

SORTED BULK DATA ECHO

CARD
COUNT |...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10...|

1 -      BEAMFSD 100      1      6.895E092.592E09.33      .00001  1.50      1.5E6
```

```

2 -          .5      .05      .000005 6750.      .0001
3 -      TIMESP 201      0.000      60.000 120.000 180.000 240.000 282.000
4 -      TRAJCT 100      10
5 -          12.0      6.9300 26068.      -0.130
6 -          24.0      6.9400 25964.      -0.150
7 -          36.0      6.9600 25815.      -0.160
8 -          48.0      6.9700 25651.      -0.180
9 -          60.0      6.9900 25507.      -0.200
10 -         72.0      7.0100 25414.      -0.210
11 -         84.0      7.0200 25395.      -0.230
12 -         96.0      7.0300 25456.      -0.250
13 -        108.0      7.0400 25590.      -0.260
14 -        120.0      7.0500 25778.      -0.280
15 -        132.0      7.0600 25990.      -0.300
16 -        144.0      7.0700 26191.      -0.310
17 -        156.0      7.0700 26347.      -0.330
18 -        168.0      7.0800 26430.      -0.350
19 -        180.0      7.0900 26425.      -0.360
20 -        192.0      7.1000 26335.      -0.380
21 -        204.0      7.1200 26181.      -0.400
22 -        216.0      7.1500 26001.      -0.410
23 -        228.0      7.1900 25850.      -0.430
24 -        240.0      7.2300 25789.      -0.450
25 -        252.0      7.2900 25878.      -0.460
26 -        264.0      7.3500 26167.      -0.480
27 -        276.0      7.4300 26694.      -0.500
28 -        282.0      7.4700 27056.      -0.510      TECPLOT      1283.PLT
29 -      TRJLST 1
30 -          100
31 -      ENDDATA

```

```

*****
*
*
*   SUBCASE      =      1   *
*
*   DISCIPLINE   = BEAM    *
*
*   BULK ENTRY ID =      100 *
*
*
*****

```

FINITE ELEMENT MODEL DESCRIPTION

	GRID ID	COORDINATE			CONCENTRATED
		X	Y	Z	
	1	0.000	0.000	0.000	4.216
	2	0.330	0.000	0.000	17.987
	3	0.660	0.000	0.000	34.816
	4	0.990	0.000	0.000	51.390
	5	1.319	0.000	0.000	60.339
	6	1.649	0.000	0.000	65.753
	7	1.979	0.000	0.000	67.084
	8	2.309	0.000	0.000	67.186
	9	2.639	0.000	0.000	67.186
	10	2.969	0.000	0.000	67.186
	11	3.299	0.000	0.000	67.186
	12	3.628	0.000	0.000	67.186
	13	3.958	0.000	0.000	67.186
	14	4.288	0.000	0.000	67.186
	15	4.618	0.000	0.000	64.915
	16	4.948	0.000	0.000	51.284
	17	5.278	0.000	0.000	59.791
	18	5.607	0.000	0.000	124.796
	19	5.937	0.000	0.000	137.024
	20	6.267	0.000	0.000	67.285

*TOTAL MASS = 0.12769855E+04

ELEMENT	CROSS SECTION (BOX)			MOMENT OF INERTIA			STIFFNESS	
ID	WIDTH	HEIGHT	THICKNESS	Izz	Iyy	J	BENDING (EI)	TORSION (GJ)
1	0.48E+0	0.11E+0	0.10E-4	0.32E-6	0.34E-7	0.10E-6	0.23733E+03	0.26721E+03
2	0.53E+0	0.24E+0	0.10E-4	0.59E-6	0.18E-6	0.43E-6	0.12571E+04	0.11191E+04
3	0.56E+0	0.39E+0	0.10E-4	0.90E-6	0.53E-6	0.10E-5	0.36286E+04	0.25992E+04
4	0.58E+0	0.49E+0	0.10E-4	0.11E-5	0.89E-6	0.15E-5	0.61152E+04	0.38984E+04
5	0.60E+0	0.53E+0	0.10E-4	0.13E-5	0.11E-5	0.18E-5	0.75459E+04	0.46416E+04
6	0.61E+0	0.55E+0	0.10E-4	0.14E-5	0.12E-5	0.19E-5	0.82579E+04	0.50121E+04
7	0.61E+0	0.55E+0	0.10E-4	0.14E-5	0.12E-5	0.20E-5	0.83490E+04	0.50585E+04
8	0.61E+0	0.55E+0	0.10E-4	0.14E-5	0.12E-5	0.20E-5	0.83490E+04	0.50585E+04
9	0.61E+0	0.55E+0	0.10E-4	0.14E-5	0.12E-5	0.20E-5	0.83490E+04	0.50585E+04
10	0.61E+0	0.55E+0	0.10E-4	0.14E-5	0.12E-5	0.20E-5	0.83490E+04	0.50585E+04
11	0.61E+0	0.55E+0	0.10E-4	0.14E-5	0.12E-5	0.20E-5	0.83490E+04	0.50585E+04
12	0.61E+0	0.55E+0	0.10E-4	0.14E-5	0.12E-5	0.20E-5	0.83490E+04	0.50585E+04
13	0.61E+0	0.55E+0	0.10E-4	0.14E-5	0.12E-5	0.20E-5	0.83490E+04	0.50585E+04
14	0.61E+0	0.55E+0	0.10E-4	0.14E-5	0.12E-5	0.20E-5	0.83490E+04	0.50585E+04
15	0.61E+0	0.48E+0	0.10E-4	0.13E-5	0.88E-6	0.16E-5	0.60474E+04	0.40427E+04
16	0.61E+0	0.40E+0	0.10E-4	0.11E-5	0.60E-6	0.12E-5	0.41643E+04	0.30892E+04
17	0.91E+0	0.48E+0	0.10E-4	0.32E-5	0.12E-5	0.28E-5	0.85587E+04	0.71520E+04
18	0.12E+1	0.57E+0	0.10E-4	0.71E-5	0.22E-5	0.53E-5	0.15436E+05	0.13680E+05
19	0.12E+1	0.56E+0	0.10E-4	0.71E-5	0.22E-5	0.52E-5	0.15222E+05	0.13530E+05

FULLY STRESSED DESIGN RESULT

DESIGN VARIABLE : THICKNESS OF CROSS SECTION (BOX)

MINIMUM THICKNESS : 0.1000000E-03

ELEMENTS ID	INITIAL THICKNESS	OPTIMUM THICKNESS	INCREMENTS
1	0.99999997E-05	0.99999997E-04	0.90000001E-04
2	0.99999997E-05	0.99999997E-04	0.90000001E-04
3	0.99999997E-05	0.99999997E-04	0.90000001E-04
4	0.99999997E-05	0.99999997E-04	0.90000001E-04

5	0.99999997E-05	0.99999997E-04	0.90000001E-04
6	0.99999997E-05	0.99999997E-04	0.90000001E-04
7	0.99999997E-05	0.99999997E-04	0.90000001E-04
8	0.99999997E-05	0.99999997E-04	0.90000001E-04
9	0.99999997E-05	0.99999997E-04	0.90000001E-04
10	0.99999997E-05	0.99999997E-04	0.90000001E-04
11	0.99999997E-05	0.99999997E-04	0.90000001E-04
12	0.99999997E-05	0.99999997E-04	0.90000001E-04
13	0.99999997E-05	0.99999997E-04	0.90000001E-04
14	0.99999997E-05	0.99999997E-04	0.90000001E-04
15	0.99999997E-05	0.99999997E-04	0.90000001E-04
16	0.99999997E-05	0.99999997E-04	0.90000001E-04
17	0.99999997E-05	0.99999997E-04	0.90000001E-04
18	0.99999997E-05	0.99999997E-04	0.90000001E-04
19	0.99999997E-05	0.99999997E-04	0.90000001E-04

GRID ID	COORDINATE			CONCENTATED
	X	Y	Z	
1	0.000	0.000	0.000	4.336
2	0.330	0.000	0.000	18.262
3	0.660	0.000	0.000	35.161
4	0.990	0.000	0.000	51.794
5	1.319	0.000	0.000	60.780
6	1.649	0.000	0.000	66.211
7	1.979	0.000	0.000	67.549
8	2.309	0.000	0.000	67.652
9	2.639	0.000	0.000	67.652
10	2.969	0.000	0.000	67.652
11	3.299	0.000	0.000	67.652
12	3.628	0.000	0.000	67.652
13	3.958	0.000	0.000	67.652
14	4.288	0.000	0.000	67.652
15	4.618	0.000	0.000	65.365
16	4.948	0.000	0.000	51.705
17	5.278	0.000	0.000	60.272
18	5.607	0.000	0.000	125.431

19 5.937 0.000 0.000 137.735

20 6.267 0.000 0.000 67.641

*TOTAL MASS = 0.12858082E+04

ELEMENT	CROSS SECTION (BOX)			MOMENT OF INERTIA			STIFFNESS	
ID	WIDTH	HEIGHT	THICKNESS	Izz	Iyy	J	BENDING (EI)	TORSION (GJ)
1	0.48E+0	0.11E+0	0.10E-3	0.32E-5	0.34E-6	0.10E-5	0.23776E+04	0.26765E+04
2	0.53E+0	0.24E+0	0.10E-3	0.59E-5	0.18E-5	0.43E-5	0.12583E+05	0.11201E+05
3	0.56E+0	0.39E+0	0.10E-3	0.90E-5	0.53E-5	0.10E-4	0.36309E+05	0.26007E+05
4	0.58E+0	0.49E+0	0.10E-3	0.11E-4	0.89E-5	0.15E-4	0.61184E+05	0.39004E+05
5	0.60E+0	0.53E+0	0.10E-3	0.13E-4	0.11E-4	0.18E-4	0.75496E+05	0.46439E+05
6	0.61E+0	0.55E+0	0.10E-3	0.14E-4	0.12E-4	0.19E-4	0.82619E+05	0.50145E+05
7	0.61E+0	0.55E+0	0.10E-3	0.14E-4	0.12E-4	0.20E-4	0.83529E+05	0.50609E+05
8	0.61E+0	0.55E+0	0.10E-3	0.14E-4	0.12E-4	0.20E-4	0.83529E+05	0.50609E+05
9	0.61E+0	0.55E+0	0.10E-3	0.14E-4	0.12E-4	0.20E-4	0.83529E+05	0.50609E+05
10	0.61E+0	0.55E+0	0.10E-3	0.14E-4	0.12E-4	0.20E-4	0.83529E+05	0.50609E+05
11	0.61E+0	0.55E+0	0.10E-3	0.14E-4	0.12E-4	0.20E-4	0.83529E+05	0.50609E+05
12	0.61E+0	0.55E+0	0.10E-3	0.14E-4	0.12E-4	0.20E-4	0.83529E+05	0.50609E+05
13	0.61E+0	0.55E+0	0.10E-3	0.14E-4	0.12E-4	0.20E-4	0.83529E+05	0.50609E+05
14	0.61E+0	0.55E+0	0.10E-3	0.14E-4	0.12E-4	0.20E-4	0.83529E+05	0.50609E+05
15	0.61E+0	0.48E+0	0.10E-3	0.13E-4	0.88E-5	0.16E-4	0.60506E+05	0.40447E+05
16	0.61E+0	0.40E+0	0.10E-3	0.11E-4	0.60E-5	0.12E-4	0.41668E+05	0.30910E+05
17	0.91E+0	0.48E+0	0.10E-3	0.32E-4	0.12E-4	0.28E-4	0.85629E+05	0.71551E+05
18	0.12E+1	0.57E+0	0.10E-3	0.71E-4	0.22E-4	0.53E-4	0.15443E+06	0.13685E+06
19	0.12E+1	0.56E+0	0.10E-3	0.71E-4	0.22E-4	0.52E-4	0.15228E+06	0.13535E+06

MAXIMUM STRESS AFTER FULLY STRESSED DESIGN

LOAD CASE NUMBER	ELEMENT ID	STRESS
1	10	0.81600E+05
2	10	0.78126E+05
3	10	0.70777E+05
4	10	0.78910E+05

5 10 0.68358E+05

REAL EIGENVALUES OF OPTIMUM SYSTEM

MODE	EXTRACTION	EIGENVALUE	RADIANS	CYCLES	GENERALIZED	GENERALIZED
NO.	ORDER				MASS	STIFFNESS
1	1	0.581375E-03	0.241117E-01	0.383750E-02	0.100000E+01	0.581375E-03
2	2	0.551645E-02	0.742728E-01	0.118209E-01	0.100000E+01	0.551645E-02
3	3	0.133828E-01	0.115684E+00	0.184117E-01	0.100000E+01	0.133828E-01
4	4	0.144711E+03	0.120296E+02	0.191457E+01	0.100000E+01	0.144711E+03
5	5	0.103320E+04	0.321435E+02	0.511579E+01	0.100000E+01	0.103320E+04
6	6	0.197907E+04	0.444868E+02	0.708029E+01	0.100000E+01	0.197907E+04
7	7	0.366857E+04	0.605687E+02	0.963981E+01	0.100000E+01	0.366857E+04
8	8	0.829653E+04	0.910853E+02	0.144967E+02	0.100000E+01	0.829653E+04
9	9	0.922441E+04	0.960438E+02	0.152858E+02	0.100000E+01	0.922441E+04
10	10	0.188928E+05	0.137451E+03	0.218760E+02	0.100000E+01	0.188928E+05
11	11	0.196447E+05	0.140160E+03	0.223071E+02	0.100000E+01	0.196447E+05
12	12	0.344090E+05	0.185497E+03	0.295227E+02	0.100000E+01	0.344090E+05
13	13	0.355948E+05	0.188666E+03	0.300271E+02	0.100000E+01	0.355948E+05
14	14	0.541596E+05	0.232722E+03	0.370389E+02	0.100000E+01	0.541596E+05
15	15	0.581265E+05	0.241094E+03	0.383714E+02	0.100000E+01	0.581265E+05
16	16	0.718023E+05	0.267959E+03	0.426471E+02	0.100000E+01	0.718023E+05
17	17	0.916527E+05	0.302742E+03	0.481829E+02	0.100000E+01	0.916527E+05
18	18	0.925040E+05	0.304145E+03	0.484061E+02	0.100000E+01	0.925040E+05
19	19	0.116102E+06	0.340738E+03	0.542301E+02	0.100000E+01	0.116102E+06
20	20	0.140350E+06	0.374633E+03	0.596246E+02	0.100000E+01	0.140350E+06
21	21	0.141858E+06	0.376641E+03	0.599442E+02	0.100000E+01	0.141858E+06
22	22	0.166759E+06	0.408361E+03	0.649927E+02	0.100000E+01	0.166759E+06
23	23	0.189410E+06	0.435212E+03	0.692662E+02	0.100000E+01	0.189410E+06
24	24	0.205525E+06	0.453349E+03	0.721527E+02	0.100000E+01	0.205525E+06
25	25	0.206228E+06	0.454124E+03	0.722760E+02	0.100000E+01	0.206228E+06
26	26	0.224616E+06	0.473937E+03	0.754294E+02	0.100000E+01	0.224616E+06
27	27	0.246542E+06	0.496530E+03	0.790251E+02	0.100000E+01	0.246542E+06
28	28	0.266190E+06	0.515936E+03	0.821138E+02	0.100000E+01	0.266190E+06
29	29	0.280797E+06	0.529903E+03	0.843367E+02	0.100000E+01	0.280797E+06
30	30	0.293112E+06	0.541398E+03	0.861662E+02	0.100000E+01	0.293112E+06
31	31	0.293772E+06	0.542007E+03	0.862631E+02	0.100000E+01	0.293772E+06

32	32	0.327103E+06	0.571929E+03	0.910253E+02	0.100000E+01	0.327103E+06
33	33	0.407257E+06	0.638167E+03	0.101567E+03	0.100000E+01	0.407257E+06
34	34	0.539381E+06	0.734426E+03	0.116887E+03	0.100000E+01	0.539381E+06
35	35	0.704143E+06	0.839132E+03	0.133552E+03	0.100000E+01	0.704143E+06
36	36	0.764870E+06	0.874569E+03	0.139192E+03	0.100000E+01	0.764870E+06
37	37	0.908416E+06	0.953109E+03	0.151692E+03	0.100000E+01	0.908416E+06
38	38	0.111247E+07	0.105474E+04	0.167867E+03	0.100000E+01	0.111247E+07
39	39	0.133479E+07	0.115533E+04	0.183876E+03	0.100000E+01	0.133479E+07
40	40	0.155555E+07	0.124722E+04	0.198501E+03	0.100000E+01	0.155555E+07
41	41	0.581352E+10	0.762464E+05	0.121350E+05	0.100000E+01	0.581352E+10
42	42	0.920630E+10	0.959495E+05	0.152708E+05	0.100000E+01	0.920630E+10
43	43	0.129254E+11	0.113690E+06	0.180943E+05	0.100000E+01	0.129254E+11
44	44	0.135299E+11	0.116318E+06	0.185126E+05	0.100000E+01	0.135299E+11
45	45	0.149468E+11	0.122257E+06	0.194578E+05	0.100000E+01	0.149468E+11
46	46	0.159612E+11	0.126338E+06	0.201073E+05	0.100000E+01	0.159612E+11
47	47	0.175159E+11	0.132348E+06	0.210638E+05	0.100000E+01	0.175159E+11
48	48	0.193723E+11	0.139184E+06	0.221519E+05	0.100000E+01	0.193723E+11
49	49	0.209807E+11	0.144847E+06	0.230531E+05	0.100000E+01	0.209807E+11
50	50	0.227686E+11	0.150893E+06	0.240153E+05	0.100000E+01	0.227686E+11
51	51	0.250535E+11	0.158283E+06	0.251915E+05	0.100000E+01	0.250535E+11
52	52	0.275608E+11	0.166014E+06	0.264220E+05	0.100000E+01	0.275608E+11
53	53	0.301299E+11	0.173580E+06	0.276260E+05	0.100000E+01	0.301299E+11
54	54	0.319905E+11	0.178859E+06	0.284663E+05	0.100000E+01	0.319905E+11
55	55	0.343759E+11	0.185407E+06	0.295085E+05	0.100000E+01	0.343759E+11
56	56	0.373675E+11	0.193307E+06	0.307657E+05	0.100000E+01	0.373675E+11
57	57	0.389052E+11	0.197244E+06	0.313924E+05	0.100000E+01	0.389052E+11
58	58	0.402897E+11	0.200723E+06	0.319460E+05	0.100000E+01	0.402897E+11
59	59	0.427208E+11	0.206690E+06	0.328958E+05	0.100000E+01	0.427208E+11
60	60	0.443468E+11	0.210587E+06	0.335159E+05	0.100000E+01	0.443468E+11

N A S T R A N I N P U T D E C K

SOL 101

CEND

SUBCASE = 1

LOAD = 1

DISP = ALL

STRESS = ALL

SUBCASE = 2

LOAD = 2

DISP = ALL

STRESS = ALL

SUBCASE = 3

LOAD = 3

DISP = ALL

STRESS = ALL

SUBCASE = 4

LOAD = 4

DISP = ALL

STRESS = ALL

SUBCASE = 5

LOAD = 5

DISP = ALL

STRESS = ALL

BEGIN BULK

PARAM, INREL, -1

PARAM, GRDPNT, 1

SUPPORT, 1, 123456

GRID	1	0.000	0.000	0.000
GRID	2	0.330	0.000	0.000
GRID	3	0.660	0.000	0.000
GRID	4	0.990	0.000	0.000
GRID	5	1.319	0.000	0.000
GRID	6	1.649	0.000	0.000
GRID	7	1.979	0.000	0.000
GRID	8	2.309	0.000	0.000
GRID	9	2.639	0.000	0.000
GRID	10	2.969	0.000	0.000
GRID	11	3.299	0.000	0.000

GRID	12		3.628	0.000	0.000		
GRID	13		3.958	0.000	0.000		
GRID	14		4.288	0.000	0.000		
GRID	15		4.618	0.000	0.000		
GRID	16		4.948	0.000	0.000		
GRID	17		5.278	0.000	0.000		
GRID	18		5.607	0.000	0.000		
GRID	19		5.937	0.000	0.000		
GRID	20		6.267	0.000	0.000		
CBAR	1	1	1	2	1.000	1.000	0.000
CBAR	2	2	2	3	1.000	1.000	0.000
CBAR	3	3	3	4	1.000	1.000	0.000
CBAR	4	4	4	5	1.000	1.000	0.000
CBAR	5	5	5	6	1.000	1.000	0.000
CBAR	6	6	6	7	1.000	1.000	0.000
CBAR	7	7	7	8	1.000	1.000	0.000
CBAR	8	8	8	9	1.000	1.000	0.000
CBAR	9	9	9	10	1.000	1.000	0.000
CBAR	10	10	10	11	1.000	1.000	0.000
CBAR	11	11	11	12	1.000	1.000	0.000
CBAR	12	12	12	13	1.000	1.000	0.000
CBAR	13	13	13	14	1.000	1.000	0.000
CBAR	14	14	14	15	1.000	1.000	0.000
CBAR	15	15	15	16	1.000	1.000	0.000
CBAR	16	16	16	17	1.000	1.000	0.000
CBAR	17	17	17	18	1.000	1.000	0.000
CBAR	18	18	18	19	1.000	1.000	0.000
CBAR	19	19	19	20	1.000	1.000	0.000
FORCE	1	1	0-0.65E-1	0.000	0.000	1.000	
FORCE	1	2	0-0.11E+0	0.000	0.000	1.000	
FORCE	1	3	0-0.29E+0	0.000	0.000	1.000	
FORCE	1	4	0-0.11E+1	0.000	0.000	1.000	
FORCE	1	5	0-0.22E+1	0.000	0.000	1.000	
FORCE	1	6	0-0.94E-1	0.000	0.000	1.000	
FORCE	1	7	0 0.30E+0	0.000	0.000	1.000	
FORCE	1	8	0 0.65E+0	0.000	0.000	1.000	

FORCE	1	9	0 0.88E+0	0.000	0.000	1.000
FORCE	1	10	0 0.65E+0	0.000	0.000	1.000
FORCE	1	11	0 0.65E+0	0.000	0.000	1.000
FORCE	1	12	0 0.65E+0	0.000	0.000	1.000
FORCE	1	13	0 0.65E+0	0.000	0.000	1.000
FORCE	1	14	0 0.65E+0	0.000	0.000	1.000
FORCE	1	15	0 0.65E+0	0.000	0.000	1.000
FORCE	1	16	0 0.65E+0	0.000	0.000	1.000
FORCE	1	17	0 0.65E+0	0.000	0.000	1.000
FORCE	1	18	0 0.65E+0	0.000	0.000	1.000
FORCE	1	19	0 0.65E+0	0.000	0.000	1.000
FORCE	1	20	0 0.44E+0	0.000	0.000	1.000
FORCE	2	1	0-0.62E-1	0.000	0.000	1.000
FORCE	2	2	0-0.10E+0	0.000	0.000	1.000
FORCE	2	3	0-0.28E+0	0.000	0.000	1.000
FORCE	2	4	0-0.10E+1	0.000	0.000	1.000
FORCE	2	5	0-0.21E+1	0.000	0.000	1.000
FORCE	2	6	0-0.95E-1	0.000	0.000	1.000
FORCE	2	7	0 0.29E+0	0.000	0.000	1.000
FORCE	2	8	0 0.61E+0	0.000	0.000	1.000
FORCE	2	9	0 0.83E+0	0.000	0.000	1.000
FORCE	2	10	0 0.61E+0	0.000	0.000	1.000
FORCE	2	11	0 0.62E+0	0.000	0.000	1.000
FORCE	2	12	0 0.61E+0	0.000	0.000	1.000
FORCE	2	13	0 0.61E+0	0.000	0.000	1.000
FORCE	2	14	0 0.62E+0	0.000	0.000	1.000
FORCE	2	15	0 0.61E+0	0.000	0.000	1.000
FORCE	2	16	0 0.61E+0	0.000	0.000	1.000
FORCE	2	17	0 0.61E+0	0.000	0.000	1.000
FORCE	2	18	0 0.62E+0	0.000	0.000	1.000
FORCE	2	19	0 0.61E+0	0.000	0.000	1.000
FORCE	2	20	0 0.42E+0	0.000	0.000	1.000
FORCE	3	1	0-0.55E-1	0.000	0.000	1.000
FORCE	3	2	0-0.92E-1	0.000	0.000	1.000
FORCE	3	3	0-0.25E+0	0.000	0.000	1.000
FORCE	3	4	0-0.96E+0	0.000	0.000	1.000

FORCE	3	5	0-0.19E+1	0.000	0.000	1.000
FORCE	3	6	0-0.89E-1	0.000	0.000	1.000
FORCE	3	7	0 0.26E+0	0.000	0.000	1.000
FORCE	3	8	0 0.55E+0	0.000	0.000	1.000
FORCE	3	9	0 0.75E+0	0.000	0.000	1.000
FORCE	3	10	0 0.55E+0	0.000	0.000	1.000
FORCE	3	11	0 0.55E+0	0.000	0.000	1.000
FORCE	3	12	0 0.55E+0	0.000	0.000	1.000
FORCE	3	13	0 0.55E+0	0.000	0.000	1.000
FORCE	3	14	0 0.55E+0	0.000	0.000	1.000
FORCE	3	15	0 0.55E+0	0.000	0.000	1.000
FORCE	3	16	0 0.55E+0	0.000	0.000	1.000
FORCE	3	17	0 0.55E+0	0.000	0.000	1.000
FORCE	3	18	0 0.55E+0	0.000	0.000	1.000
FORCE	3	19	0 0.55E+0	0.000	0.000	1.000
FORCE	3	20	0 0.37E+0	0.000	0.000	1.000
FORCE	4	1	0-0.60E-1	0.000	0.000	1.000
FORCE	4	2	0-0.10E+0	0.000	0.000	1.000
FORCE	4	3	0-0.28E+0	0.000	0.000	1.000
FORCE	4	4	0-0.11E+1	0.000	0.000	1.000
FORCE	4	5	0-0.22E+1	0.000	0.000	1.000
FORCE	4	6	0-0.11E+0	0.000	0.000	1.000
FORCE	4	7	0 0.28E+0	0.000	0.000	1.000
FORCE	4	8	0 0.60E+0	0.000	0.000	1.000
FORCE	4	9	0 0.82E+0	0.000	0.000	1.000
FORCE	4	10	0 0.60E+0	0.000	0.000	1.000
FORCE	4	11	0 0.61E+0	0.000	0.000	1.000
FORCE	4	12	0 0.60E+0	0.000	0.000	1.000
FORCE	4	13	0 0.60E+0	0.000	0.000	1.000
FORCE	4	14	0 0.61E+0	0.000	0.000	1.000
FORCE	4	15	0 0.60E+0	0.000	0.000	1.000
FORCE	4	16	0 0.60E+0	0.000	0.000	1.000
FORCE	4	17	0 0.60E+0	0.000	0.000	1.000
FORCE	4	18	0 0.61E+0	0.000	0.000	1.000
FORCE	4	19	0 0.61E+0	0.000	0.000	1.000
FORCE	4	20	0 0.41E+0	0.000	0.000	1.000

FORCE	5	1	0-0.51E-1	0.000	0.000	1.000
FORCE	5	2	0-0.87E-1	0.000	0.000	1.000
FORCE	5	3	0-0.25E+0	0.000	0.000	1.000
FORCE	5	4	0-0.95E+0	0.000	0.000	1.000
FORCE	5	5	0-0.19E+1	0.000	0.000	1.000
FORCE	5	6	0-0.10E+0	0.000	0.000	1.000
FORCE	5	7	0 0.24E+0	0.000	0.000	1.000
FORCE	5	8	0 0.51E+0	0.000	0.000	1.000
FORCE	5	9	0 0.70E+0	0.000	0.000	1.000
FORCE	5	10	0 0.51E+0	0.000	0.000	1.000
FORCE	5	11	0 0.52E+0	0.000	0.000	1.000
FORCE	5	12	0 0.51E+0	0.000	0.000	1.000
FORCE	5	13	0 0.51E+0	0.000	0.000	1.000
FORCE	5	14	0 0.52E+0	0.000	0.000	1.000
FORCE	5	15	0 0.51E+0	0.000	0.000	1.000
FORCE	5	16	0 0.51E+0	0.000	0.000	1.000
FORCE	5	17	0 0.51E+0	0.000	0.000	1.000
FORCE	5	18	0 0.52E+0	0.000	0.000	1.000
FORCE	5	19	0 0.52E+0	0.000	0.000	1.000
FORCE	5	20	0 0.35E+0	0.000	0.000	1.000
PBAR	1		1.120E-03.323E-05.345E-06.103E-05			
			-.24E+000.57E-010.24E+000.57E-010.24E+00-.57E-01-.24E+00-.57E-01			
PBAR	2		1.155E-03.587E-05.182E-05.432E-05			
			-.26E+000.12E+000.26E+000.12E+000.26E+00-.12E+00-.26E+00-.12E+00			
PBAR	3		1.190E-03.898E-05.527E-05.100E-04			
			-.28E+000.20E+000.28E+000.20E+000.28E+00-.20E+00-.28E+00-.20E+00			
PBAR	4		1.214E-03.115E-04.887E-05.150E-04			
			-.29E+000.24E+000.29E+000.24E+000.29E+00-.24E+00-.29E+00-.24E+00			
PBAR	5		1.226E-03.131E-04.109E-04.179E-04			
			-.30E+000.27E+000.30E+000.27E+000.30E+00-.27E+00-.30E+00-.27E+00			
PBAR	6		1.232E-03.139E-04.120E-04.193E-04			
			-.30E+000.27E+000.30E+000.27E+000.30E+00-.27E+00-.30E+00-.27E+00			
PBAR	7		1.232E-03.140E-04.121E-04.195E-04			
			-.30E+000.28E+000.30E+000.28E+000.30E+00-.28E+00-.30E+00-.28E+00			
PBAR	8		1.232E-03.140E-04.121E-04.195E-04			
			-.30E+000.28E+000.30E+000.28E+000.30E+00-.28E+00-.30E+00-.28E+00			

PBAR	9	1.232E-03.140E-04.121E-04.195E-04	
		- .30E+000.28E+000.30E+000.28E+000.30E+00-.28E+00-.30E+00-.28E+00	
PBAR	10	1.232E-03.140E-04.121E-04.195E-04	
		- .30E+000.28E+000.30E+000.28E+000.30E+00-.28E+00-.30E+00-.28E+00	
PBAR	11	1.232E-03.140E-04.121E-04.195E-04	
		- .30E+000.28E+000.30E+000.28E+000.30E+00-.28E+00-.30E+00-.28E+00	
PBAR	12	1.232E-03.140E-04.121E-04.195E-04	
		- .30E+000.28E+000.30E+000.28E+000.30E+00-.28E+00-.30E+00-.28E+00	
PBAR	13	1.232E-03.140E-04.121E-04.195E-04	
		- .30E+000.28E+000.30E+000.28E+000.30E+00-.28E+00-.30E+00-.28E+00	
PBAR	14	1.232E-03.140E-04.121E-04.195E-04	
		- .30E+000.28E+000.30E+000.28E+000.30E+00-.28E+00-.30E+00-.28E+00	
PBAR	15	1.217E-03.127E-04.878E-05.156E-04	
		- .30E+000.24E+000.30E+000.24E+000.30E+00-.24E+00-.30E+00-.24E+00	
PBAR	16	1.203E-03.113E-04.604E-05.119E-04	
		- .30E+000.20E+000.30E+000.20E+000.30E+00-.20E+00-.30E+00-.20E+00	
PBAR	17	1.278E-03.325E-04.124E-04.276E-04	
		- .45E+000.24E+000.45E+000.24E+000.45E+00-.24E+00-.45E+00-.24E+00	
PBAR	18	1.355E-03.709E-04.224E-04.528E-04	
		- .60E+000.28E+000.60E+000.28E+000.60E+00-.28E+00-.60E+00-.28E+00	
PBAR	19	1.354E-03.706E-04.221E-04.522E-04	
		- .60E+000.28E+000.60E+000.28E+000.60E+00-.28E+00-.60E+00-.28E+00	
CONM2	21	1	0.43E+1
	1.E-6	1.E-6	1.E-6
CONM2	22	2	0.18E+2
	1.E-6	1.E-6	1.E-6
CONM2	23	3	0.35E+2
	1.E-6	1.E-6	1.E-6
CONM2	24	4	0.52E+2
	1.E-6	1.E-6	1.E-6
CONM2	25	5	0.61E+2
	1.E-6	1.E-6	1.E-6
CONM2	26	6	0.66E+2
	1.E-6	1.E-6	1.E-6
CONM2	27	7	0.68E+2
	1.E-6	1.E-6	1.E-6

CONM2	28	8	0.68E+2	
	1.E-6	1.E-6		1.E-6
CONM2	29	9	0.68E+2	
	1.E-6	1.E-6		1.E-6
CONM2	30	10	0.68E+2	
	1.E-6	1.E-6		1.E-6
CONM2	31	11	0.68E+2	
	1.E-6	1.E-6		1.E-6
CONM2	32	12	0.68E+2	
	1.E-6	1.E-6		1.E-6
CONM2	33	13	0.68E+2	
	1.E-6	1.E-6		1.E-6
CONM2	34	14	0.68E+2	
	1.E-6	1.E-6		1.E-6
CONM2	35	15	0.65E+2	
	1.E-6	1.E-6		1.E-6
CONM2	36	16	0.52E+2	
	1.E-6	1.E-6		1.E-6
CONM2	37	17	0.60E+2	
	1.E-6	1.E-6		1.E-6
CONM2	38	18	0.13E+3	
	1.E-6	1.E-6		1.E-6
CONM2	39	19	0.14E+3	
	1.E-6	1.E-6		1.E-6
CONM2	40	20	0.68E+2	
	1.E-6	1.E-6		1.E-6

MAT1 1 0.7E+10 0.3E+10 0.33E+0

ENDDATA

