

MissileLab: An Expert System for Rapid Aerodynamic Trade Studies

L.M. Auman
U.S. Army Aviation and Missile RDEC
Redstone Arsenal, AL 35898

ABSTRACT

An expert system for aerodynamic trade-space analysis has been developed and is being used by several government agencies and industry. Expert systems, like *MissileLab*, are needed in all areas of the missile/UAV design-space technology areas and will enable the Army to meet transformation goals of a lighter, rapidly deployable force with increased lethality and survivability, in a cost-effective and timely manner.

This paper presents an overview of the functionality and capabilities of *MissileLab* and briefly discusses enhancements being made by a joint Army/Air Force team on the legacy aerodynamic prediction tool *Missile DATCOM*.

1. BACKGROUND

To meet the Army's transformation goals of a lighter, rapidly deployable force with increased lethality and survivability, the missile community must develop new missile systems that are themselves lighter, more lethal, cost-effective and compact. Several Army missile technology programs currently underway will play an important role in improving survivability of Army personnel and material. To meet the technology objectives, these programs must find a solution-space where lethality, cost, and size are tightly woven together.

These new, compact missile systems will likely be highly integrated systems that evolve from numerous system level trade-studies addressing the various mission needs statements. The trade-studies must be performed quickly, but with increased fidelity to reduce the possibilities of unforeseen problems requiring "configuration re-design/re-start."

The Aerodynamics Technology Functional Area of the System Simulation and Development Directorate of the US Army Aviation and Missile Research, Development, and Engineering

Center (AMRDEC) is actively working two fronts that address the issues of rapid trade-studies and increased fidelity in our aerodynamic predictions. The first is the development of *MissileLab*, a *MicroSoft® Windows*-based graphical expert system that allows the aerodynamicist to define a candidate missile/UAV configuration one time and then run multiple aerodynamic prediction codes. The second front being addressed is improvement of the predictive capabilities of the industry-standard aerodynamic prediction code *Missile DATCOM*. This paper shall focus on *MissileLab*, and summarize the *Missile DATCOM* enhancements.

2. INTRODUCTION

In the early stages of missile system design, it is necessary to have the means to quickly and accurately estimate the aerodynamics of a wide variety of missile configuration designs operating over many different flight regimes. The ultimate shape and aerodynamic performance of a missile are highly dependent on mission requirements (range, maneuverability, weight, radar cross-section) and subsystems (payload, propulsion, control actuation system, launch mechanism). Therefore, the applied aerodynamicist must be capable of reliably predicting aerodynamic trends on a wide variety of configurations in a timely manner.

Engineering-level codes provide an immediate means to determine the aerodynamic characteristics of a flight vehicle configuration. The foundations of these codes are extensive databases of experimental tests performed by NASA, the Army, Air Force, and Navy. A combination of mathematical expressions and table lookups define the semi-empirical nature of these Aerodynamic Prediction Engines (APEs).

For missile applications, the most frequently used semi-empirical codes are *Missile DATCOM*¹, *AeroPrediction* code (version AP98², AP02³, and the recently released AP05⁴), *NEAR*

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MISL3⁵, NEAR MISDL⁶, and HASC⁷. Unfortunately, these codes require significantly different input decks; therefore, the applied aerodynamicist must work through the tedious process of setting up input files for the different codes. This process introduces the potential for error, slowing the aerodynamicist's ability to quickly and reliably provide results to the design team. Additionally, while these APEs have very thick user's guides to aid the engineer in setting up cases, it has been found that not all users "interpret" the documentation the same, leading to additional sources for error.

It is advisable to run multiple APEs during the design trade process to increase the confidence level associated with the results. However, with ever-increasing demands to shorten program development timelines, the aerodynamicist must sometimes choose between conducting additional analysis and meeting schedule demands. The entire design team must find ways to increase the efficiency and accuracy of the initial configuration trade study phase.

MissileLab was created to address these issues. *MissileLab* queries the user for standard missile geometric data, draws 2D and 3D representations of the missile allowing the user to confirm the configuration, validates data entries against an APE code specific rule-set, generates APE specific input files, runs the APE specific codes, and archives the results for data analysis. *MissileLab* has built-in help, mass properties, and automatic calculation functions to aid the aerodynamicist in case setup.

