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## 13. ABSTRACT

A prominent phenomenon of the transonic flight regime is the potential for limit cycle oscillation (LCO) development. LCO is a stable oscillation produced by aeroelastic interactions within a component of the aircraft. Such oscillation shortens the fatigue life of the aircraft and increases the amount of maintenance necessary. These aspects are of great concern to the aerospace industry, particularly with high performance military aircraft that are required to operate beyond their planned service lives. The research here focused specifically on the aircraft wing and the influence of external stores attached to that wing on its aeroelastic properties. Monte Carlo simulations were performed to estimate the probability of a wing undergoing limit cycle oscillations due to external stores. Simulations were conducted with a finite element structural model of a wing coupled with multiple subsonic and transonic unsteady aerodynamics solvers to compare computational cost and accuracy. The results provide guidance for implementing probabilistic analysis methods with industry-standard software to predict dangerous aeroelastic response processes that sometimes occur during flight tests. For the low transitional Mach numbers (between 0.7 and 0.88), the linear aerodynamic model was found to be a viable alternative to the more computationally costly alternatives. For Mach numbers above 0.88, nonlinear, viscous methods were necessary.

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**VARIABILITY AND MODEL ADEQUACY IN SIMULATIONS OF STORE-  
INDUCED LIMIT CYCLE OSCILLATIONS**

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**Abstract.** A prominent phenomenon of the transonic flight regime is the potential for limit cycle oscillation (LCO) development. LCO is a stable oscillation produced by aeroelastic interactions within a component of the aircraft. Such oscillation shortens the fatigue life of the aircraft and increases the amount of maintenance necessary. These aspects are of great concern to the aerospace industry, particularly with high performance military aircraft that are required to operate beyond their planned service lives.

The research here focused specifically on the aircraft wing and the influence of external stores attached to that wing on its aeroelastic properties. Monte Carlo simulations were performed to estimate the probability of a wing undergoing limit cycle oscillations due to external stores. Simulations were conducted with a finite element structural model of a wing coupled with multiple subsonic and transonic unsteady aerodynamics solvers to compare computational cost and accuracy.

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**Keywords.** Aeroelasticity, Limit Cycle Oscillation, Goland Wing

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## 1 INTRODUCTION

### 1.1 Background

Risk management is a key component of engineering. As technology advances systems become increasingly complex, and with this complexity comes increased risk of unanticipated failure modes [1]. A single component's misfire or unanticipated dynamics can cause the entire system's malfunction. For complex military aircraft, system malfunction can mean lost mission objectives, multi-million dollar national investments, or human life. The negative impact of any one of these failures makes the field of risk assessment research an integral component to improving the future success of the United States military.

The flight conditions that fighter aircraft experience are extreme. The demands of high maneuverability at transonic speeds place the aircraft in a league of their own for performance requirements. In entering this demanding flight regime, however, the aircraft has exited the realm of current predictability, as accurate computational flight models for practical design usage have not been fully developed for certain important aspects of transonic flight.

One piece of the complete flight model involves developing an understanding of the aeroelasticity involved in modern day aircraft. Aeroelasticity combines the principles of structural dynamics and aerodynamics to study their interaction and potential instabilities [2].

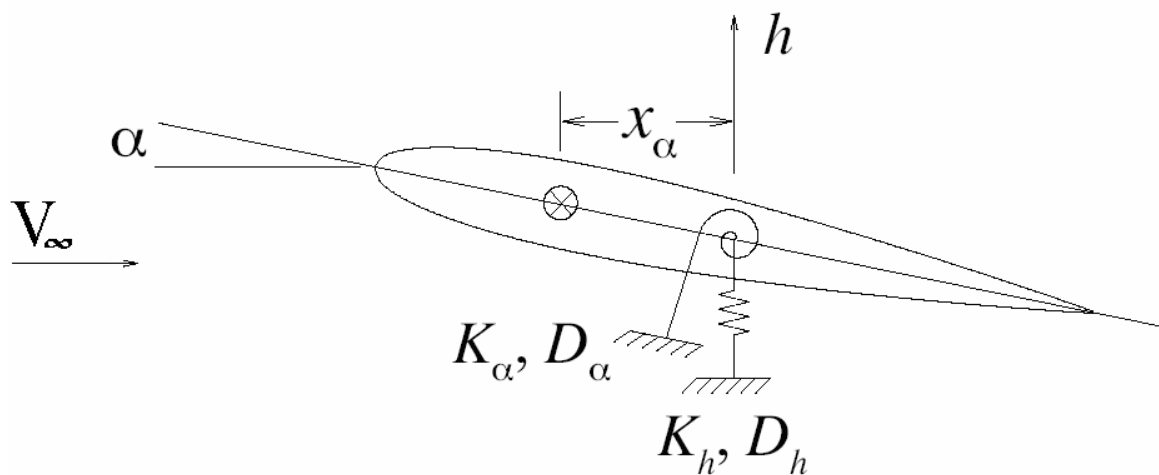


Figure 1. Airfoil with Lumped Structural Properties and Degrees of Freedom [3]

Figure 1 depicts an aeroelastic model of a standard, symmetric airfoil with two degrees of freedom, pitch and plunge. Structural stiffness terms  $K_h$  and  $K_\alpha$  and damping terms  $D_h$  and  $D_\alpha$  are incorporated in the pitch and plunge degrees of freedom of the airfoil [4]. Additionally,  $\alpha$  represents the angle of attack,  $h$  represents the vertical displacement, and  $x_\alpha$  represents the offset of the elastic axis from the aerodynamic center. The dependence of the aerodynamic forces on the structural response creates the potential for static and dynamic instabilities to occur.

Interaction between aerodynamic loads and structural deformation further complicates the already complex process of analyzing air flow in the viscous, transonic regime. To compute unsteady aeroelastic forces acting on an aircraft, a coupled method is often required to predict the time-dependent response. The researcher must first predict the surface pressure distribution over the aircraft, and then compute the resulting material deformation. The new deformed body surface is used to predict the new surface pressure distribution, and this process is repeated until a converged solution is achieved at the specified time. If the structure is vibrating or the aerodynamic forces vary with time, this procedure must be repeated at each interval.

This process becomes even more complex in the transonic region of flight. This region corresponds to Mach numbers 0.8 through 1.2. In this transitional region, the aircraft itself may not be flying faster than the speed of sound, but some locations in the air flow around the aircraft will have already broken the barrier. Such locations will experience the compressibility effects of shock waves and flow expansion that characterize supersonic flow while those locations that are still subsonic will not. The relatively unpredictable co-existence of subsonic and supersonic flow characteristics creates non-linearity in the flow field and thus complicates the flight model [5]. Viscous interactions of the shocks with the boundary layer even further complicate the flow physics and reduce the predictability.

A prominent aeroelastic behavior in transonic flight is limit cycle oscillation (LCO). LCO is a self-sustained, stable oscillation of limited amplitude produced by aeroelastic interactions [6]. The limited-amplitude nature of these oscillations can arise from aerodynamic and structural nonlinearities. LCO develops when nonlinear structural and aerodynamic forces are in a balance with inertial forces such that the oscillation is bounded and self-sustaining. Under small disturbances, this oscillation remains stable in frequency and amplitude. An example of LCO is illustrated in the front and side views of an F-16 in Figure 2.. During LCO, the wing and the store tip missile will oscillate continuously, bending and twisting back and forth between the limits outlined in red.

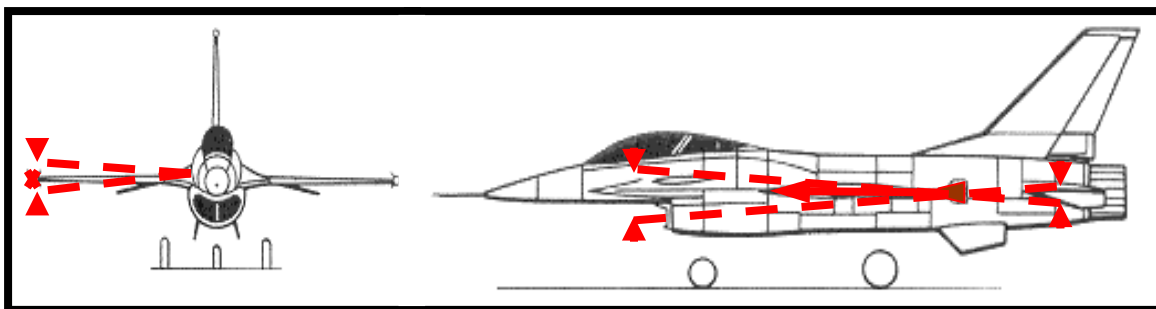


Figure 2. LCO Illustrated with an F-16 Aircraft [7]

While such oscillation is not likely to lead to catastrophic failure, it does put more oscillatory stress on the structure than it was designed to withstand, so a reduced fatigue life for materials must be anticipated. Mission readiness of aircraft is impacted, as maintenance schedules must be stepped up to check for the formation of fatigue cracks and the existence of small but still tolerable cracks may lead to restrictions on payload capacity or configurations. LCO in some cases also impacts the comfort level and performance of the pilot. Finally, the safe release of external stores can be inhibited. At present, no dependable

methods exist for predicting LCO in complex aeroelastic systems before they are observed and analytical models must be calibrated to reproduce the observed behavior.

## 1.2 Current Research

The prediction of LCO is one of many barriers to the development of all-encompassing computational flight models. In addition to the complexities of military aircraft flight performance, LCO is made more complex with the addition of external stores to the wing because each unique store contributes its own aerodynamic, inertial, and structural influences to the overall aeroelastic characteristics of the platform.

Certain configurations of stores on particular aircraft have proven in practice to be more likely to induce LCO behavior than others. With no reliable predictive models, the military has developed guidelines for possible store configurations based primarily on trial-and-error. For example, the U. S. Military's 15% flutter safety margin in use today was developed from empirical data collected prior to 1960 [3]. LCO avoidance measures are similar in character.

For stores clearance, the repeated flight tests needed to assess the safety margins are significant drains on time and money. Further, the impracticality of testing every possible aircraft with every possible weapons configuration under all possible flight conditions is obvious. As computers have evolved, so has their ability to produce accurate models of structural behaviors. Software technology advancements are beginning to provide viable alternatives to the trial-and-error test methods, but the most time- and cost-effective approach to providing reliable information to decision-makers has not been agreed upon.

Within the research presented here, such alternative methods are considered and compared for two criteria: predictive accuracy and computational cost. Predictive accuracy is the superior requirement. Computational models will never produce the realistic data that flight testing does, but, through research, computational models can produce data that are close enough to the real world for researchers to draw conclusions with confidence. In many fields, such results are already being produced, but computational LCO research has, thus far, been only marginally successful. The overall possibility of having such fidelity is not really in question, however, as Kim and Lee [8] have demonstrated. While this fidelity is increasing, however, the computational models are not yet at a level where they can begin to replace some of the flight tested requirements of the past. The computational cost of such fidelity cannot be ignored. The complexities of aircraft, especially those with external stores, can require far more processing time than the researcher can afford, let alone the practicing analyst. The research presented here investigates the following hypothesis: results of sufficient accuracy can be produced with an efficient computational model to estimate the probability of LCO occurring across a range of flight conditions. The most complex aeroelastic analysis will not significantly increase the confidence in the results or their utility in designing safe aircraft, only the time needed to generate those results.

To investigate this premise, this research presents the aeroelastic analysis of a linear structural model of the heavy Golland wing [9] for the onset of instability, usually called the flutter speed, with a series of different computational tools. Each successive study uses a more complex aeroelastic model. The possibility of researching LCO with each tool can be considered only after the flutter speed analysis is validated.

ZAERO<sup>®</sup> [10] is an aeroelastic modeling program that combines the necessary disciplines into a single package suited for either analysis or design. ZONA6, the subsonic unsteady aerodynamics tool within ZAERO<sup>®</sup>, is the chief tool for performing linear aeroelastic analysis of the heavy Golland wing. ZONA6 generates both steady and unsteady aerodynamic forces on bodies with external stores. According to the documentation provided with ZONA6, it provides higher accuracy than similar linear models because it uses a higher-order paneling method than the more commonly used Doublet Lattice Method [10], which is poorer at modeling complex geometries like tip stores.

The first of the nonlinear aerodynamics models employed here is ZTRAN, which is a transonic flow solver. ZTRAN, developed by ZONA Technology, Inc., was created to overlap with and extend the range of Mach numbers explored with ZONA6. It offers an approximate but simple-to-use approach to analyzing transonic aerodynamics and leaves the user with some flexibility in determining how the transonic flow is mathematically modeled. This study investigated the implications of using ZTRAN with both the Euler equations to model inviscid, transonic aerodynamics and the Navier-Stokes equations to model viscous transonic flow. Probabilistic sampling was employed to evaluate the benefits and costs of using these more complex and computationally costly models instead of the inviscid, subsonic aerodynamics in ZONA6. The data generated through sampling permitted assessment of each solver's sensitivity to small changes in the model. For simplicity, the three solvers are referred to as ZONA6; ZTRAN, Euler; and ZTRAN, Navier-Stokes. A summary of the computer software used for this research is presented in Table 1.

Table 1. Analysis Tools Used

Analysis Tool	Use
MD NASTRAN <sup>®</sup>	finite element software, a general purpose tool for structural analysis
ZONA6	subsonic unsteady aerodynamics tool within ZAERO <sup>®</sup> , chief tool for performing linear aeroelastic analysis
ZTRAN, Euler	a transonic flow solver using the Euler equations to define the Aerodynamic model with inviscid, nonlinear flow
ZTRAN, Navier Stokes	a transonic flow solver using the Navier-Stokes equations to define the Aerodynamic model with viscous, nonlinear flow

The probability of flutter was estimated with each tool by estimating the statistics of the flutter speed as a function of the Mach number. While LCO does not always occur near or above the flutter speed, this marks the transition from a stable aeroelastic system to one that could possibly exhibit dangerous motion like LCO or flutter. Once the flutter speeds' statistics were determined, they were then compared to see if the higher complexity in the more advanced computational models has a significant impact on the end results. In particular, dependable estimation of the flutter speed is a prerequisite for pursuing the estimation of LCO onset conditions.

In an environment of declining design and testing budgets, the research presented here will provide insight into using probability predictions to assess the safety of aircraft within time and resource constraints.

## 2 COMPUTATIONAL TESTING

### 2.1 Development of the Goland Wing Model

The heavy Goland wing finite element model in Figures 3 and 4 is a two-cell box structure with ribs at evenly-spaced span-wise stations. In these figures, the positive  $x$  direction points out the trailing edge of the wing, the positive  $y$  direction points from the fuselage out along the span of the wing, and the positive  $z$  direction is normal two the upper surface of the wing. Each rib, spar, and skin panel is modeled as an assumed material with negligible mass. The desired inertial properties of the wing are simulated with the placement and adjustment of separate concentrated masses.