```

*****
***                                     ***
*** S M B   T E R M I N A T E D ***
***                                     ***
***           N O R M A L L Y           ***

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***
***      10:58:06      10/13/2009      ***
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*****

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Listing 9.7.3 Eigenvalues and Eigenvectors of the Beam Model: RDOF_EIGEN.FREE

```

20      20
1      0.00000000E+00  0.00000000E+00  0.00000000E+00
2      0.32985264E+00  0.00000000E+00  0.00000000E+00
3      0.65970528E+00  0.00000000E+00  0.00000000E+00
4      0.98955792E+00  0.00000000E+00  0.00000000E+00
5      0.13194106E+01  0.00000000E+00  0.00000000E+00
6      0.16492631E+01  0.00000000E+00  0.00000000E+00
7      0.19791158E+01  0.00000000E+00  0.00000000E+00
8      0.23089683E+01  0.00000000E+00  0.00000000E+00
9      0.26388211E+01  0.00000000E+00  0.00000000E+00
10     0.29686737E+01  0.00000000E+00  0.00000000E+00
11     0.32985263E+01  0.00000000E+00  0.00000000E+00
12     0.36283789E+01  0.00000000E+00  0.00000000E+00
13     0.39582317E+01  0.00000000E+00  0.00000000E+00
14     0.42880840E+01  0.00000000E+00  0.00000000E+00
15     0.46179366E+01  0.00000000E+00  0.00000000E+00
16     0.49477897E+01  0.00000000E+00  0.00000000E+00
17     0.52776423E+01  0.00000000E+00  0.00000000E+00
18     0.56074948E+01  0.00000000E+00  0.00000000E+00
19     0.59373474E+01  0.00000000E+00  0.00000000E+00
20     0.62672000E+01  0.00000000E+00  0.00000000E+00
$MODE 1
0.24111725E-01  0.10000000E+01
1 -0.278876328E-01  0.00000000E+00  0.112659199E-05  0.00000000E+00 -0.131874517E-05  0.00000000E+00
2 -0.278876328E-01  0.00000000E+00  0.156158370E-05  0.00000000E+00 -0.131874616E-05  0.00000000E+00
3 -0.278876348E-01  0.00000000E+00  0.199657550E-05  0.00000000E+00 -0.131874523E-05  0.00000000E+00
4 -0.278876364E-01  0.00000000E+00  0.243156709E-05  0.00000000E+00 -0.131874513E-05  0.00000000E+00
5 -0.278876407E-01  0.00000000E+00  0.286655839E-05  0.00000000E+00 -0.131874271E-05  0.00000000E+00
6 -0.278876445E-01  0.00000000E+00  0.330154774E-05  0.00000000E+00 -0.131873266E-05  0.00000000E+00
7 -0.278876480E-01  0.00000000E+00  0.373653169E-05  0.00000000E+00 -0.131870764E-05  0.00000000E+00
8 -0.278876513E-01  0.00000000E+00  0.417150394E-05  0.00000000E+00 -0.131866388E-05  0.00000000E+00
9 -0.278876515E-01  0.00000000E+00  0.460645919E-05  0.00000000E+00 -0.131860165E-05  0.00000000E+00
10 -0.278876486E-01  0.00000000E+00  0.504139134E-05  0.00000000E+00 -0.131852787E-05  0.00000000E+00
11 -0.278876455E-01  0.00000000E+00  0.547629834E-05  0.00000000E+00 -0.131844911E-05  0.00000000E+00
12 -0.278876421E-01  0.00000000E+00  0.591117857E-05  0.00000000E+00 -0.131836563E-05  0.00000000E+00
13 -0.278876385E-01  0.00000000E+00  0.634603075E-05  0.00000000E+00 -0.131827717E-05  0.00000000E+00
14 -0.278876376E-01  0.00000000E+00  0.678085319E-05  0.00000000E+00 -0.131819208E-05  0.00000000E+00
15 -0.278876393E-01  0.00000000E+00  0.721564925E-05  0.00000000E+00 -0.131811303E-05  0.00000000E+00
16 -0.278876440E-01  0.00000000E+00  0.765041483E-05  0.00000000E+00 -0.131800367E-05  0.00000000E+00
17 -0.278876521E-01  0.00000000E+00  0.808513655E-05  0.00000000E+00 -0.131785376E-05  0.00000000E+00
18 -0.278876578E-01  0.00000000E+00  0.851982451E-05  0.00000000E+00 -0.131780157E-05  0.00000000E+00
19 -0.278876601E-01  0.00000000E+00  0.895450277E-05  0.00000000E+00 -0.131779307E-05  0.00000000E+00
20 -0.278876603E-01  0.00000000E+00  0.938918049E-05  0.00000000E+00 -0.131779433E-05  0.00000000E+00
$MODE 2
0.74272821E-01  0.10000000E+01
1 -0.590135654E-05  0.00000000E+00 -0.310373703E-01  0.00000000E+00 -0.855877568E-03  0.00000000E+00
2 -0.590135649E-05  0.00000000E+00 -0.307550586E-01  0.00000000E+00 -0.855861192E-03  0.00000000E+00
3 -0.590135672E-05  0.00000000E+00 -0.304727516E-01  0.00000000E+00 -0.855854660E-03  0.00000000E+00
4 -0.590135661E-05  0.00000000E+00 -0.301904499E-01  0.00000000E+00 -0.855826006E-03  0.00000000E+00
5 -0.590135681E-05  0.00000000E+00 -0.299081556E-01  0.00000000E+00 -0.855817760E-03  0.00000000E+00
6 -0.590135657E-05  0.00000000E+00 -0.296258560E-01  0.00000000E+00 -0.855869346E-03  0.00000000E+00
7 -0.59013589E-05  0.00000000E+00 -0.293435221E-01  0.00000000E+00 -0.856034073E-03  0.00000000E+00
8 -0.590135477E-05  0.00000000E+00 -0.290611107E-01  0.00000000E+00 -0.856338226E-03  0.00000000E+00
9 -0.590135258E-05  0.00000000E+00 -0.287785773E-01  0.00000000E+00 -0.856769639E-03  0.00000000E+00
10 -0.590134933E-05  0.00000000E+00 -0.284958867E-01  0.00000000E+00 -0.857277176E-03  0.00000000E+00
11 -0.590134563E-05  0.00000000E+00 -0.282130243E-01  0.00000000E+00 -0.857809629E-03  0.00000000E+00
12 -0.590134148E-05  0.00000000E+00 -0.279299840E-01  0.00000000E+00 -0.858353217E-03  0.00000000E+00
13 -0.590133687E-05  0.00000000E+00 -0.276467643E-01  0.00000000E+00 -0.858893951E-03  0.00000000E+00
14 -0.590133242E-05  0.00000000E+00 -0.273633731E-01  0.00000000E+00 -0.859381798E-03  0.00000000E+00
15 -0.590132838E-05  0.00000000E+00 -0.270798332E-01  0.00000000E+00 -0.859803354E-03  0.00000000E+00
16 -0.590132390E-05  0.00000000E+00 -0.267961365E-01  0.00000000E+00 -0.860325023E-03  0.00000000E+00
17 -0.590132141E-05  0.00000000E+00 -0.265122538E-01  0.00000000E+00 -0.860901326E-03  0.00000000E+00
18 -0.590131983E-05  0.00000000E+00 -0.262282551E-01  0.00000000E+00 -0.861049662E-03  0.00000000E+00
19 -0.590131938E-05  0.00000000E+00 -0.259442311E-01  0.00000000E+00 -0.861068348E-03  0.00000000E+00
20 -0.590131655E-05  0.00000000E+00 -0.256602063E-01  0.00000000E+00 -0.861064754E-03  0.00000000E+00
$MODE 3
0.11569397E+00  0.10000000E+01
1 0.263429112E-05  0.00000000E+00 -0.576067672E-01  0.00000000E+00 -0.158799367E-01  0.00000000E+00
2 0.263429106E-05  0.00000000E+00 -0.523687351E-01  0.00000000E+00 -0.158798715E-01  0.00000000E+00
3 0.263429102E-05  0.00000000E+00 -0.471307271E-01  0.00000000E+00 -0.158797988E-01  0.00000000E+00
4 0.263429067E-05  0.00000000E+00 -0.418927506E-01  0.00000000E+00 -0.158796803E-01  0.00000000E+00
5 0.263429025E-05  0.00000000E+00 -0.366548139E-01  0.00000000E+00 -0.158795665E-01  0.00000000E+00
6 0.263428940E-05  0.00000000E+00 -0.314169139E-01  0.00000000E+00 -0.158794752E-01  0.00000000E+00
7 0.263428808E-05  0.00000000E+00 -0.261790343E-01  0.00000000E+00 -0.158794381E-01  0.00000000E+00
8 0.263428628E-05  0.00000000E+00 -0.209411598E-01  0.00000000E+00 -0.158794638E-01  0.00000000E+00
9 0.263428372E-05  0.00000000E+00 -0.157032639E-01  0.00000000E+00 -0.158795283E-01  0.00000000E+00
10 0.263428040E-05  0.00000000E+00 -0.104653482E-01  0.00000000E+00 -0.158795970E-01  0.00000000E+00
11 0.263427658E-05  0.00000000E+00 -0.522741415E-02  0.00000000E+00 -0.158796378E-01  0.00000000E+00