3. MISSILELAB

Six examples of various missile and Unmanned Aerial Vehicles (UAV) configurations are presented in **Figure 1** to illustrate the range of airframes that *MissileLab* has been designed to address. Armed with a line drawing of the configuration, a new *MissileLab* user following the step-by-step input screens and built-in help topics can typically generate any of these configurations in 15 minutes.

Figure 2 and **Figure 3** present the body and wing/fin input screens. These screens represent two typical examples of the various input screens. From these figures it is seen that a combination of pull-down menus, radio button

controls and text-box entry fields are used to interrogate the user. A "Help Topics" panel is featured on each screen to provide on-line documentation pertinent to the particular screen. Additional detailed documentation is also provided via the Help control located in the menu bar at the top of the screen.

The wing/fin geometry input screen (**Figure 3**) features additional controls that allow the user to view the geometry as defined, view the geometry as it will be exported to the various APEs (if simplifications are required by the specific APE), and view important aerodynamic parameters of the lifting surface (such as planform area, aspect ratio, mean aerodynamic chord length, and area centroid).

The vast majority of the input fields are automatically mapped by *MissileLab* to the input file for the specific APE(s) that the user chooses to run. However, as each APE has its own unique capabilities and functionality, additional code-specific inputs are occasionally required. When this is the case, the particular parameter is called out for the specific APE. This way the user knows that these inputs are specific to a single Aerodynamic Prediction Engine.

Once the geometry has been defined, the user should use the various 2D and 3D geometry sketching tools to view the configuration as this is the simplest way of confirming that the data entered is truly representative of the intended configuration. **Figure 4** presents the 2D sketch window and controls, and **Figure 5** presents additional examples of the types of sketches that are available. As configuration documentation is an important part of the trade analysis, all sketches can be copied to the *Microsoft* "Clipboard" and then inserted into most *Windows*-based applications.

Once the geometry has been viewed in the sketcher, and other inputs (such as reference length, reference area, flight conditions, etc.) have been entered, the user should then view the *MissileLab* Warning Screen. For most typical missile configurations, the user will find the comment "No Warnings/Errors detected". However, as illustrated in **Figure 6**, *MissileLab* has scanned all inputs and found both "non-critical warnings" (shown in blue) and "critical errors" (shown in red) for the example configuration.

Non-critical warnings may be generated by a number of things but usually relate to slight modification of the geometry that *MissileLab* has to make to run a specific APE. Critical errors are generated when the configuration can not be exported to a specific APE as the configuration is outside the bounds of the specific code. In both cases, *MissileLab* provides a detailed explanation of the warning/error. If only non-critical warnings are generated, the user may proceed and run the desired prediction code(s) or may elect to return to the geometry screens and make changes. If critical errors are encountered, *MissileLab* disables the associated APE and the user is not allowed to select that code on the Export Data/Run Codes screen (shown in **Figure 7**). All communication between *MissileLab* and the various APEs is conducted via the documented input and output files for the specific APE.

The warnings and errors feature of *MissileLab* significantly improves user confidence in APE results by meticulously checking all input fields against a rule set. The rule set was developed by critical inspection of input/output files generated by users of various experience levels, by consultation with the various APE code developers, and by careful review of APE documentation. The various warnings and errors may be generalized into several classes of message types. The number of message types per prediction code is presented in **Table 1**.

Additional tools, such as the mass properties estimator tool shown in **Figure 8** and APE output file parsing scripts provide additional time savings for the applied aerodynamicist.

4. MISSILE DATCOM

A joint collaborative effort between the Air Force (Wright-Patterson AFB) and the Army (Redstone Arsenal) began in 2005 to address gaps in the aerodynamic predictive capabilities in the legacy code *Missile DATCOM*. The 2005 efforts resulted in a new version released by the Air Force in January 2006. This version included elimination of “dead” and redundant code, code “clean-up”, improvements to the cylindrical body prediction methods, and the addition of new data output formats.