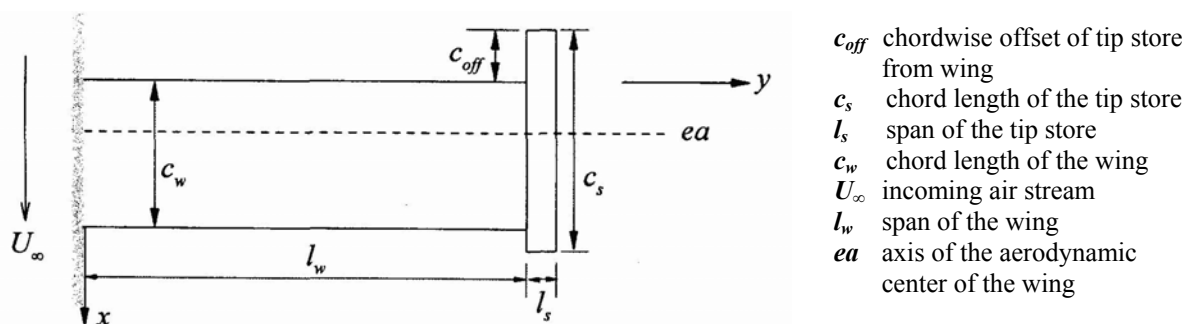


Figure 3. Planform Geometry of the Goland Wing [1]

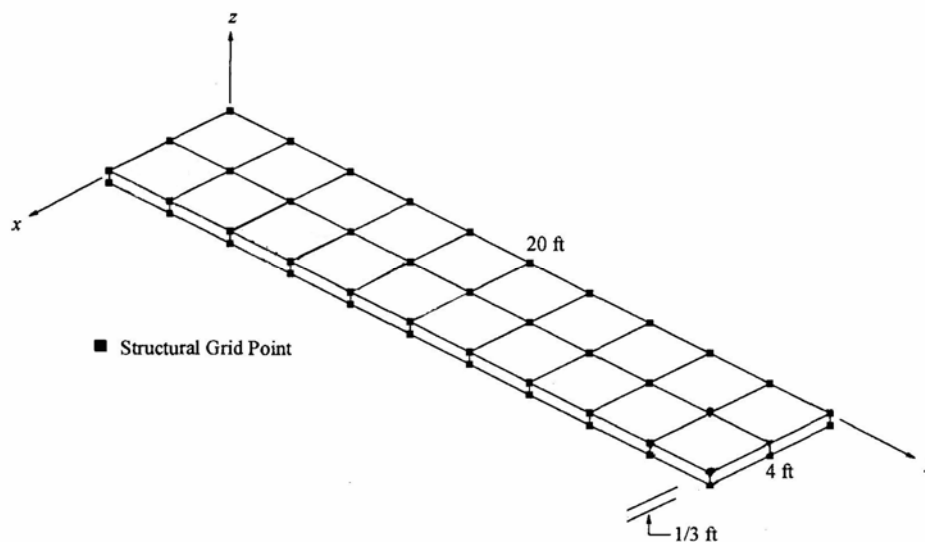


Figure 4. Structural Model of the Goland Wing [1]

The grid points shown in Figure 4 define the finite elements of the structure. These locations are linked by rod elements used to stabilize the quadrilateral shear panels, which represent the ribs and spar webs. CQUAD4 elements are used for the upper and lower skins. The Goland wing developed in the test case included the wing structure itself, as well as a simplified external store. The store is modeled as a non-structural mass of 22.5 pounds located 1.75 ft

forward of the wing's center of gravity, and is attached to the wing by an additional rigid element. The baseline thickness of each component is presented in Table 2.

Table 2. Component Thickness Specifications

Component	Thickness (ft)
Upper Wing Spar Shell	0.0155
Lower Wing Spar Shell	0.0155
Spar	0.006
Rib	0.0347
Post	0.0008
Upper Spar Cap	0.0416
Lower Spar Cap	0.0416
Upper Rib Cap	0.0422
Lower Rib Spar Cap	0.0422

The baseline Goland Wing model was run through a modal analysis to determine the first ten natural vibration modes of the structure. The results developed for this case exactly matched those of previous studies with this model, [1] and thereby provided confidence for the continuation of the research.

## 2.2 Goland Wing Model Structural Analysis

For the present study of limit cycle oscillation, MSC Nastran [11] is used to assess the impact of varying the material properties on the stiffness and vibration characteristics of a structure to model manufacturing tolerances and random variations in the inertial properties, such as varying internal fuel loads.

The baseline, or mean, model is the classical Goland wing [9] with uniform material properties and component dimensions. The natural frequencies of the original baseline wing are presented in Table 3. Although the initial structural model was analyzed in MSC Nastran for the first 10 eigenmodes, only the first four were carried through the complete aeroelastic analysis. The results produced at the higher modes were not credible because the coarseness of the finite element mesh suggested that the higher modes were not properly resolved; therefore reliable comparisons between the aeroelastic analysis methods could only be completed with modes one through four. A finer mesh would permit further investigation of the higher level modes, but was not necessary for the goals of this effort.

Table 3. Natural Frequencies of the Baseline Case

		Baseline natural frequency	
		Mode	(Hz)
Clean Wing		1	1.97
		2	4.05
		3	9.65
		4	13.43
Wing with External Store		1	1.69
		2	3.05
		3	9.17
		4	10.83

The first four modes of the baseline wing are depicted in Figures 5 - 8. For both the clean wing and the wing with the external store, the first mode is a pure bending mode as displayed in Figure 5; the second, third and fourth modes are combinations of bending and torsion and are displayed in Figures 6 - 8. Only the mean of the top and bottom surfaces is modeled for simplicity even though the structural study involved the complete finite element model described in section 2.1. For reference, the origin of each figure is located at the leading edge of the root chord at exactly the midpoint of the wing's thickness and the orientation of each figure matches that of Figure 4. The boundary condition applied to the wing rigidly constrained the root cross section.

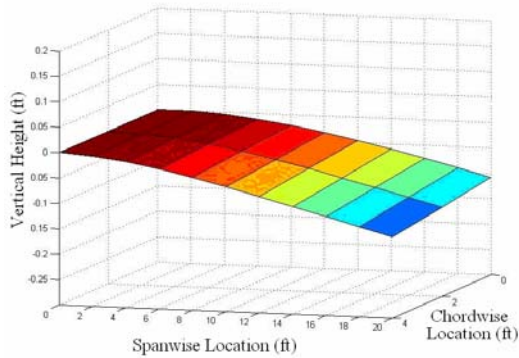


Figure 5. First Natural Mode of the Goland Wing (no external store present).

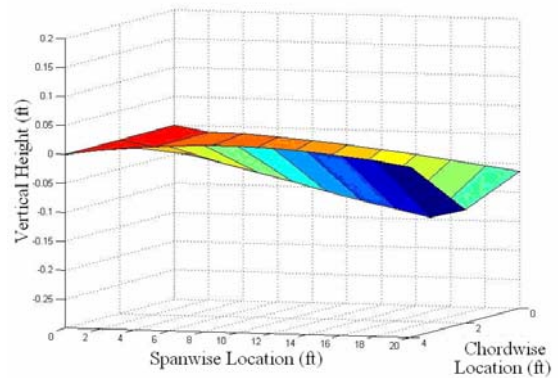


Figure 6. Second Natural Mode of the Goland Wing (with no external store)

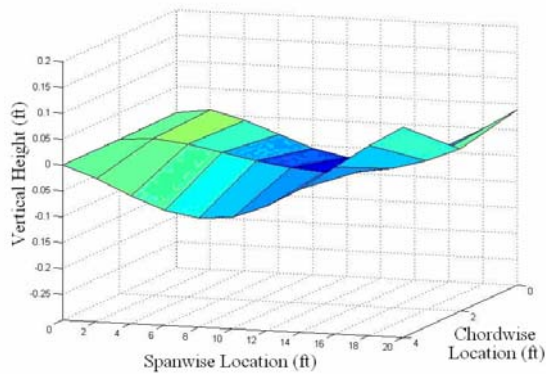


Figure 7. Third Natural Mode of the Goland Wing (with no external store)

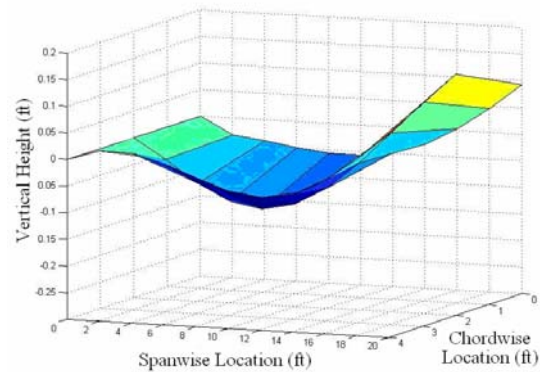


Figure 8. Fourth Natural Mode of the Goland Wing (with no external store)

### 2.3 Monte Carlo Simulation of the Modal Analysis

While this baseline provides a good beginning for exploration, real-world manufacturing never produces perfectly uniform structures. Alternatively, there always exists imprecision in the measured properties of a structure in practice. To mimic the effect of random variations in the structure, a process was written using FORTRAN 90 to generate a set of 2,000 variations of the Goland Wing structures. Half of this set included a tip store identical in both mass and location, while the other half did not.

The standard deviation for the component thickness parameters was set at 5% and each parameter was assumed to experience the same relative random variation in a given sample of the structure. The thickness of each component was modeled as normally distributed around the baseline specification. This collection of realizations of the structure formed the initial sample population for the Monte Carlo simulation of the wing's aeroelastic properties.

The structural study described for the baseline case was achieved for the complete set of 2,000 variations of the Goland wing. Each of the realizations was analyzed for its first four eigenmodes. For each of the four modes, histograms and normal probability plots were developed to examine the distribution of each natural frequency. Each modal frequency exhibited a unimodal distribution within 1.5% of the mean model.

Table 4 presents the mean, standard deviation, and coefficient of variation of the eigenvalue for each mode. Figure 9 presents a histogram of the variation of the first mode for the clean wing. An approximately normal distribution was observed, as can be seen by the linear trend of the corresponding normal probability plot in Figure 10. Similar results were seen for both the other three modes of the clean wing and for all four modes of the wing with the tip store.

Table 4. Statistical Summary for Eigenvalues of Goland Wing Model

	Mode	Sample Mean (hz)	Sample Standard Deviation	Sample Coefficient of Variation
Clean Wing	1	1.97	0.0274	1.39%
	2	4.048	0.0506	1.25%
	3	9.644	0.1125	1.17%
	4	13.289	0.1746	1.31%
Tip Store	1	1.69	0.0244	1.44%
	2	3.048	0.0393	1.29%
	3	9.162	0.1039	1.13%
	4	10.803	0.1399	1.29%

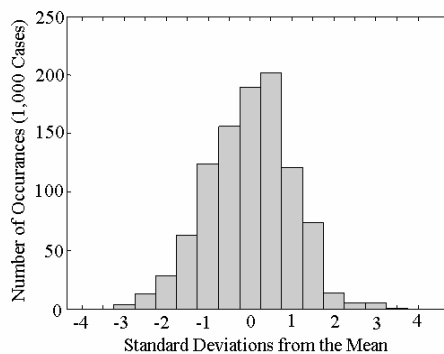
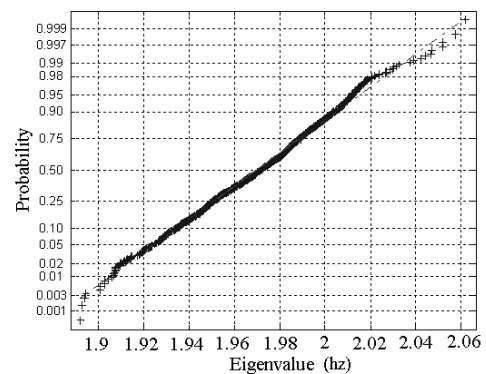


Figure 9. Histogram of Goland Wing Variation for Clean Wing, First Mode

Figure 10. Normal Probability Plot for Clean Wing, 1<sup>st</sup> Mode in 1,000 Models

## 2.4 Aeroelastic Analysis

The linear analysis with ZONA6 determined flutter speed for each of the 2,000 wings at ten Mach numbers: 0.70, 0.80, 0.825, 0.85, 0.88, 0.90, 0.91, 0.92, 0.93, and 0.95. Because the theory underlying ZONA6 is purely subsonic, any results from above Mach 0.8 are suspect; however, these values were included in the study for continuity purposes in comparing the ZONA6 tool to the ZTRAN tool, which can more reliably simulate transonic Mach numbers. Flutter and LCO are commonly observed in the transitional, less predictable range between Mach 0.8 and 1.2 and so these numbers must remain the focus of research in this field.

Taking a cross section of the methods at Mach 0.8 which is within the comfortable Mach limitations of all three programs produces the histograms and normal probability plots presented in Figure 11. The normally distributed structural properties resulted in approximately normally distributed flutter speeds. Deviations in the Gaussian behavior in the normal probability plots are limited to the tails of the distributions. This is expected because of the limited number of samples which results in the tails being the least accurately estimated portions of the distributions.

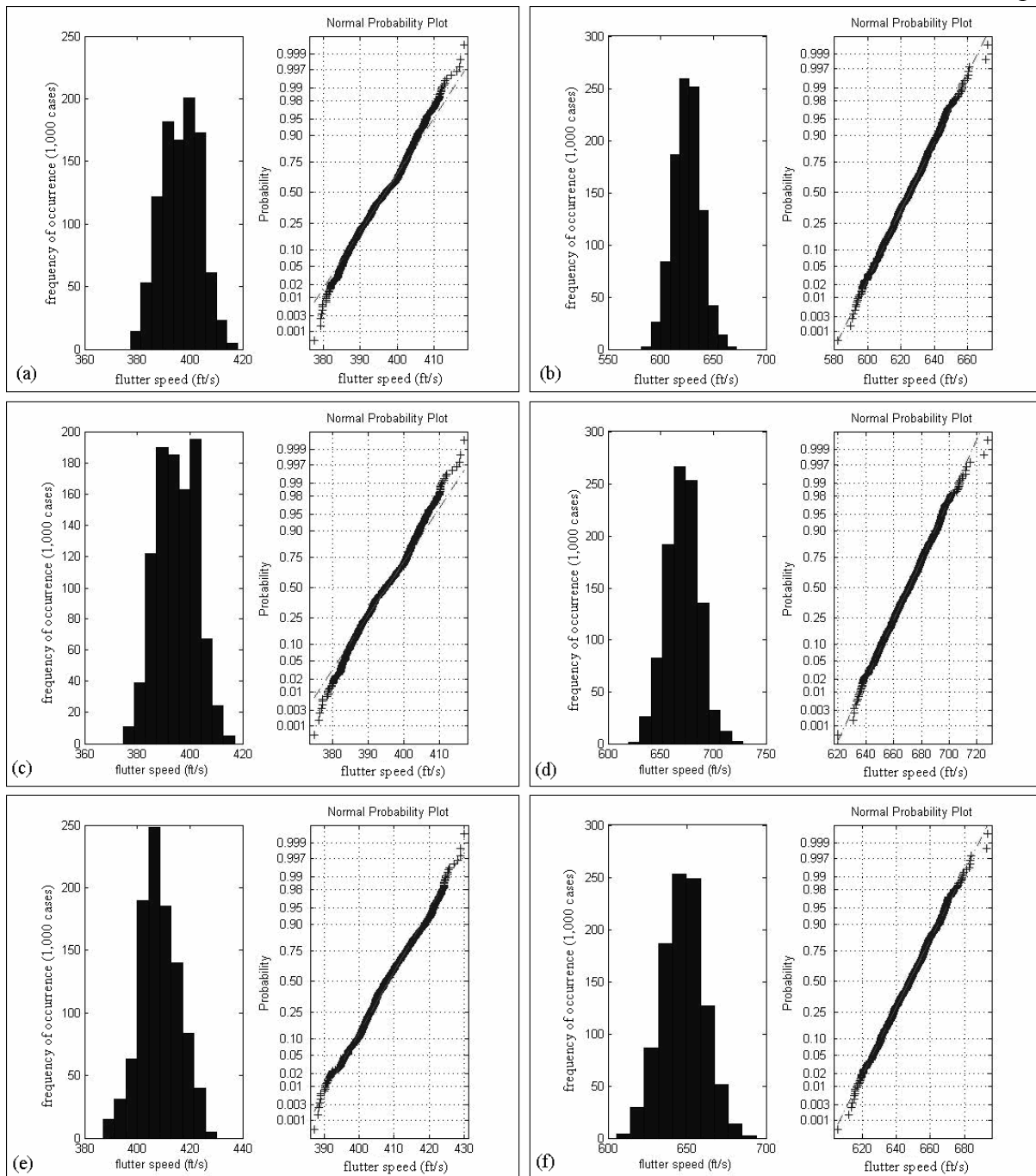


Figure 11. Histograms and Probability Plots of Flutter Speeds at Mach 0.8 for the (a) Clean Wing, ZONA6; (b) Wing with Tip Store, ZONA6; (c) Clean Wing, ZTRAN, Euler; (d) Wing with Tip Store, ZTRAN, Euler; (e) Clean Wing, ZTRAN, Navier-Stokes, and (f) Wing with Tip Store, ZTRAN, Navier-Stokes

Although the exact velocity where LCO is exhibited cannot be determined from ZONA6 or ZTRAN, the influence of structural thickness on the structural stiffness and on the flutter speed is evident. Given that wing LCO in practice is likely to start out as an aeroelastic dynamic instability, it is reasonable to expect that the distribution of LCO exhibition in the 2,000 wings would be similar to the distribution of the flutter speed. Further, at such a preliminary stage in evaluating the commercially available software for a new purpose, the

instability boundary is the starting point for determining the viability of ZAERO<sup>®</sup> as a research tool for LCO.