```

12	0.263427228E-05	0.000000000E+00	0.105274241E-04	0.000000000E+00	-0.158796414E-01	0.000000000E+00
13	0.263426748E-05	0.000000000E+00	0.524846637E-02	0.000000000E+00	-0.158795985E-01	0.000000000E+00
14	0.263426246E-05	0.000000000E+00	0.104863755E-01	0.000000000E+00	-0.158795094E-01	0.000000000E+00
15	0.263425736E-05	0.000000000E+00	0.157242531E-01	0.000000000E+00	-0.158793830E-01	0.000000000E+00
16	0.263425218E-05	0.000000000E+00	0.209620807E-01	0.000000000E+00	-0.158791592E-01	0.000000000E+00
17	0.263424892E-05	0.000000000E+00	0.261998071E-01	0.000000000E+00	-0.158788363E-01	0.000000000E+00
18	0.263424675E-05	0.000000000E+00	0.314374643E-01	0.000000000E+00	-0.158787404E-01	0.000000000E+00
19	0.263424598E-05	0.000000000E+00	0.366751062E-01	0.000000000E+00	-0.158787379E-01	0.000000000E+00
20	0.263424238E-05	0.000000000E+00	0.419127512E-01	0.000000000E+00	-0.158787484E-01	0.000000000E+00
SMODE 4						
0.12029574E+02 0.10000000E+01						
1	0.964906826E-10	0.000000000E+00	0.840124977E-01	0.000000000E+00	0.490409242E-01	0.000000000E+00
2	0.964664986E-10	0.000000000E+00	0.679688411E-01	0.000000000E+00	0.478347277E-01	0.000000000E+00
3	0.963688526E-10	0.000000000E+00	0.523760494E-01	0.000000000E+00	0.463744401E-01	0.000000000E+00
4	0.961657482E-10	0.000000000E+00	0.373023769E-01	0.000000000E+00	0.447728358E-01	0.000000000E+00
5	0.958241807E-10	0.000000000E+00	0.228399398E-01	0.000000000E+00	0.426867590E-01	0.000000000E+00
6	0.953227208E-10	0.000000000E+00	0.920851840E-02	0.000000000E+00	0.397296335E-01	0.000000000E+00
7	0.946450444E-10	0.000000000E+00	-0.326712114E-02	0.000000000E+00	0.356797776E-01	0.000000000E+00
8	0.937789716E-10	0.000000000E+00	-0.141867277E-01	0.000000000E+00	0.303044584E-01	0.000000000E+00
9	0.927239588E-10	0.000000000E+00	-0.231207738E-01	0.000000000E+00	0.236707850E-01	0.000000000E+00
10	0.914820785E-10	0.000000000E+00	-0.296902770E-01	0.000000000E+00	0.160166804E-01	0.000000000E+00
11	0.900559105E-10	0.000000000E+00	-0.336118902E-01	0.000000000E+00	0.767889728E-02	0.000000000E+00
12	0.884482921E-10	0.000000000E+00	-0.347252917E-01	0.000000000E+00	-0.938953964E-03	0.000000000E+00
13	0.866625302E-10	0.000000000E+00	-0.330095688E-01	0.000000000E+00	-0.940116352E-02	0.000000000E+00
14	0.847021141E-10	0.000000000E+00	-0.285879038E-01	0.000000000E+00	-0.172757883E-01	0.000000000E+00
15	0.823218006E-10	0.000000000E+00	-0.217204306E-01	0.000000000E+00	-0.241701020E-01	0.000000000E+00
16	0.813811565E-10	0.000000000E+00	-0.124190210E-01	0.000000000E+00	-0.318981230E-01	0.000000000E+00
17	0.813434078E-10	0.000000000E+00	-0.453939923E-03	0.000000000E+00	-0.401316382E-01	0.000000000E+00
18	0.812431433E-10	0.000000000E+00	0.132361151E-01	0.000000000E+00	-0.426224373E-01	0.000000000E+00
19	0.810432696E-10	0.000000000E+00	0.274166292E-01	0.000000000E+00	-0.432463852E-01	0.000000000E+00
20	0.790250282E-10	0.000000000E+00	0.417136351E-01	0.000000000E+00	-0.433922420E-01	0.000000000E+00
SMODE 5						
0.32143455E+02 0.10000000E+01						
1	0.199871818E-10	0.000000000E+00	0.108050990E+00	0.000000000E+00	0.108405427E+00	0.000000000E+00
2	0.199513906E-10	0.000000000E+00	0.735110336E-01	0.000000000E+00	0.973290378E-01	0.000000000E+00
3	0.198071414E-10	0.000000000E+00	0.429865841E-01	0.000000000E+00	0.850537745E-01	0.000000000E+00
4	0.195083016E-10	0.000000000E+00	0.166608636E-01	0.000000000E+00	0.728529219E-01	0.000000000E+00
5	0.190094579E-10	0.000000000E+00	-0.524957251E-02	0.000000000E+00	0.587152778E-01	0.000000000E+00
6	0.182849603E-10	0.000000000E+00	-0.218968969E-01	0.000000000E+00	0.412631890E-01	0.000000000E+00
7	0.173200194E-10	0.000000000E+00	-0.322629299E-01	0.000000000E+00	0.210413027E-01	0.000000000E+00
8	0.161091952E-10	0.000000000E+00	-0.356189568E-01	0.000000000E+00	-0.745847165E-03	0.000000000E+00
9	0.146666090E-10	0.000000000E+00	-0.319140730E-01	0.000000000E+00	-0.212307101E-01	0.000000000E+00
10	0.130130160E-10	0.000000000E+00	-0.220941673E-01	0.000000000E+00	-0.373388713E-01	0.000000000E+00
11	0.111721895E-10	0.000000000E+00	-0.803298100E-02	0.000000000E+00	-0.466116597E-01	0.000000000E+00
12	0.917068790E-11	0.000000000E+00	0.775343463E-02	0.000000000E+00	-0.476775830E-01	0.000000000E+00
13	0.703731898E-11	0.000000000E+00	0.225164239E-01	0.000000000E+00	-0.405238905E-01	0.000000000E+00
14	0.480280202E-11	0.000000000E+00	0.337350184E-01	0.000000000E+00	-0.265286060E-01	0.000000000E+00
15	0.283745848E-11	0.000000000E+00	0.395467900E-01	0.000000000E+00	-0.825247037E-02	0.000000000E+00
16	-0.140902184E-11	0.000000000E+00	0.378509104E-01	0.000000000E+00	0.183662741E-01	0.000000000E+00
17	-0.600914391E-11	0.000000000E+00	0.259102665E-01	0.000000000E+00	0.529084154E-01	0.000000000E+00
18	-0.886789818E-11	0.000000000E+00	0.625033164E-02	0.000000000E+00	0.654067384E-01	0.000000000E+00
19	-0.970276222E-11	0.000000000E+00	-0.160292664E-01	0.000000000E+00	0.690932937E-01	0.000000000E+00
20	-0.934700025E-11	0.000000000E+00	-0.390341700E-01	0.000000000E+00	0.700678327E-01	0.000000000E+00
SMODE 6						
0.44486765E+02 0.10000000E+01						
1	0.415391010E-01	0.000000000E+00	-0.840198079E-10	0.000000000E+00	-0.105042882E-09	0.000000000E+00
2	0.413966492E-01	0.000000000E+00	-0.511760075E-10	0.000000000E+00	-0.885674265E-10	0.000000000E+00
3	0.408232078E-01	0.000000000E+00	-0.242056235E-10	0.000000000E+00	-0.712494060E-10	0.000000000E+00
4	0.396401595E-01	0.000000000E+00	-0.303548833E-11	0.000000000E+00	-0.549449893E-10	0.000000000E+00
5	0.376808809E-01	0.000000000E+00	0.124010427E-10	0.000000000E+00	-0.372744926E-10	0.000000000E+00
6	0.348683388E-01	0.000000000E+00	0.215301893E-10	0.000000000E+00	-0.173138866E-10	0.000000000E+00
7	0.311817128E-01	0.000000000E+00	0.238689120E-10	0.000000000E+00	0.322321273E-11	0.000000000E+00
8	0.266481304E-01	0.000000000E+00	0.196247767E-10	0.000000000E+00	0.218869998E-10	0.000000000E+00
9	0.213801924E-01	0.000000000E+00	0.100286050E-10	0.000000000E+00	0.351023792E-10	0.000000000E+00
10	0.155230781E-01	0.000000000E+00	-0.263819065E-11	0.000000000E+00	0.402102695E-10	0.000000000E+00
11	0.923819160E-02	0.000000000E+00	-0.155337281E-10	0.000000000E+00	0.365610122E-10	0.000000000E+00
12	0.269872670E-02	0.000000000E+00	-0.259694036E-10	0.000000000E+00	0.257406762E-10	0.000000000E+00
13	-0.391511296E-02	0.000000000E+00	-0.321285313E-10	0.000000000E+00	0.114272145E-10	0.000000000E+00
14	-0.104210534E-01	0.000000000E+00	-0.336118528E-10	0.000000000E+00	-0.191840324E-11	0.000000000E+00
15	-0.166398250E-01	0.000000000E+00	-0.313656232E-10	0.000000000E+00	-0.106251903E-10	0.000000000E+00
16	-0.228123536E-01	0.000000000E+00	-0.270701093E-10	0.000000000E+00	-0.139730055E-10	0.000000000E+00
17	-0.288888705E-01	0.000000000E+00	-0.250077723E-10	0.000000000E+00	0.846500330E-11	0.000000000E+00
18	-0.327192076E-01	0.000000000E+00	-0.312624952E-10	0.000000000E+00	0.293823538E-10	0.000000000E+00
19	-0.346265852E-01	0.000000000E+00	-0.423241457E-10	0.000000000E+00	0.360884212E-10	0.000000000E+00
20	-0.352638127E-01	0.000000000E+00	-0.544417511E-10	0.000000000E+00	0.370604333E-10	0.000000000E+00
SMODE 7						
0.60568742E+02 0.10000000E+01						
1	-0.157071915E-10	0.000000000E+00	-0.146473810E+00	0.000000000E+00	-0.231409075E+00	0.000000000E+00
2	-0.156073325E-10	0.000000000E+00	-0.760049069E-01	0.000000000E+00	-0.178094660E+00	0.000000000E+00
3	-0.152063543E-10	0.000000000E+00	-0.241108832E-01	0.000000000E+00	-0.125859035E+00	0.000000000E+00
4	-0.143853589E-10	0.000000000E+00	0.108493324E-01	0.000000000E+00	-0.808556818E-01	0.000000000E+00
5	-0.130450368E-10	0.000000000E+00	0.307425413E-01	0.000000000E+00	-0.372525420E-01	0.000000000E+00
6	-0.111616129E-10	0.000000000E+00	0.360676504E-01	0.000000000E+00	0.535285715E-02	0.000000000E+00
7	-0.876482203E-11	0.000000000E+00	0.282228388E-01	0.000000000E+00	0.406444638E-01	0.000000000E+00
8	-0.592813575E-11	0.000000000E+00	0.108390402E-01	0.000000000E+00	0.616895581E-01	0.000000000E+00
9	-0.278861588E-11	0.000000000E+00	-0.102565053E-01	0.000000000E+00	0.625658035E-01	0.000000000E+00
10	-0.493359032E-12	0.000000000E+00	-0.282080249E-01	0.000000000E+00	0.431790634E-01	0.000000000E+00
11	-0.375012347E-11	0.000000000E+00	-0.371976375E-01	0.000000000E+00	0.974679138E-02	0.000000000E+00
12	-0.681538703E-11	0.000000000E+00	-0.342561362E-01	0.000000000E+00	-0.271588246E-01	0.000000000E+00
13	-0.953243719E-11	0.000000000E+00	-0.201688244E-01	0.000000000E+00	-0.559879762E-01	0.000000000E+00
14	-0.117626185E-10	0.000000000E+00	0.824117689E-03	0.000000000E+00	-0.679432884E-01	0.000000000E+00
15	-0.135319732E-10	0.000000000E+00	0.224546034E-01	0.000000000E+00	-0.598979128E-01	0.000000000E+00
16	-0.137572527E-10	0.000000000E+00	0.371430507E-01	0.000000000E+00	-0.262051871E-01	0.000000000E+00
17	-0.136003648E-10	0.000000000E+00	0.351878011E-01	0.000000000E+00	0.392888226E-01	0.000000000E+00
18	-0.135923731E-10	0.000000000E+00	0.170226636E-01	0.000000000E+00	0.698021650E-01	0.000000000E+00

19	0.144028607E-10	0.000000000E+00	-0.800874209E-02	0.000000000E+00	0.804691269E-01	0.000000000E+00
20	0.146828531E-10	0.000000000E+00	-0.352386296E-01	0.000000000E+00	0.835929802E-01	0.000000000E+00
SMODE 8						
0.91085315E+02 0.10000000E+01						
1	0.486046744E-01	0.000000000E+00	-0.615091886E-10	0.000000000E+00	-0.137958169E-09	0.000000000E+00
2	0.479059208E-01	0.000000000E+00	-0.215781245E-10	0.000000000E+00	-0.872069459E-10	0.000000000E+00
3	0.451180218E-01	0.000000000E+00	0.143525607E-11	0.000000000E+00	-0.443955372E-10	0.000000000E+00
4	0.395300384E-01	0.000000000E+00	0.114391337E-10	0.000000000E+00	-0.137377312E-10	0.000000000E+00
5	0.307691829E-01	0.000000000E+00	0.122167219E-10	0.000000000E+00	0.906685267E-11	0.000000000E+00
6	0.191985832E-01	0.000000000E+00	0.663164912E-11	0.000000000E+00	0.233567132E-10	0.000000000E+00
7	0.573528155E-02	0.000000000E+00	-0.187181199E-11	0.000000000E+00	0.260902843E-10	0.000000000E+00
8	-0.834933873E-02	0.000000000E+00	-0.927113360E-11	0.000000000E+00	0.169087703E-10	0.000000000E+00
9	-0.214694297E-01	0.000000000E+00	-0.121693257E-10	0.000000000E+00	-0.683335989E-13	0.000000000E+00
10	-0.321092880E-01	0.000000000E+00	-0.923090057E-11	0.000000000E+00	-0.169998573E-10	0.000000000E+00
11	-0.390397742E-01	0.000000000E+00	-0.182214357E-11	0.000000000E+00	-0.260490252E-10	0.000000000E+00
12	-0.414602554E-01	0.000000000E+00	0.664351032E-11	0.000000000E+00	-0.231802753E-10	0.000000000E+00
13	-0.390911060E-01	0.000000000E+00	0.123567385E-10	0.000000000E+00	-0.101803897E-10	0.000000000E+00
14	-0.322060325E-01	0.000000000E+00	0.129979194E-10	0.000000000E+00	0.613146646E-11	0.000000000E+00
15	-0.216004107E-01	0.000000000E+00	0.895433644E-11	0.000000000E+00	0.165540121E-10	0.000000000E+00
16	-0.768952060E-02	0.000000000E+00	0.291276007E-11	0.000000000E+00	0.183906918E-10	0.000000000E+00
17	0.802661037E-02	0.000000000E+00	-0.121048707E-11	0.000000000E+00	0.306064256E-11	0.000000000E+00
18	0.187754234E-01	0.000000000E+00	-0.269058856E-12	0.000000000E+00	-0.835920034E-11	0.000000000E+00
19	0.245663136E-01	0.000000000E+00	0.315503354E-11	0.000000000E+00	-0.115919927E-10	0.000000000E+00
20	0.265798168E-01	0.000000000E+00	0.706845509E-11	0.000000000E+00	-0.120002371E-10	0.000000000E+00
SMODE 9						
0.96043815E+02 0.10000000E+01						
1	-0.118311570E-10	0.000000000E+00	-0.190061228E+00	0.000000000E+00	-0.447342843E+00	0.000000000E+00
2	-0.116420340E-10	0.000000000E+00	-0.616300092E-01	0.000000000E+00	-0.273393625E+00	0.000000000E+00
3	-0.108885200E-10	0.000000000E+00	0.915922105E-02	0.000000000E+00	-0.129906339E+00	0.000000000E+00
4	-0.938467036E-11	0.000000000E+00	0.368905308E-01	0.000000000E+00	-0.307390709E-01	0.000000000E+00
5	-0.704655292E-11	0.000000000E+00	0.353776408E-01	0.000000000E+00	0.391381597E-01	0.000000000E+00
6	-0.399883833E-11	0.000000000E+00	0.152167735E-01	0.000000000E+00	0.777120202E-01	0.000000000E+00
7	-0.521845317E-12	0.000000000E+00	-0.114945238E-01	0.000000000E+00	0.772803593E-01	0.000000000E+00
8	0.301168410E-11	0.000000000E+00	-0.317458597E-01	0.000000000E+00	0.401741901E-01	0.000000000E+00
9	0.615838813E-11	0.000000000E+00	-0.358962654E-01	0.000000000E+00	-0.160438435E-01	0.000000000E+00
10	0.851408638E-11	0.000000000E+00	-0.220831031E-01	0.000000000E+00	-0.638813728E-01	0.000000000E+00
11	0.977620973E-11	0.000000000E+00	0.273416931E-02	0.000000000E+00	-0.797734440E-01	0.000000000E+00
12	0.978262706E-11	0.000000000E+00	0.261667458E-01	0.000000000E+00	-0.558559467E-01	0.000000000E+00
13	0.853267431E-11	0.000000000E+00	0.364970483E-01	0.000000000E+00	-0.387521114E-02	0.000000000E+00
14	0.618673905E-11	0.000000000E+00	0.284380250E-01	0.000000000E+00	0.506997352E-01	0.000000000E+00
15	0.307666506E-11	0.000000000E+00	0.566675410E-02	0.000000000E+00	0.814770172E-01	0.000000000E+00
16	-0.125624964E-11	0.000000000E+00	-0.211700735E-01	0.000000000E+00	0.720839937E-01	0.000000000E+00
17	-0.598732336E-11	0.000000000E+00	-0.331797150E-01	0.000000000E+00	-0.817119032E-02	0.000000000E+00
18	-0.948187330E-11	0.000000000E+00	-0.217586392E-01	0.000000000E+00	-0.615052754E-01	0.000000000E+00
19	-0.125202160E-10	0.000000000E+00	0.262655711E-02	0.000000000E+00	-0.836303031E-01	0.000000000E+00
20	-0.133506200E-10	0.000000000E+00	0.317694569E-01	0.000000000E+00	-0.907118081E-01	0.000000000E+00
SMODE 10						
0.13745102E+03 0.10000000E+01						
1	-0.246574144E-10	0.000000000E+00	-0.211240645E+00	0.000000000E+00	-0.703891609E+00	0.000000000E+00
2	-0.238501994E-10	0.000000000E+00	-0.225982289E-01	0.000000000E+00	-0.307917874E+00	0.000000000E+00
3	-0.206778819E-10	0.000000000E+00	0.423576344E-01	0.000000000E+00	-0.497547363E-01	0.000000000E+00
4	-0.146320296E-10	0.000000000E+00	0.383106762E-01	0.000000000E+00	0.727769033E-01	0.000000000E+00
5	-0.606183786E-11	0.000000000E+00	0.671915168E-02	0.000000000E+00	0.106761986E+00	0.000000000E+00
6	0.351785649E-11	0.000000000E+00	-0.244010324E-01	0.000000000E+00	0.703426600E-01	0.000000000E+00
7	0.119535875E-10	0.000000000E+00	-0.355937659E-01	0.000000000E+00	-0.636596109E-02	0.000000000E+00
8	0.172242595E-10	0.000000000E+00	-0.210619130E-01	0.000000000E+00	-0.757297929E-01	0.000000000E+00
9	0.179637550E-10	0.000000000E+00	0.846936050E-02	0.000000000E+00	-0.914677846E-01	0.000000000E+00
10	0.139775500E-10	0.000000000E+00	0.322310864E-01	0.000000000E+00	-0.430974136E-01	0.000000000E+00
11	0.631432870E-11	0.000000000E+00	0.335773669E-01	0.000000000E+00	0.355007295E-01	0.000000000E+00
12	-0.301004722E-11	0.000000000E+00	0.115107659E-01	0.000000000E+00	0.895453077E-01	0.000000000E+00
13	-0.115425690E-10	0.000000000E+00	-0.186696566E-01	0.000000000E+00	0.815032575E-01	0.000000000E+00
14	-0.170385168E-10	0.000000000E+00	-0.360861060E-01	0.000000000E+00	0.173339658E-01	0.000000000E+00
15	-0.180790047E-10	0.000000000E+00	-0.289453280E-01	0.000000000E+00	-0.573819796E-01	0.000000000E+00
16	-0.124411695E-10	0.000000000E+00	-0.238405268E-03	0.000000000E+00	-0.101478865E+00	0.000000000E+00
17	-0.317168047E-11	0.000000000E+00	0.255630130E-01	0.000000000E+00	-0.327928255E-01	0.000000000E+00
18	0.470419848E-11	0.000000000E+00	0.240043415E-01	0.000000000E+00	0.468674461E-01	0.000000000E+00
19	0.113506740E-10	0.000000000E+00	0.134899950E-02	0.000000000E+00	0.863832671E-01	0.000000000E+00
20	0.134787415E-10	0.000000000E+00	-0.301739843E-01	0.000000000E+00	0.100158763E+00	0.000000000E+00
SMODE 11						
0.14015957E+03 0.10000000E+01						
1	-0.576291542E-01	0.000000000E+00	0.980725269E-10	0.000000000E+00	0.333242682E-09	0.000000000E+00
2	-0.556674342E-01	0.000000000E+00	0.915710684E-11	0.000000000E+00	0.142236436E-09	0.000000000E+00
3	-0.479663635E-01	0.000000000E+00	-0.203000887E-10	0.000000000E+00	0.196413091E-10	0.000000000E+00
4	-0.333434330E-01	0.000000000E+00	-0.172936900E-10	0.000000000E+00	-0.366727253E-10	0.000000000E+00
5	-0.127725064E-01	0.000000000E+00	-0.199744418E-11	0.000000000E+00	-0.501725289E-10	0.000000000E+00
6	0.991298862E-02	0.000000000E+00	0.121848098E-10	0.000000000E+00	-0.304458686E-10	0.000000000E+00
7	0.293789839E-01	0.000000000E+00	0.163587104E-10	0.000000000E+00	0.659049826E-11	0.000000000E+00
8	0.407627449E-01	0.000000000E+00	0.851681997E-11	0.000000000E+00	0.376644694E-10	0.000000000E+00
9	0.409963232E-01	0.000000000E+00	-0.550707781E-11	0.000000000E+00	0.416219107E-10	0.000000000E+00
10	0.303158201E-01	0.000000000E+00	-0.156767713E-10	0.000000000E+00	0.158738949E-10	0.000000000E+00
11	0.108248340E-01	0.000000000E+00	-0.147259636E-10	0.000000000E+00	-0.212766396E-10	0.000000000E+00
12	-0.113271610E-01	0.000000000E+00	-0.328217995E-11	0.000000000E+00	-0.435006629E-10	0.000000000E+00
13	-0.303807559E-01	0.000000000E+00	0.106165107E-10	0.000000000E+00	-0.352212832E-10	0.000000000E+00
14	-0.411240236E-01	0.000000000E+00	0.173048815E-10	0.000000000E+00	-0.286157598E-11	0.000000000E+00
15	-0.406183041E-01	0.000000000E+00	0.126151584E-10	0.000000000E+00	0.284597181E-10	0.000000000E+00
16	-0.286052067E-01	0.000000000E+00	0.648870766E-13	0.000000000E+00	0.414527431E-10	0.000000000E+00
17	-0.884350721E-02	0.000000000E+00	-0.977004608E-11	0.000000000E+00	0.105932084E-10	0.000000000E+00
18	0.733984027E-02	0.000000000E+00	-0.876257858E-11	0.000000000E+00	-0.173007938E-10	0.000000000E+00
19	0.175849757E-01	0.000000000E+00	-0.817496843E-12	0.000000000E+00	-0.294238969E-10	0.000000000E+00
20	0.214286212E-01	0.000000000E+00	0.975524492E-11	0.000000000E+00	-0.333674641E-10	0.000000000E+00
SMODE 12						
0.18549657E+03 0.10000000E+01						
1	-0.404638507E-10	0.000000000E+00	-0.201509387E+00	0.000000000E+00	-0.919062790E+00	0.000000000E+00
2	-0.380511930E-10	0.000000000E+00	0.260030227E-01	0.000000000E+00	-0.231102444E+00	0.000000000E+00
3	-0.287813835E-10	0.000000000E+00	0.528310696E-01	0.000000000E+00	0.882162354E-01	0.000000000E+00