Table 1: Classes of Error/Warning Messages

APE	# of Message Classes	
	Critical Error	Warnings
DATCOM ¹	15	13
APxx ^{2,3,4}	18	17
NEAR MISL3 ⁵	21	23
NEAR MISDL ⁶	Under Dev	Under Dev
HASC ⁷	Under Dev	Under Dev

The current effort is focusing on virtually every area of *Missile DATCOM* and includes improvements for low aspect ratio wings/fins, improvements for high fineness ratio bodies (high length-to-diameter ratio), improvements for non-traditional body shapes (such as elliptical cross-section bodies), improvements for fins with flaps for control, and other areas. This version of *Missile DATCOM* is scheduled to be released in January 2007.

CONCLUSIONS

MissileLab was first introduced to the US missile community in January of 2005. Since that time numerous US industry missile developers as well as several other US government agencies have requested the use of *MissileLab* as a means of increasing their efficiency and the accuracy of their aerodynamic predictions.

In January of 2006, the 2005 enhancements to *Missile DATCOM* were briefed to the missile community and as a result the Air Force has received over 40 requests for the updated code. This response illustrates the need for quick aerodynamic prediction codes, and underscores the fact that these types of codes must be maintained and enhanced to address the evolving needs of the missile community.

Investment in process improvement and upgrades to legacy aerodynamic prediction tools has allowed AMRDEC and our industry users to increase aerodynamic trade-space analysis throughput and have greater confidence in the initial trade analysis. Leveraging wind tunnel test data acquired for AMRDEC technology programs, new methods and capabilities are being incorporated into legacy prediction tools used by all branches of the government and industry.

To meet the Army's transformation goals of a lighter, rapidly deployable force with increased lethality and survivability, the missile community must continue to invest in technology and process improvement which enables the development of new missile systems that are themselves lighter, more lethal, cost effective and compact. Development of Expert Systems, like *MissileLab*, increases productivity and serves as a tool for training young engineers.

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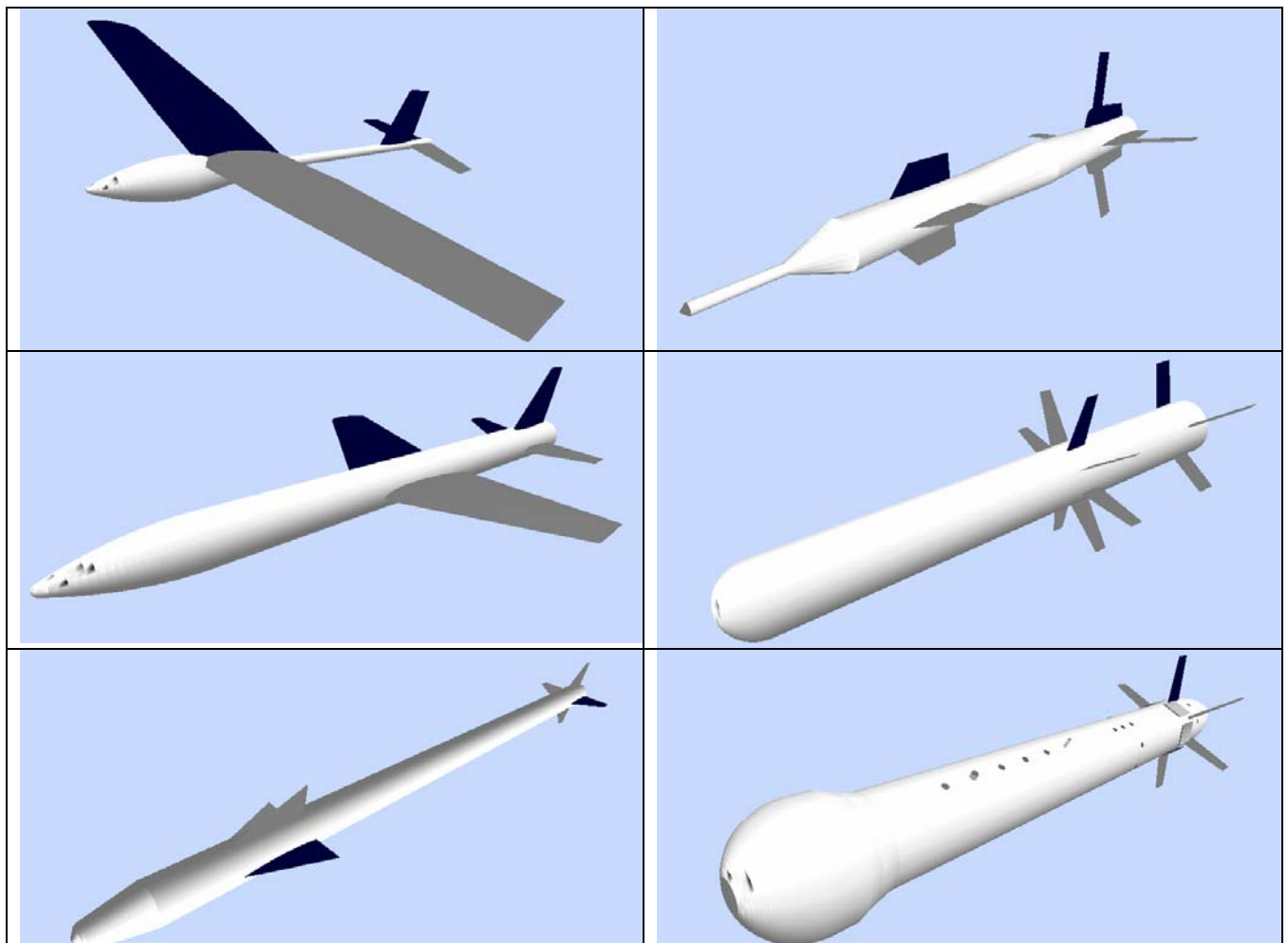