Table 5 presents the mean flutter speed for 1,000 cases determined by each software package over a range of Mach numbers. For the purposes of this research, “flutter speed” refers to the speed where the damping of one of the first four natural vibration modes of the wing transitions to instability. These values are also presented in Figures 12 and 13. The absence of values for ZTRAN, Euler at Mach 0.825 is not significant. These values were inadvertently omitted from the study, but the interpolation of this data point from its neighbors provides the same insight that the calculations itself would have likely provided.

Table 5. Flutter Speed in ft/s for Heavy Goland Wing Over a Range of Mach Numbers

Mach Number	CLEAN WING			WING WITH TIP STORE		
	ZONA6	ZTRAN, Euler	ZTRAN, Navier-Stokes	ZONA6	ZTRAN, Euler	ZTRAN, Navier-Stokes
0.700	428.90	428.99	436.12	647.28	662.95	659.21
0.800	396.65	394.84	408.27	625.08	670.88	647.64
0.825	385.86	not studied	398.58	618.81	not studied	646.27
0.850	373.83	364.09	386.99	612.93	902.70	648.20
0.880	358.02	351.75	366.25	608.39	1180.00	665.75
0.900	347.37	379.16	369.03	611.19	536.72	1270.20
0.910	342.89	383.31	380.17	617.11	515.97	1285.10
0.920	339.55	400.42	409.13	645.60	1360.20	445.99
0.930	338.29	414.38	468.61	710.18	345.20	366.96
0.950	344.12	423.57	412.16	1178.90	340.42	851.71

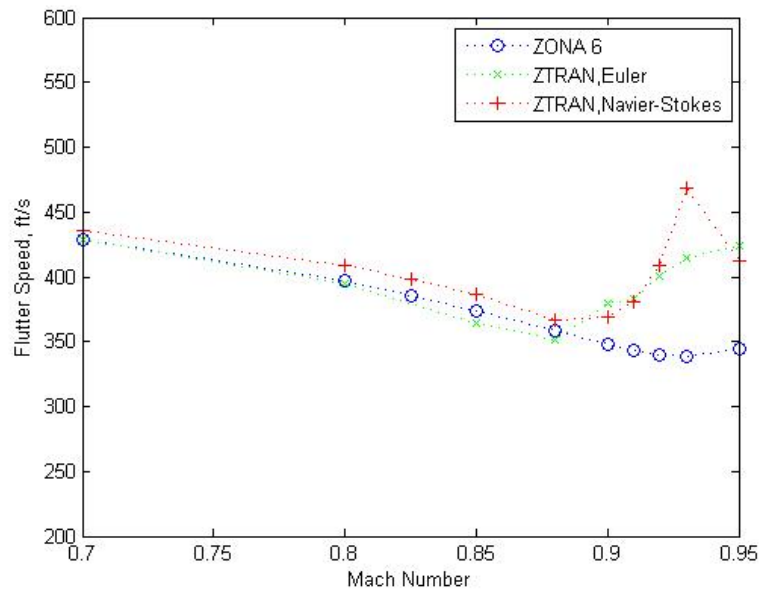


Figure 12. Flutter Speed Trends for Each Software Package Over the Range of Mach Numbers for the Heavy Goland Wing, Clean Version

Flutter speed empirically appears to decrease with increasing Mach number throughout the transonic regime to a minimum, or “dip”, and then rise in the supersonic regime [8]. For both ZTRAN tools, the onset of this dip occurs at Mach 0.88. The ZONA6 method, which was not designed for transonic research and so does not account for the theoretical flutter dip, does not exhibit the behavior at all.

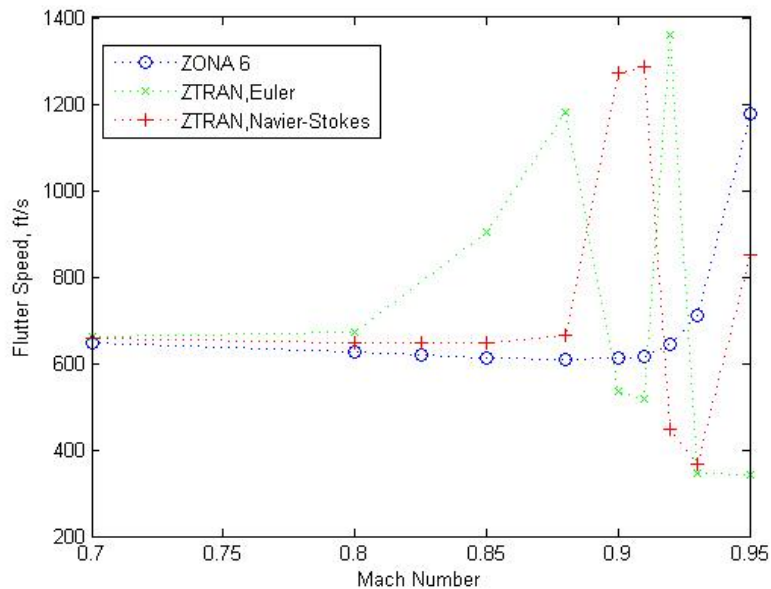


Figure 13. Flutter Speed Trends for Each Software Package Over the Range of Mach Numbers for the Heavy Goland Wing with Tip Store

From Figure 13, the expected flutter dip [8] can be observed in the ZTRAN, Navier-Stokes analysis near Mach 0.88, just where it occurred for the clean wing. The breakdown in the agreement between the three tools occurs where the upward trend in the flutter dip begins. When compared to ZTRAN, Navier-Stokes, the other two either predicted the flutter dip onset would occur prematurely at 0.8 in the case of ZTRAN, Euler, or late at 0.92 in the case of ZONA6.

Because the ZTRAN method that uses the Navier-Stokes equations to model viscous aerodynamics has the highest fidelity of any tool used in this study, it produces the most accurate and computationally expensive results. The results determined using ZONA6 and ZTRAN, Euler are compared to those from ZTRAN, Navier-Stokes results to determine the viability of each of the faster but simpler tools in determining the transition of the wing to instability.

Figure 14 illustrates the trend in percent error based on each research method across the studied range of Mach numbers for the clean wing. Both ZONA6 and ZTRAN, Euler underestimate the flutter speed up through Mach 0.88 and so would provide larger than necessary safety margins that should prevent the wing from experiencing either flutter or LCO. Above this point, even though only ZONA6 continues to underestimate the flutter speed, ZTRAN, Euler never over predicts it by more than 3%.

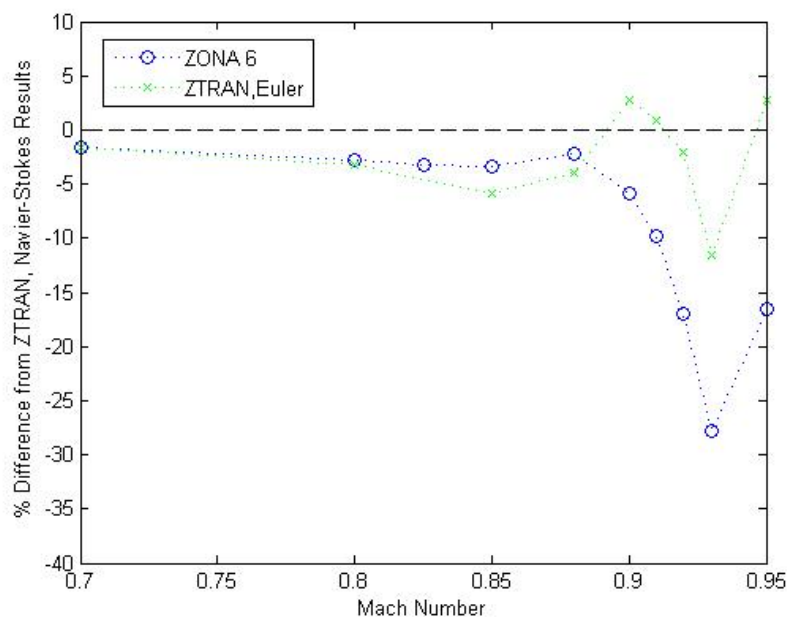


Figure 14. Percent Error from ZTRAN, Navier-Stokes for the Clean Wing

Figure 15 presents the data for the wing including the external tip store. The clear difference in method agreement between Figures 14 and 15 demonstrates why the presence of a tip store is of such concern in the study of instability and LCO. Here, once again, the ZONA6 results develop a margin of safety by under predicting flutter speeds in flight regimes between Mach 0.7 and Mach 0.88. The error in this prediction grows greater than 10% beyond Mach 0.88 where ZONA6's subsonic methods falter, largely because of the flutter dip. With the tip store

present, ZTRAN, Euler only stayed in an acceptable limit of agreement up through Mach 0.8 where the flutter dip occurs for ZTRAN, Euler in Figure 13.

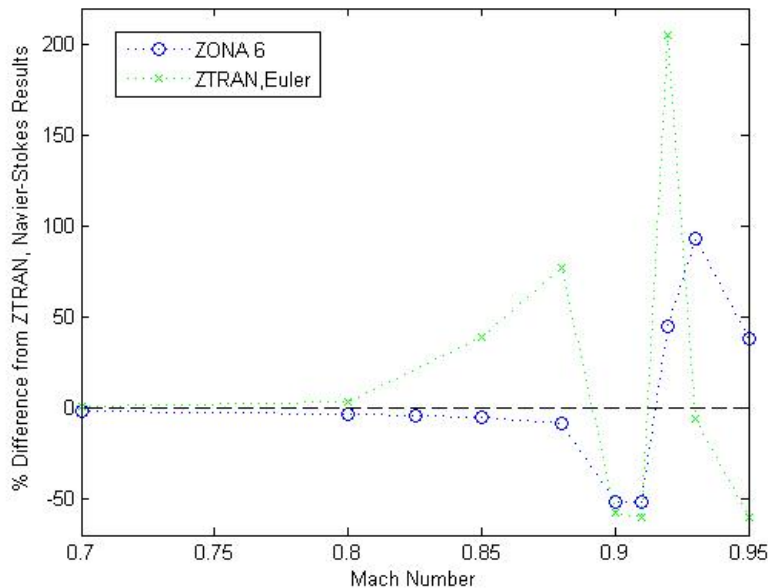


Figure 15. Percent Error from ZTRAN, Navier-Stokes for the Wing with the Tip Store

### 3 SUMMARY AND CONCLUSIONS

#### 3.1 Implications of Results

For the relatively simple wing and store configurations explored here, a significant amount of computational time can be saved by using ZONA6 rather than the more computationally costly alternatives for the lower transitional Mach numbers. This tool builds a more conservative picture of the flight envelope up through Mach 0.85 that would ensure the prevention of LCO and flutter by placing a safety limit beneath the point of instability where flutter and LCO are most likely to occur. Further, the limit would be within 5% of the values predicted by the most complicated of the tools used in this study.

ZTRAN, Euler is equally useful for a clean wing from Mach 0.7 through Mach 0.95. It is more computationally costly than ZONA6; however, it also provided extended functionality by following the ZTRAN, Navier-Stokes trends up into the higher Mach numbers.

When an external store is present at Mach numbers greater than 0.9, however, the computational cost to produce the viscous results with ZTRAN coupled with the Navier-Stokes equations is necessary for confidence in the results. These transonic speeds were not accurately or even predictably modeled by either of the faster alternatives because discrepancies in flutter dip prediction; the error percentages quickly grow to even 16 times what they were between Mach 0.7 and 0.88. This observation is supported by Marsden and Price [12] who concluded that full Navier-Stokes solvers are necessary for the details of LCO or instability predictions even for the two dimensional airfoil.

### 3.2 Further Research

The properties of the external store are a point of interest for future research. Variation in either the location or mass of the store could alter the simulated response significantly, potentially developing deeper insight into the factors that promote limit cycle oscillation.

The small (<1.5%) standard deviations in the eigenvalues of the wing determined in the structural study point to the need for future analysis of the effects of mass distribution, rather than the stiffness of the structure that the thickness of the components controls. There is an apparent insensitivity to the thickness variation because its standard deviation is more than three times greater than the resulting standard deviations in the eigenvalues of any of the first four natural modes.

Further, the Computational Aeroelasticity Program-Transonic Small Disturbance (CAP-TSDv) developed by NASA Langley Research Center implements transonic small-disturbance theory coupled with a boundary layer model to approximate viscous effects. This theory provides a stepping stone between the ZTRAN environment and the full computational fluid dynamics programs. CAP-TSDv is currently being integrated extended through the OVERCAP software developed cooperatively by ZONA and the Air Force Research Laboratory. This helps to simplify communication between NASTRAN and CAP-TSDv. It is similar in format to both ZAERO and NASTRAN. Probabilistic simulations conducted through OVERCAP would be more computationally costly than the research described here because OVERCAP generates results based on a more precise and higher-fidelity model of the flow field than either ZONA6 or ZTRAN. OVERCAP generates time domain estimates of aeroelastic response that should lead to insight into LCO rather than the simplified instability boundary analysis conducted thus far.