4	-0.124550558E-10	0.000000000E+00	0.103583327E-01	0.000000000E+00	0.144242441E+00	0.000000000E+00
5	0.700349952E-11	0.000000000E+00	-0.286319824E-01	0.000000000E+00	0.718209970E-01	0.000000000E+00
6	0.223093093E-10	0.000000000E+00	-0.337885403E-01	0.000000000E+00	-0.426620603E-01	0.000000000E+00
7	0.267462480E-10	0.000000000E+00	-0.644849833E-02	0.000000000E+00	-0.108138426E+00	0.000000000E+00
8	0.183747313E-10	0.000000000E+00	0.266180697E-01	0.000000000E+00	-0.742932677E-01	0.000000000E+00
9	0.119949323E-11	0.000000000E+00	0.350849221E-01	0.000000000E+00	0.275657554E-01	0.000000000E+00
10	-0.165504652E-10	0.000000000E+00	0.112403409E-01	0.000000000E+00	0.103890459E+00	0.000000000E+00
11	-0.263707108E-10	0.000000000E+00	-0.229223128E-01	0.000000000E+00	0.844470314E-01	0.000000000E+00
12	-0.235562509E-10	0.000000000E+00	-0.358873191E-01	0.000000000E+00	-0.130534743E-01	0.000000000E+00
13	-0.945550873E-11	0.000000000E+00	-0.155317805E-01	0.000000000E+00	-0.994497062E-01	0.000000000E+00
14	0.917557331E-11	0.000000000E+00	0.199277637E-01	0.000000000E+00	-0.967849148E-01	0.000000000E+00
15	0.232854759E-10	0.000000000E+00	0.392581119E-01	0.000000000E+00	-0.117238642E-01	0.000000000E+00
16	0.243752766E-10	0.000000000E+00	0.225861810E-01	0.000000000E+00	0.983544682E-01	0.000000000E+00
17	0.145431683E-10	0.000000000E+00	-0.131395540E-01	0.000000000E+00	0.797819963E-01	0.000000000E+00
18	0.187924312E-11	0.000000000E+00	-0.244277528E-01	0.000000000E+00	-0.242919674E-01	0.000000000E+00
19	-0.113623925E-10	0.000000000E+00	-0.505771197E-02	0.000000000E+00	-0.879574032E-01	0.000000000E+00
20	-0.164037194E-10	0.000000000E+00	0.293153727E-01	0.000000000E+00	-0.112332562E+00	0.000000000E+00
SMODE 13						
0.18866591E+03 0.100000000E+01						
1	0.635456904E-01	0.000000000E+00	-0.128079834E-09	0.000000000E+00	-0.595027517E-09	0.000000000E+00
2	0.596262662E-01	0.000000000E+00	0.184466311E-10	0.000000000E+00	-0.142630666E-09	0.000000000E+00
3	0.445932641E-01	0.000000000E+00	0.336042251E-10	0.000000000E+00	0.619395460E-10	0.000000000E+00
4	0.182827976E-01	0.000000000E+00	0.520964192E-11	0.000000000E+00	0.931262188E-10	0.000000000E+00
5	-0.126132500E-01	0.000000000E+00	-0.192533068E-10	0.000000000E+00	0.421772862E-10	0.000000000E+00
6	-0.360622671E-01	0.000000000E+00	-0.209869909E-10	0.000000000E+00	-0.322093635E-10	0.000000000E+00
7	-0.413893820E-01	0.000000000E+00	-0.232926801E-11	0.000000000E+00	-0.705454456E-10	0.000000000E+00
8	-0.262178436E-01	0.000000000E+00	0.183234681E-10	0.000000000E+00	-0.432087710E-10	0.000000000E+00
9	0.194814539E-02	0.000000000E+00	0.217658578E-10	0.000000000E+00	0.242314316E-10	0.000000000E+00
10	0.291485491E-01	0.000000000E+00	0.483710339E-11	0.000000000E+00	0.689086061E-10	0.000000000E+00
11	0.419019812E-01	0.000000000E+00	-0.165994622E-10	0.000000000E+00	0.490460267E-10	0.000000000E+00
12	0.338874248E-01	0.000000000E+00	-0.224529192E-10	0.000000000E+00	-0.168914751E-10	0.000000000E+00
13	0.907712925E-02	0.000000000E+00	-0.71224271E-11	0.000000000E+00	-0.67667245E-10	0.000000000E+00
14	-0.202320451E-01	0.000000000E+00	0.154316753E-10	0.000000000E+00	-0.570045845E-10	0.000000000E+00
15	-0.395135858E-01	0.000000000E+00	0.252629817E-10	0.000000000E+00	0.111229779E-11	0.000000000E+00
16	-0.398975614E-01	0.000000000E+00	0.125320985E-10	0.000000000E+00	0.657282754E-10	0.000000000E+00
17	-0.229669845E-01	0.000000000E+00	-0.964425189E-11	0.000000000E+00	0.458824898E-10	0.000000000E+00
18	-0.217392360E-02	0.000000000E+00	-0.155140169E-10	0.000000000E+00	-0.168695751E-10	0.000000000E+00
19	0.154271620E-01	0.000000000E+00	-0.339842644E-11	0.000000000E+00	-0.535861511E-10	0.000000000E+00
20	0.228552354E-01	0.000000000E+00	0.173654672E-10	0.000000000E+00	-0.676305216E-10	0.000000000E+00
SMODE 14						
0.23272215E+03 0.100000000E+01						
1	0.629441732E-01	0.000000000E+00	0.381452117E-10	0.000000000E+00	0.223647642E-09	0.000000000E+00
2	0.570369925E-01	0.000000000E+00	-0.130972860E-10	0.000000000E+00	0.187294540E-10	0.000000000E+00
3	0.34998252E-01	0.000000000E+00	-0.840209429E-11	0.000000000E+00	-0.414391601E-10	0.000000000E+00
4	0.253051461E-03	0.000000000E+00	0.441981227E-11	0.000000000E+00	-0.263159255E-10	0.000000000E+00
5	-0.307485051E-01	0.000000000E+00	0.794513811E-11	0.000000000E+00	0.721423131E-11	0.000000000E+00
6	-0.386506051E-01	0.000000000E+00	0.166087382E-11	0.000000000E+00	0.264532754E-10	0.000000000E+00
7	-0.177459453E-01	0.000000000E+00	-0.617960661E-11	0.000000000E+00	0.157279450E-10	0.000000000E+00
8	0.164587127E-01	0.000000000E+00	-0.683988368E-11	0.000000000E+00	-0.121296363E-10	0.000000000E+00
9	0.382513236E-01	0.000000000E+00	0.290908844E-12	0.000000000E+00	-0.260831878E-10	0.000000000E+00
10	0.311972872E-01	0.000000000E+00	0.712371065E-11	0.000000000E+00	-0.105282004E-10	0.000000000E+00
11	0.616320528E-03	0.000000000E+00	0.592138413E-11	0.000000000E+00	0.169641350E-10	0.000000000E+00
12	-0.304294343E-01	0.000000000E+00	-0.194812553E-11	0.000000000E+00	0.251872584E-10	0.000000000E+00
13	-0.385273216E-01	0.000000000E+00	-0.753954195E-11	0.000000000E+00	0.469814659E-11	0.000000000E+00
14	-0.175704640E-01	0.000000000E+00	-0.440525282E-11	0.000000000E+00	-0.216322321E-10	0.000000000E+00
15	0.166368826E-01	0.000000000E+00	0.420566895E-11	0.000000000E+00	-0.249305757E-10	0.000000000E+00
16	0.402391557E-01	0.000000000E+00	0.849457361E-11	0.000000000E+00	0.152034946E-11	0.000000000E+00
17	0.389683581E-01	0.000000000E+00	0.264264466E-11	0.000000000E+00	0.252984815E-10	0.000000000E+00
18	0.161759943E-01	0.000000000E+00	-0.340773330E-11	0.000000000E+00	0.496645049E-11	0.000000000E+00
19	-0.164870406E-01	0.000000000E+00	-0.179292871E-11	0.000000000E+00	-0.136446403E-10	0.000000000E+00
20	-0.326162494E-01	0.000000000E+00	0.441064323E-11	0.000000000E+00	-0.213883944E-10	0.000000000E+00
SMODE 15						
0.24109437E+03 0.100000000E+01						
1	-0.128965633E-10	0.000000000E+00	0.174376328E+00	0.000000000E+00	0.106444443E+01	0.000000000E+00
2	-0.115975736E-10	0.000000000E+00	-0.662214216E-01	0.000000000E+00	0.589590428E-01	0.000000000E+00
3	-0.678081910E-11	0.000000000E+00	-0.355138989E-01	0.000000000E+00	-0.207183277E+00	0.000000000E+00
4	0.635080091E-12	0.000000000E+00	0.252304352E-01	0.000000000E+00	-0.111722142E+00	0.000000000E+00
5	0.678992500E-11	0.000000000E+00	0.359866380E-01	0.000000000E+00	0.533108757E-01	0.000000000E+00
6	0.753484821E-11	0.000000000E+00	0.186750973E-02	0.000000000E+00	0.128542777E+00	0.000000000E+00
7	0.227497559E-11	0.000000000E+00	-0.324954528E-01	0.000000000E+00	0.553688494E-01	0.000000000E+00
8	-0.480771752E-11	0.000000000E+00	-0.280230460E-01	0.000000000E+00	-0.789625936E-01	0.000000000E+00
9	-0.799913295E-11	0.000000000E+00	0.938053712E-02	0.000000000E+00	-0.120379743E+00	0.000000000E+00
10	-0.471632615E-11	0.000000000E+00	0.359262969E-01	0.000000000E+00	-0.211365652E-01	0.000000000E+00
11	0.238378008E-11	0.000000000E+00	0.206170566E-01	0.000000000E+00	0.102730016E+00	0.000000000E+00
12	0.755457792E-11	0.000000000E+00	-0.186299703E-01	0.000000000E+00	0.106404988E+00	0.000000000E+00
13	0.661101344E-11	0.000000000E+00	-0.358040402E-01	0.000000000E+00	-0.152009527E-01	0.000000000E+00
14	0.316764311E-12	0.000000000E+00	-0.101557245E-01	0.000000000E+00	-0.122674731E+00	0.000000000E+00
15	-0.652850854E-11	0.000000000E+00	0.306289516E-01	0.000000000E+00	-0.983074011E-01	0.000000000E+00
16	-0.104800683E-10	0.000000000E+00	0.390623823E-01	0.000000000E+00	0.486143128E-01	0.000000000E+00
17	-0.862821076E-11	0.000000000E+00	0.296745791E-02	0.000000000E+00	0.121241840E+00	0.000000000E+00
18	-0.218104947E-11	0.000000000E+00	-0.224647857E-01	0.000000000E+00	0.691695211E-02	0.000000000E+00
19	0.276990111E-11	0.000000000E+00	-0.872605313E-02	0.000000000E+00	-0.854280070E-01	0.000000000E+00
20	0.597666417E-11	0.000000000E+00	0.281462488E-01	0.000000000E+00	-0.124962539E+00	0.000000000E+00
SMODE 16						
0.26795948E+03 0.100000000E+01						
1	0.602908611E-01	0.000000000E+00	0.730095316E-11	0.000000000E+00	0.504949754E-10	0.000000000E+00
2	0.527895178E-01	0.000000000E+00	-0.360892840E-11	0.000000000E+00	-0.170562411E-11	0.000000000E+00
3	0.255533062E-01	0.000000000E+00	-0.977328933E-12	0.000000000E+00	-0.107301965E-10	0.000000000E+00
4	-0.128886269E-01	0.000000000E+00	0.166468632E-11	0.000000000E+00	-0.284279312E-11	0.000000000E+00
5	-0.36285813E-01	0.000000000E+00	0.124893102E-11	0.000000000E+00	0.499090766E-11	0.000000000E+00
6	-0.24930456E-01	0.000000000E+00	-0.744430537E-12	0.000000000E+00	0.546657819E-11	0.000000000E+00
7	0.106413916E-01	0.000000000E+00	-0.165049698E-11	0.000000000E+00	-0.691230242E-12	0.000000000E+00
8	0.354565709E-01	0.000000000E+00	-0.406355382E-12	0.000000000E+00	-0.581057073E-11	0.000000000E+00
9	0.248224140E-01	0.000000000E+00	0.135938201E-11	0.000000000E+00	-0.343523969E-11	0.000000000E+00
10	-0.106290889E-01	0.000000000E+00	0.137350332E-11	0.000000000E+00	0.335336909E-11	0.000000000E+00

11	-0.354536745E-01	0.000000000E+00	-0.379501097E-12	0.000000000E+00	0.583453557E-11	0.000000000E+00
12	-0.248318288E-01	0.000000000E+00	-0.166070661E-11	0.000000000E+00	0.899303906E-12	0.000000000E+00
13	0.106168102E-01	0.000000000E+00	-0.862482353E-12	0.000000000E+00	-0.501725591E-11	0.000000000E+00
14	0.354507620E-01	0.000000000E+00	0.946757565E-12	0.000000000E+00	-0.455557497E-11	0.000000000E+00
15	0.248412319E-01	0.000000000E+00	0.144090469E-11	0.000000000E+00	0.225205972E-11	0.000000000E+00
16	-0.121424675E-01	0.000000000E+00	-0.549016461E-12	0.000000000E+00	0.743323508E-11	0.000000000E+00
17	-0.412071811E-01	0.000000000E+00	-0.181389226E-11	0.000000000E+00	-0.190286052E-11	0.000000000E+00
18	-0.317051694E-01	0.000000000E+00	-0.489581826E-12	0.000000000E+00	-0.440140522E-11	0.000000000E+00
19	0.142055207E-01	0.000000000E+00	0.793317129E-12	0.000000000E+00	-0.359385194E-11	0.000000000E+00
20	0.412476863E-01	0.000000000E+00	0.196193732E-11	0.000000000E+00	-0.351739795E-11	0.000000000E+00
SMODE 17						
0.30274189E+03 0.100000000E+01						
1	0.678914109E-01	0.000000000E+00	-0.242836547E-10	0.000000000E+00	-0.193735907E-09	0.000000000E+00
2	0.571091667E-01	0.000000000E+00	0.153328053E-10	0.000000000E+00	0.271708447E-10	0.000000000E+00
3	0.191703626E-01	0.000000000E+00	0.219952386E-12	0.000000000E+00	0.414001045E-10	0.000000000E+00
4	-0.272981552E-01	0.000000000E+00	-0.753557041E-11	0.000000000E+00	-0.269515625E-11	0.000000000E+00
5	-0.395507567E-01	0.000000000E+00	-0.175638377E-11	0.000000000E+00	-0.266985746E-10	0.000000000E+00
6	-0.451088286E-02	0.000000000E+00	0.568658078E-11	0.000000000E+00	-0.114895782E-10	0.000000000E+00
7	0.353186265E-01	0.000000000E+00	0.445836376E-11	0.000000000E+00	0.177196561E-10	0.000000000E+00
8	0.300240927E-01	0.000000000E+00	-0.317578892E-11	0.000000000E+00	0.213470800E-10	0.000000000E+00
9	-0.135871719E-01	0.000000000E+00	-0.628072161E-11	0.000000000E+00	-0.545993891E-11	0.000000000E+00
10	-0.398584769E-01	0.000000000E+00	-0.427459359E-12	0.000000000E+00	-0.245057174E-10	0.000000000E+00
11	-0.152624755E-01	0.000000000E+00	0.604546871E-11	0.000000000E+00	-0.864209259E-11	0.000000000E+00
12	0.288114658E-01	0.000000000E+00	0.393373653E-11	0.000000000E+00	0.194185528E-10	0.000000000E+00
13	0.361162672E-01	0.000000000E+00	-0.367574057E-11	0.000000000E+00	0.193849955E-10	0.000000000E+00
14	-0.267041190E-02	0.000000000E+00	-0.575036263E-11	0.000000000E+00	-0.884793895E-11	0.000000000E+00
15	-0.380491465E-01	0.000000000E+00	0.108629456E-11	0.000000000E+00	-0.272628822E-10	0.000000000E+00
16	-0.257182729E-01	0.000000000E+00	0.835145739E-11	0.000000000E+00	-0.981592811E-11	0.000000000E+00
17	0.163077765E-01	0.000000000E+00	0.431622863E-11	0.000000000E+00	0.284897279E-10	0.000000000E+00
18	0.314095494E-01	0.000000000E+00	-0.369399397E-11	0.000000000E+00	0.107854254E-10	0.000000000E+00
19	-0.539753052E-02	0.000000000E+00	-0.324926132E-11	0.000000000E+00	-0.129681227E-10	0.000000000E+00
20	-0.330836428E-01	0.000000000E+00	0.350574488E-11	0.000000000E+00	-0.242343211E-10	0.000000000E+00
SMODE 18						
0.30414468E+03 0.100000000E+01						
1	-0.114110200E-10	0.000000000E+00	-0.136579397E+00	0.000000000E+00	-0.109550701E+01	0.000000000E+00
2	-0.958194820E-11	0.000000000E+00	0.869411842E-01	0.000000000E+00	0.158070589E+00	0.000000000E+00
3	-0.315484076E-11	0.000000000E+00	0.449925024E-03	0.000000000E+00	0.233643471E+00	0.000000000E+00
4	0.466571232E-11	0.000000000E+00	-0.427691843E-01	0.000000000E+00	-0.183148292E-01	0.000000000E+00
5	0.660582078E-11	0.000000000E+00	-0.923623327E-02	0.000000000E+00	-0.151999977E+00	0.000000000E+00
6	0.580500229E-12	0.000000000E+00	0.325968338E-01	0.000000000E+00	-0.624248959E-01	0.000000000E+00
7	-0.603067412E-11	0.000000000E+00	0.245868805E-01	0.000000000E+00	0.103011886E+00	0.000000000E+00
8	-0.486608707E-11	0.000000000E+00	-0.1886686097E-01	0.000000000E+00	0.119226742E+00	0.000000000E+00
9	0.256628217E-11	0.000000000E+00	-0.353127679E-01	0.000000000E+00	-0.351316561E-01	0.000000000E+00
10	0.669312808E-11	0.000000000E+00	-0.121861749E-02	0.000000000E+00	-0.139226880E+00	0.000000000E+00
11	0.219889376E-11	0.000000000E+00	0.346378867E-01	0.000000000E+00	-0.441617480E-01	0.000000000E+00
12	-0.512764206E-11	0.000000000E+00	0.209938906E-01	0.000000000E+00	0.113851201E+00	0.000000000E+00
13	-0.584957288E-11	0.000000000E+00	-0.224602545E-01	0.000000000E+00	0.108064005E+00	0.000000000E+00
14	0.963119406E-12	0.000000000E+00	-0.329435777E-01	0.000000000E+00	-0.555464437E-01	0.000000000E+00
15	0.619305086E-11	0.000000000E+00	0.670781103E-02	0.000000000E+00	-0.151161485E+00	0.000000000E+00
16	0.270256080E-11	0.000000000E+00	0.439705572E-01	0.000000000E+00	-0.403912630E-01	0.000000000E+00
17	-0.594964533E-11	0.000000000E+00	0.197833091E-01	0.000000000E+00	0.145448225E+00	0.000000000E+00
18	-0.637834283E-11	0.000000000E+00	-0.187101250E-01	0.000000000E+00	0.443490736E-01	0.000000000E+00
19	0.132146968E-11	0.000000000E+00	-0.125650402E-01	0.000000000E+00	-0.802927503E-01	0.000000000E+00
20	0.814970105E-11	0.000000000E+00	0.273769109E-01	0.000000000E+00	-0.141489568E+00	0.000000000E+00
SMODE 19						
0.34073782E+03 0.100000000E+01						
1	-0.707538826E-01	0.000000000E+00	0.286928532E-12	0.000000000E+00	0.262347720E-11	0.000000000E+00
2	-0.565194476E-01	0.000000000E+00	-0.221984002E-12	0.000000000E+00	-0.690287092E-12	0.000000000E+00
3	-0.840091489E-02	0.000000000E+00	0.480007977E-13	0.000000000E+00	-0.495289349E-12	0.000000000E+00
4	0.394299547E-01	0.000000000E+00	0.105439962E-12	0.000000000E+00	0.235797171E-12	0.000000000E+00
5	0.288337445E-01	0.000000000E+00	-0.219086549E-13	0.000000000E+00	0.399183609E-12	0.000000000E+00
6	-0.242519715E-01	0.000000000E+00	-0.938925746E-13	0.000000000E+00	-0.298463827E-13	0.000000000E+00
7	-0.375458217E-01	0.000000000E+00	-0.115502451E-13	0.000000000E+00	-0.367137329E-12	0.000000000E+00
8	0.980588267E-02	0.000000000E+00	0.869057320E-13	0.000000000E+00	-0.124434647E-12	0.000000000E+00
9	0.413050297E-01	0.000000000E+00	0.469408709E-13	0.000000000E+00	0.322686439E-12	0.000000000E+00
10	0.602871042E-02	0.000000000E+00	-0.675104098E-13	0.000000000E+00	0.247050254E-12	0.000000000E+00
11	-0.389938711E-01	0.000000000E+00	-0.712141591E-13	0.000000000E+00	-0.237902197E-12	0.000000000E+00
12	-0.209773503E-01	0.000000000E+00	0.541938680E-13	0.000000000E+00	-0.403252596E-12	0.000000000E+00
13	0.309520756E-01	0.000000000E+00	0.149909210E-12	0.000000000E+00	-0.172574001E-12	0.000000000E+00
14	0.328430569E-01	0.000000000E+00	0.122588716E-12	0.000000000E+00	0.472429997E-12	0.000000000E+00
15	-0.183613752E-01	0.000000000E+00	-0.103128223E-12	0.000000000E+00	0.583827601E-12	0.000000000E+00
16	-0.424328354E-01	0.000000000E+00	-0.503939203E-13	0.000000000E+00	-0.107313464E-11	0.000000000E+00
17	-0.811679272E-02	0.000000000E+00	0.242277663E-12	0.000000000E+00	0.105857230E-11	0.000000000E+00
18	0.266238962E-01	0.000000000E+00	-0.370053959E-12	0.000000000E+00	0.164557042E-11	0.000000000E+00
19	0.161849488E-02	0.000000000E+00	-0.771139226E-12	0.000000000E+00	0.103414361E-11	0.000000000E+00
20	-0.269328262E-01	0.000000000E+00	-0.112669386E-11	0.000000000E+00	0.109978557E-11	0.000000000E+00
SMODE 20						
0.37463267E+03 0.100000000E+01						
1	-0.355947090E-11	0.000000000E+00	0.958891159E-01	0.000000000E+00	0.995287908E+00	0.000000000E+00
2	-0.269382803E-11	0.000000000E+00	-0.855826082E-01	0.000000000E+00	-0.340053935E+00	0.000000000E+00
3	0.113863383E-12	0.000000000E+00	0.332714032E-01	0.000000000E+00	-0.148576036E+00	0.000000000E+00
4	0.225867224E-11	0.000000000E+00	0.320750366E-01	0.000000000E+00	0.154238522E+00	0.000000000E+00
5	0.488809278E-12	0.000000000E+00	-0.248642677E-01	0.000000000E+00	0.120952523E+00	0.000000000E+00
6	-0.206780838E-11	0.000000000E+00	-0.303011707E-01	0.000000000E+00	-0.938110068E-01	0.000000000E+00
7	-0.594716624E-12	0.000000000E+00	0.170112184E-01	0.000000000E+00	-0.136577282E+00	0.000000000E+00
8	0.203444028E-11	0.000000000E+00	0.345172400E-01	0.000000000E+00	0.512864949E-01	0.000000000E+00
9	0.687752556E-12	0.000000000E+00	-0.711062651E-02	0.000000000E+00	0.150819297E+00	0.000000000E+00
10	-0.200299372E-11	0.000000000E+00	-0.366317617E-01	0.000000000E+00	-0.746299547E-02	0.000000000E+00
11	-0.779376076E-12	0.000000000E+00	-0.358257357E-02	0.000000000E+00	-0.153054996E+00	0.000000000E+00
12	0.196727405E-11	0.000000000E+00	0.356003830E-01	0.000000000E+00	-0.372691834E-01	0.000000000E+00
13	0.869093832E-12	0.000000000E+00	0.140355313E-01	0.000000000E+00	0.141894644E+00	0.000000000E+00
14	-0.192748717E-11	0.000000000E+00	-0.312268376E-01	0.000000000E+00	0.774851990E-01	0.000000000E+00
15	-0.116408916E-11	0.000000000E+00	-0.219896528E-01	0.000000000E+00	-0.124185553E+00	0.000000000E+00
16	0.272999754E-11	0.000000000E+00	0.343504652E-01	0.000000000E+00	-0.144112587E+00	0.000000000E+00
17	0.341732276E-12	0.000000000E+00	0.346565590E-01	0.000000000E+00	0.140226171E+00	0.000000000E+00

18	-0.142483334E-11	0.000000000E+00	-0.131227186E-01	0.000000000E+00	0.864021047E-01	0.000000000E+00
19	-0.653929602E-12	0.000000000E+00	-0.168075647E-01	0.000000000E+00	-0.719059785E-01	0.000000000E+00
20	0.323921072E-11	0.000000000E+00	0.271864737E-01	0.000000000E+00	-0.164110128E+00	0.000000000E+00

Listing 9.7.4 Output of Mass change due to Structure: masschg.dat

0.00000000	0.11994028E+00
0.32985264	0.27478981E+00
0.65970528	0.34499741E+00
0.98955792	0.40436554E+00
1.31941056	0.44068909E+00
1.64926314	0.45864868E+00
1.97911584	0.46505737E+00
2.30896831	0.46575165E+00
2.63882113	0.46575165E+00
2.96867371	0.46575165E+00
3.29852629	0.46575165E+00
3.62837887	0.46575165E+00
3.95823169	0.46575165E+00
4.28808403	0.46575165E+00
4.61793661	0.45078278E+00
4.94778967	0.42084122E+00
5.27764225	0.48175430E+00
5.60749483	0.63463593E+00
5.93734741	0.71089172E+00
6.26719999	0.35507202E+00

9.8 Run UCDA to get TRIM and ASE solution

This section corresponds to the Step 6 in the Graphical User Interface (GUI). See Figure 9.8.1 below.

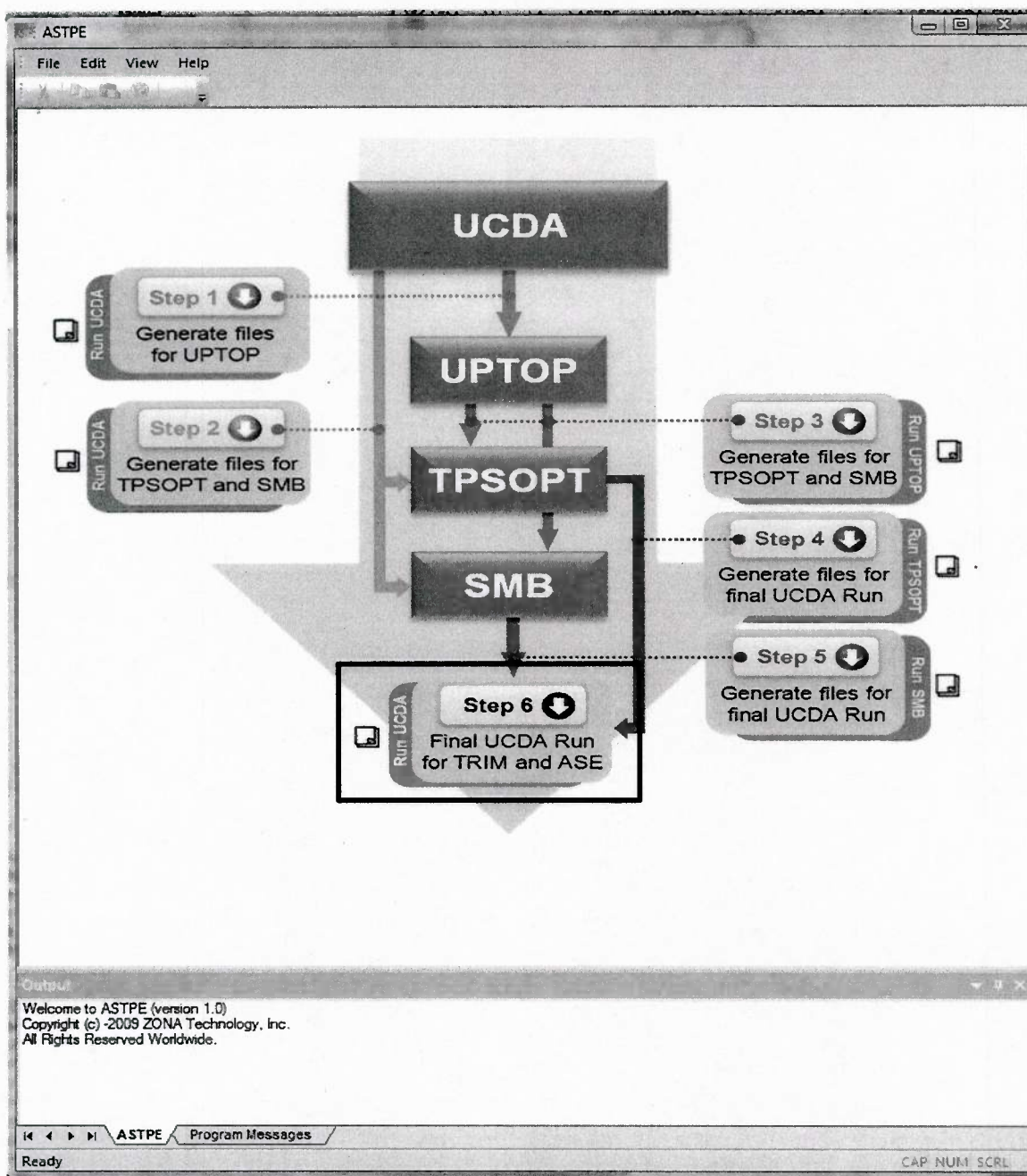


Figure 9.8.1 Section Corresponding to Step 6 of GUI

Input Files:

File Name	Type	Remarks	See Listing
vehicle.inp	Standard input file	Also look at Table 9.8.1	Shown in Listing 9.8.1
chem.bin	Engine chemistry information	Required	Shown in Listing 9.2.2
SEDvehicle.inp	Standard input file for SED type vehicle	Required	Shown in Listing 9.2.3
mass_tps.dat	Generated by TPSOPT	iffeedback needs to be 1	Shown in Listing 9.8.2
masschng.dat	Generated by SMB	iffeedback needs to be 1	Shown in Listing 9.8.3
RDOF_EIGEN.FREE	Generated by SMB	iffeedback needs to be 1	Shown in Listing 9.8.4

Output Files:

File Name	Type	Remarks	See Listing
trim_output.dat	Trim results by UCDA	See Fig. 9.8.2	Shown in Listing 9.8.5
Prep_ASE.dat	ASE results by UCDA	See Tables 9.8.2-9.8.3	Shown in Listing 9.8.6

Input File Descriptions

vehicle.inp: See Listing 9.8.1 for the entire input file. Also, Table 9.8.1 shows the necessary block and change in input parameters therein. The user should turn on **itrim** so that UCDA includes control surface in its calculation. **ideriv** is the input switch parameter that is to be set to 1 for running TRIM and ASE. **itps** should be turned back to 0 so that TPS geometry information is not created and in the process that saves some computational run time. Finally, **iffeedback** should be turned on to include the mass update from TPS and SMB. The user should note at this point that before this step, **iffeedback** was always set to 0. That is because before this step, TPSOPT and SMB was never run (look at Figure 9.8.1). This step finishes one design cycle. After this step, for all the subsequent design cycles, this **iffeedback** parameter should ALWAYS be set to 1. The code internally keeps track of the mass for each design cycle and that needs **iffeedback** to be set to 1. If **iffeedback** value is set to 0 by mistake, the mass information is not going to be right.