Figure 1. Possible *MissileLab* geometry configurations

MissileLab

File Setup Sketch Help

MENU OPTIONS

- 1 Set up MissileLab Project
- 2 Define Geometry
 - Body
 - FinSets
 - Protuberances
 - Inlets
- 3 Define Reference Values
- 4 Define RunTime Conditions
- 5 Define DATCOM-Specific Inputs
- 6 Define APxx-Specific Inputs
- 7 Define NEAR MSL3 Specific Inputs
- 8 Define Multiple Runs
- 9 Define AeroLab Database
- 10 View Warnings
 - DATCOM Warnings
 - AP Warnings
 - MSL3/M3FLR Warnings
- 11 Export Data / Run Predictions
- 12 Tools
 - View Data / Create Database
 - Estimate Mass Properties

HELP TOPICS

This form is used to build body geometry.

The units for all length inputs are inches and degrees for any angles.

When using User-Defined geometry, the longitudinal position is measured from station 0.0 (typically the nose tip). Also when using User-Defined geometry, Right-Clicking on a column will allow removal of that body point or notation of a discontinuity.

*When using the User-Defined body type, the camber variable only applies to DATCOM. If data is entered, it will be output to the DATCOM file, but only versions '05 and above will run. If no data is entered in this row, then no Z variable will be output.

Project Name: Example Configuration Name: Sample-001 Input Units: INCHES

BODY

Cross Section Shape: Axisymmetric AP INPUT: Height of Rotating Band (HB): Display Geometric Coordinates Sketch Body

Define Nose

Geometry: Ogive

Length of Nose: 31.00 Nose Tip: Pointed

Radius at Base of Nose: 6.75

Define CenterBody

Number of Segments: 1

Segment 1

Geometry: Cylinder or Const Radius Length: 153.00

Cylinder or Const Radius
Cone - Known Radius
Cone - Known Half-Angle
User-Defined

Define AltBody

Alt Type: None

Figure 2. Body geometry definition screen

MissileLab

File Setup Sketch Help

MENU OPTIONS

- 1 Set up MissileLab Project
- 2 Define Geometry
 - Body
 - FinSets
 - Protuberances
 - Inlets
- 3 Define Reference Values
 - Body References
- 4 Define RunTime Conditions
 - Geometry Parameters
 - Flight Conditions
 - Deflections / Trim
 - Base Effects
 - Inlet Additive Drag
- 5 Define DATCOM-Specific Inputs
- 6 Define APxx-Specific Inputs
- 7 Define NEAR MSL3 Specific Inputs
- 8 Define Multiple Runs
- 9 Define AeroLab Database
- 10 View Warnings

HELP TOPICS

This form is used to build fin geometry.