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**APPENDIX A: GLOSSARY OF TERMS**

Aeroelasticity	The study of the interactions between aerodynamic, structural, and inertial forces acting within a system
Clean Wing	That version of the wing where no external stores are present
Computational Cost	Amount of time a computational process requires
Doublet Lattice Method	A method for modeling the aerodynamics of a system as a lattice of doublets where a doublet is a co-located source-sink pair
Eigenmode	Natural vibrational mode, or shape, of a system
Eigenvalue	Frequency of a natural vibration mode within a system
Euler Equations	Governing equations that describe fluid dynamics when viscous effects are ignored
External Stores	Anything attached to an aircraft wing, for example external fuel tanks or air-to-air missiles
Finite Element Analysis	Computational analysis to obtain approximate solutions by representing a more complex model as the collection of many discrete subsections of the larger component
Flutter	Neutrally stable oscillation of an aircraft component, typically the wing, owing to aeroelastic interactions. These severe vibrations can cause the separation of the component from the aircraft and overall structural failure.
Flutter Speed	The onset of instability in the aeroelastic model; the speed where the structural damping needed to maintain neutrally stable motion at a given dynamic pressure transitions to positive in at least one vibration mode. Does not necessarily mark the advent of either flutter or LCO
Goland Wing Model	A simple wing model produced in the 1950s by Martin Goland for flutter research; see reference [9] for more information.
Inertial Forces	Sometimes called “fictional forces,” inertial forces are those forces that act on a system when it is considered within its own accelerating reference system. These forces are the reaction of the body to its own accelerations. A common example of such a force is the centrifugal force of rotational motion, which seems to push the accelerated body toward the center of rotation.
Limit Cycle Oscillation	Self-sustained, stable oscillation of an aircraft or structural component produced by aeroelastic interactions. These moderate to mild vibrations put unexpected fatigue on structural components.
Linear Structural Analysis	Analysis which makes an assumption that a structure will behave linearly in response to external loads
Lower Rib Cap	Elements that run along the lower surfaces of the ribs

Lower Spar Cap	Elements that run along the lower surfaces of the spars
Lower Wing Skin	Material that covers the bottom surface of the wing box.
MD NASTRAN <sup>®</sup>	Finite Element Analysis software produced by the MSC corporation for broad use by all engineering disciplines to perform simulations
Navier-Stokes Equations	Governing equations that describe the dynamics of Newtonian, Stokesian viscous flow or how the velocity, pressure, temperature, and density of a moving fluid are related when the effects of viscosity are included
Outlier	A value that lies significantly away from an accepted or mean value; in the present study, any value more than two standard deviations away from the accepted or mean value
Posts	The vertical components of the wing finite element model that connect the upper and lower wing surfaces together.
Predictive Accuracy	How closely computational results resemble real-world behavior
Ribs	Components that run the length of the wing parallel to the wing chord line or the fuselage chord line drawn from the aircraft nose to its tail.
Spars	Components that run the span of a wing from the root (where the fuselage would be) to the tip
Structural stiffness	Static resistance of a structure to deflection from equilibrium
Tip Store	An external store located at the edge of a wing span that is furthest from the fuselage
Transonic airflow	Airflow characterized by a Mach number in the transitional range between subsonic and supersonic, typically $0.8 < M < 1.2$
Transonic Small Disturbance	A simplified model of transonic flight that assumes inviscid behavior and small variations from free-stream conditions
Upper Rib Cap	Elements that run along the upper surfaces of the ribs
Upper Spar Cap	Elements that run along the upper surfaces of the spars
Upper Wing Skin	Material that covers the top surface of the wing box.
Viscosity	A measure of a fluid's resistance to deformation by shear (friction) forces
ZAERO <sup>®</sup>	An aeroelastic modeling program produced by ZONA Technologies <sup>®</sup>
ZONA6	the subsonic unsteady aerodynamics tool within ZAERO <sup>®</sup>
ZTRAN	a transonic flow solver within ZAERO <sup>®</sup>

## APPENDIX B: Bulk Data File of Cleanwing.bdf Model

```

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. . . . . $
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$ RBARS at Root
$. . . . .2. . . . .3. . . . .4. . . . .5. . . . .6. . . . .7. . . . .8. . . . .9. . . . .10.
. . . . . $
RBAR    100      100      10000      123456          123456
RBAR    101      100      10001      123456          123456
RBAR    102      100      10002      123456          123456
RBAR    200      100      20000      123456          123456
RBAR    201      100      20001      123456          123456
RBAR    202      100      20002      123456          123456
$ Upper Surface Grids
$. . . . .2. . . . .3. . . . .4. . . . .5. . . . .6. . . . .7. . . . .8. . . . .9. . . . .10.
. . . . . $
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GRID    10001          2.0      0.0      0.16667
GRID    10002          4.0      0.0      0.16667
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GRID    10101          2.0      2.0      0.16667
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GRID    10301          2.0      6.0      0.16667
GRID    10302          4.0      6.0      0.16667
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GRID    10401          2.0      8.0      0.16667
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GRID    10501          2.0     10.0      0.16667
GRID    10502          4.0     10.0      0.16667
GRID    10600          0.0     12.0      0.16667
GRID    10601          2.0     12.0      0.16667
GRID    10602          4.0     12.0      0.16667
GRID    10700          0.0     14.0      0.16667
GRID    10701          2.0     14.0      0.16667
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GRID    10801          2.0     16.0      0.16667
GRID    10802          4.0     16.0      0.16667
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GRID    11000          0.0     20.0      0.16667
GRID    11001          2.0     20.0      0.16667
GRID    11002          4.0     20.0      0.16667
$ Lower Surface Grids
$. . . . .2. . . . .3. . . . .4. . . . .5. . . . .6. . . . .7. . . . .8. . . . .9. . . . .10.
. . . . . $
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GRID    20100          0.0      2.0     -0.16667

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GRID	20901	2.0	18.0	-0.16667
GRID	20902	4.0	18.0	-0.16667
GRID	21000	0.0	20.0	-0.16667
GRID	21001	2.0	20.0	-0.16667
GRID	21002	4.0	20.0	-0.16667

\$ Upper Wing Skins

\$.....2.....3.....4.....5.....6.....7.....8.....9.....10.  
 ....\$

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CQUAD4	210401	210401	10401	10402	10502	10501
CQUAD4	210500	210500	10500	10501	10601	10600
CQUAD4	210501	210501	10501	10502	10602	10601
CQUAD4	210600	210600	10600	10601	10701	10700
CQUAD4	210601	210601	10601	10602	10702	10701
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CQUAD4	210900	210900	10900	10901	11001	11000
CQUAD4	210901	210901	10901	10902	11002	11001

\$ Lower Wing Skins

\$.....2.....3.....4.....5.....6.....7.....8.....9.....10.  
 ....\$

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CQUAD4	220101	220101	20101	20102	20202	20201

CQUAD4	220200	220200	20200	20201	20301	20300
CQUAD4	220201	220201	20201	20202	20302	20301
CQUAD4	220300	220300	20300	20301	20401	20400
CQUAD4	220301	220301	20301	20302	20402	20401
CQUAD4	220400	220400	20400	20401	20501	20500
CQUAD4	220401	220401	20401	20402	20502	20501
CQUAD4	220500	220500	20500	20501	20601	20600
CQUAD4	220501	220501	20501	20502	20602	20601
CQUAD4	220600	220600	20600	20601	20701	20700
CQUAD4	220601	220601	20601	20602	20702	20701
CQUAD4	220700	220700	20700	20701	20801	20800
CQUAD4	220701	220701	20701	20702	20802	20801
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CQUAD4	220901	220901	20901	20902	21002	21001

\$ Spars

\$.....2.....3.....4.....5.....6.....7.....8.....9.....10.  
 ....\$

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\$ Ribs

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 ....\$

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CSHEAR	241001	241001	11001	11002	21002	21001

\$ Posts

\$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 .  
 . . . . \$

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CROD	110300	110300	10300	20300
CROD	110301	110301	10301	20301
CROD	110302	110302	10302	20302
CROD	110400	110400	10400	20400
CROD	110401	110401	10401	20401
CROD	110402	110402	10402	20402
CROD	110500	110500	10500	20500
CROD	110501	110501	10501	20501
CROD	110502	110502	10502	20502
CROD	110600	110600	10600	20600
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CROD	111000	111000	11000	21000
CROD	111001	111001	11001	21001
CROD	111002	111002	11002	21002

\$ Upper Spar Caps

\$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 .  
 . . . . \$

CROD	120000	120000	10000	10100
CROD	120001	120001	10100	10200
CROD	120002	120002	10200	10300
CROD	120003	120003	10300	10400
CROD	120004	120004	10400	10500

CROD	120005	120005	10500	10600
CROD	120006	120006	10600	10700
CROD	120007	120007	10700	10800
CROD	120008	120008	10800	10900
CROD	120009	120009	10900	11000
CROD	120100	120100	10001	10101
CROD	120101	120101	10101	10201
CROD	120102	120102	10201	10301
CROD	120103	120103	10301	10401
CROD	120104	120104	10401	10501
CROD	120105	120105	10501	10601
CROD	120106	120106	10601	10701
CROD	120107	120107	10701	10801
CROD	120108	120108	10801	10901
CROD	120109	120109	10901	11001
CROD	120200	120200	10002	10102
CROD	120201	120201	10102	10202
CROD	120202	120202	10202	10302
CROD	120203	120203	10302	10402
CROD	120204	120204	10402	10502
CROD	120205	120205	10502	10602
CROD	120206	120206	10602	10702
CROD	120207	120207	10702	10802
CROD	120208	120208	10802	10902
CROD	120209	120209	10902	11002

\$ Lower Spar Caps

\$.....2.....3.....4.....5.....6.....7.....8.....9.....10.  
 ....\$

CROD	130000	130000	20000	20100
CROD	130001	130001	20100	20200
CROD	130002	130002	20200	20300
CROD	130003	130003	20300	20400
CROD	130004	130004	20400	20500
CROD	130005	130005	20500	20600
CROD	130006	130006	20600	20700
CROD	130007	130007	20700	20800
CROD	130008	130008	20800	20900
CROD	130009	130009	20900	21000
CROD	130100	130100	20001	20101
CROD	130101	130101	20101	20201
CROD	130102	130102	20201	20301
CROD	130103	130103	20301	20401
CROD	130104	130104	20401	20501
CROD	130105	130105	20501	20601
CROD	130106	130106	20601	20701
CROD	130107	130107	20701	20801
CROD	130108	130108	20801	20901
CROD	130109	130109	20901	21001
CROD	130200	130200	20002	20102
CROD	130201	130201	20102	20202
CROD	130202	130202	20202	20302
CROD	130203	130203	20302	20402
CROD	130204	130204	20402	20502
CROD	130205	130205	20502	20602
CROD	130206	130206	20602	20702
CROD	130207	130207	20702	20802
CROD	130208	130208	20802	20902
CROD	130209	130209	20902	21002

\$ Upper Rib Caps

\$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 .  
 . . . . . \$

CROD	140000	140000	10000	10001
CROD	140001	140001	10001	10002
CROD	140100	140100	10100	10101
CROD	140101	140101	10101	10102
CROD	140200	140200	10200	10201
CROD	140201	140201	10201	10202
CROD	140300	140300	10300	10301
CROD	140301	140301	10301	10302
CROD	140400	140400	10400	10401
CROD	140401	140401	10401	10402
CROD	140500	140500	10500	10501
CROD	140501	140501	10501	10502
CROD	140600	140600	10600	10601
CROD	140601	140601	10601	10602
CROD	140700	140700	10700	10701
CROD	140701	140701	10701	10702
CROD	140800	140800	10800	10801
CROD	140801	140801	10801	10802
CROD	140900	140900	10900	10901
CROD	140901	140901	10901	10902
CROD	141000	141000	11000	11001
CROD	141001	141001	11001	11002

\$ Lower Rib Caps

\$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 .  
 . . . . . \$

CROD	150000	150000	20000	20001
CROD	150001	150001	20001	20002
CROD	150100	150100	20100	20101
CROD	150101	150101	20101	20102
CROD	150200	150200	20200	20201
CROD	150201	150201	20201	20202
CROD	150300	150300	20300	20301
CROD	150301	150301	20301	20302
CROD	150400	150400	20400	20401
CROD	150401	150401	20401	20402
CROD	150500	150500	20500	20501
CROD	150501	150501	20501	20502
CROD	150600	150600	20600	20601
CROD	150601	150601	20601	20602
CROD	150700	150700	20700	20701
CROD	150701	150701	20701	20702
CROD	150800	150800	20800	20801
CROD	150801	150801	20801	20802
CROD	150900	150900	20900	20901
CROD	150901	150901	20901	20902
CROD	151000	151000	21000	21001
CROD	151001	151001	21001	21002

\$ Material Data

\$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 .  
 . . . . . \$

\$ Eastep's Material

MAT1 101 1.4976E95.616E8 0.000001

\$ Upper Surface Concentrated Masses

\$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 .  
 . . . . . \$

CONM2	10000	10000	0.9825
CONM2	10001	10001	1.9721

CONM2	10002	10002	2.6699
CONM2	10100	10100	1.9650
CONM2	10101	10101	3.9442
CONM2	10102	10102	5.3398
CONM2	10200	10200	1.9650
CONM2	10201	10201	3.9442
CONM2	10202	10202	5.3398
CONM2	10300	10300	1.9650
CONM2	10301	10301	3.9442
CONM2	10302	10302	5.3398
CONM2	10400	10400	1.9650
CONM2	10401	10401	3.9442
CONM2	10402	10402	5.3398
CONM2	10500	10500	1.9650
CONM2	10501	10501	3.9442
CONM2	10502	10502	5.3398
CONM2	10600	10600	1.9650
CONM2	10601	10601	3.9442
CONM2	10602	10602	5.3398
CONM2	10700	10700	1.9650
CONM2	10701	10701	3.9442
CONM2	10702	10702	5.3398
CONM2	10800	10800	1.9650
CONM2	10801	10801	3.9442
CONM2	10802	10802	5.3398
CONM2	10900	10900	1.9650
CONM2	10901	10901	3.9442
CONM2	10902	10902	5.3398
CONM2	11000	11000	0.9825
CONM2	11001	11001	1.9721
CONM2	11002	11002	2.6699

\$ Lower Surface Concentrated Masses

\$.....2.....3.....4.....5.....6.....7.....8.....9.....10.

....\$

CONM2	20000	20000	0.9825
CONM2	20001	20001	1.9721
CONM2	20002	20002	2.6699
CONM2	20100	20100	1.9650
CONM2	20101	20101	3.9442
CONM2	20102	20102	5.3398
CONM2	20200	20200	1.9650
CONM2	20201	20201	3.9442
CONM2	20202	20202	5.3398
CONM2	20300	20300	1.9650
CONM2	20301	20301	3.9442
CONM2	20302	20302	5.3398
CONM2	20400	20400	1.9650
CONM2	20401	20401	3.9442
CONM2	20402	20402	5.3398
CONM2	20500	20500	1.9650
CONM2	20501	20501	3.9442
CONM2	20502	20502	5.3398
CONM2	20600	20600	1.9650
CONM2	20601	20601	3.9442
CONM2	20602	20602	5.3398
CONM2	20700	20700	1.9650
CONM2	20701	20701	3.9442
CONM2	20702	20702	5.3398
CONM2	20800	20800	1.9650

CONM2	20801	20801	3.9442
CONM2	20802	20802	5.3398
CONM2	20900	20900	1.9650
CONM2	20901	20901	3.9442
CONM2	20902	20902	5.3398
CONM2	21000	21000	0.9825
CONM2	21001	21001	1.9721
CONM2	21002	21002	2.6699

### APPENDIX C: Bulk Data File of Tipstoremass.bdf Model

```

$ Tip Missile Model
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
GRID 30100          -3.0   20.5   0.0
GRID 30101          1.0   20.5   0.0
GRID 30102          2.0   20.5   0.0
GRID 30103          3.0   20.5   0.0
GRID 30104          7.0   20.5   0.0
RBAR 310    30101   30100   123456          123456
RBAR 311    30102   30101   123456          123456
RBAR 312    30102   30103   123456          123456
RBAR 313    30103   30104   123456          123456
$Tip MASS CONM2
CONM2 30102   30102          22.4980  -1.75  0.0    0.0          +M11003
+M11003          50.3396
$ Connection to Tip Rib
RBAR 320    30001   30102   123456          123456
$ Tip Rib Store Connection Points
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
GRID 30000          1.0   20.0   0.0
GRID 30001          2.0   20.0   0.0
GRID 30002          3.0   20.0   0.0
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
RBE3 300          30000   123456   1.0    123    11000   11001   +BE3300
+BE3300 21000   21001
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
RBE3 301          30002   123456   1.0    123    11001   11002   +BE3301
+BE3301 21001   21002
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
RBE3 302          30001   123456   1.0    1234   30000   30002

```

**APPENDIX D: Example Input File for MD NASTRAN®**