Table 9.8.1: Showing Necessary Block on Vehicle.inp to Compute TRIM and ASE

TEST INPUT DECK: Note - this line must be here!	
2	ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1	ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle
1	iunits - Output unit switch: SI (1) or English (2)
3	ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1	iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2	inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1	iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
0	itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0	icone - cone flow data: exact (0), curve-fit approximation (1)
4	imodel - Forebody type: WA (1), VWA (2), or VWA + cone flow (3)
1	itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
1	ideriv - Calculate derivatives: no (0), yes (1)
0	itps - If itps is 1, then prepare for tps and smb. nderiv and itps cannot be 1 at one time
1	ifedback - If 1, then gets weight and Cg information from SMB and TPSOPT

chem.bin: This file does not change for any UCDA run. Please see Section 9.2 for description on this file.

mass_tps.dat: This file is shown in Listing 9.8.2. It is generated by TPSOPT run. More on this can be found in Section 6.

masschng.dat: This file is shown in Listing 9.8.3 and it is generated by SMB run. When UCDA was run to generate the geometry for TPSOPT and SMB that were described in Section 9.5, the structure was approximated by a finite number of discrete points. masschng.dat outputs the additional mass due to skin thickness at each of those points. More on this can be found in Section 9.7.

RDOF_EIGEN.DAT: This file is shown in Listing 9.8.4. It is also generated by SMB run. Natural frequencies and generalized masses of the first 20 modes are recorded in the file. More on this can be found in Section 9.7.

Output File descriptions

Trim_output.dat: This file is shown in Listing 9.8.5. It outputs the summary of information related to trim iterations. Geometric information such as C.G., reference area, reference chord and aerodynamic information such as Coefficients of lift, drag and moment due to change in angle of attack and control surface deflection angle are some of the information. Also, trim variables angle of attack and control surface deflection angles are listed for each iteration.

The iteration history from trim_output.dat file is shown in Figure 9.8.2. It can be seen that this iterative process requires only less than 10 iterations to achieve a fully converged solution. In fact, the mean flow condition in terms of α_0 and δ_0 does not change significantly after 5 iterations. Meanwhile, the lift and moment at the fifth iteration have already nearly satisfied the lift-equal-weight and zero-pitch-moment conditions. From the fifth to the tenth iteration, the trim solution remains nearly the same; indicating that this iterative process is stable and provides a fast converging rate.

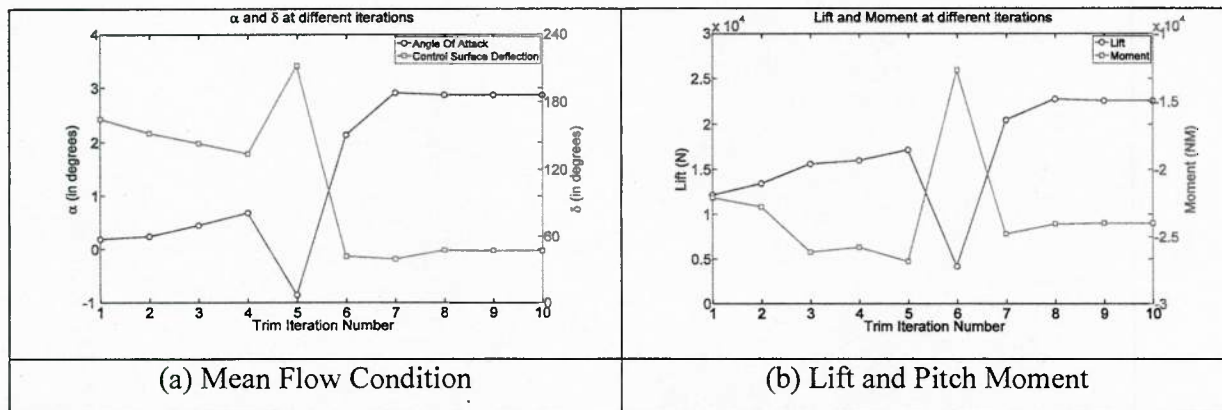


Figure 9.8.2 Iteration history of the iterative process for solving the nonlinear trim problem

Prep_ASE.dat: This file is shown in Listing 9.8.6. It outputs the summary of information related to ASE matrix preparation. As shown in the listing, A and B matrices are listed first. Then, the eigenvalues of matrix A is given. Frequency and damping ratio corresponding to the eigenvalues are then output. Finally, other aerodynamic information are written out so that the results can be compared with analytical expressions.

Validation of the ASE module

The validation of the ASE module can be achieved by first excluding the elastic modes then comparing the eigenvalues of the matrix $[\bar{A}]$ to those of analytical flight dynamic equations shown in the following equations³:

For Phugoid mode:

$$\omega_{np} = \frac{\rho S U \sqrt{-C_{L_u} C_{L_o}}}{2m} \quad (9.8.1)$$

$$\zeta_p = \frac{-C_{x_u}}{2 \frac{mU}{Sq} \sqrt{-C_{L_u} C_{L_o}}} = \frac{-C_{D_u}}{2 \sqrt{-C_{L_u} C_{L_o}}} \quad (9.8.2)$$

For short period mode:

$$\omega = \left(\frac{\frac{c}{2U} C_{m_q} C_{L_\alpha} - \frac{mU}{Sq} C_{m_\alpha}}{\left(\frac{I_y}{Sq c} \right) \left(\frac{mU}{Sq} \right)} \right)^{1/2} \quad (9.8.3)$$

$$\zeta = -\frac{1}{4} \left(C_{m_q} + C_{m_\alpha} + \frac{2l_y}{mc^2} C_{L_\alpha} \right) \left(\frac{mc^2}{I_y \left(\frac{C_{m_q} C_{L_\alpha}}{2} - \frac{2mC_{m_\alpha}}{pSc} \right)} \right)^{1/2} \quad (9.8.4)$$

The aerodynamic stability derivatives are computed first on the selected scramjet flight vehicle at the trim condition of $\alpha = 2.86^\circ$, $\delta = 46.98^\circ$. These aerodynamic stability derivatives are shown in

³ Blakelock, J. H., "Automated Control of Aircraft and Missiles," Air Force Institute of Technology, 1981.

Table 9.8.2. Other parameters required by the analytical flight dynamic equations are: mass (m) = 1328.874, moment of inertia (I_y) = 18848.73, velocity (U) = 2090.866, surface area (S) = 1.829348, dynamic pressure (q) = 81396.51 and reference chord (c) = 6.267200.

Table 9.8.2 Aerodynamic Stability Derivatives of a Scramjet Flight Vehicle

Airframe State	C_D	C_L	C_M
Mean Flow	0.1399257	0.1511889	-2.5678078E-02
Forward Velocity	2.9367459E-04	1.9072900E-04	-6.6151595E-05
Angle of Attack	2.717112	1.752287	-0.1032690
Pitch Rate	0.5058688	0.1237800	-4.5670047E-02

It can be seen in Table 9.8.2 that the pitch moment stability derivative of angle of attack (C_{m_α}) is positive; indicating a statically stable flight vehicle.

Two sets of the ASE module of ASTPE are computed, one without the elastic mode (rigid body modes only) and the other with the first bending mode and compared to the analytical solution. This comparison is presented in Table 9.8.3 where an excellent agreement between the ASE module result without the elastic mode and the analytical solution can be seen. Meanwhile, the ASE module result with the first bending mode shows only a slight difference from that with only the rigid modes. This suggests that the structure designed by the SMB module provides sufficient stiffness by which the impact of aeroelastic effects on the flight dynamics is minimized.

Table 9.8.3 Validation of the ASE module with Analytical Solution

Longitudinal Dynamics	ASTPE				Analytical (Rigid)	
	+ Bending		Rigid			
	Damping	Frequency	Damping	Frequency	Damping	Frequency
ShortPeriod	0.012	0.6843 (Hz)	0.0583	0.3264 (Hz)	0.044	0.3264 (Hz)
Phugoid	-1.0	0.00114 (Hz)	-1.0	0.01145 (Hz)	-1.0	0.01145 (Hz)

Note that the negative damping of the short period mode leading to a statically unstable flight vehicle must be stabilized by a flight control system. A flight control system is designed for studied SED and is given in Figure 9.8.3.

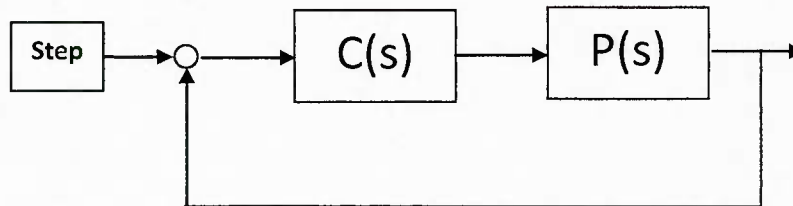


Figure 9.8.3 Block diagram of closed loop system

The compensator $C(s)$ takes the form:

$$C(s) = \frac{9297.4(s^2 + 0.019s + 0.00018)(s^2 + 3.5s + 5.079)(s^2 - 0.0045s + 112.4)(s^2 + 0.0019s + 829.4)}{s(s^2 + 0.01953s + 0.0002)(s^2 + 0.00739s + 110.3)(s^2 + 0.01718s + 829.4)(s^2 + 79.2s + 3081)}$$

Listing 9.8.1: Vehicle.inp Input File for TRIM and ASE

```

TEST INPUT DECK: Note - this line must be here!
2   ialtdyn - Inlet specified alt. (0), Fixed alt. (1), or Fixed dyn. press. (2)
1   ithrottle - Run engine as a function of: (0) equivalence ratio, (1) % throttle, (2) max throttle
1   iunits - Output unit switch: SI (1) or English (2)
3   ivisc - Viscous flag: inviscid (1), laminar (2), transitional (3), turbulent (4)
1   iequiv - find max equiv ratio for choked flow: off (0) -> single run, on (1)
2   inozorder - Nozzle polynomial order: 1st (flat plate) -> 3rd
1   iheight - Height constrained vehicle: no (0) = inlet set, yes (1) = height set
0   itrajectory - Run multiple trajectory points: no (0), discrete (1), matrix (2)
0   icone - cone flow data: exact (0), curve-fit approximation (1)
4   imodel - Forebody type: WA (1), VWA (2), VWA + cone flow (3), or SED (4)
  
```

```

1      itrim - Control surface deflection to trim the vehicle: no (0), yes (1), or optimize (2)
1      nderiv - Calculate derivatives: no (0), yes (1)
0      itps - If itps is 1, then prepare for tps and smb. nderiv and itps cannot be 1 at one time
1      ifeedback - If 1, then gets weight and Cg information from SMB and TPSOPT

```

OUTPUT FILE SWITCHES AND NAMES:

```

0      'plot.dat'          VEHICLEFIG:      off (0), select (1), x,y,z (2), all (3)
3 1 2 3 8 18 23          1st # -> # of variables to read, others -> vars to plot
0      'metrics.dat'      METRICS: off (0), on-real (1), on-cmplx (2)
0      'cowlexit.dat'     COWLEXIT:      off (0), on (1)
0      'moc.dat'          NOZFIG: off (0), P,T,M (1), all (2)
0      'offdesign.dat'    AOA: off (0), on (1), UPTOP input tables (2), UPTOP input files (3)
0      'scramjet.dat'     CKENGINE: off (0), on (1)
0      IPRINTINLET:      off (0), all (1), results (2), all-real (3), results-real (4)
0      IPRINTENGINE:     off (0), on (1)
0      IDEBUG:           off (0), on (1) [print debugging info]

```

ZONE DATA AND GRID SIZES:

```

21      NUMBER OF ZONES
'forebody : top'          3          3
'keel : top'              3          3
'aftbody : top'           3          3
'forebody : bot'         31         31
'ramps : bot'            55          6
'comb : bot'             101         6
'cowl : top'             101         6
'nozzle : bot'           31          6
'ramp walls : inside'    35          6
'comb wall : inside'     101         7
'nozzle wall : inside'   21          7
'aftbody : bot'          101        31
'cowl : bot'             101         6
'ramp walls : outside'   35          6
'comb wall : outside'    101         7
'nozzle wall : outside'  21          7
'SEDbody : top'          121        46
'Control_1 : top'        31          31 (Control surface dimensions must be the same)
'Control_1 : bottom'     31          31 (Control surface dimensions must be the same)
'Control_2 : top'        31          31 (Control surface dimensions must be the same)
'Control_2 : bottom'     31          31 (Control surface dimensions must be the same)

```

INPUT DATA: (0 = degrees, 1 = m, 2 = ft, 3 = atm, 4 = dimensionless, K or kg, 5 = psf)

```

X1      x      xu      unit      res      name
22500.  26290.  30000.  1      2500.    'altitude' - altitude (if required)
1500.   1700.   2000.0  5      250.    'q0'      - dynamic pressure (if required)
.50     1.0299  1.0      4      .250    'equiv'   - equivalence ratio
1.       1.0     0.0      4      -.10    'throttle' - engine throttle (if required)
6.0     7.0     8.00    4      .5      'm0'      - Mach number
-2.00   0.0     3.00    0      .5      'AOA'     - angle of attack
5.0      4      'Mdes'    - design Mach number
0.2935  0      'AOades'  - design angle of attack
26000.  1      'Zdes'    - design altitude
6.2672  1      'lvehicle' - vehicle length
5.5939  0      'thforclu' - forebody upper surface angle
3.8700  0      'thforcli' - forebody ramp angle
0.5873  1      'lcontrol' - control surface length
5.0      0      'th_control' - control surface deflection angle
0.9920  0      'th_expn'  - nozzle initial expansion angle
10.8958 0      'th_exit'  - nozzle exit angle
0.0      4      'p_nozpoly' - % diff between nozzle designs [DON'T USE-defaulted to 1.]
2.901   1      'lcowl'    - cowl length (isolator/combustor)
.3       1      'lcowlxt'  - cowl extension length (internal nozzle)
0.545   4      'p_iso'    - percent of lcowl that is isolator
.3238   1      'height'   - height of vehicle (if required)
20.0    1      'linlet'   - inlet length of vehicle (if required)
.28     1      'wengine'  - width of the engine (currently defaulted to unit width)
3.00    4      'iramps'   - number of inlet ramps in addition to the forebody
4.4615  0      'th_ramp1' - inlet ramp 1 angle
5.1567  0      'th_ramp2' - inlet ramp 2 angle
5.9844  0      'th_ramp3' - inlet ramp 3 angle
0.0      0      'th_ramp4' - inlet ramp 4 angle
0.0      0      'th_ramp5' - inlet ramp 5 angle
3.09    0      'th_div1'  - first combustor expansion angle
1.2     0      'th_div2'  - second combustor expansion angle
0.01    1      'Xinjs'    - beginning of injectors (m)
0.02    1      'Xinje'    - end of injectors (m)
0.01    1      'Lmix'     - fuel mixing length (m)
1.00    4      'eta_mix'  - fuel mixing and burning efficiency
4000.   4      'Tlimit'   - maximum engine temperature (K)
90.     0      'Thetainj' - injector angle (degrees) [90 deg. is normal to flow]
1200.   4      'Tw'       - adiabatic wall temperature (K)
0.1527  4      'nfor'     - forebody exponent n
2.0     2      'wfor'     - forebody width
2.0     1      'lfor'     - forebody length
0.2427  4      'mfor'     - forebody exponent m
5.797   0      'thforle'  - forebody leading edge angle
21.519  0      'th_le'    - leading edge attachment angle
0.0000  4      'p_kl'     - keel-line height percentage
0.25     4      'fuelfrac' - vehicle fuel volume fraction
0.0104  2      't_plate'  - shell plate thickness (Tungsten)
0.00000 4      'mass_smb' - mass due to Structural Modal Base (SMB) analysis
0.00000 4      'mass_tps' - mass due to Thermal Protection System (TPS) analysis
0.00000 4      'mass_nose' - mass due to Thermal Protection System (TPS) analysis

```

Listing 9.8.2 mass_tps.DAT

43.06581 165.0017

Listing 9.8.3 masschnng.dat

```
0.00000000 0.11994028E+00
0.32985264 0.27478981E+00
0.65970528 0.34499741E+00
0.98955792 0.40436554E+00
1.31941056 0.44068909E+00
1.64926314 0.45864868E+00
1.97911584 0.46505737E+00
2.30896831 0.46575165E+00
2.63882113 0.46575165E+00
2.96867371 0.46575165E+00
3.29852629 0.46575165E+00
3.62837887 0.46575165E+00
3.95823169 0.46575165E+00
4.28808403 0.46575165E+00
4.61793661 0.45078278E+00
4.94778967 0.42084122E+00
5.27764225 0.48175430E+00
5.60749483 0.63463593E+00
5.93734741 0.71089172E+00
6.26719999 0.35507202E+00
```

Listing 9.8.4 Eigenvalues and Eigenvectors of the Beam Model: RDOF_EIGEN.FREE

```
20      20
1      0.00000000E+00  0.00000000E+00  0.00000000E+00
2      0.32985264E+00  0.00000000E+00  0.00000000E+00
3      0.65970528E+00  0.00000000E+00  0.00000000E+00
4      0.98955792E+00  0.00000000E+00  0.00000000E+00
5      0.13194106E+01  0.00000000E+00  0.00000000E+00
6      0.16492631E+01  0.00000000E+00  0.00000000E+00
7      0.19791158E+01  0.00000000E+00  0.00000000E+00
8      0.23089683E+01  0.00000000E+00  0.00000000E+00
9      0.26388211E+01  0.00000000E+00  0.00000000E+00
10     0.29686737E+01  0.00000000E+00  0.00000000E+00
11     0.32985263E+01  0.00000000E+00  0.00000000E+00
12     0.36283789E+01  0.00000000E+00  0.00000000E+00
13     0.39582317E+01  0.00000000E+00  0.00000000E+00
14     0.42880840E+01  0.00000000E+00  0.00000000E+00
15     0.46179366E+01  0.00000000E+00  0.00000000E+00
16     0.49477897E+01  0.00000000E+00  0.00000000E+00
17     0.52776423E+01  0.00000000E+00  0.00000000E+00
18     0.56074948E+01  0.00000000E+00  0.00000000E+00
19     0.59373474E+01  0.00000000E+00  0.00000000E+00
20     0.62672000E+01  0.00000000E+00  0.00000000E+00
SMODE 1
0.24111725E-01  0.10000000E+01
1 -0.278876328E-01  0.00000000E+00  0.112659199E-05  0.00000000E+00 -0.131874517E-05  0.00000000E+00
2 -0.278876328E-01  0.00000000E+00  0.156158370E-05  0.00000000E+00 -0.131874616E-05  0.00000000E+00
3 -0.278876348E-01  0.00000000E+00  0.199657550E-05  0.00000000E+00 -0.131874523E-05  0.00000000E+00
4 -0.278876364E-01  0.00000000E+00  0.243156709E-05  0.00000000E+00 -0.131874513E-05  0.00000000E+00
5 -0.278876407E-01  0.00000000E+00  0.286655839E-05  0.00000000E+00 -0.131874271E-05  0.00000000E+00
6 -0.278876445E-01  0.00000000E+00  0.330154774E-05  0.00000000E+00 -0.131873266E-05  0.00000000E+00
7 -0.278876480E-01  0.00000000E+00  0.373653169E-05  0.00000000E+00 -0.131870764E-05  0.00000000E+00
8 -0.278876513E-01  0.00000000E+00  0.417150394E-05  0.00000000E+00 -0.131866388E-05  0.00000000E+00
9 -0.278876515E-01  0.00000000E+00  0.460645919E-05  0.00000000E+00 -0.131860165E-05  0.00000000E+00
10 -0.278876486E-01  0.00000000E+00  0.504139134E-05  0.00000000E+00 -0.131852787E-05  0.00000000E+00
11 -0.278876455E-01  0.00000000E+00  0.547629834E-05  0.00000000E+00 -0.131844911E-05  0.00000000E+00
12 -0.278876421E-01  0.00000000E+00  0.591117857E-05  0.00000000E+00 -0.131836563E-05  0.00000000E+00
13 -0.278876385E-01  0.00000000E+00  0.634603075E-05  0.00000000E+00 -0.131827717E-05  0.00000000E+00
14 -0.278876376E-01  0.00000000E+00  0.678085319E-05  0.00000000E+00 -0.131819208E-05  0.00000000E+00
15 -0.278876393E-01  0.00000000E+00  0.721564925E-05  0.00000000E+00 -0.131811303E-05  0.00000000E+00
16 -0.278876440E-01  0.00000000E+00  0.765041483E-05  0.00000000E+00 -0.131800367E-05  0.00000000E+00
17 -0.278876521E-01  0.00000000E+00  0.808513655E-05  0.00000000E+00 -0.131785376E-05  0.00000000E+00
18 -0.278876578E-01  0.00000000E+00  0.851982451E-05  0.00000000E+00 -0.131780157E-05  0.00000000E+00
19 -0.278876601E-01  0.00000000E+00  0.895450277E-05  0.00000000E+00 -0.131779307E-05  0.00000000E+00
20 -0.278876603E-01  0.00000000E+00  0.938918049E-05  0.00000000E+00 -0.131779433E-05  0.00000000E+00
SMODE 2
0.74272821E-01  0.10000000E+01
1 -0.590135654E-05  0.00000000E+00 -0.310373703E-01  0.00000000E+00 -0.855877568E-03  0.00000000E+00
2 -0.590135649E-05  0.00000000E+00 -0.307550586E-01  0.00000000E+00 -0.855861192E-03  0.00000000E+00
3 -0.590135672E-05  0.00000000E+00 -0.304727516E-01  0.00000000E+00 -0.855854660E-03  0.00000000E+00
```