The units for all length inputs are inches and degrees for any angles.

Right-Clicking on a column will allow removal of that column. The minimum number of Span locations is two and the maximum is 10.

For User-Defined Airfoils, the minimum number of User coordinates is 2 and the maximum is 50. If using a User-Defined airfoil, the origin of the coordinates is the Leading Edge on the chord line. Note that the inputs for the User type are in fraction of chord. Also, note that HEX and ARC inputs have been simplified and are dimensional inputs now.

Hinge line longitudinal position should be

Project Name: Example Configuration Name: Sample-001 Input Units: INCHES

FINSETS

Number of FinSets: 2

FinSet 1

Copy FinSet # OK

Define Fin

Define by Leading Edge Locations Define by Sweep Angle

Airfoil Section Type: HEX Distance to Root Chord Leading Edge: 59.10

Number of Spanwise Stations: 4

	Sta1	Sta2	Sta3	Sta4
Semi-Span	6.75	8.75	8.76	11.75
Chord Length	104.00	97.00	73.20	62.18
Ratio of Flap Chord to Fin Chord				
Leading Edge Radius	0.125	0.125	0.05	0.05
Sweep Angle	0.00	0.00	0.00	
Sweep at LE (0.0) or TE (1.0)	1.00	1.00	1.00	
Fin Thickness	1.9968	1.9982	1.99104	0.24872
Length of Leading Edge Wedge	5.20	5.335	5.124	4.9744
Length of Flat Section	93.60	86.33	62.952	52.2312

AP05 Input

Truncated Leading Edge

APxx \ MSL3 Inputs

Root Trailing Edge Radius: Tip Trailing Edge Radius:

Define Panels

Number of Panels: 4

	Panel1	Panel2	Panel3	Panel4
Orientation	0	90	180	270
Dihedral				

Define Hinge Line

Longitudinal Position: Skew Angle:

Figure 3. Fin/wing geometry definition screen

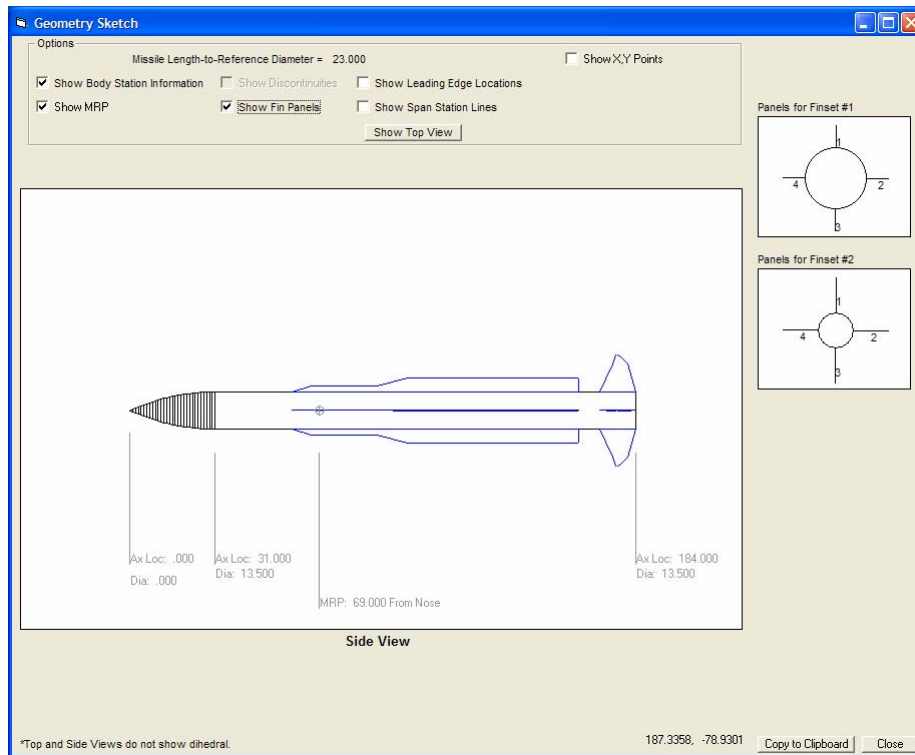


Figure 4. 2D sketcher control screen

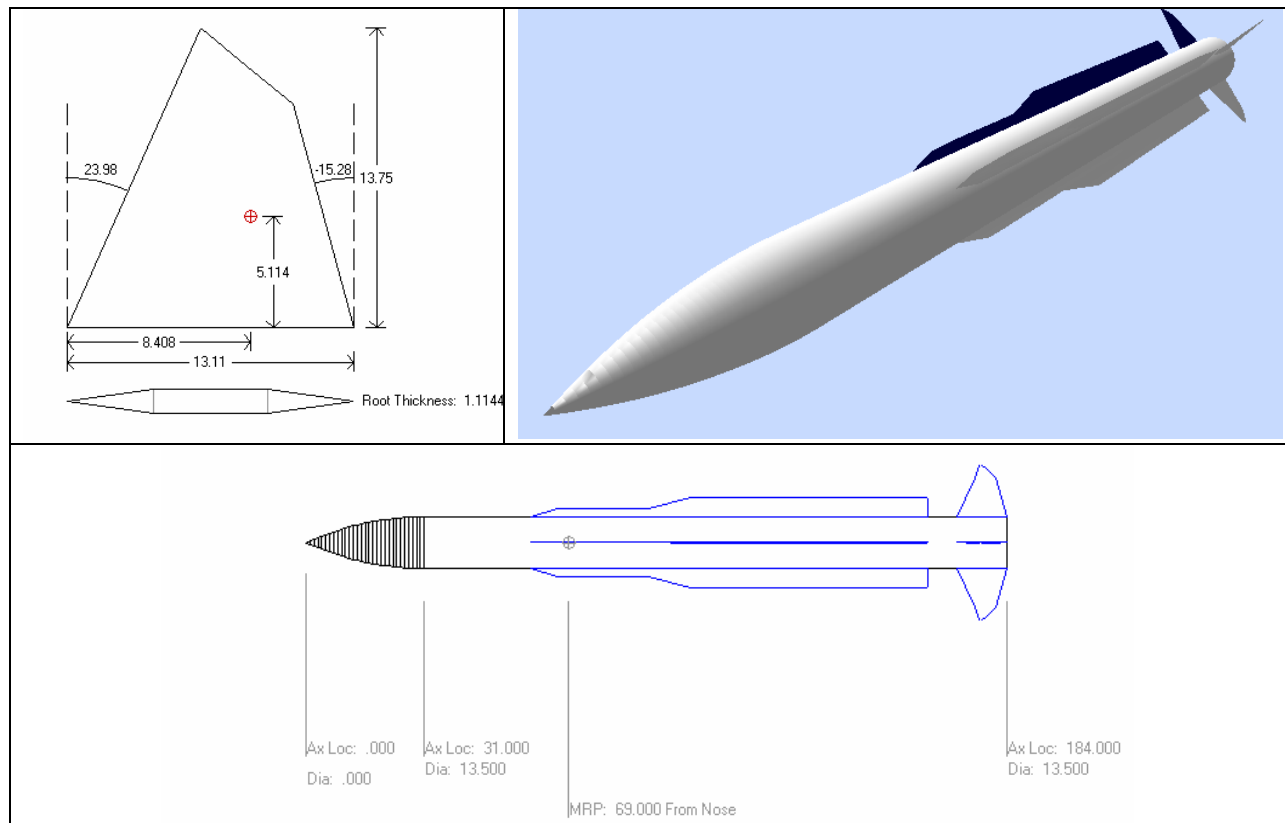


Figure 5. 2D and 3D sketch output

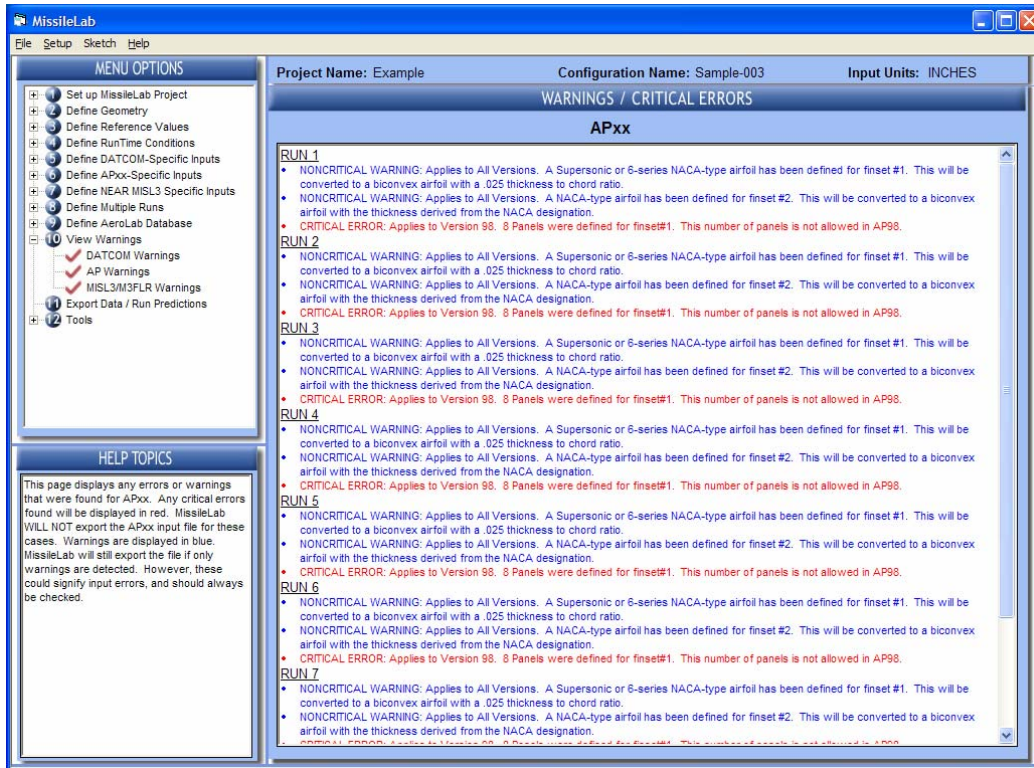


Figure 6. Warning and error screen

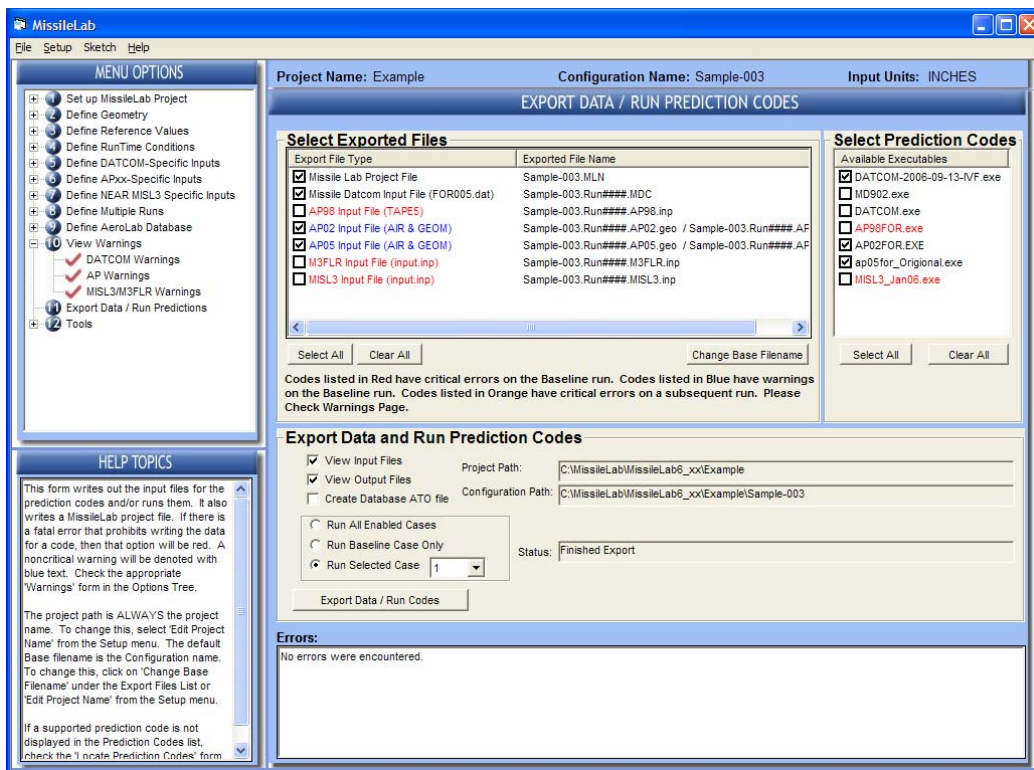


Figure 7. Export data/run codes screen

MissileLab
File Setup Sketch Help

MENU OPTIONS

- 1 Set up MissileLab Project
- 2 Define Geometry
- 3 Define Reference Values
- 4 Define RunTime Conditions
- 5 Define DATCOM-Specific Inputs
- 6 Define APxx-Specific Inputs
- 7 Define NEAR MSL3 Specific Inputs
- 8 Define Multiple Runs
- 9 Define AeroLab Database
- 10 View Warnings
 - DATCOM Warnings
 - AP Warnings
 - MSL3/M3FLR Warnings
- 11 Export Data / Run Predictions
- 12 Tools
 - View Data / Create Database
 - Estimate Mass Properties

Project Name: Example
Configuration Name: Sample-003