```

$ Built-up Goland Wing Model
$
ASSIGN OUTPUT4='testcw.mgh' STATUS=UNKNOWN UNIT=12 FORM=FORMATTED
SOL 103 $ Normal Modes Analysis
COMPILE SEMODES SOUIN=MSCSOU LIST NOREF $
ALTER 359 $
MPYAD MGG,PHG,/MGH $
OUTPUT4 MGH///12/2//9$
ENDALTER
CEND
$
TITLE = BUILT-UP GOLAND WING MODEL
SUBTITLE = CLEAN WING NORMAL MODES ANALYSIS
$
METHOD = 10 $ SELECT EIGR ENTRY
SPC = 10 $ SELECT SPC
$
$ SELECT OUTPUT
DISPLACEMENT = ALL
$
BEGIN BULK
$ Solution Control Data
$. . . . .2. . . . .3. . . . .4. . . . .5. . . . .6. . . . .7. . . . .8. . . . .9. . . . .10. . . . . $
EIGRL 10 0.0 10
$EIGRL 10 0.0 30.0
SPC1 10 123456 100
$ PARAM GRDPNT 100
$ PARAM POST 0
$
INCLUDE 'CleanWing.bdf'
$INCLUDE 'Tipstoremass.bdf'
$
ENDDATA

```

## APPENDIX E: Example Input File for ZAERO® ZONA6

```

$ ... Executive Control
ASSIGN FEM=basecw0000.f06, PRINT=0, FORM=MSC, BOUND=SYM
ASSIGN MATRIX =basecw0000.mgh, FORM=FORMAT, MNAME=SMGH, PRINT=0
MEMORY 800MB
$SOL -2
CEND
$ ... Case Control
TITLE   = AEROELASTIC ANALYSIS OF Goland Wing
ECHO    = SORT
        SUBCASE = 70
          SUBTITLE = LINEAR FLUTTER ANALYSIS
          LABEL    = MACH NUMBER = 0.70, NON MATCHED-POINT FLUTTER ANALYSIS
          FLUTTER  = 70
        SUBCASE = 80
          SUBTITLE = LINEAR FLUTTER ANALYSIS
          LABEL    = MACH NUMBER = 0.80, NON MATCHED-POINT FLUTTER ANALYSIS
          FLUTTER  = 80
        SUBCASE = 825
          SUBTITLE = LINEAR FLUTTER ANALYSIS
          LABEL    = MACH NUMBER = 0.825, NON MATCHED-POINT FLUTTER ANALYSIS
          FLUTTER  = 825
$
$   SUBTITLE = LINEAR FLUTTER ANALYSIS
$   LABEL    = MACH NUMBER = 0.85, NON MATCHED-POINT FLUTTER ANALYSIS
$   FLUTTER  = 85
        SUBCASE = 88
          SUBTITLE = LINEAR FLUTTER ANALYSIS
          LABEL    = MACH NUMBER = 0.88, NON MATCHED-POINT FLUTTER ANALYSIS
          FLUTTER  = 88
        SUBCASE = 90
          SUBTITLE = LINEAR FLUTTER ANALYSIS
          LABEL    = MACH NUMBER = 0.90, NON MATCHED-POINT FLUTTER ANALYSIS
          FLUTTER  = 90
        SUBCASE = 91
          SUBTITLE = LINEAR FLUTTER ANALYSIS
          LABEL    = MACH NUMBER = 0.91, NON MATCHED-POINT FLUTTER ANALYSIS
          FLUTTER  = 91
        SUBCASE = 92
          SUBTITLE = LINEAR FLUTTER ANALYSIS
          LABEL    = MACH NUMBER = 0.92, NON MATCHED-POINT FLUTTER ANALYSIS
          FLUTTER  = 92
        SUBCASE = 93
          SUBTITLE = LINEAR FLUTTER ANALYSIS
          LABEL    = MACH NUMBER = 0.93, NON MATCHED-POINT FLUTTER ANALYSIS
          FLUTTER  = 93
        SUBCASE = 95
          SUBTITLE = LINEAR FLUTTER ANALYSIS
          LABEL    = MACH NUMBER = 0.95, NON MATCHED-POINT FLUTTER ANALYSIS
          FLUTTER  = 95
$ ... Bulk Data Deck
BEGIN BULK
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . .
PLTVG      70      70      EQUV TABLE CBZ60700000.dat
PLTVG      80      80      EQUV TABLE CBZ60800000.dat
PLTVG      825     825     EQUV TABLE CBZ68250000.dat
PLTVG      85      85      EQUV TABLE CBZ60850000.dat
PLTVG      88      88      EQUV TABLE CBZ60880000.dat
PLTVG      90      90      EQUV TABLE CBZ60900000.dat
PLTVG      91      91      EQUV TABLE CBZ60910000.dat
PLTVG      92      92      EQUV TABLE CBZ60920000.dat
PLTVG      93      93      EQUV TABLE CBZ60930000.dat
PLTVG      95      95      EQUV TABLE CBZ60950000.dat
include 'baseaero.inp'
include 'alt_mach_mkz_fluts.inp'
ENDDATA
$ alt_mach_mkz_fluta.inp
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . .
$   IDMK   MACH   METHOD IDFLT   SAVE   <---FILENAME-->   PRINT   $
$   FREQ1  FREQ2   ETC
$MKAEROZ 70      0.70   0      70      SAVE   CBZ60700.AIC   0      +MK1
MKAEROZ 70      0.70   0      70      ACQUIRE CBZ60700.AIC   0      +MK1

```

+MK1	0.025	0.075	0.15	0.3	0.5	0.75	1.0	1.2	+
+	1.6	2.0							
TRIMFLT	70	0	1.0						
FLUTTER	70	SYMML	70		0	0	0		
FIXMDEN	70	70	0.002377	LBF/	FT				+FIX701
+FIX701	300.0	320.0	340.0	360.0	380.0	400.0	420.0	440.0	+FIX702
+FIX702	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	+FIX703
+FIX703	620.0	640.0	660.0	680.0	700.0	720.0	740.0	760.0	+FIX704
+FIX704	780.0	800.0	820.0	840.0	860.0	880.0	900.0	920.0	+FIX705
+FIX705	940.0	960.0	980.0	1000.0	1020.0	1040.0	1060.0	1080.0	+FIX706
+FIX706	1100.0	1120.0	1140.0	1160.0	1180.0	1200.0	1220.0	1240.0	+FIX707
+FIX707	1260.0	1280.0	1300.0	1320.0	1340.0	1360.0	1380.0	1400.0	+FIX708
+FIX708	1420.0	1440.0	1460.0	1480.0	1500.0				
\$. . . 1 . . .   . . . 2 . . .   . . . 3 . . .   . . . 4 . . .   . . . 5 . . .   . . . 6 . . .   . . . 7 . . .   . . . 8 . . .   . . . 9 . . .   . . . 10 . . .									
\$MKAEROZ	80	0.80	0	80	SAVE	CBZ60800.AIC	0		+MK1
MKAEROZ	80	0.80	0	80	ACQUIRE	CBZ60800.AIC	0		+MK1
+MK1	0.025	0.075	0.15	0.3	0.5	0.75	1.0	1.2	+
+	1.6	2.0							
TRIMFLT	80	0	1.0						
FLUTTER	80	SYMML	80		0	0	0		
FIXMDEN	80	80	0.002377	LBF/	FT				+FIX701
+FIX701	300.0	320.0	340.0	360.0	380.0	400.0	420.0	440.0	+FIX702
+FIX702	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	+FIX703
+FIX703	620.0	640.0	660.0	680.0	700.0	720.0	740.0	760.0	+FIX704
+FIX704	780.0	800.0	820.0	840.0	860.0	880.0	900.0	920.0	+FIX705
+FIX705	940.0	960.0	980.0	1000.0	1020.0	1040.0	1060.0	1080.0	+FIX706
+FIX706	1100.0	1120.0	1140.0	1160.0	1180.0	1200.0	1220.0	1240.0	+FIX707
+FIX707	1260.0	1280.0	1300.0	1320.0	1340.0	1360.0	1380.0	1400.0	+FIX708
+FIX708	1420.0	1440.0	1460.0	1480.0	1500.0				
\$. . . 1 . . .   . . . 2 . . .   . . . 3 . . .   . . . 4 . . .   . . . 5 . . .   . . . 6 . . .   . . . 7 . . .   . . . 8 . . .   . . . 9 . . .   . . . 10 . . .									
MKAEROZ	825	0.825	0	825	SAVE	CBZ60825.AIC	0		+MK1
\$MKAEROZ	825	0.825	0	825	ACQUIRE	CBZ60825.AIC	0		+MK1
+MK1	0.025	0.075	0.15	0.3	0.5	0.75	1.0	1.2	+
+	1.6	2.0							
TRIMFLT	825	0	1.0						
FLUTTER	825	SYMML	825		0	0	0		
FIXMDEN	825	825	0.002377	LBF/	FT				+FIX701
+FIX701	300.0	320.0	340.0	360.0	380.0	400.0	420.0	440.0	+FIX702
+FIX702	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	+FIX703
+FIX703	620.0	640.0	660.0	680.0	700.0	720.0	740.0	760.0	+FIX704
+FIX704	780.0	800.0	820.0	840.0	860.0	880.0	900.0	920.0	+FIX705
+FIX705	940.0	960.0	980.0	1000.0	1020.0	1040.0	1060.0	1080.0	+FIX706
+FIX706	1100.0	1120.0	1140.0	1160.0	1180.0	1200.0	1220.0	1240.0	+FIX707
+FIX707	1260.0	1280.0	1300.0	1320.0	1340.0	1360.0	1380.0	1400.0	+FIX708
+FIX708	1420.0	1440.0	1460.0	1480.0	1500.0				
\$. . . 1 . . .   . . . 2 . . .   . . . 3 . . .   . . . 4 . . .   . . . 5 . . .   . . . 6 . . .   . . . 7 . . .   . . . 8 . . .   . . . 9 . . .   . . . 10 . . .									
MKAEROZ	85	0.85	0	85	SAVE	CBZ60850.AIC	0		+MK1
\$MKAEROZ	85	0.85	0	85	ACQUIRE	CBZ60850.AIC	0		+MK1
+MK1	0.025	0.075	0.15	0.3	0.5	0.75	1.0	1.2	+
+	1.6	2.0							
TRIMFLT	85	0	1.0						
FLUTTER	85	SYMML	85		0	0	0		
FIXMDEN	85	85	0.002377	LBF/	FT				+FIX701
+FIX701	300.0	320.0	340.0	360.0	380.0	400.0	420.0	440.0	+FIX702
+FIX702	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	+FIX703
+FIX703	620.0	640.0	660.0	680.0	700.0	720.0	740.0	760.0	+FIX704
+FIX704	780.0	800.0	820.0	840.0	860.0	880.0	900.0	920.0	+FIX705
+FIX705	940.0	960.0	980.0	1000.0	1020.0	1040.0	1060.0	1080.0	+FIX706
+FIX706	1100.0	1120.0	1140.0	1160.0	1180.0	1200.0	1220.0	1240.0	+FIX707
+FIX707	1260.0	1280.0	1300.0	1320.0	1340.0	1360.0	1380.0	1400.0	+FIX708
+FIX708	1420.0	1440.0	1460.0	1480.0	1500.0				
\$. . . 1 . . .   . . . 2 . . .   . . . 3 . . .   . . . 4 . . .   . . . 5 . . .   . . . 6 . . .   . . . 7 . . .   . . . 8 . . .   . . . 9 . . .   . . . 10 . . .									
\$\$ . . . 1 . . .   . . . 2 . . .   . . . 3 . . .   . . . 4 . . .   . . . 5 . . .   . . . 6 . . .   . . . 7 . . .   . . . 8 . . .   . . . 9 . . .   . . . 10 . . .									
\$MKAEROZ	88	0.88	0	88	SAVE	CBZ60880.AIC	0		+MK1
MKAEROZ	88	0.88	0	88	ACQUIRE	CBZ60880.AIC	0		+MK1
+MK1	0.025	0.075	0.15	0.3	0.5	0.75	1.0	1.2	+
+	1.6	2.0							
TRIMFLT	88	0	1.0						
FLUTTER	88	SYMML	88		0	0	0		
FIXMDEN	88	88	0.002377	LBF/	FT				+FIX701
+FIX701	300.0	320.0	340.0	360.0	380.0	400.0	420.0	440.0	+FIX702
+FIX702	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	+FIX703
+FIX703	620.0	640.0	660.0	680.0	700.0	720.0	740.0	760.0	+FIX704
+FIX704	780.0	800.0	820.0	840.0	860.0	880.0	900.0	920.0	+FIX705

+FIX705	940.0	960.0	980.0	1000.0	1020.0	1040.0	1060.0	1080.0	+FIX706
+FIX706	1100.0	1120.0	1140.0	1160.0	1180.0	1200.0	1220.0	1240.0	+FIX707
+FIX707	1260.0	1280.0	1300.0	1320.0	1340.0	1360.0	1380.0	1400.0	+FIX708
+FIX708	1420.0	1440.0	1460.0	1480.0	1500.0				
\$...1..	...2...	...3...	...4...	...5...	...6...	...7...	...8...	...9...	...10..
\$MKAEROZ	90	0.90	0	90	SAVE	CBZ60900.AIC	0		+MK1
MKAEROZ	90	0.90	0	90	ACQUIRE	CBZ60900.AIC	0		+MK1
+MK1	0.025	0.075	0.15	0.3	0.5	0.75	1.0	1.2	+
+	1.6	2.0							
TRIMFLT	90	0	1.0						
FLUTTER	90	SYMLL	90		0	0	0		
FIXMDEN	90	90	0.002377	LBF/	FT				+FIX701
+FIX701	300.0	320.0	340.0	360.0	380.0	400.0	420.0	440.0	+FIX702
+FIX702	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	+FIX703
+FIX703	620.0	640.0	660.0	680.0	700.0	720.0	740.0	760.0	+FIX704
+FIX704	780.0	800.0	820.0	840.0	860.0	880.0	900.0	920.0	+FIX705
+FIX705	940.0	960.0	980.0	1000.0	1020.0	1040.0	1060.0	1080.0	+FIX706
+FIX706	1100.0	1120.0	1140.0	1160.0	1180.0	1200.0	1220.0	1240.0	+FIX707
+FIX707	1260.0	1280.0	1300.0	1320.0	1340.0	1360.0	1380.0	1400.0	+FIX708
+FIX708	1420.0	1440.0	1460.0	1480.0	1500.0				
\$...1..	...2...	...3...	...4...	...5...	...6...	...7...	...8...	...9...	...10..
\$MKAEROZ	91	0.91	0	91	SAVE	CBZ60910.AIC	0		+MK1
MKAEROZ	91	0.91	0	91	ACQUIRE	CBZ60910.AIC	0		+MK1
+MK1	0.025	0.075	0.15	0.3	0.5	0.75	1.0	1.2	+
+	1.6	2.0							
TRIMFLT	91	0	1.0						
FLUTTER	91	SYMLL	91		0	0	0		
FIXMDEN	91	91	0.002377	LBF/	FT				+FIX701
+FIX701	300.0	320.0	340.0	360.0	380.0	400.0	420.0	440.0	+FIX702
+FIX702	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	+FIX703
+FIX703	620.0	640.0	660.0	680.0	700.0	720.0	740.0	760.0	+FIX704
+FIX704	780.0	800.0	820.0	840.0	860.0	880.0	900.0	920.0	+FIX705
+FIX705	940.0	960.0	980.0	1000.0	1020.0	1040.0	1060.0	1080.0	+FIX706
+FIX706	1100.0	1120.0	1140.0	1160.0	1180.0	1200.0	1220.0	1240.0	+FIX707
+FIX707	1260.0	1280.0	1300.0	1320.0	1340.0	1360.0	1380.0	1400.0	+FIX708
+FIX708	1420.0	1440.0	1460.0	1480.0	1500.0				
\$...1..	...2...	...3...	...4...	...5...	...6...	...7...	...8...	...9...	...10..
\$MKAEROZ	92	0.92	0	92	SAVE	CBZ60920.AIC	0		+MK1
MKAEROZ	92	0.92	0	92	ACQUIRE	CBZ60920.AIC	0		+MK1
+MK1	0.025	0.075	0.15	0.3	0.5	0.75	1.0	1.2	+
+	1.6	2.0							
TRIMFLT	92	0	1.0						
FLUTTER	92	SYMLL	92		0	0	0		
FIXMDEN	92	92	0.002377	LBF/	FT				+FIX701
+FIX701	300.0	320.0	340.0	360.0	380.0	400.0	420.0	440.0	+FIX702
+FIX702	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	+FIX703
+FIX703	620.0	640.0	660.0	680.0	700.0	720.0	740.0	760.0	+FIX704
+FIX704	780.0	800.0	820.0	840.0	860.0	880.0	900.0	920.0	+FIX705
+FIX705	940.0	960.0	980.0	1000.0	1020.0	1040.0	1060.0	1080.0	+FIX706
+FIX706	1100.0	1120.0	1140.0	1160.0	1180.0	1200.0	1220.0	1240.0	+FIX707
+FIX707	1260.0	1280.0	1300.0	1320.0	1340.0	1360.0	1380.0	1400.0	+FIX708
+FIX708	1420.0	1440.0	1460.0	1480.0	1500.0				
\$...1..	...2...	...3...	...4...	...5...	...6...	...7...	...8...	...9...	...10..
\$MKAEROZ	93	0.93	0	93	SAVE	CBZ60930.AIC	0		+MK1
MKAEROZ	93	0.93	0	93	ACQUIRE	CBZ60930.AIC	0		+MK1
+MK1	0.025	0.075	0.15	0.3	0.5	0.75	1.0	1.2	+
+	1.6	2.0							
TRIMFLT	93	0	1.0						
FLUTTER	93	SYMLL	93		0	0	0		
FIXMDEN	93	93	0.002377	LBF/	FT				+FIX701
+FIX701	300.0	320.0	340.0	360.0	380.0	400.0	420.0	440.0	+FIX702
+FIX702	460.0	480.0	500.0	520.0	540.0	560.0	580.0	600.0	+FIX703
+FIX703	620.0	640.0	660.0	680.0	700.0	720.0	740.0	760.0	+FIX704
+FIX704	780.0	800.0	820.0	840.0	860.0	880.0	900.0	920.0	+FIX705
+FIX705	940.0	960.0	980.0	1000.0	1020.0	1040.0	1060.0	1080.0	+FIX706
+FIX706	1100.0	1120.0	1140.0	1160.0	1180.0	1200.0	1220.0	1240.0	+FIX707
+FIX707	1260.0	1280.0	1300.0	1320.0	1340.0	1360.0	1380.0	1400.0	+FIX708
+FIX708	1420.0	1440.0	1460.0	1480.0	1500.0				
\$...1..	...2...	...3...	...4...	...5...	...6...	...7...	...8...	...9...	...10..
\$MKAEROZ	95	0.95	0	95	SAVE	CBZ60950.AIC	0		+MK1
MKAEROZ	95	0.95	0	95	ACQUIRE	CBZ60950.AIC	0		+MK1
+MK1	0.025	0.075	0.15	0.3	0.5	0.75	1.0	1.2	+
+	1.6	2.0							