4	-0.590135661E-05	0.000000000E+00	-0.301904499E-01	0.000000000E+00	-0.855826006E-03	0.000000000E+00
5	-0.590135681E-05	0.000000000E+00	-0.299081556E-01	0.000000000E+00	-0.855817760E-03	0.000000000E+00
6	-0.590135657E-05	0.000000000E+00	-0.296258560E-01	0.000000000E+00	-0.855869346E-03	0.000000000E+00
7	-0.590135589E-05	0.000000000E+00	-0.293435221E-01	0.000000000E+00	-0.856034073E-03	0.000000000E+00
8	-0.590135477E-05	0.000000000E+00	-0.290611107E-01	0.000000000E+00	-0.856338226E-03	0.000000000E+00
9	-0.590135258E-05	0.000000000E+00	-0.287785773E-01	0.000000000E+00	-0.856769638E-03	0.000000000E+00
10	-0.590134933E-05	0.000000000E+00	-0.284959867E-01	0.000000000E+00	-0.857277176E-03	0.000000000E+00
11	-0.590134563E-05	0.000000000E+00	-0.282130243E-01	0.000000000E+00	-0.857809629E-03	0.000000000E+00
12	-0.590134148E-05	0.000000000E+00	-0.279299840E-01	0.000000000E+00	-0.858353217E-03	0.000000000E+00
13	-0.590133687E-05	0.000000000E+00	-0.276467643E-01	0.000000000E+00	-0.858893951E-03	0.000000000E+00
14	-0.590133242E-05	0.000000000E+00	-0.273633731E-01	0.000000000E+00	-0.859381798E-03	0.000000000E+00
15	-0.590132838E-05	0.000000000E+00	-0.270798332E-01	0.000000000E+00	-0.859803354E-03	0.000000000E+00
16	-0.590132390E-05	0.000000000E+00	-0.267961365E-01	0.000000000E+00	-0.860325023E-03	0.000000000E+00
17	-0.590132141E-05	0.000000000E+00	-0.265122538E-01	0.000000000E+00	-0.860901326E-03	0.000000000E+00
18	-0.590131983E-05	0.000000000E+00	-0.262282551E-01	0.000000000E+00	-0.861049662E-03	0.000000000E+00
19	-0.590131938E-05	0.000000000E+00	-0.259442311E-01	0.000000000E+00	-0.861068348E-03	0.000000000E+00
20	-0.590131655E-05	0.000000000E+00	-0.256602063E-01	0.000000000E+00	-0.861064754E-03	0.000000000E+00
SMODE 3						
0.11568397E+00 0.10000000E+01						
1	0.263429112E-05	0.000000000E+00	-0.576067672E-01	0.000000000E+00	-0.158799367E-01	0.000000000E+00
2	0.263429106E-05	0.000000000E+00	-0.523687351E-01	0.000000000E+00	-0.158798715E-01	0.000000000E+00
3	0.263429102E-05	0.000000000E+00	-0.471307271E-01	0.000000000E+00	-0.158797988E-01	0.000000000E+00
4	0.263429067E-05	0.000000000E+00	-0.418927506E-01	0.000000000E+00	-0.158796803E-01	0.000000000E+00
5	0.263429025E-05	0.000000000E+00	-0.366548139E-01	0.000000000E+00	-0.158795665E-01	0.000000000E+00
6	0.263428940E-05	0.000000000E+00	-0.314169139E-01	0.000000000E+00	-0.158794752E-01	0.000000000E+00
7	0.263428808E-05	0.000000000E+00	-0.261790343E-01	0.000000000E+00	-0.158794381E-01	0.000000000E+00
8	0.263428628E-05	0.000000000E+00	-0.209411598E-01	0.000000000E+00	-0.158794638E-01	0.000000000E+00
9	0.263428372E-05	0.000000000E+00	-0.157032639E-01	0.000000000E+00	-0.158795283E-01	0.000000000E+00
10	0.263428040E-05	0.000000000E+00	-0.104653482E-01	0.000000000E+00	-0.158795970E-01	0.000000000E+00
11	0.263427658E-05	0.000000000E+00	-0.522741415E-02	0.000000000E+00	-0.158796378E-01	0.000000000E+00
12	0.263427228E-05	0.000000000E+00	0.105274241E-04	0.000000000E+00	-0.158796414E-01	0.000000000E+00
13	0.263426748E-05	0.000000000E+00	0.524846637E-02	0.000000000E+00	-0.158795985E-01	0.000000000E+00
14	0.263426246E-05	0.000000000E+00	0.104863755E-01	0.000000000E+00	-0.158795094E-01	0.000000000E+00
15	0.263425736E-05	0.000000000E+00	0.157242531E-01	0.000000000E+00	-0.158793803E-01	0.000000000E+00
16	0.263425218E-05	0.000000000E+00	0.209620807E-01	0.000000000E+00	-0.158791592E-01	0.000000000E+00
17	0.263424892E-05	0.000000000E+00	0.261998071E-01	0.000000000E+00	-0.158788363E-01	0.000000000E+00
18	0.263424675E-05	0.000000000E+00	0.314374643E-01	0.000000000E+00	-0.158787404E-01	0.000000000E+00
19	0.263424598E-05	0.000000000E+00	0.366751062E-01	0.000000000E+00	-0.158787379E-01	0.000000000E+00
20	0.263424238E-05	0.000000000E+00	0.419127512E-01	0.000000000E+00	-0.158787484E-01	0.000000000E+00
SMODE 4						
0.12029574E+02 0.10000000E+01						
1	0.96496826E-10	0.000000000E+00	0.840124977E-01	0.000000000E+00	0.490409242E-01	0.000000000E+00
2	0.964664986E-10	0.000000000E+00	0.679688411E-01	0.000000000E+00	0.478347277E-01	0.000000000E+00
3	0.963688526E-10	0.000000000E+00	0.523760494E-01	0.000000000E+00	0.463744401E-01	0.000000000E+00
4	0.961657482E-10	0.000000000E+00	0.373023769E-01	0.000000000E+00	0.447728358E-01	0.000000000E+00
5	0.958241807E-10	0.000000000E+00	0.228399398E-01	0.000000000E+00	0.426867590E-01	0.000000000E+00
6	0.953227208E-10	0.000000000E+00	0.920851840E-02	0.000000000E+00	0.397296335E-01	0.000000000E+00
7	0.946450444E-10	0.000000000E+00	-0.326712114E-02	0.000000000E+00	0.356797776E-01	0.000000000E+00
8	0.937789716E-10	0.000000000E+00	-0.141867277E-01	0.000000000E+00	0.303044584E-01	0.000000000E+00
9	0.927235988E-10	0.000000000E+00	-0.231207738E-01	0.000000000E+00	0.236707850E-01	0.000000000E+00
10	0.914820785E-10	0.000000000E+00	-0.296902770E-01	0.000000000E+00	0.160166804E-01	0.000000000E+00
11	0.900559105E-10	0.000000000E+00	-0.336118902E-01	0.000000000E+00	0.767889728E-02	0.000000000E+00
12	0.884482921E-10	0.000000000E+00	-0.347252917E-01	0.000000000E+00	-0.938953964E-03	0.000000000E+00
13	0.866625302E-10	0.000000000E+00	-0.330095688E-01	0.000000000E+00	-0.940116352E-02	0.000000000E+00
14	0.847021141E-10	0.000000000E+00	-0.285879038E-01	0.000000000E+00	-0.172757883E-01	0.000000000E+00
15	0.823218006E-10	0.000000000E+00	-0.217204306E-01	0.000000000E+00	-0.241701020E-01	0.000000000E+00
16	0.813811565E-10	0.000000000E+00	-0.124190210E-01	0.000000000E+00	-0.318981230E-01	0.000000000E+00
17	0.813434078E-10	0.000000000E+00	-0.453939923E-03	0.000000000E+00	-0.401316382E-01	0.000000000E+00
18	0.812431433E-10	0.000000000E+00	0.132361151E-01	0.000000000E+00	-0.426224373E-01	0.000000000E+00
19	0.810432696E-10	0.000000000E+00	0.274166292E-01	0.000000000E+00	-0.432463852E-01	0.000000000E+00
20	0.790250282E-10	0.000000000E+00	0.417136351E-01	0.000000000E+00	-0.433922420E-01	0.000000000E+00
SMODE 5						
0.32143455E+02 0.10000000E+01						
1	0.199871818E-10	0.000000000E+00	0.108050990E+00	0.000000000E+00	0.108405427E+00	0.000000000E+00
2	0.199513906E-10	0.000000000E+00	0.735110336E-01	0.000000000E+00	0.973290378E-01	0.000000000E+00
3	0.198071414E-10	0.000000000E+00	0.429865841E-01	0.000000000E+00	0.850537745E-01	0.000000000E+00
4	0.195083016E-10	0.000000000E+00	0.166608636E-01	0.000000000E+00	0.728529219E-01	0.000000000E+00
5	0.190094579E-10	0.000000000E+00	-0.524957251E-02	0.000000000E+00	0.587152778E-01	0.000000000E+00
6	0.182849603E-10	0.000000000E+00	-0.218968969E-01	0.000000000E+00	0.412631890E-01	0.000000000E+00
7	0.173200194E-10	0.000000000E+00	-0.322629299E-01	0.000000000E+00	0.210413027E-01	0.000000000E+00
8	0.161091952E-10	0.000000000E+00	-0.356189568E-01	0.000000000E+00	-0.745847165E-03	0.000000000E+00
9	0.146666090E-10	0.000000000E+00	-0.319140730E-01	0.000000000E+00	-0.212307101E-01	0.000000000E+00
10	0.130130160E-10	0.000000000E+00	-0.220941673E-01	0.000000000E+00	-0.373388713E-01	0.000000000E+00
11	0.111721895E-10	0.000000000E+00	-0.803298100E-02	0.000000000E+00	-0.466116597E-01	0.000000000E+00
12	0.917068790E-11	0.000000000E+00	0.775343463E-02	0.000000000E+00	-0.476775830E-01	0.000000000E+00
13	0.703731898E-11	0.000000000E+00	0.225164239E-01	0.000000000E+00	-0.405238905E-01	0.000000000E+00
14	0.480280220E-11	0.000000000E+00	0.337350184E-01	0.000000000E+00	-0.265286060E-01	0.000000000E+00
15	0.283745848E-11	0.000000000E+00	0.395467900E-01	0.000000000E+00	-0.825247037E-02	0.000000000E+00
16	-0.140902184E-11	0.000000000E+00	0.378509104E-01	0.000000000E+00	0.183662741E-01	0.000000000E+00
17	-0.600914391E-11	0.000000000E+00	0.259102665E-01	0.000000000E+00	0.529084154E-01	0.000000000E+00
18	-0.886789818E-11	0.000000000E+00	0.625033164E-02	0.000000000E+00	0.654067384E-01	0.000000000E+00
19	-0.970276222E-11	0.000000000E+00	-0.160292664E-01	0.000000000E+00	0.690932937E-01	0.000000000E+00
20	-0.934700025E-11	0.000000000E+00	-0.390341700E-01	0.000000000E+00	0.700678327E-01	0.000000000E+00
SMODE 6						
0.44486765E+02 0.10000000E+01						
1	0.415391010E-01	0.000000000E+00	-0.840198079E-10	0.000000000E+00	-0.105042882E-09	0.000000000E+00
2	0.413966492E-01	0.000000000E+00	-0.511760075E-10	0.000000000E+00	-0.885674265E-10	0.000000000E+00
3	0.408232078E-01	0.000000000E+00	-0.242056235E-10	0.000000000E+00	-0.712494060E-10	0.000000000E+00
4	0.396401595E-01	0.000000000E+00	-0.303548833E-11	0.000000000E+00	-0.549449893E-10	0.000000000E+00
5	0.376808809E-01	0.000000000E+00	0.124010427E-10	0.000000000E+00	-0.372744926E-10	0.000000000E+00
6	0.348683388E-01	0.000000000E+00	0.215301893E-10	0.000000000E+00	-0.173138866E-10	0.000000000E+00
7	0.311817128E-01	0.000000000E+00	0.238689120E-10	0.000000000E+00	0.322321273E-11	0.000000000E+00
8	0.266481304E-01	0.000000000E+00	0.196247767E-10	0.000000000E+00	0.218869998E-10	0.000000000E+00
9	0.213801924E-01	0.000000000E+00	0.100286050E-10	0.000000000E+00	0.351023792E-10	0.000000000E+00
10	0.155230781E-01	0.000000000E+00	-0.263819065E-11	0.000000000E+00	0.402102695E-10	0.000000000E+00

11	0.923819160E-02	0.000000000E+00	-0.155337281E-10	0.000000000E+00	0.365610122E-10	0.000000000E+00
12	0.269872670E-02	0.000000000E+00	-0.259694036E-10	0.000000000E+00	0.257406762E-10	0.000000000E+00
13	-0.391511296E-02	0.000000000E+00	-0.321285313E-10	0.000000000E+00	0.114272145E-10	0.000000000E+00
14	-0.104210534E-01	0.000000000E+00	-0.336118528E-10	0.000000000E+00	-0.191840324E-11	0.000000000E+00
15	-0.166398250E-01	0.000000000E+00	-0.313656232E-10	0.000000000E+00	-0.106251903E-10	0.000000000E+00
16	-0.228123536E-01	0.000000000E+00	-0.270701093E-10	0.000000000E+00	-0.139730055E-10	0.000000000E+00
17	-0.288888705E-01	0.000000000E+00	-0.250077723E-10	0.000000000E+00	0.846500330E-11	0.000000000E+00
18	-0.327192076E-01	0.000000000E+00	-0.312624952E-10	0.000000000E+00	0.293823538E-10	0.000000000E+00
19	-0.346265852E-01	0.000000000E+00	-0.423241457E-10	0.000000000E+00	0.360884212E-10	0.000000000E+00
20	-0.352638127E-01	0.000000000E+00	-0.544417511E-10	0.000000000E+00	0.370604333E-10	0.000000000E+00
SMODE 7						
0.60568742E+02 0.10000000E+01						
1	-0.157071915E-10	0.000000000E+00	-0.146473810E+00	0.000000000E+00	-0.231409075E+00	0.000000000E+00
2	-0.156073325E-10	0.000000000E+00	-0.760049069E-01	0.000000000E+00	-0.178094660E+00	0.000000000E+00
3	-0.152063543E-10	0.000000000E+00	-0.241108832E-01	0.000000000E+00	-0.125859035E+00	0.000000000E+00
4	-0.143853589E-10	0.000000000E+00	0.108493324E-01	0.000000000E+00	-0.808556818E-01	0.000000000E+00
5	-0.130450368E-10	0.000000000E+00	0.307425413E-01	0.000000000E+00	-0.372525420E-01	0.000000000E+00
6	-0.111616129E-10	0.000000000E+00	0.360676504E-01	0.000000000E+00	0.535285715E-02	0.000000000E+00
7	-0.876482203E-11	0.000000000E+00	0.282228388E-01	0.000000000E+00	0.406444638E-01	0.000000000E+00
8	-0.592813575E-11	0.000000000E+00	0.108390402E-01	0.000000000E+00	0.616895581E-01	0.000000000E+00
9	-0.278861588E-11	0.000000000E+00	-0.102565053E-01	0.000000000E+00	0.625658035E-01	0.000000000E+00
10	0.493359032E-12	0.000000000E+00	-0.282080249E-01	0.000000000E+00	0.431790634E-01	0.000000000E+00
11	0.375012347E-11	0.000000000E+00	-0.371976375E-01	0.000000000E+00	0.974679138E-02	0.000000000E+00
12	0.681538703E-11	0.000000000E+00	-0.342561362E-01	0.000000000E+00	-0.271588246E-01	0.000000000E+00
13	0.953243719E-11	0.000000000E+00	-0.201688244E-01	0.000000000E+00	-0.559879762E-01	0.000000000E+00
14	0.117626185E-10	0.000000000E+00	0.824117689E-03	0.000000000E+00	-0.679432884E-01	0.000000000E+00
15	0.135319732E-10	0.000000000E+00	0.224546034E-01	0.000000000E+00	-0.598979128E-01	0.000000000E+00
16	0.137572527E-10	0.000000000E+00	0.371430507E-01	0.000000000E+00	-0.262051871E-01	0.000000000E+00
17	0.136003648E-10	0.000000000E+00	0.351878011E-01	0.000000000E+00	0.392888226E-01	0.000000000E+00
18	0.135923731E-10	0.000000000E+00	0.170226636E-01	0.000000000E+00	0.698021650E-01	0.000000000E+00
19	0.144028607E-10	0.000000000E+00	-0.800874209E-02	0.000000000E+00	0.804691269E-01	0.000000000E+00
20	0.146828531E-10	0.000000000E+00	-0.352386296E-01	0.000000000E+00	0.835929802E-01	0.000000000E+00
SMODE 8						
0.91085315E+02 0.10000000E+01						
1	0.486046744E-01	0.000000000E+00	-0.615091886E-10	0.000000000E+00	-0.137958169E-09	0.000000000E+00
2	0.479059208E-01	0.000000000E+00	-0.215781245E-10	0.000000000E+00	-0.872069459E-10	0.000000000E+00
3	0.451180218E-01	0.000000000E+00	0.143525607E-11	0.000000000E+00	-0.443955372E-10	0.000000000E+00
4	0.395300384E-01	0.000000000E+00	0.114391337E-10	0.000000000E+00	-0.137377312E-10	0.000000000E+00
5	0.307691829E-01	0.000000000E+00	0.122167219E-10	0.000000000E+00	0.906685267E-11	0.000000000E+00
6	0.191985832E-01	0.000000000E+00	0.663164912E-11	0.000000000E+00	0.233567132E-10	0.000000000E+00
7	0.573528155E-02	0.000000000E+00	-0.187181199E-11	0.000000000E+00	0.260902843E-10	0.000000000E+00
8	-0.834933873E-02	0.000000000E+00	-0.927113360E-11	0.000000000E+00	0.169087703E-10	0.000000000E+00
9	-0.214694297E-01	0.000000000E+00	-0.121693257E-10	0.000000000E+00	-0.683335989E-13	0.000000000E+00
10	-0.321092880E-01	0.000000000E+00	0.923090057E-11	0.000000000E+00	-0.169998573E-10	0.000000000E+00
11	-0.390397742E-01	0.000000000E+00	-0.182214357E-11	0.000000000E+00	-0.260490252E-10	0.000000000E+00
12	-0.414602554E-01	0.000000000E+00	0.664351032E-11	0.000000000E+00	-0.231802753E-10	0.000000000E+00
13	-0.390911060E-01	0.000000000E+00	0.123567385E-10	0.000000000E+00	-0.101803897E-10	0.000000000E+00
14	-0.322060325E-01	0.000000000E+00	0.129979194E-10	0.000000000E+00	0.613146646E-11	0.000000000E+00
15	-0.216004107E-01	0.000000000E+00	0.895433644E-11	0.000000000E+00	0.165540121E-10	0.000000000E+00
16	-0.768952606E-02	0.000000000E+00	0.291276007E-11	0.000000000E+00	0.183906918E-10	0.000000000E+00
17	0.802661037E-02	0.000000000E+00	-0.121048707E-11	0.000000000E+00	0.306064256E-11	0.000000000E+00
18	0.187754234E-01	0.000000000E+00	-0.269058856E-12	0.000000000E+00	-0.835920034E-11	0.000000000E+00
19	0.245663136E-01	0.000000000E+00	0.315503354E-11	0.000000000E+00	-0.115919927E-10	0.000000000E+00
20	0.265798168E-01	0.000000000E+00	0.706845509E-11	0.000000000E+00	-0.120002371E-10	0.000000000E+00
SMODE 9						
0.96043815E+02 0.10000000E+01						
1	-0.118311570E-10	0.000000000E+00	-0.190061228E+00	0.000000000E+00	-0.447342843E+00	0.000000000E+00
2	-0.116420340E-10	0.000000000E+00	-0.616300092E-01	0.000000000E+00	-0.273393625E+00	0.000000000E+00
3	-0.108885200E-10	0.000000000E+00	0.915922105E-02	0.000000000E+00	-0.129906339E+00	0.000000000E+00
4	-0.938467036E-11	0.000000000E+00	0.368905308E-01	0.000000000E+00	-0.307390709E-01	0.000000000E+00
5	-0.704655292E-11	0.000000000E+00	0.353776408E-01	0.000000000E+00	0.391381597E-01	0.000000000E+00
6	-0.399883833E-11	0.000000000E+00	0.152167735E-01	0.000000000E+00	0.777120202E-01	0.000000000E+00
7	-0.521845317E-12	0.000000000E+00	-0.114945238E-01	0.000000000E+00	0.772803593E-01	0.000000000E+00
8	0.301168410E-11	0.000000000E+00	-0.317458597E-01	0.000000000E+00	0.401741901E-01	0.000000000E+00
9	0.615838813E-11	0.000000000E+00	-0.358962654E-01	0.000000000E+00	-0.160438435E-01	0.000000000E+00
10	0.851408638E-11	0.000000000E+00	-0.220831031E-01	0.000000000E+00	-0.638813728E-01	0.000000000E+00
11	0.977620973E-11	0.000000000E+00	0.273416931E-02	0.000000000E+00	-0.797734440E-01	0.000000000E+00
12	0.978262706E-11	0.000000000E+00	0.261667458E-01	0.000000000E+00	-0.558559467E-01	0.000000000E+00
13	0.853267431E-11	0.000000000E+00	0.364970483E-01	0.000000000E+00	-0.387521114E-02	0.000000000E+00
14	0.618673905E-11	0.000000000E+00	0.284380205E-01	0.000000000E+00	0.506997352E-01	0.000000000E+00
15	0.307666506E-11	0.000000000E+00	0.566675410E-02	0.000000000E+00	0.814770172E-01	0.000000000E+00
16	-0.125624964E-11	0.000000000E+00	-0.211700735E-01	0.000000000E+00	0.720839937E-01	0.000000000E+00
17	-0.598732336E-11	0.000000000E+00	-0.331797150E-01	0.000000000E+00	-0.817119032E-02	0.000000000E+00
18	-0.948187330E-11	0.000000000E+00	-0.217586392E-01	0.000000000E+00	-0.615052754E-01	0.000000000E+00
19	-0.125202160E-10	0.000000000E+00	0.262655711E-02	0.000000000E+00	-0.836303031E-01	0.000000000E+00
20	-0.133506200E-10	0.000000000E+00	0.317694569E-01	0.000000000E+00	-0.907118081E-01	0.000000000E+00
SMODE 10						
0.13745102E+03 0.10000000E+01						
1	-0.246574144E-10	0.000000000E+00	-0.211240645E+00	0.000000000E+00	-0.703891609E+00	0.000000000E+00
2	-0.238501994E-10	0.000000000E+00	-0.225982289E-01	0.000000000E+00	-0.307917874E+00	0.000000000E+00
3	-0.206778819E-10	0.000000000E+00	0.423576344E-01	0.000000000E+00	-0.497547363E-01	0.000000000E+00
4	-0.146320296E-10	0.000000000E+00	0.383106762E-01	0.000000000E+00	0.727769033E-01	0.000000000E+00
5	-0.606183786E-11	0.000000000E+00	0.671915168E-02	0.000000000E+00	0.106761986E+00	0.000000000E+00
6	0.351785649E-11	0.000000000E+00	-0.244010324E-01	0.000000000E+00	0.703426600E-01	0.000000000E+00
7	0.119535875E-10	0.000000000E+00	-0.355937659E-01	0.000000000E+00	-0.636596109E-02	0.000000000E+00
8	0.172242595E-10	0.000000000E+00	-0.210619130E-01	0.000000000E+00	-0.757297929E-01	0.000000000E+00
9	0.179637550E-10	0.000000000E+00	0.846936050E-02	0.000000000E+00	-0.914677846E-01	0.000000000E+00
10	0.139775500E-10	0.000000000E+00	0.322310864E-01	0.000000000E+00	-0.430974136E-01	0.000000000E+00
11	0.631432870E-11	0.000000000E+00	0.335773669E-01	0.000000000E+00	0.355007295E-01	0.000000000E+00
12	-0.301004722E-11	0.000000000E+00	0.115107659E-01	0.000000000E+00	0.895453077E-01	0.000000000E+00
13	-0.115425690E-10	0.000000000E+00	-0.186696566E-01	0.000000000E+00	0.815032575E-01	0.000000000E+00
14	-0.170385168E-10	0.000000000E+00	-0.360861060E-01	0.000000000E+00	0.173339658E-01	0.000000000E+00
15	-0.180790047E-10	0.000000000E+00	-0.289453280E-01	0.000000000E+00	-0.573819796E-01	0.000000000E+00
16	-0.124411695E-10	0.000000000E+00	-0.238405268E-03	0.000000000E+00	-0.101478865E+00	0.000000000E+00
17	-0.317168047E-11	0.000000000E+00	0.255630130E-01	0.000000000E+00	-0.327928255E-01	0.000000000E+00

18	0.470419848E-11	0.000000000E+00	0.240043415E-01	0.000000000E+00	0.468674461E-01	0.000000000E+00
19	0.113506740E-10	0.000000000E+00	0.134899950E-02	0.000000000E+00	0.863832671E-01	0.000000000E+00
20	0.134787415E-10	0.000000000E+00	-0.301739843E-01	0.000000000E+00	0.100158763E+00	0.000000000E+00
SMODE 11						
0.14015957E+03 0.10000000E+01						
1	-0.576291542E-01	0.000000000E+00	0.980725269E-10	0.000000000E+00	0.333242682E-09	0.000000000E+00
2	-0.556674342E-01	0.000000000E+00	0.915710684E-11	0.000000000E+00	0.142236436E-09	0.000000000E+00
3	-0.479663635E-01	0.000000000E+00	-0.203000887E-10	0.000000000E+00	0.196413091E-10	0.000000000E+00
4	-0.333434330E-01	0.000000000E+00	-0.172936900E-10	0.000000000E+00	-0.366727253E-10	0.000000000E+00
5	-0.127725064E-01	0.000000000E+00	-0.199744418E-11	0.000000000E+00	-0.501725289E-10	0.000000000E+00
6	0.991298862E-02	0.000000000E+00	0.121848098E-10	0.000000000E+00	-0.304458686E-10	0.000000000E+00
7	0.293789839E-01	0.000000000E+00	0.163587104E-10	0.000000000E+00	0.659049826E-11	0.000000000E+00
8	0.407627449E-01	0.000000000E+00	0.851681997E-11	0.000000000E+00	0.376644694E-10	0.000000000E+00
9	0.409963232E-01	0.000000000E+00	-0.550707781E-11	0.000000000E+00	0.416219107E-10	0.000000000E+00
10	0.300158201E-01	0.000000000E+00	-0.156767713E-10	0.000000000E+00	0.158738949E-10	0.000000000E+00
11	0.108248340E-01	0.000000000E+00	-0.147259636E-10	0.000000000E+00	-0.212766396E-10	0.000000000E+00
12	-0.113271610E-01	0.000000000E+00	-0.328217995E-11	0.000000000E+00	-0.435006629E-10	0.000000000E+00
13	-0.303807559E-01	0.000000000E+00	0.106165107E-10	0.000000000E+00	-0.352212832E-10	0.000000000E+00
14	-0.411240236E-01	0.000000000E+00	0.173048815E-10	0.000000000E+00	-0.286157598E-11	0.000000000E+00
15	-0.406183041E-01	0.000000000E+00	0.126151584E-10	0.000000000E+00	0.284597181E-10	0.000000000E+00
16	-0.286052067E-01	0.000000000E+00	0.648870766E-13	0.000000000E+00	0.414527431E-10	0.000000000E+00
17	-0.884350721E-02	0.000000000E+00	-0.977004608E-11	0.000000000E+00	0.105932084E-10	0.000000000E+00
18	0.733984027E-02	0.000000000E+00	-0.876257858E-11	0.000000000E+00	-0.173007938E-10	0.000000000E+00
19	0.175849757E-01	0.000000000E+00	-0.817496843E-12	0.000000000E+00	-0.294238969E-10	0.000000000E+00
20	0.214286212E-01	0.000000000E+00	0.975524492E-11	0.000000000E+00	-0.333674641E-10	0.000000000E+00
SMODE 12						
0.18549657E+03 0.10000000E+01						
1	-0.404638507E-10	0.000000000E+00	-0.201509387E+00	0.000000000E+00	-0.919062790E+00	0.000000000E+00
2	-0.380511930E-10	0.000000000E+00	0.260030227E-01	0.000000000E+00	-0.231102444E+00	0.000000000E+00
3	-0.287813835E-10	0.000000000E+00	0.528310696E-01	0.000000000E+00	0.882162354E-01	0.000000000E+00
4	-0.12455058E-10	0.000000000E+00	0.103583327E-01	0.000000000E+00	0.144242441E+00	0.000000000E+00
5	0.700349952E-11	0.000000000E+00	-0.286319824E-01	0.000000000E+00	0.718209970E-01	0.000000000E+00
6	0.223093093E-10	0.000000000E+00	-0.337885403E-01	0.000000000E+00	-0.426620603E-01	0.000000000E+00
7	0.267462480E-10	0.000000000E+00	-0.644849833E-02	0.000000000E+00	-0.108138426E+00	0.000000000E+00
8	0.183747313E-10	0.000000000E+00	0.266180697E-01	0.000000000E+00	-0.742932677E-01	0.000000000E+00
9	0.119949323E-11	0.000000000E+00	0.350849221E-01	0.000000000E+00	0.275657554E-01	0.000000000E+00
10	-0.165504652E-10	0.000000000E+00	0.112403409E-01	0.000000000E+00	0.103890459E+00	0.000000000E+00
11	-0.263707108E-10	0.000000000E+00	-0.229232128E-01	0.000000000E+00	0.844470314E-01	0.000000000E+00
12	-0.235562509E-10	0.000000000E+00	-0.358873191E-01	0.000000000E+00	-0.130534743E-01	0.000000000E+00
13	-0.945550873E-11	0.000000000E+00	-0.155317805E-01	0.000000000E+00	-0.994497062E-01	0.000000000E+00
14	0.917557331E-11	0.000000000E+00	0.199277637E-01	0.000000000E+00	-0.967849148E-01	0.000000000E+00
15	0.232854759E-10	0.000000000E+00	0.392581119E-01	0.000000000E+00	-0.117238642E-01	0.000000000E+00
16	0.243752766E-10	0.000000000E+00	0.225861810E-01	0.000000000E+00	0.983544682E-01	0.000000000E+00
17	0.145431683E-10	0.000000000E+00	-0.131395540E-01	0.000000000E+00	0.797819963E-01	0.000000000E+00
18	0.187924312E-11	0.000000000E+00	-0.244277528E-01	0.000000000E+00	-0.242919674E-01	0.000000000E+00
19	-0.113623925E-10	0.000000000E+00	-0.505771197E-02	0.000000000E+00	-0.879574032E-01	0.000000000E+00
20	-0.164037194E-10	0.000000000E+00	0.293153727E-01	0.000000000E+00	-0.112332562E+00	0.000000000E+00
SMODE 13						
0.18866591E+03 0.10000000E+01						
1	0.635456904E-01	0.000000000E+00	-0.128079834E-09	0.000000000E+00	-0.595027517E-09	0.000000000E+00
2	0.596262662E-01	0.000000000E+00	0.184466311E-10	0.000000000E+00	-0.142630666E-09	0.000000000E+00
3	0.445932641E-01	0.000000000E+00	0.336042251E-10	0.000000000E+00	0.619395460E-10	0.000000000E+00
4	0.182827976E-01	0.000000000E+00	0.520964192E-11	0.000000000E+00	0.931262188E-10	0.000000000E+00
5	-0.126132500E-01	0.000000000E+00	-0.192533068E-10	0.000000000E+00	0.421772862E-10	0.000000000E+00
6	-0.360622671E-01	0.000000000E+00	-0.209869909E-10	0.000000000E+00	-0.322093635E-10	0.000000000E+00
7	-0.413893820E-01	0.000000000E+00	-0.232926801E-11	0.000000000E+00	-0.705454456E-10	0.000000000E+00
8	-0.262178436E-01	0.000000000E+00	0.183234681E-10	0.000000000E+00	-0.432087710E-10	0.000000000E+00
9	0.194814539E-02	0.000000000E+00	0.217658578E-10	0.000000000E+00	0.242314316E-10	0.000000000E+00
10	0.291485491E-01	0.000000000E+00	0.483710339E-11	0.000000000E+00	0.689086061E-10	0.000000000E+00
11	0.419019812E-01	0.000000000E+00	-0.165994622E-10	0.000000000E+00	0.490460267E-10	0.000000000E+00
12	0.338874248E-01	0.000000000E+00	-0.224529192E-10	0.000000000E+00	-0.168914751E-10	0.000000000E+00
13	0.907712925E-02	0.000000000E+00	-0.712224271E-11	0.000000000E+00	0.676667245E-10	0.000000000E+00
14	-0.202320451E-01	0.000000000E+00	0.154316753E-10	0.000000000E+00	-0.570045845E-10	0.000000000E+00
15	-0.395135858E-01	0.000000000E+00	0.252629817E-10	0.000000000E+00	0.111229779E-11	0.000000000E+00
16	-0.398975614E-01	0.000000000E+00	0.125320985E-10	0.000000000E+00	0.657282754E-10	0.000000000E+00
17	-0.229669845E-01	0.000000000E+00	-0.964425189E-11	0.000000000E+00	0.458824898E-10	0.000000000E+00
18	-0.217392360E-02	0.000000000E+00	-0.155140169E-10	0.000000000E+00	-0.168695751E-10	0.000000000E+00
19	0.154271620E-01	0.000000000E+00	-0.339842644E-11	0.000000000E+00	-0.535861511E-10	0.000000000E+00
20	0.228552354E-01	0.000000000E+00	0.173654672E-10	0.000000000E+00	-0.676305216E-10	0.000000000E+00
SMODE 14						
0.23272215E+03 0.10000000E+01						
1	0.629441732E-01	0.000000000E+00	0.381452117E-10	0.000000000E+00	0.223647642E-09	0.000000000E+00
2	0.570369925E-01	0.000000000E+00	-0.130972860E-10	0.000000000E+00	0.187294540E-10	0.000000000E+00
3	0.349998252E-01	0.000000000E+00	-0.840209429E-11	0.000000000E+00	-0.414391601E-10	0.000000000E+00
4	0.253051461E-03	0.000000000E+00	0.441981227E-11	0.000000000E+00	-0.263159255E-10	0.000000000E+00
5	-0.307485051E-01	0.000000000E+00	0.794513811E-11	0.000000000E+00	0.721423131E-11	0.000000000E+00
6	-0.386506051E-01	0.000000000E+00	0.166087382E-11	0.000000000E+00	0.264532754E-10	0.000000000E+00
7	-0.177459453E-01	0.000000000E+00	-0.617960661E-11	0.000000000E+00	0.157279450E-10	0.000000000E+00
8	0.164587127E-01	0.000000000E+00	-0.683988368E-11	0.000000000E+00	-0.121296363E-10	0.000000000E+00
9	0.382513236E-01	0.000000000E+00	0.290908844E-12	0.000000000E+00	-0.260831878E-10	0.000000000E+00
10	0.311972872E-01	0.000000000E+00	0.712371065E-11	0.000000000E+00	-0.105282004E-10	0.000000000E+00
11	0.616320528E-03	0.000000000E+00	0.592138413E-11	0.000000000E+00	0.169641350E-10	0.000000000E+00
12	-0.304294343E-01	0.000000000E+00	-0.194812553E-11	0.000000000E+00	0.251872584E-10	0.000000000E+00
13	-0.385273216E-01	0.000000000E+00	-0.753954195E-11	0.000000000E+00	0.469814659E-11	0.000000000E+00
14	-0.175704640E-01	0.000000000E+00	-0.440525282E-11	0.000000000E+00	-0.216322321E-10	0.000000000E+00
15	0.166368826E-01	0.000000000E+00	0.420566895E-11	0.000000000E+00	-0.249305757E-10	0.000000000E+00
16	0.402391557E-01	0.000000000E+00	0.849457361E-11	0.000000000E+00	0.152034946E-11	0.000000000E+00
17	0.389683581E-01	0.000000000E+00	0.264264466E-11	0.000000000E+00	0.252984815E-10	0.000000000E+00
18	0.161759943E-01	0.000000000E+00	-0.340773330E-11	0.000000000E+00	0.496645049E-11	0.000000000E+00
19	-0.164870406E-01	0.000000000E+00	-0.179292871E-11	0.000000000E+00	-0.136446403E-10	0.000000000E+00
20	-0.326162494E-01	0.000000000E+00	0.441064323E-11	0.000000000E+00	-0.213883944E-10	0.000000000E+00
SMODE 15						
0.24109437E+03 0.10000000E+01						
1	-0.128965633E-10	0.000000000E+00	0.174376328E+00	0.000000000E+00	0.106464443E+01	0.000000000E+00
2	-0.115975736E-10	0.000000000E+00	-0.662214216E-01	0.000000000E+00	0.589590428E-01	0.000000000E+00

3	-0.678081910E-11	0.000000000E+00	-0.355138989E-01	0.000000000E+00	-0.207183277E+00	0.000000000E+00
4	0.635080091E-12	0.000000000E+00	0.252304352E-01	0.000000000E+00	-0.111722142E+00	0.000000000E+00
5	0.678992500E-11	0.000000000E+00	0.359866380E-01	0.000000000E+00	0.533108757E-01	0.000000000E+00
6	0.753484821E-11	0.000000000E+00	0.186750973E-02	0.000000000E+00	0.128542777E+00	0.000000000E+00
7	0.227497559E-11	0.000000000E+00	-0.324954528E-01	0.000000000E+00	0.553688494E-01	0.000000000E+00
8	-0.480771752E-11	0.000000000E+00	-0.280230460E-01	0.000000000E+00	-0.789625936E-01	0.000000000E+00
9	-0.799913295E-11	0.000000000E+00	0.938053712E-02	0.000000000E+00	-0.120379743E+00	0.000000000E+00
10	-0.471632615E-11	0.000000000E+00	0.359262969E-01	0.000000000E+00	-0.211365652E-01	0.000000000E+00
11	0.238378008E-11	0.000000000E+00	0.206170566E-01	0.000000000E+00	0.102730016E+00	0.000000000E+00
12	0.755457792E-11	0.000000000E+00	-0.186299703E-01	0.000000000E+00	0.106404988E+00	0.000000000E+00
13	0.661101344E-11	0.000000000E+00	-0.358040402E-01	0.000000000E+00	-0.15209527E-01	0.000000000E+00
14	0.316764311E-12	0.000000000E+00	-0.101557245E-01	0.000000000E+00	-0.122674731E+00	0.000000000E+00
15	-0.652850854E-11	0.000000000E+00	0.306289516E-01	0.000000000E+00	-0.983074011E-01	0.000000000E+00
16	-0.104800683E-10	0.000000000E+00	0.390623823E-01	0.000000000E+00	0.486143128E-01	0.000000000E+00
17	-0.862821076E-11	0.000000000E+00	0.296745791E-02	0.000000000E+00	0.121241840E+00	0.000000000E+00
18	-0.218104947E-11	0.000000000E+00	-0.224647857E-01	0.000000000E+00	0.691695211E-02	0.000000000E+00
19	0.276990111E-11	0.000000000E+00	-0.872605313E-02	0.000000000E+00	-0.854280070E-01	0.000000000E+00
20	0.597666417E-11	0.000000000E+00	0.281462488E-01	0.000000000E+00	-0.124962539E+00	0.000000000E+00
SMODE 16						
0.26795948E+03 0.10000000E+01						
1	0.602908611E-01	0.000000000E+00	0.730095316E-11	0.000000000E+00	0.504949754E-10	0.000000000E+00
2	0.527895178E-01	0.000000000E+00	-0.360892840E-11	0.000000000E+00	-0.170562411E-11	0.000000000E+00
3	0.255533062E-01	0.000000000E+00	-0.977328933E-12	0.000000000E+00	-0.107301965E-10	0.000000000E+00
4	-0.128886269E-01	0.000000000E+00	0.166468632E-11	0.000000000E+00	-0.284279312E-11	0.000000000E+00
5	-0.362865813E-01	0.000000000E+00	0.124893102E-11	0.000000000E+00	0.499090766E-11	0.000000000E+00
6	-0.249030456E-01	0.000000000E+00	-0.74430537E-12	0.000000000E+00	0.546657819E-11	0.000000000E+00
7	0.106413916E-01	0.000000000E+00	-0.165049698E-11	0.000000000E+00	-0.691230242E-12	0.000000000E+00
8	0.354565709E-01	0.000000000E+00	-0.406355382E-12	0.000000000E+00	-0.581057073E-11	0.000000000E+00
9	0.248224140E-01	0.000000000E+00	0.135938201E-11	0.000000000E+00	-0.343523969E-11	0.000000000E+00
10	-0.106290889E-01	0.000000000E+00	0.137350332E-11	0.000000000E+00	0.335336909E-11	0.000000000E+00
11	-0.354536745E-01	0.000000000E+00	-0.379501097E-12	0.000000000E+00	0.583453557E-11	0.000000000E+00
12	-0.248318288E-01	0.000000000E+00	-0.166070661E-11	0.000000000E+00	0.899303906E-12	0.000000000E+00
13	0.106168102E-01	0.000000000E+00	-0.862482353E-12	0.000000000E+00	-0.501725591E-11	0.000000000E+00
14	0.354507620E-01	0.000000000E+00	0.946757565E-12	0.000000000E+00	-0.455557497E-11	0.000000000E+00
15	0.248412319E-01	0.000000000E+00	0.144090469E-11	0.000000000E+00	0.225205972E-11	0.000000000E+00
16	-0.121424675E-01	0.000000000E+00	-0.549016461E-12	0.000000000E+00	0.743323508E-11	0.000000000E+00
17	-0.412071811E-01	0.000000000E+00	-0.181389226E-11	0.000000000E+00	-0.190286052E-11	0.000000000E+00
18	-0.317051694E-01	0.000000000E+00	-0.489581826E-12	0.000000000E+00	-0.440140522E-11	0.000000000E+00
19	0.142055207E-01	0.000000000E+00	0.793317129E-12	0.000000000E+00	-0.359385194E-11	0.000000000E+00
20	0.412476863E-01	0.000000000E+00	0.196193732E-11	0.000000000E+00	-0.351739795E-11	0.000000000E+00
SMODE 17						
0.30274189E+03 0.10000000E+01						
1	0.678914109E-01	0.000000000E+00	-0.242836547E-10	0.000000000E+00	-0.193735907E-09	0.000000000E+00
2	0.571091667E-01	0.000000000E+00	0.153328053E-10	0.000000000E+00	0.271708447E-10	0.000000000E+00
3	0.191703626E-01	0.000000000E+00	0.219952386E-12	0.000000000E+00	0.414001045E-10	0.000000000E+00
4	-0.272981552E-01	0.000000000E+00	-0.753557041E-11	0.000000000E+00	-0.269515625E-11	0.000000000E+00
5	-0.395507567E-01	0.000000000E+00	-0.175638377E-11	0.000000000E+00	-0.266985746E-10	0.000000000E+00
6	-0.451088286E-02	0.000000000E+00	0.568658078E-11	0.000000000E+00	-0.114895782E-10	0.000000000E+00
7	0.353186265E-01	0.000000000E+00	0.445836376E-11	0.000000000E+00	0.177196561E-10	0.000000000E+00
8	0.300240927E-01	0.000000000E+00	-0.317578892E-11	0.000000000E+00	0.213470800E-10	0.000000000E+00
9	-0.135871719E-01	0.000000000E+00	-0.628072161E-11	0.000000000E+00	-0.545993891E-11	0.000000000E+00
10	-0.398584769E-01	0.000000000E+00	-0.427459359E-12	0.000000000E+00	-0.245057174E-10	0.000000000E+00
11	-0.152624755E-01	0.000000000E+00	0.604546871E-11	0.000000000E+00	-0.864209259E-11	0.000000000E+00
12	0.288114658E-01	0.000000000E+00	0.393373653E-11	0.000000000E+00	0.194185528E-10	0.000000000E+00
13	0.361162672E-01	0.000000000E+00	-0.367574057E-11	0.000000000E+00	0.193849955E-10	0.000000000E+00
14	-0.267041190E-02	0.000000000E+00	-0.575036263E-11	0.000000000E+00	-0.884793895E-11	0.000000000E+00
15	-0.380491465E-01	0.000000000E+00	0.108629456E-11	0.000000000E+00	-0.272628822E-10	0.000000000E+00
16	-0.257182729E-01	0.000000000E+00	0.835145739E-11	0.000000000E+00	-0.981592811E-11	0.000000000E+00
17	0.163077765E-01	0.000000000E+00	0.431622863E-11	0.000000000E+00	0.284897279E-10	0.000000000E+00
18	0.314095494E-01	0.000000000E+00	-0.369399397E-11	0.000000000E+00	0.107854254E-10	0.000000000E+00
19	-0.539753052E-02	0.000000000E+00	-0.324926132E-11	0.000000000E+00	-0.129681227E-10	0.000000000E+00
20	-0.330836428E-01	0.000000000E+00	0.350574488E-11	0.000000000E+00	-0.242343211E-10	0.000000000E+00
SMODE 18						
0.30414468E+03 0.10000000E+01						
1	-0.114110200E-10	0.000000000E+00	-0.136579397E+00	0.000000000E+00	-0.109550701E+01	0.000000000E+00
2	-0.958194820E-11	0.000000000E+00	0.869411842E-01	0.000000000E+00	0.158070589E+00	0.000000000E+00
3	-0.315484076E-11	0.000000000E+00	0.449925024E-03	0.000000000E+00	0.233643471E+00	0.000000000E+00
4	0.466571232E-11	0.000000000E+00	-0.427691843E-01	0.000000000E+00	-0.183148292E-01	0.000000000E+00
5	0.660582078E-11	0.000000000E+00	-0.923623327E-02	0.000000000E+00	-0.151999977E+00	0.000000000E+00
6	0.580500229E-12	0.000000000E+00	0.325968338E-01	0.000000000E+00	-0.624248959E-01	0.000000000E+00
7	-0.603067412E-11	0.000000000E+00	0.245868805E-01	0.000000000E+00	0.103011886E+00	0.000000000E+00
8	-0.486608707E-11	0.000000000E+00	-0.188686097E-01	0.000000000E+00	0.119226742E+00	0.000000000E+00
9	0.256628217E-11	0.000000000E+00	-0.353127679E-01	0.000000000E+00	-0.351316561E-01	0.000000000E+00
10	0.669312808E-11	0.000000000E+00	-0.121861749E-02	0.000000000E+00	-0.139226880E+00	0.000000000E+00
11	0.219889376E-11	0.000000000E+00	0.346378867E-01	0.000000000E+00	-0.441617480E-01	0.000000000E+00
12	-0.512764206E-11	0.000000000E+00	0.209938906E-01	0.000000000E+00	0.113851201E+00	0.000000000E+00
13	-0.584957288E-11	0.000000000E+00	-0.224602545E-01	0.000000000E+00	0.108064005E+00	0.000000000E+00
14	0.963119406E-12	0.000000000E+00	-0.329435777E-01	0.000000000E+00	-0.555464437E-01	0.000000000E+00
15	0.619306086E-11	0.000000000E+00	0.670781103E-02	0.000000000E+00	-0.151161485E+00	0.000000000E+00
16	0.270256080E-11	0.000000000E+00	0.439705572E-01	0.000000000E+00	-0.403912630E-01	0.000000000E+00
17	-0.594964533E-11	0.000000000E+00	0.197833091E-01	0.000000000E+00	0.145448225E+00	0.000000000E+00
18	-0.637834283E-11	0.000000000E+00	-0.187101250E-01	0.000000000E+00	0.443490736E-01	0.000000000E+00
19	0.132146968E-11	0.000000000E+00	-0.125650402E-01	0.000000000E+00	-0.802927503E-01	0.000000000E+00
20	0.814970105E-11	0.000000000E+00	0.273769109E-01	0.000000000E+00	-0.141489568E+00	0.000000000E+00
SMODE 19						
0.34073782E+03 0.10000000E+01						
1	-0.707538826E-01	0.000000000E+00	0.286928532E-12	0.000000000E+00	0.262347720E-11	0.000000000E+00
2	-0.565194476E-01	0.000000000E+00	-0.221984002E-12	0.000000000E+00	-0.690287092E-12	0.000000000E+00
3	-0.840091489E-02	0.000000000E+00	0.480007977E-13	0.000000000E+00	-0.495289349E-12	0.000000000E+00
4	0.394299547E-01	0.000000000E+00	0.105439962E-12	0.000000000E+00	0.235797171E-12	0.000000000E+00
5	0.288337445E-01	0.000000000E+00	-0.219086549E-13	0.000000000E+00	0.399183609E-12	0.000000000E+00
6	-0.242519715E-01	0.000000000E+00	-0.938925746E-13	0.000000000E+00	-0.298463827E-13	0.000000000E+00
7	-0.375458217E-01	0.000000000E+00	-0.115502451E-13	0.000000000E+00	-0.367137329E-12	0.000000000E+00
8	0.980588267E-02	0.000000000E+00	0.869057320E-13	0.000000000E+00	-0.124434647E-12	0.000000000E+00
9	0.413050297E-01	0.000000000E+00	0.469408709E-13	0.000000000E+00	0.322686439E-12	0.000000000E+00