```

TRIMFLT 95      0      1.0
FLUTTER 95      SYMML  95      0      0      0
FIXMDEN 95      95      0.002377  LBF/  FT
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX701
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX702
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX703
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX704
+FIX705 940.0   960.0   980.0  1000.0  1020.0  1040.0  1060.0  1080.0  +FIX705
+FIX706 1100.0  1120.0  1140.0  1160.0  1180.0  1200.0  1220.0  1240.0  +FIX706
+FIX707 1260.0  1280.0  1300.0  1320.0  1340.0  1360.0  1380.0  1400.0  +FIX707
+FIX708 1420.0  1440.0  1460.0  1480.0  1500.0

$ baseaero.inp
$ AERODYNAMIC PANELS AND SPLINE
$
$. . . 1 . . | . . . 2 . . | . . . 3 . . | . . . 4 . . | . . . 5 . . | . . . 6 . . | . . . 7 . . | . . . 8 . . | . . . 9 . . | . . . 10 . . |
CORD2R      11      0.000  0.000  0.000  0.000  0.000  0.000  1.000+CR11
+CR11      0.000  -1.000  1.000
$
$ MAIN WING
$. . . 1 . . | . . . 2 . . | . . . 3 . . | . . . 4 . . | . . . 5 . . | . . . 6 . . | . . . 7 . . | . . . 8 . . | . . . 9 . . | . . . 10 . . |
ACoord      50      0.0    0.0    0.0    0.0    0.0    0.0
$
$ Aerodynamic Model
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
$CAERO7 100001  GOLAND      6      20      0      +ARO101
CAERO7 100001  GOLAND      21     39      100001  +ARO101
+ARO101 0.0    0.0    0.0    6.0
+ARO102 0.0    20.0  0.0    6.0
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
PAFOIL7 100001  100002  100003  100004      100003  100004
AEFACT 100002  0.00    5.00    10.00   15.00   20.00   25.00   30.00   +AEF201
+AEF201 35.00   40.00   45.00   50.00   55.00   60.00   65.00   70.00   +AEF202
+AEF202 75.00   80.00   85.00   90.00   95.00  100.00
AEFACT 100003  0.0000  0.0038  0.0072  0.0102  0.0128  0.0150  0.0168  +AEF301
+AEF301 0.0182  0.0192  0.0198  0.0200  0.0198  0.0192  0.0182  0.0168  +AEF302
+AEF302 0.0150  0.0128  0.0102  0.0072  0.0038  0.0000
AEFACT 100004  0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    +AEF401
+AEF401 0.00    0.00    0.00    0.00    0.00    0.00    0.00    0.00    +AEF402
+AEF402 0.00    0.00    0.00    0.00    0.00    0.00
AEROZ      YES      NO      6.0    20.0    120.0  +AERO01
+AERO01 1.5    0.0    0.0
$ Spline
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
SPLINE1 100001      100001  101    0.0
PANLST3 100001  GOLAND
SET1     101    10000  10001  10002  10100  10101  10102  10200  +ET101
+ET101  10201  10202  10300  10301  10302  10400  10401  10402  +ET101A
+ET101A 10500  10501  10502  10600  10601  10602  10700  10701  +ET101B
+ET101B 10702  10800  10801  10802  10900  10901  10902  11000  +ET101C
+ET101C 11001  11002
$ STATEMENT TO CHECK COORDINATE SYSTEM OF CFD MESH, AERODYNAMIC MODEL AND
$ FINITE ELEMENT MODEL.
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
PLTAERO 100      YES      TECPLOT AEROSTRUC_CS.PLTYES      YES

```

## APPENDIX F: Example Input File for ZAERO® ZTRAN, Euler CFD Model

```

$ ... Executive Control
ASSIGN FEM=basecw0000.f06, PRINT=0, FORM=MSC, BOUND=SYM
ASSIGN MATRIX =basecw0000.mgh, FORM=FORMAT, MNAME=SMGH, PRINT=0
MEMORY 850MB
$SOL -2
CEND
$ ... Case Control
TITLE   = AEROELASTIC ANALYSIS OF Goland Wing
ECHO    = SORT
  SUBCASE = 70
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.70, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 70
  SUBCASE = 80
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.80, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 80
  SUBCASE = 85
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.85, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 85
  SUBCASE = 88
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.88, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 88
  SUBCASE = 90
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.90, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 90
  SUBCASE = 91
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.91, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 91
  SUBCASE = 92
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.92, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 92
  SUBCASE = 93
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.93, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 93
  SUBCASE = 95
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.95, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 95
$ ... Bulk Data Deck
BEGIN BULK
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
PLTVG      88      88                EQUV TABLE CBTE0880000.dat
PLTVG      70      70                EQUV TABLE CBTE0700000.dat
PLTVG      80      80                EQUV TABLE CBTE0800000.dat
PLTVG      85      85                EQUV TABLE CBTE0850000.dat
PLTVG      90      90                EQUV TABLE CBTE0900000.dat
PLTVG      91      91                EQUV TABLE CBTE0910000.dat
PLTVG      92      92                EQUV TABLE CBTE0920000.dat
PLTVG      93      93                EQUV TABLE CBTE0930000.dat
PLTVG      95      95                EQUV TABLE CBTE0950000.dat
include 'baseaero.inp'
include 'alt_mkz_cw_eu.inp'
ENDDATA

'$baseaero.inp'
$ AERODYNAMIC PANELS AND SPLINE
$
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
CORD2R      11      0.000  0.000  0.000  0.000  0.000  1.000+CR11
+CR11      0.000 -1.000  1.000
$
$ MAIN WING
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
ACOORD      50      0.0    0.0    0.0    0.0    0.0    0.0

```

```

$
$ Aerodynamic Model
$. . . . .2. . . . .3. . . . .4. . . . .5. . . . .6. . . . .7. . . . .8. . . . .9. . . . .10. . . . . $
CAERO7 100001 GOLAND 21 39 100001 +ARO101
+ARO101 0.0 0.0 0.0 6.0 0 0 +ARO102
+ARO102 0.0 20.0 0.0 6.0 0 0
CELLWNG 10001 100001 1 3 20001
7 6.0 6.0 0. 0. COS 4 6
7 6.0 6.0 0. 0. COS 4 6
2 .6 .6 2 .6 .6
CELLWNG 20001 100001 3 5 10001 30001
7 6.0 6.0 0. 0. COS 4 6
7 6.0 6.0 0. 0. COS 4 6
2 .6 .6 2 .6 .6
CELLWNG 30001 100001 5 7 20001 40001
7 6.0 6.0 0. 0. COS 4 6
7 6.0 6.0 0. 0. COS 4 6
2 .6 .6 2 .6 .6
CELLWNG 40001 100001 7 9 30001 50001
7 6.0 6.0 0. 0. COS 4 6
7 6.0 6.0 0. 0. COS 4 6
2 .6 .6 2 .6 .6
CELLWNG 50001 100001 9 11 40001 60001
7 6.0 6.0 0. 0. COS 4 6
7 6.0 6.0 0. 0. COS 4 6
2 .6 .6 2 .6 .6
CELLWNG 60001 100001 11 13 50001 70001
7 6.0 6.0 0. 0. COS 4 6
7 6.0 6.0 0. 0. COS 4 6
2 .6 .6 2 .6 .6
CELLWNG 70001 100001 13 15 60001 80001
7 6.0 6.0 0. 0. COS 4 6
7 6.0 6.0 0. 0. COS 4 6
2 .6 .6 2 .6 .6
CELLWNG 80001 100001 15 17 70001 90001
7 6.0 6.0 0. 0. COS 4 6
7 6.0 6.0 0. 0. COS 4 6
2 .6 .6 2 .6 .6
CELLWNG 90001 100001 17 19 80001 100001
7 6.0 6.0 0. 0. COS 4 6
7 6.0 6.0 0. 0. COS 4 6
2 .6 .6 2 .6 .6
CELLWNG 100001 100001 19 21 90001
7 6.0 6.0 0. 0. COS 4 6
7 6.0 6.0 0. 0. COS 4 6
2 .6 .6 2 .6 .6
$. . . . .2. . . . .3. . . . .4. . . . .5. . . . .6. . . . .7. . . . .8. . . . .9. . . . .10. . . . . $
PAFOIL7 100001 100002 100003 100004 100003 100004
AEFACT 100002 0.00 5.00 10.00 15.00 20.00 25.00 30.00 +AEF201
+AEF201 35.00 40.00 45.00 50.00 55.00 60.00 65.00 70.00 +AEF202
+AEF202 75.00 80.00 85.00 90.00 95.00 100.00
AEFACT 100003 0.0000 0.38 0.72 1.02 1.28 1.50 1.68 +AEF301
+AEF301 1.82 1.92 1.98 2.00 1.98 1.92 1.82 1.68 +AEF302
+AEF302 1.50 1.28 1.02 0.72 0.38 0.0000
AEFACT 100004 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 +AEF401
+AEF401 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 +AEF402
+AEF402 0.00 0.00 0.00 0.00 0.00 0.00
AEROZ 0 YES NO 6.0 20.0 120.0 +AERO01
+AERO01 1.5 0.0 0.0
$ Spline
$ SPLINE1 100001 100001 101
$ PANLST3 100001 GOLAND
$. . . . .2. . . . .3. . . . .4. . . . .5. . . . .6. . . . .7. . . . .8. . . . .9. . . . .10. . . . . $
SET1 101 10000 10001 10002 10100 10101 10102 10200+ET101
+ET101 10201 10202 10300 10301 10302 10400 10401 10402+ET101A
+ET101A 10500 10501 10502 10600 10601 10602 10700 10701+ET101B
+ET101B 10702 10800 10801 10802 10900 10901 10902 11000+ET101C
+ET101C 11001 11002
$ STATEMENT TO CHECK COORDINATE SYSTEM OF CFD MESH, AERODYNAMIC MODEL AND
$ FINITE ELEMENT MODEL.
$. . . . .2. . . . .3. . . . .4. . . . .5. . . . .6. . . . .7. . . . .8. . . . .9. . . . .10. . . . . $
PLTAERO 100 YES TECPLOT AEROSTRUC_CS.PLTYES YES

```

```

$ 'alt_mkz_cw_eu.inp'
$ case 70 Mach 0.70
$...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10..|
$      IDMK      MACH      METHOD  IDFLT  SAVE      <--FILENAME-->  PRINT  $
$      FREQ1     FREQ2     ETC
$MKAEROZ 70      0.70      -3      70      SAVE      CBTE0700r2.AIC      0      +MK1
MKAEROZ 70      0.70      -3      70      ACQUIRE   CBTE0700r2.AIC      0      +MK1
+MK1     0.025   0.075   0.15   0.3     0.5     0.75   1.0    1.2    +
+       1.6     2.0
$...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10..|
TRIMFLT 70      70      1.0
INPCFD 70      101     10      P3D     goland.grid  goland_0.70.sol
FLUTTER 70     SYM     70      0      0      0
FIXMDEN 70     70      0.002377 LBF/    FT      +FIX701
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX702
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX703
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX704
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX705
+FIX705 940.0   960.0   980.0   1000.0  1020.0  1040.0  1060.0  1080.0  +FIX706
+FIX706 1100.0  1120.0  1140.0  1160.0  1180.0  1200.0  1220.0  1240.0  +FIX707
+FIX707 1260.0  1280.0  1300.0  1320.0  1340.0  1360.0  1380.0  1400.0  +FIX708
+FIX708 1420.0  1440.0  1460.0  1480.0  1500.0
$ case 80 Mach 0.80
$...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10..|
$MKAEROZ 80      0.80      -3      80      SAVE      CBTE0800r2.AIC      0      +MK1
MKAEROZ 80      0.80      -3      80      ACQUIRE   CBTE0800r2.AIC      0      +MK1
+MK1     0.025   0.075   0.15   0.3     0.5     0.75   1.0    1.2    +
+       1.6     2.0
TRIMFLT 80      80      1.0
INPCFD 80      101     10      P3D     goland.grid  goland_0.80.sol
FLUTTER 80     SYM     80      0      0      0
FIXMDEN 80     80      0.002377 LBF/    FT      +FIX701
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX702
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX703
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX704
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX705
+FIX705 940.0   960.0   980.0   1000.0  1020.0  1040.0  1060.0  1080.0  +FIX706
+FIX706 1100.0  1120.0  1140.0  1160.0  1180.0  1200.0  1220.0  1240.0  +FIX707
+FIX707 1260.0  1280.0  1300.0  1320.0  1340.0  1360.0  1380.0  1400.0  +FIX708
+FIX708 1420.0  1440.0  1460.0  1480.0  1500.0
$...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10..|
$MKAEROZ 85      0.85      -3      85      SAVE      CBTE0850r2.AIC      0      +MK1
MKAEROZ 85      0.85      -3      85      ACQUIRE   CBTE0850r2.AIC      0      +MK1
+MK1     0.025   0.075   0.15   0.3     0.5     0.75   1.0    1.2    +
+       1.6     2.0
TRIMFLT 85      85      1.0
$...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10..|
INPCFD 85      101     10      P3D     goland.grid  goland_0.85.sol
FLUTTER 85     SYM     85      0      0      0
FIXMDEN 85     85      0.002377 LBF/    FT      +FIX701
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX702
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX703
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX704
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX705
+FIX705 940.0   960.0   980.0   1000.0  1020.0  1040.0  1060.0  1080.0  +FIX706
+FIX706 1100.0  1120.0  1140.0  1160.0  1180.0  1200.0  1220.0  1240.0  +FIX707
+FIX707 1260.0  1280.0  1300.0  1320.0  1340.0  1360.0  1380.0  1400.0  +FIX708
+FIX708 1420.0  1440.0  1460.0  1480.0  1500.0
$...1...|...2...|...3...|...4...|...5...|...6...|...7...|...8...|...9...|...10..|
$MKAEROZ 88      0.88      -3      88      SAVE      CBTE0880r2.AIC      0      +MK1
MKAEROZ 88      0.88      -3      88      ACQUIRE   CBTE0880r2.AIC      0      +MK1
+MK1     0.025   0.075   0.15   0.3     0.5     0.75   1.0    1.2    +
+       1.6     2.0
TRIMFLT 88      88      1.0
INPCFD 88      101     10      P3D     goland.grid  goland_0.88.sol
FLUTTER 88     SYM     88      0      0      0
FIXMDEN 88     88      0.002377 LBF/    FT      +FIX701
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX702
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX703
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX704
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX705
+FIX705 940.0   960.0   980.0   1000.0  1020.0  1040.0  1060.0  1080.0  +FIX706

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+FIX706 1100.0 1120.0 1140.0 1160.0 1180.0 1200.0 1220.0 1240.0 +FIX707
+FIX707 1260.0 1280.0 1300.0 1320.0 1340.0 1360.0 1380.0 1400.0 +FIX708
+FIX708 1420.0 1440.0 1460.0 1480.0 1500.0
$. . . 1 . . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . . |
$MKAEROZ 90 0.90 -3 90 SAVE CBTE0900r2.AIC 0 +MK1
MKAEROZ 90 0.90 -3 90 ACQUIRE CBTE0900r2.AIC 0 +MK1
+MK1 0.025 0.075 0.15 0.3 0.5 0.75 1.0 1.2 +
+ 1.6 2.0
TRIMFLT 90 90 1.0
INPCFD 90 101 10 P3D goland.grid goland_0.90.sol
FLUTTER 90 SYM 90 0 0 0
FIXMDEN 90 90 0.002377 LBF/ FT +FIX701
+FIX701 300.0 320.0 340.0 360.0 380.0 400.0 420.0 440.0 +FIX702
+FIX702 460.0 480.0 500.0 520.0 540.0 560.0 580.0 600.0 +FIX703
+FIX703 620.0 640.0 660.0 680.0 700.0 720.0 740.0 760.0 +FIX704
+FIX704 780.0 800.0 820.0 840.0 860.0 880.0 900.0 920.0 +FIX705
+FIX705 940.0 960.0 980.0 1000.0 1020.0 1040.0 1060.0 1080.0 +FIX706
+FIX706 1100.0 1120.0 1140.0 1160.0 1180.0 1200.0 1220.0 1240.0 +FIX707
+FIX707 1260.0 1280.0 1300.0 1320.0 1340.0 1360.0 1380.0 1400.0 +FIX708
+FIX708 1420.0 1440.0 1460.0 1480.0 1500.0
$. . . 1 . . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . . |
$MKAEROZ 91 0.91 -3 91 SAVE CBTE0910r2.AIC 0 +MK1
MKAEROZ 91 0.91 -3 91 ACQUIRE CBTE0910r2.AIC 0 +MK1
+MK1 0.025 0.075 0.15 0.3 0.5 0.75 1.0 1.2 +
+ 1.6 2.0
TRIMFLT 91 91 1.0
INPCFD 91 101 10 P3D goland.grid goland_0.90.sol
FLUTTER 91 SYM 91 0 0 0
FIXMDEN 91 91 0.002377 LBF/ FT +FIX701
+FIX701 300.0 320.0 340.0 360.0 380.0 400.0 420.0 440.0 +FIX702
+FIX702 460.0 480.0 500.0 520.0 540.0 560.0 580.0 600.0 +FIX703
+FIX703 620.0 640.0 660.0 680.0 700.0 720.0 740.0 760.0 +FIX704
+FIX704 780.0 800.0 820.0 840.0 860.0 880.0 900.0 920.0 +FIX705
+FIX705 940.0 960.0 980.0 1000.0 1020.0 1040.0 1060.0 1080.0 +FIX706
+FIX706 1100.0 1120.0 1140.0 1160.0 1180.0 1200.0 1220.0 1240.0 +FIX707
+FIX707 1260.0 1280.0 1300.0 1320.0 1340.0 1360.0 1380.0 1400.0 +FIX708
+FIX708 1420.0 1440.0 1460.0 1480.0 1500.0
$. . . 1 . . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . . |
$MKAEROZ 92 0.92 -3 92 SAVE CBTE0920r2.AIC 0 +MK1
MKAEROZ 92 0.92 -3 92 ACQUIRE CBTE0920r2.AIC 0 +MK1
+MK1 0.025 0.075 0.15 0.3 0.5 0.75 1.0 1.2 +
+ 1.6 2.0
TRIMFLT 92 92 1.0
INPCFD 92 101 10 P3D goland.grid goland_0.92.sol
FLUTTER 92 SYM 92 0 0 0
FIXMDEN 92 92 0.002377 LBF/ FT +FIX701
+FIX701 300.0 320.0 340.0 360.0 380.0 400.0 420.0 440.0 +FIX702
+FIX702 460.0 480.0 500.0 520.0 540.0 560.0 580.0 600.0 +FIX703
+FIX703 620.0 640.0 660.0 680.0 700.0 720.0 740.0 760.0 +FIX704
+FIX704 780.0 800.0 820.0 840.0 860.0 880.0 900.0 920.0 +FIX705
+FIX705 940.0 960.0 980.0 1000.0 1020.0 1040.0 1060.0 1080.0 +FIX706
+FIX706 1100.0 1120.0 1140.0 1160.0 1180.0 1200.0 1220.0 1240.0 +FIX707
+FIX707 1260.0 1280.0 1300.0 1320.0 1340.0 1360.0 1380.0 1400.0 +FIX708
+FIX708 1420.0 1440.0 1460.0 1480.0 1500.0
$. . . 1 . . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . . |
$MKAEROZ 93 0.93 -3 93 SAVE CBTE0930r2.AIC 0 +MK1
MKAEROZ 93 0.93 -3 93 ACQUIRE CBTE0930r2.AIC 0 +MK1
+MK1 0.025 0.075 0.15 0.3 0.5 0.75 1.0 1.2 +
+ 1.6 2.0
TRIMFLT 93 93 1.0
INPCFD 93 101 10 P3D goland.grid goland_0.93.sol
FLUTTER 93 SYM 93 0 0 0
FIXMDEN 93 93 0.002377 LBF/ FT +FIX701
+FIX701 300.0 320.0 340.0 360.0 380.0 400.0 420.0 440.0 +FIX702
+FIX702 460.0 480.0 500.0 520.0 540.0 560.0 580.0 600.0 +FIX703
+FIX703 620.0 640.0 660.0 680.0 700.0 720.0 740.0 760.0 +FIX704
+FIX704 780.0 800.0 820.0 840.0 860.0 880.0 900.0 920.0 +FIX705
+FIX705 940.0 960.0 980.0 1000.0 1020.0 1040.0 1060.0 1080.0 +FIX706
+FIX706 1100.0 1120.0 1140.0 1160.0 1180.0 1200.0 1220.0 1240.0 +FIX707
+FIX707 1260.0 1280.0 1300.0 1320.0 1340.0 1360.0 1380.0 1400.0 +FIX708
+FIX708 1420.0 1440.0 1460.0 1480.0 1500.0
$. . . 1 . . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . . |
$MKAEROZ 95 0.95 -3 95 SAVE CBTE0950r2.AIC 0 +MK1

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MKAEROZ 95      0.95   -3      95      ACQUIRE  CBTE0950r2.AIC      0      +MK1
+MK1      0.025  0.075  0.15   0.3      0.5      0.75   1.0     1.2     +
+      1.6     2.0
TRIMFLT 95      95      1.0
INPCFD 95      101     10      P3D      goland.grid  goland_0.95.sol
FLUTTER 95      SYM     95      0        0        0
FIXMDEN 95      95      0.002377 LBF/    FT
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX701
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX703
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX704
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX705
+FIX705 940.0   960.0   980.0   1000.0  1020.0  1040.0  1060.0  1080.0  +FIX706
+FIX706 1100.0  1120.0  1140.0  1160.0  1180.0  1200.0  1220.0  1240.0  +FIX707
+FIX707 1260.0  1280.0  1300.0  1320.0  1340.0  1360.0  1380.0  1400.0  +FIX708
+FIX708 1420.0  1440.0  1460.0  1480.0  1500.0
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . . |
OMITCFD 10      TECPLOT SURFACE.PLT  SURFACE.SOL
      1      41      121     1      42      51      51
      2      41      121     1      42      1       1
CORD2R 101     0.0     0.0     0.0     0.0     0.0     -1.     0.0
      1.0     0.0     0.0

```

## APPENDIX G: Example Input File for ZAERO® ZTRAN, Navier Stokes CFD Model

```

$ ... Executive Control
ASSIGN FEM=basecw0000.f06, PRINT=0, FORM=MSC, BOUND=SYM
ASSIGN MATRIX =basecw0000.mgh, FORM=FORMAT, MNAME=SMGH, PRINT=0
MEMORY 850MB
$SOL -2
CEND
$ ... Case Control
TITLE   = AEROELASTIC ANALYSIS OF Goland Wing
ECHO    = SORT
  SUBCASE = 70
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.70, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 70
  SUBCASE = 80
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.80, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 80
  SUBCASE = 825
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.825, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 825
  SUBCASE = 85
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.85, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 85
  SUBCASE = 88
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.88, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 88
  SUBCASE = 90
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.90, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 90
  SUBCASE = 91
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.91, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 91
  SUBCASE = 92
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.92, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 92
  SUBCASE = 93
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.93, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 93
  SUBCASE = 95
    SUBTITLE = LINEAR FLUTTER ANALYSIS
    LABEL    = MACH NUMBER = 0.95, NON MATCHED-POINT FLUTTER ANALYSIS
    FLUTTER  = 95
$ ... Bulk Data Deck
BEGIN BULK
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
PLTVG      70      70      EQUV TABLE CBTN0700000.dat
PLTVG      80      80      EQUV TABLE CBTN0800000.dat
PLTVG     825     825     EQUV TABLE CBTN8250000.dat
PLTVG      85      85      EQUV TABLE CBTN0850000.dat
PLTVG      88      88      EQUV TABLE CBTN0880000.dat
PLTVG      90      90      EQUV TABLE CBTN0900000.dat
PLTVG      91      91      EQUV TABLE CBTN0910000.dat
PLTVG      92      92      EQUV TABLE CBTN0920000.dat
PLTVG      93      93      EQUV TABLE CBTN0930000.dat
PLTVG      95      95      EQUV TABLE CBTN0950000.dat
include 'baseaero.inp'
include 'alt_mkz_cw_ns.inp'
ENDDATA

$ 'baseaero.inp'
$ AERODYNAMIC PANELS AND SPLINE
$
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
CORD2R      11      0.000  0.000  0.000  0.000  0.000  1.000+CR11

```

```

+CR11      0.000  -1.000   1.000
$
$ MAIN WING
$. . . 1 . . | . . . 2 . . | . . . 3 . . | . . . 4 . . | . . . 5 . . | . . . 6 . . | . . . 7 . . | . . . 8 . . | . . . 9 . . | . . . 10 . . |
ACOORD      50      0.0      0.0      0.0      0.0      0.0      0.0      0.0
$
$ Aerodynamic Model
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
CAERO7 100001  GOLAND      21      39      0      0      100001  +ARO101
+ARO101 0.0      0.0      0.0      6.0      0      0      0      0      +ARO102
+ARO102 0.0      20.0     0.0      6.0      0      0      0      0
CELLWNG 10001  100001     1      3      20001
7      6.0      6.0      0.      0.      COS      4      6
7      6.0      6.0      0.      0.      COS      4      6
2      .6      .6      2      .6      .6
CELLWNG 20001  100001     3      5      10001  30001
7      6.0      6.0      0.      0.      COS      4      6
7      6.0      6.0      0.      0.      COS      4      6
2      .6      .6      2      .6      .6
CELLWNG 30001  100001     5      7      20001  40001
7      6.0      6.0      0.      0.      COS      4      6
7      6.0      6.0      0.      0.      COS      4      6
2      .6      .6      2      .6      .6
CELLWNG 40001  100001     7      9      30001  50001
7      6.0      6.0      0.      0.      COS      4      6
7      6.0      6.0      0.      0.      COS      4      6
2      .6      .6      2      .6      .6
CELLWNG 50001  100001     9      11     40001  60001
7      6.0      6.0      0.      0.      COS      4      6
7      6.0      6.0      0.      0.      COS      4      6
2      .6      .6      2      .6      .6
CELLWNG 60001  100001    11     13     50001  70001
7      6.0      6.0      0.      0.      COS      4      6
7      6.0      6.0      0.      0.      COS      4      6
2      .6      .6      2      .6      .6
CELLWNG 70001  100001    13     15     60001  80001
7      6.0      6.0      0.      0.      COS      4      6
7      6.0      6.0      0.      0.      COS      4      6
2      .6      .6      2      .6      .6
CELLWNG 80001  100001    15     17     70001  90001
7      6.0      6.0      0.      0.      COS      4      6
7      6.0      6.0      0.      0.      COS      4      6
2      .6      .6      2      .6      .6
CELLWNG 90001  100001    17     19     80001  100001
7      6.0      6.0      0.      0.      COS      4      6
7      6.0      6.0      0.      0.      COS      4      6
2      .6      .6      2      .6      .6
CELLWNG 100001 100001    19     21     90001
7      6.0      6.0      0.      0.      COS      4      6
7      6.0      6.0      0.      0.      COS      4      6
2      .6      .6      2      .6      .6
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
PAFOIL7 100001  100002  100003  100004      100003  100004
AEFACT 100002  0.00      5.00     10.00    15.00    20.00    25.00    30.00      +AEF201
+AEF201 35.00     40.00     45.00    50.00    55.00    60.00    65.00    70.00      +AEF202
+AEF202 75.00     80.00     85.00    90.00    95.00    100.00
AEFACT 100003  0.0000    0.38     0.72     1.02     1.28     1.50     1.68      +AEF301
+AEF301 1.82      1.92      1.98     2.00     1.98     1.92     1.82     1.68      +AEF302
+AEF302 1.50      1.28      1.02     0.72     0.38     0.0000
AEFACT 100004  0.00      0.00     0.00     0.00     0.00     0.00     0.00     0.00      +AEF401
+AEF401 0.00      0.00     0.00     0.00     0.00     0.00     0.00     0.00      +AEF402
+AEF402 0.00      0.00     0.00     0.00     0.00     0.00
AEROZ 0      YES      NO      6.0      20.0     120.0    +AERO01
+AERO01 1.5      0.0      0.0
$ Spline
SPLINE1 100001      100001  101
PANLST3 100001  GOLAND
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
SET1 101      10000  10001  10002  10100  10101  10102      10200+ET101
+ET101 10201  10202  10300  10301  10302  10400  10401      10402+ET101A
+ET101A 10500  10501  10502  10600  10601  10602  10700      10701+ET101B
+ET101B 10702  10800  10801  10802  10900  10901  10902      11000+ET101C
+ET101C 11001  11002

```