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10 0.602871042E-02 0.000000000E+00 -0.675104098E-13 0.000000000E+00 0.247050254E-12 0.000000000E+00
11 -0.389938711E-01 0.000000000E+00 -0.712141591E-13 0.000000000E+00 -0.237902197E-12 0.000000000E+00
12 -0.209773503E-01 0.000000000E+00 0.541938680E-13 0.000000000E+00 -0.403252596E-12 0.000000000E+00
13 0.309520756E-01 0.000000000E+00 0.149909210E-12 0.000000000E+00 -0.172574001E-12 0.000000000E+00
14 0.328430569E-01 0.000000000E+00 0.122588716E-12 0.000000000E+00 0.472429997E-12 0.000000000E+00
15 -0.183613752E-01 0.000000000E+00 -0.103128223E-12 0.000000000E+00 0.583827601E-12 0.000000000E+00
16 -0.424328354E-01 0.000000000E+00 -0.503939203E-13 0.000000000E+00 -0.107313464E-11 0.000000000E+00
17 -0.811679272E-02 0.000000000E+00 0.242277663E-12 0.000000000E+00 0.105857230E-11 0.000000000E+00
18 0.266238962E-01 0.000000000E+00 -0.370053959E-12 0.000000000E+00 0.164557042E-11 0.000000000E+00
19 0.161849488E-02 0.000000000E+00 -0.771139226E-12 0.000000000E+00 0.103414361E-11 0.000000000E+00
20 -0.269328262E-01 0.000000000E+00 -0.112669386E-11 0.000000000E+00 0.109978557E-11 0.000000000E+00
$MODE 20
0.37463267E+03 0.10000000E+01
1 -0.355947090E-11 0.000000000E+00 0.958891159E-01 0.000000000E+00 0.995287908E+00 0.000000000E+00
2 -0.269382803E-11 0.000000000E+00 -0.855826082E-01 0.000000000E+00 -0.340053935E+00 0.000000000E+00
3 0.113863383E-12 0.000000000E+00 0.332714032E-01 0.000000000E+00 -0.148576036E+00 0.000000000E+00
4 0.225867224E-11 0.000000000E+00 0.320750366E-01 0.000000000E+00 0.154238522E+00 0.000000000E+00
5 0.488809278E-12 0.000000000E+00 -0.248642677E-01 0.000000000E+00 0.120952523E+00 0.000000000E+00
6 -0.206780838E-11 0.000000000E+00 -0.303011707E-01 0.000000000E+00 -0.938110068E-01 0.000000000E+00
7 -0.594716624E-12 0.000000000E+00 0.170112184E-01 0.000000000E+00 -0.136577282E+00 0.000000000E+00
8 0.203444028E-11 0.000000000E+00 0.345172400E-01 0.000000000E+00 0.512864949E-01 0.000000000E+00
9 0.687752556E-12 0.000000000E+00 -0.711062651E-02 0.000000000E+00 0.150819297E+00 0.000000000E+00
10 -0.200299372E-11 0.000000000E+00 -0.366317617E-01 0.000000000E+00 -0.746299547E-02 0.000000000E+00
11 -0.779376076E-12 0.000000000E+00 -0.358257357E-02 0.000000000E+00 -0.153054996E+00 0.000000000E+00
12 0.196727405E-11 0.000000000E+00 0.356003830E-01 0.000000000E+00 -0.372691834E-01 0.000000000E+00
13 0.869093832E-12 0.000000000E+00 0.140355313E-01 0.000000000E+00 0.141894644E+00 0.000000000E+00
14 -0.192748717E-11 0.000000000E+00 -0.312268376E-01 0.000000000E+00 0.774851990E-01 0.000000000E+00
15 -0.116408916E-11 0.000000000E+00 -0.219896528E-01 0.000000000E+00 -0.124185553E+00 0.000000000E+00
16 0.272999754E-11 0.000000000E+00 0.343504652E-01 0.000000000E+00 -0.144112587E+00 0.000000000E+00
17 0.341732276E-12 0.000000000E+00 0.346565590E-01 0.000000000E+00 0.140226171E+00 0.000000000E+00
18 -0.142483334E-11 0.000000000E+00 -0.131227186E-01 0.000000000E+00 0.864021047E-01 0.000000000E+00
19 -0.653929602E-12 0.000000000E+00 -0.168075647E-01 0.000000000E+00 -0.719059785E-01 0.000000000E+00
20 0.323921072E-11 0.000000000E+00 0.271864737E-01 0.000000000E+00 -0.164110128E+00 0.000000000E+00

```

Listing 9.8.5 trim_output.dat

TRIM ITERATION NUMBER : 1

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.700000E+01
ALTITUDE IN METERS : 0.254684E+05
DYNAMIC PRESSURE IN N/M^2 : 0.813965E+05
ANGLE OF ATTACK IN DEGREES : 0.000000E+00
CONTROL SURFACE DEFLECTION IN DEGREES : 0.500000E+01

TRIM VARIABLE: ALPHA = 0.187930E+00(DEG), DELTA = 0.159617E+03(DEG)

FINAL TRIM POSITION: ALPHA = 0.187930E+00(DEG), DELTA = 0.164617E+03(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.829348 REFERENCE CHORD = 6.267200
X-CG = 3.369830 Z-CG = 6.4264284E-03
TOTAL WEIGHT = 6515.901 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 7.569181

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.5378E-01	0.5216E-01	0.8156E-01	0.8187E-01	-.2366E-01	-.2383E-01
ALPHA(/RAD)	0.1395E+01	0.1406E+01	0.1122E+03	0.1121E+03	-.3759E+02	-.3725E+02
DELTA(/RAD)	0.2236E-01	0.2236E-01	-.1300E+00	-.1300E+00	0.5388E-01	0.5241E-01

TRIM ITERATION NUMBER : 2

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.700000E+01
ALTITUDE IN METERS : 0.254684E+05
DYNAMIC PRESSURE IN N/M^2 : 0.813965E+05
ANGLE OF ATTACK IN DEGREES : 0.187930E+00
CONTROL SURFACE DEFLECTION IN DEGREES : 0.500000E+01

TRIM VARIABLE: ALPHA = 0.510449E-01(DEG), DELTA = 0.147227E+03(DEG)

FINAL TRIM POSITION: ALPHA = 0.238975E+00(DEG), DELTA = 0.152227E+03(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.829348 REFERENCE CHORD = 6.267200
X-CG = 3.369830 Z-CG = 6.4264284E-03
TOTAL WEIGHT = 6515.901 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 7.612310

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.5802E-01	0.5643E-01	0.9009E-01	0.9007E-01	-.2439E-01	-.2446E-01
ALPHA(/RAD)	0.5685E+01	0.5694E+01	0.3612E+03	0.3611E+03	-.1223E+03	-.1220E+03
DELTA(/RAD)	0.2134E-01	0.2134E-01	-.1262E+00	-.1262E+00	0.5229E-01	0.5181E-01

TRIM ITERATION NUMBER : 3

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.700000E+01
ALTITUDE IN METERS : 0.254684E+05
DYNAMIC PRESSURE IN N/M^2 : 0.813965E+05
ANGLE OF ATTACK IN DEGREES : 0.238975E+00
CONTROL SURFACE DEFLECTION IN DEGREES : 0.500000E+01

TRIM VARIABLE: ALPHA = 0.207079E+00(DEG), DELTA = 0.138391E+03(DEG)

FINAL TRIM POSITION: ALPHA = 0.446054E+00(DEG), DELTA = 0.143391E+03(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.829348 REFERENCE CHORD = 6.267200
X-CG = 3.369830 Z-CG = 6.4264284E-03
TOTAL WEIGHT = 6515.901 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 7.593318

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.5928E-01	0.5770E-01	0.1047E+00	0.1046E+00	-.2801E-01	-.2808E-01
ALPHA(/RAD)	0.3281E+01	0.3290E+01	0.7903E+02	0.7894E+02	-.2663E+02	-.2657E+02
DELTA(/RAD)	0.2107E-01	0.2107E-01	-.1252E+00	-.1252E+00	0.5186E-01	0.5138E-01

TRIM ITERATION NUMBER : 4

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.700000E+01
ALTITUDE IN METERS : 0.254684E+05
DYNAMIC PRESSURE IN N/M^2 : 0.813965E+05
ANGLE OF ATTACK IN DEGREES : 0.446054E+00
CONTROL SURFACE DEFLECTION IN DEGREES : 0.500000E+01

TRIM VARIABLE: ALPHA = 0.232966E+00(DEG), DELTA = 0.129045E+03(DEG)

FINAL TRIM POSITION: ALPHA = 0.679020E+00(DEG), DELTA = 0.134045E+03(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.829348 REFERENCE CHORD = 6.267200
X-CG = 3.369830 Z-CG = 6.4264284E-03
TOTAL WEIGHT = 6515.901 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 7.539933

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.6413E-01	0.6258E-01	0.1072E+00	0.1068E+00	-.2763E-01	-.2756E-01
ALPHA(/RAD)	0.2820E+01	0.2829E+01	0.6247E+02	0.6238E+02	-.2078E+02	-.2074E+02

DELTA(/RAD) 0.1999E-01 0.1999E-01 -.1212E+00 -.1212E+00 0.5016E-01 0.4967E-01

TRIM ITERATION NUMBER : 5

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.700000E+01
ALTITUDE IN METERS : 0.254684E+05
DYNAMIC PRESSURE IN N/M^2 : 0.813965E+05
ANGLE OF ATTACK IN DEGREES : 0.679020E+00
CONTROL SURFACE DEFLECTION IN DEGREES : 0.500000E+01

TRIM VARIABLE: ALPHA = -0.153836E+01(DEG), DELTA = 0.206640E+03(DEG)

FINAL TRIM POSITION: ALPHA = -0.859338E+00(DEG), DELTA = 0.211640E+03(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.829348 REFERENCE CHORD = 6.267200
X-CG = 3.369830 Z-CG = 6.4264284E-03
TOTAL WEIGHT = 6515.901 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 7.974348

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.7003E-01	0.6851E-01	0.1152E+00	0.1144E+00	-.2877E-01	-.2858E-01
ALPHA(/RAD)	0.1868E+01	0.1876E+01	-.1461E+02	-.1469E+02	0.5367E+01	0.5363E+01
DELTA(/RAD)	0.1882E-01	0.1882E-01	-.1169E+00	-.1169E+00	0.4835E-01	0.4785E-01

TRIM ITERATION NUMBER : 6

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.700000E+01
ALTITUDE IN METERS : 0.254684E+05
DYNAMIC PRESSURE IN N/M^2 : 0.813965E+05
ANGLE OF ATTACK IN DEGREES : -.859338E+00
CONTROL SURFACE DEFLECTION IN DEGREES : 0.500000E+01

TRIM VARIABLE: ALPHA = 0.299643E+01(DEG), DELTA = 0.368399E+02(DEG)

FINAL TRIM POSITION: ALPHA = 0.213709E+01(DEG), DELTA = 0.418399E+02(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.829348 REFERENCE CHORD = 6.267200
X-CG = 3.369830 Z-CG = 6.4264284E-03
TOTAL WEIGHT = 6515.901 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 5.540214

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.7417E-01	0.7235E-01	0.2793E-01	0.2995E-01	-.1361E-01	-.1440E-01
ALPHA(/RAD)	-.1184E+01	-.1168E+01	0.3053E+01	0.2927E+01	-.5287E+00	-.4788E+00
DELTA(/RAD)	0.2741E-01	0.2741E-01	-.1485E+00	-.1485E+00	0.6173E-01	0.6134E-01

TRIM ITERATION NUMBER : 7

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.700000E+01
ALTITUDE IN METERS : 0.254684E+05
DYNAMIC PRESSURE IN N/M^2 : 0.813965E+05
ANGLE OF ATTACK IN DEGREES : 0.213709E+01
CONTROL SURFACE DEFLECTION IN DEGREES : 0.500000E+01

TRIM VARIABLE: ALPHA = 0.767660E+00(DEG), DELTA = 0.343145E+02(DEG)

FINAL TRIM POSITION: ALPHA = 0.290475E+01(DEG), DELTA = 0.393145E+02(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.829348 REFERENCE CHORD = 6.267200
X-CG = 3.369830 Z-CG = 6.4264284E-03
TOTAL WEIGHT = 6515.901 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : -0.4764185

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.1132E+00	0.1118E+00	0.1372E+00	0.1347E+00	-.2655E-01	-.2557E-01
ALPHA(/RAD)	0.2213E+01	0.2216E+01	0.6787E+00	0.6240E+00	0.2083E+00	0.2288E+00
DELTA(/RAD)	0.1249E-01	0.1249E-01	-.9269E-01	-.9269E-01	0.3819E-01	0.3758E-01

TRIM ITERATION NUMBER : 8

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.700000E+01
ALTITUDE IN METERS : 0.254684E+05
DYNAMIC PRESSURE IN N/M^2 : 0.813965E+05
ANGLE OF ATTACK IN DEGREES : 0.290475E+01
CONTROL SURFACE DEFLECTION IN DEGREES : 0.500000E+01

TRIM VARIABLE: ALPHA = -0.392802E-01(DEG), DELTA = 0.423029E+02(DEG)

FINAL TRIM POSITION: ALPHA = 0.286547E+01(DEG), DELTA = 0.473029E+02(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.829348 REFERENCE CHORD = 6.267200
X-CG = 3.369830 Z-CG = 6.4264284E-03
TOTAL WEIGHT = 6515.901 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 3.921978

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.1419E+00	0.1406E+00	0.1525E+00	0.1493E+00	-.2575E-01	-.2449E-01
ALPHA(/RAD)	0.2804E+01	0.2806E+01	0.1737E+01	0.1695E+01	-.7652E-01	-.6039E-01
DELTA(/RAD)	0.9796E-02	0.9796E-02	-.8205E-01	-.8205E-01	0.3372E-01	0.3311E-01

TRIM ITERATION NUMBER : 9

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.700000E+01
ALTITUDE IN METERS : 0.254684E+05
DYNAMIC PRESSURE IN N/M^2 : 0.813965E+05
ANGLE OF ATTACK IN DEGREES : 0.286547E+01
CONTROL SURFACE DEFLECTION IN DEGREES : 0.500000E+01

TRIM VARIABLE: ALPHA = -0.188472E-02(DEG), DELTA = 0.419849E+02(DEG)

FINAL TRIM POSITION: ALPHA = 0.286359E+01(DEG), DELTA = 0.469849E+02(DEG)

AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
REFERENCE AREA = 1.829348 REFERENCE CHORD = 6.267200
X-CG = 3.369830 Z-CG = 6.4264284E-03
TOTAL WEIGHT = 6515.901 NEWTON
X AERODYNAMIC CENTER FROM X = 0 : 4.162561

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.1400E+00	0.1387E+00	0.1512E+00	0.1481E+00	-.2568E-01	-.2442E-01
ALPHA(/RAD)	0.2762E+01	0.2764E+01	0.1795E+01	0.1753E+01	-.1135E+00	-.9710E-01
DELTA(/RAD)	0.9925E-02	0.9925E-02	-.8256E-01	-.8256E-01	0.3394E-01	0.3332E-01

TRIM ITERATION NUMBER : 10

SUMMARY OF TOTAL AERODYNAMIC FORCES AND MOMENTS

MEAN FLOW CONDITION :

MACH NUMBER : 0.700000E+01
 ALTITUDE IN METERS : 0.254684E+05
 DYNAMIC PRESSURE IN N/M^2 : 0.813965E+05
 ANGLE OF ATTACK IN DEGREES : 0.286359E+01
 CONTROL SURFACE DEFLECTION IN DEGREES : 0.500000E+01

TRIM VARIABLE: ALPHA = -0.209324E-03(DEG), DELTA = 0.419760E+02(DEG)

FINAL TRIM POSITION: ALPHA = 0.286338E+01(DEG), DELTA = 0.469760E+02(DEG)

 AERODYNAMIC STABILITY DERIVATIVES OF FULL SPAN MODEL
 REFERENCE AREA = 1.829348 REFERENCE CHORD = 6.267200
 X-CG = 3.369830 Z-CG = 6.4264284E-03
 TOTAL WEIGHT = 6515.901 NEWTON
 X AERODYNAMIC CENTER FROM X = 0 : 4.011549

	DRAG COEFFICIENT		LIFT COEFFICIENT		MOMENT COEFFICIENT	
	RIGID	ELASTIC	RIGID	ELASTIC	RIGID	ELASTIC
MEAN FLOW	0.1399E+00	0.1386E+00	0.1512E+00	0.1480E+00	-.2568E-01	-.2442E-01
ALPHA(/RAD)	0.2751E+01	0.2754E+01	0.1718E+01	0.1676E+01	-.8795E-01	-.7123E-01
DELTA(/RAD)	0.9931E-02	0.9931E-02	-.8258E-01	-.8258E-01	0.3395E-01	0.3333E-01

 FINAL TRIM ANGLE OF ATTACK IN DEGREES = 0.286338E+01
 FINAL TRIM DELTA IN DEGREES = 0.469760E+02

Listing 9.8.6 Prep_ASE.dat

A Matrix:

	1	2	3	4	5	6	7	8	9	10
1	0.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
2	0.0000E+00	-1.5029E-02	0.0000E+00	-2.8752E+02	-9.8067E+00	-8.5328E-02	4.8194E+00	4.8070E+00	6.6040E-09	-2.5374E-09
3	0.0000E+00	0.0000E+00	0.0000E+00	-2.0909E+03	2.0909E+03	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
4	0.0000E+00	-7.7600E-06	0.0000E+00	-1.0141E-01	-2.1371E-09	9.9999E-01	-9.4810E-13	-9.4787E-13	3.4793E-11	4.6974E-12
5	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
6	0.0000E+00	-1.2192E-03	0.0000E+00	-5.1129E+00	1.5581E-07	-3.1123E-02	4.4854E-02	4.5135E-02	-5.5019E-08	-1.2848E-08
7	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000E+00	0.0000E+00
8	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	1.0000E+00
9	0.0000E+00	3.7082E-02	0.0000E+00	3.7481E+02	-7.4961E+02	-5.3790E-02	-1.4471E+02	-3.1946E-08	-2.4324E-03	-4.2473E-06
10	0.0000E+00	3.5547E-01	0.0000E+00	1.6674E+03	-3.3349E+03	3.0120E-01	-4.3638E-08	-1.0332E+03	-4.2653E-06	-6.4571E-03

B matrix:

0.000000E+00
 -0.111283E+01
 0.000000E+00
 0.442585E-02
 0.000000E+00
 0.168089E+01
 0.000000E+00
 0.000000E+00
 -0.160677E+03
 0.861835E+02

Eigenvalues of A:

(0.0000000E+00,0.0000000E+00)
 (0.0000000E+00,0.0000000E+00)
 (-4.0625930E-03,32.14232)
 (-4.0625930E-03,-32.14232)


```
(-1.8121749E-03,12.02456)
(-1.8121749E-03,-12.02456)
(-9.8287821E-02,2.304482)
(-9.8287821E-02,-2.304482)
(6.4862937E-02,0.0000000E+00)
(-1.2984279E-02,0.0000000E+00)
```

Damping Ratio (Zeta) and Frequency (Omega)

```
Zeta : -1.2639390E-04 Omega : 5.113551 Hz
Zeta : -1.5070618E-04 Omega : 1.912998 Hz
Zeta : -4.2611990E-02 Omega : 0.3669554 Hz
Zeta : 1.000000 Omega : 1.0319103E-02 Hz
Zeta : -1.000000 Omega : 2.0656807E-03 Hz
```

Output Prepared for Analytical Solution of Flight Dynamic Model

```
-----
Mass (m) = 1328.874
Velocity (U) = 2090.866
Surface Area (S) = 1.829348
Dynamic Pressure (q) = 81396.51
Moment of Inertia (Iyy) = 18848.73
Reference Length (c) = 6.267200
Cd wrt u (Cdu) = 2.9367459E-04
Cm wrt u (Cmu) = -6.6151595E-05
Cl wrt u (Clu) = 1.9072900E-04

Cd wrt q (Cdq) = 0.5058688
Cm wrt q (Cmq) = -4.5670047E-02
Cl wrt q (Clq) = 0.1237800

Cd wrt alpha (Cd_alpha) = 2.717112
Cm wrt alpha (Cm_alpha) = -0.1032690
Cl wrt alpha (Cl_alpha) = 1.752287

Coefficient of drag (Cd) = 0.1399257
Coefficient of moment (Cm) = -2.5678078E-02
Coefficient of lift (Cl) = 0.1511889
```

9.9 Subsequent Design Cycles for Converged Configuration

The trim angle of attack obtained from the TRIM analysis may not agree with the initially guessed design angle of attack specified in the UCDA input file vehicle.inp with the parameter AOADES. In order to match these two angles of attack, it is required to perform multiple design cycles by repeating the entire cycle described in Sections 9.1 through 9.8. For each new design cycle, the parameter AOADES is updated by the trim angle of attack computed by the previous design cycle. This multiple design cycle process terminates when the variation between AOADES and trim angle of attack becomes small; leading to a converged configuration.

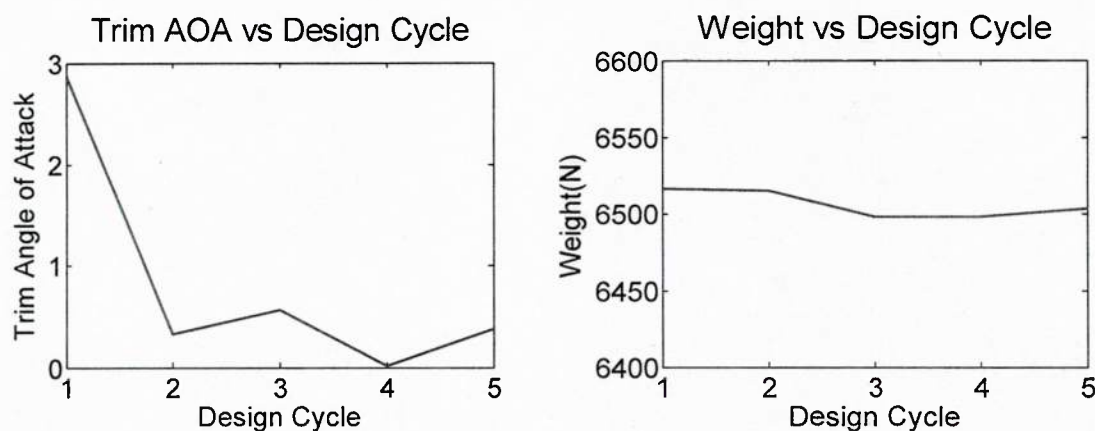


Figure 9.9.1 Convergence History of Angle of Attack and Weight for SED Vehicle

For the present SED configuration, it is found that this converged configuration is obtained after three design cycles. Figure 9.9.1 shows the trim angle of attack, control surface deflection angle and weight at each design cycle. It can be seen that at the third design cycle, the trim angle of attack is nearly converged at 0.5668 degrees and the weight is converged at 6498 Newton respectively.

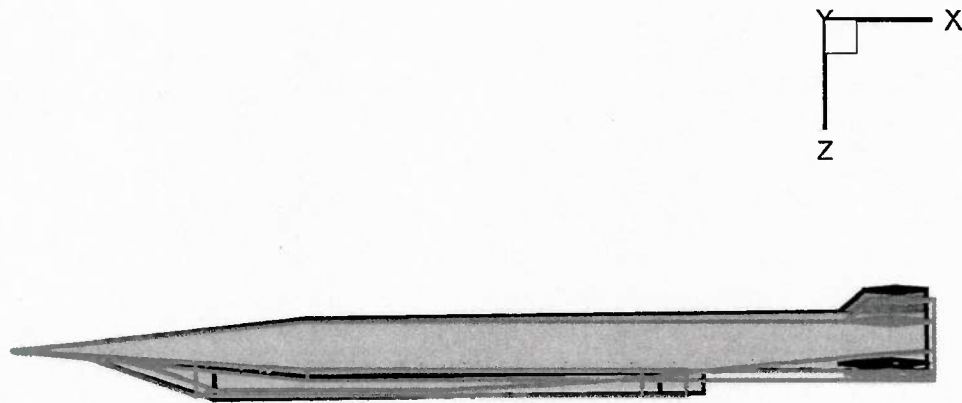


Figure. 9.9.2 Comparison of the SED vehicle between first and final design cycles

Figure 9.9.2 shows the comparison of the vehicle geometry between first design cycle and the last design cycle. It can be seen that for the first design cycle, the vehicle had a higher negative design angle of attack. That made the ramp angle shallower and thus in order to satisfy shock-on-lip condition, the inlet of the combustor was pushed downstream by the design. On the other hand, for the final converged design, the design angle of attack is larger. Thus, to satisfy shock-on-lip condition, the inlet of the combustor is pushed upstream.

The result of the SED configuration suggests that this multiple design cycle process is a viable method to design such a vehicle even though there is not solid theoretical foundation to guarantee such a convergence at present.

REFERENCES

Chapter 1

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- 1.2 Bowcutt, K. G., "Hypersonic technology Status and Development Roadmap," *AIAA HyTASP Program Committee, Technical Fellowship Advisory Board Study*, December 18, 2003.
- 1.3 Starkey, R. P., and Lewis, M. J., "Sensitivity of Hydrocarbon Combustion Modeling for Hypersonic Missile Design," *AIAA Journal of Propulsion and Power*, Vol. 19, No. 1, Jan-Feb 2003, pp. 89-97.
- 1.4 Chavez, F. R., and Schmidt, D. K., "Analytical Aeropropulsive/Aeroelastic Hypersonic-Vehicle Model with Dynamic Analysis," *Journal of Guidance, Control & Dynamics*, Vol. 17, No. 6, November-December 1994, pp. 1308-1319.
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