```

$ STATEMENT TO CHECK COORDINATE SYSTEM OF CFD MESH, AERODYNAMIC MODEL AND
$ FINITE ELEMENT MODEL.
$. . . . . 2 . . . . . 3 . . . . . 4 . . . . . 5 . . . . . 6 . . . . . 7 . . . . . 8 . . . . . 9 . . . . . 10 . . . . . $
PLTAERO 100   YES          TECPLOT AEROSTRUC_CS.PLTYES   YES
$

$'alt_mkz_cw_ns.inp'
$ case 70 Mach 0.70
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
$      IDMK   MACH   METHOD  IDFLT   SAVE   <--FILENAME-->  PRINT   $
$      FREQ1  FREQ2  ETC
$MKAEROZ 70    0.70   -3      70      SAVE   CBTN0700r2.AIC    0      +MK1
MKAEROZ 70    0.70   -3      70      ACQUIRE CBTN0700r2.AIC    0      +MK1
+MK1     0.025  0.075  0.15   0.3     0.5     0.75    1.0     1.2     +
+       1.6    2.0
TRIMFLT 70    70      1.0
INPCFD  70    101     10      PLOT3D  goland_NS.grid    $70
EXTFILE 70    goland_0.7_ns.sol
FLUTTER 70    SYM     70      0       0       0
FIXMDEN 70    70      0.002377 LBF/    FT
+FIX701 300.0  320.0  340.0  360.0  380.0  400.0  420.0  440.0  +FIX701
+FIX702 460.0  480.0  500.0  520.0  540.0  560.0  580.0  600.0  +FIX702
+FIX703 620.0  640.0  660.0  680.0  700.0  720.0  740.0  760.0  +FIX703
+FIX704 780.0  800.0  820.0  840.0  860.0  880.0  900.0  920.0  +FIX704
+FIX705 940.0  960.0  980.0  1000.0 1020.0 1040.0 1060.0 1080.0 +FIX705
+FIX706 1100.0 1120.0 1140.0 1160.0 1180.0 1200.0 1220.0 1240.0 +FIX706
+FIX707 1260.0 1280.0 1300.0 1320.0 1340.0 1360.0 1380.0 1400.0 +FIX707
+FIX708 1420.0 1440.0 1460.0 1480.0 1500.0
$ case 80 Mach 0.80
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
$MKAEROZ 80    0.80   -3      80      SAVE   CBTN0800r2.AIC    0      +MK1
MKAEROZ 80    0.80   -3      80      ACQUIRE CBTN0800r2.AIC    0      +MK1
+MK1     0.025  0.075  0.15   0.3     0.5     0.75    1.0     1.2     +
+       1.6    2.0
TRIMFLT 80    80      1.0
INPCFD  80    101     10      PLOT3D  goland_NS.grid    $80
EXTFILE 80    goland_0.8_ns.sol
FLUTTER 80    SYM     80      0       0       0
FIXMDEN 80    80      0.002377 LBF/    FT
+FIX701 300.0  320.0  340.0  360.0  380.0  400.0  420.0  440.0  +FIX701
+FIX702 460.0  480.0  500.0  520.0  540.0  560.0  580.0  600.0  +FIX702
+FIX703 620.0  640.0  660.0  680.0  700.0  720.0  740.0  760.0  +FIX703
+FIX704 780.0  800.0  820.0  840.0  860.0  880.0  900.0  920.0  +FIX704
+FIX705 940.0  960.0  980.0  1000.0 1020.0 1040.0 1060.0 1080.0 +FIX705
+FIX706 1100.0 1120.0 1140.0 1160.0 1180.0 1200.0 1220.0 1240.0 +FIX706
+FIX707 1260.0 1280.0 1300.0 1320.0 1340.0 1360.0 1380.0 1400.0 +FIX707
+FIX708 1420.0 1440.0 1460.0 1480.0 1500.0
$ case 825 Mach 0.825
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
$MKAEROZ 825   0.825  -3      825     SAVE   CBTN0825r2.AIC    0      +MK1
MKAEROZ 825   0.825  -3      825     ACQUIRE CBTN0825r2.AIC    0      +MK1
+MK1     0.025  0.075  0.15   0.3     0.5     0.75    1.0     1.2     +
+       1.6    2.0
TRIMFLT 825   825     1.0
INPCFD  825   101     10      PLOT3D  goland_NS.grid    $825
EXTFILE 825   goland_0.825_ns.sol
FLUTTER 825   SYM     825     0       0       0
FIXMDEN 825   825     0.002377 LBF/    FT
+FIX701 300.0  320.0  340.0  360.0  380.0  400.0  420.0  440.0  +FIX701
+FIX702 460.0  480.0  500.0  520.0  540.0  560.0  580.0  600.0  +FIX702
+FIX703 620.0  640.0  660.0  680.0  700.0  720.0  740.0  760.0  +FIX703
+FIX704 780.0  800.0  820.0  840.0  860.0  880.0  900.0  920.0  +FIX704
+FIX705 940.0  960.0  980.0  1000.0 1020.0 1040.0 1060.0 1080.0 +FIX705
+FIX706 1100.0 1120.0 1140.0 1160.0 1180.0 1200.0 1220.0 1240.0 +FIX706
+FIX707 1260.0 1280.0 1300.0 1320.0 1340.0 1360.0 1380.0 1400.0 +FIX707
+FIX708 1420.0 1440.0 1460.0 1480.0 1500.0
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
$MKAEROZ 85    0.85   -3      85      SAVE   CBTN0850r2.AIC    0      +MK1
MKAEROZ 85    0.85   -3      85      ACQUIRE CBTN0850r2.AIC    0      +MK1
+MK1     0.025  0.075  0.15   0.3     0.5     0.75    1.0     1.2     +
+       1.6    2.0
TRIMFLT 85    85      1.0
INPCFD  85    101     10      PLOT3D  goland_NS.grid    $85

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EXTFILE 85      goland_0.85_ns.sol
FLUTTER 85      SYM      85          0          0          0
FIXMDEN 85      85      0.002377  LBF/    FT          +FIX701
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX702
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX703
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX704
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX705
+FIX705 940.0   960.0   980.0  1000.0  1020.0  1040.0  1060.0  1080.0  +FIX706
+FIX706 1100.0  1120.0  1140.0  1160.0  1180.0  1200.0  1220.0  1240.0  +FIX707
+FIX707 1260.0  1280.0  1300.0  1320.0  1340.0  1360.0  1380.0  1400.0  +FIX708
+FIX708 1420.0  1440.0  1460.0  1480.0  1500.0
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
$MKAEROZ 88      0.88      -3          88      SAVE      CBTN0880r2.AIC      0          +MK1
MKAEROZ 88      0.88      -3          88      ACQUIRE  CBTN0880r2.AIC      0          +MK1
+MK1      0.025   0.075   0.15      0.3      0.5      0.75     1.0      1.2      +
+      1.6      2.0
TRIMFLT 88      88      1.0
INPCFD 88      101     10          PLOT3D   goland_NS.grid      $88
EXTFILE 88      goland_0.88_ns.sol
FLUTTER 88      SYM      88          0          0          0
FIXMDEN 88      88      0.002377  LBF/    FT          +FIX701
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX702
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX703
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX704
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX705
+FIX705 940.0   960.0   980.0  1000.0  1020.0  1040.0  1060.0  1080.0  +FIX706
+FIX706 1100.0  1120.0  1140.0  1160.0  1180.0  1200.0  1220.0  1240.0  +FIX707
+FIX707 1260.0  1280.0  1300.0  1320.0  1340.0  1360.0  1380.0  1400.0  +FIX708
+FIX708 1420.0  1440.0  1460.0  1480.0  1500.0
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
$MKAEROZ 90      0.90      -3          90      SAVE      CBTN0900r2.AIC      0          +MK1
MKAEROZ 90      0.90      -3          90      ACQUIRE  CBTN0900r2.AIC      0          +MK1
+MK1      0.025   0.075   0.15      0.3      0.5      0.75     1.0      1.2      +
+      1.6      2.0
TRIMFLT 90      90      1.0
INPCFD 90      101     10          PLOT3D   goland_NS.grid      $90
EXTFILE 90      goland_0.9_ns.sol
FLUTTER 90      SYM      90          0          0          0
FIXMDEN 90      90      0.002377  LBF/    FT          +FIX701
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX702
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX703
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX704
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX705
+FIX705 940.0   960.0   980.0  1000.0  1020.0  1040.0  1060.0  1080.0  +FIX706
+FIX706 1100.0  1120.0  1140.0  1160.0  1180.0  1200.0  1220.0  1240.0  +FIX707
+FIX707 1260.0  1280.0  1300.0  1320.0  1340.0  1360.0  1380.0  1400.0  +FIX708
+FIX708 1420.0  1440.0  1460.0  1480.0  1500.0
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
$MKAEROZ 91      0.91      -3          91      SAVE      CBTN0910r2.AIC      0          +MK1
MKAEROZ 91      0.91      -3          91      ACQUIRE  CBTN0910r2.AIC      0          +MK1
+MK1      0.025   0.075   0.15      0.3      0.5      0.75     1.0      1.2      +
+      1.6      2.0
TRIMFLT 91      91      1.0
INPCFD 91      101     10          PLOT3D   goland_NS.grid      $91
EXTFILE 91      goland_0.91_ns.sol
FLUTTER 91      SYM      91          0          0          0
FIXMDEN 91      91      0.002377  LBF/    FT          +FIX701
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX702
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX703
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX704
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX705
+FIX705 940.0   960.0   980.0  1000.0  1020.0  1040.0  1060.0  1080.0  +FIX706
+FIX706 1100.0  1120.0  1140.0  1160.0  1180.0  1200.0  1220.0  1240.0  +FIX707
+FIX707 1260.0  1280.0  1300.0  1320.0  1340.0  1360.0  1380.0  1400.0  +FIX708
+FIX708 1420.0  1440.0  1460.0  1480.0  1500.0
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
$MKAEROZ 92      0.92      -3          92      SAVE      CBTN0920r2.AIC      0          +MK1
MKAEROZ 92      0.92      -3          92      ACQUIRE  CBTN0920r2.AIC      0          +MK1
+MK1      0.025   0.075   0.15      0.3      0.5      0.75     1.0      1.2      +
+      1.6      2.0
TRIMFLT 92      92      1.0
INPCFD 92      101     10          PLOT3D   goland_NS.grid      $92
EXTFILE 92      goland_0.92_ns.sol

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FLUTTER 92      SYM      92          0          0          0
FIXMDEN 92      92      0.002377 LBF/      FT          +FIX701
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX702
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX703
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX704
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX705
+FIX705 940.0   960.0   980.0   1000.0  1020.0  1040.0  1060.0  1080.0  +FIX706
+FIX706 1100.0  1120.0  1140.0  1160.0  1180.0  1200.0  1220.0  1240.0  +FIX707
+FIX707 1260.0  1280.0  1300.0  1320.0  1340.0  1360.0  1380.0  1400.0  +FIX708
+FIX708 1420.0  1440.0  1460.0  1480.0  1500.0
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
$MKAEROZ 93      0.93      -3          93          SAVE      CBTN0930r2.AIC      0          +MK1
MKAEROZ 93      0.93      -3          93          ACQUIRE  CBTN0930r2.AIC      0          +MK1
+MK1      0.025   0.075   0.15      0.3          0.5          0.75      1.0          1.2          +
+      1.6          2.0
TRIMFLT 93      93          1.0
INPCFD 93      101      10          PLOT3D      goland_NS.grid      $93
EXTFILE 93      goland_0.93_ns.sol
FLUTTER 93      SYM      93          0          0          0
FIXMDEN 93      93      0.002377 LBF/      FT          +FIX701
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX702
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX703
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX704
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX705
+FIX705 940.0   960.0   980.0   1000.0  1020.0  1040.0  1060.0  1080.0  +FIX706
+FIX706 1100.0  1120.0  1140.0  1160.0  1180.0  1200.0  1220.0  1240.0  +FIX707
+FIX707 1260.0  1280.0  1300.0  1320.0  1340.0  1360.0  1380.0  1400.0  +FIX708
+FIX708 1420.0  1440.0  1460.0  1480.0  1500.0
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
$MKAEROZ 95      0.95      -3          95          SAVE      CBTN0950r2.AIC      0          +MK1
MKAEROZ 95      0.95      -3          95          ACQUIRE  CBTN0950r2.AIC      0          +MK1
+MK1      0.025   0.075   0.15      0.3          0.5          0.75      1.0          1.2          +
+      1.6          2.0
TRIMFLT 95      95          1.0
INPCFD 95      101      10          PLOT3D      goland_NS.grid      $95
EXTFILE 95      goland_0.95_ns.sol
FLUTTER 95      SYM      95          0          0          0
FIXMDEN 95      95      0.002377 LBF/      FT          +FIX701
+FIX701 300.0   320.0   340.0   360.0   380.0   400.0   420.0   440.0   +FIX702
+FIX702 460.0   480.0   500.0   520.0   540.0   560.0   580.0   600.0   +FIX703
+FIX703 620.0   640.0   660.0   680.0   700.0   720.0   740.0   760.0   +FIX704
+FIX704 780.0   800.0   820.0   840.0   860.0   880.0   900.0   920.0   +FIX705
+FIX705 940.0   960.0   980.0   1000.0  1020.0  1040.0  1060.0  1080.0  +FIX706
+FIX706 1100.0  1120.0  1140.0  1160.0  1180.0  1200.0  1220.0  1240.0  +FIX707
+FIX707 1260.0  1280.0  1300.0  1320.0  1340.0  1360.0  1380.0  1400.0  +FIX708
+FIX708 1420.0  1440.0  1460.0  1480.0  1500.0
$. . . 1 . . | . . . 2 . . . | . . . 3 . . . | . . . 4 . . . | . . . 5 . . . | . . . 6 . . . | . . . 7 . . . | . . . 8 . . . | . . . 9 . . . | . . . 10 . . |
OMITCFD 10      TECPLOT SURFACE.PLT SURFACE.SOL
      1          1          81          1          65          1          10
      2          1          81          1          65          1          10
CORD2R 101      0.0          0.0          0.0          0.0          0.0          -1.          0.0
      1.0          0.0          0.0

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