Input Units: INCHES

MASS PROPERTIES

1) Enter Component Information:

	Component	Type	Length	Radius	Weight(lb)	CG	Front Station	XX	YY	ZZ
1	Seeker	Solid Cylinder	7.4966	2.25	5.00	3.7483	0.00	12.65	1760.419	1760.
2	Electronics	Solid Cylinder	7.4966	2.25	5.00	3.7483	7.4966	12.65	646.6938	646.6
3	Warhead	Solid Cylinder	7.4966	2.25	5.00	3.7483	14.9932	12.65	94.9591	94.95
4	Empty Booster	Hollow Cylinder	7.4966	2.25	1.00	3.7483	22.4898	5.062	22.3085	22.30
	Booster Propellant	Solid Cylinder	7.4966	2.25	5.00	3.7483	22.4898	12.65	105.2143	105.2
5	Empty Sustainer	Hollow Cylinder	7.4966	2.25	1.00	3.7483	29.9864	5.062	136.7576	136.7
	Sustainer Propellant	Solid Cylinder	7.4966	2.25	5.00	3.7483	29.9864	12.65	677.4598	677.4

Current Motor Burnout Order:
Motor #1 : Booster
Motor #2 : Sustainer

Change Motor Order

2) Enter Finset Information:

ReCalculate Fin Parameters

	Fin Name	# Panels	Panel Type	XLE	SemiSpan	Chord	Thickness	Weight(lb)	XCG	YCG	XX	YY	ZZ
1	1 - Vertical Pane	4	Vertical	23.50	4.05	1.3529	6.764625E-4	1.00	1.017	1.846	14.25	38.57	24.31
2	1 - Horizontal Pai	4	Horizontal	23.50	4.05	1.3529	6.764625E-4	1.00	1.017	1.846	14.25	24.31	38.57
3	2 - Vertical Pane	2	Vertical	35.09	3.56	1.678	0.0839	1.00	1.669	1.78	6.807	424.4	417.6
4	2 - Horizontal Pai	2	Horizontal	35.09	3.56	1.678	0.0839	1.00	1.669	1.78	6.807	417.6	424.4

3) Calculate Total Mass Properties:

	Length	Weight(lb)	CG	XX (CG)	YY (CG)	ZZ (CG)
Pre-Launch Totals:	37.483	39.00	22.353	115.5309	4348.733	4348.733
After Burnout of Motor #1 Totals:	37.483	34.00	21.7817	102.8746	4232.42	4232.419
After Burnout of Motor #2 Totals:	37.483	29.00	19.7208	90.2184	3365.131	3365.131

Calculate Mass Properties

Sketch Component Layout

Write to Text File

HELP TOPICS

This form is used to estimate mass properties of the missile (moments of inertia and centers of gravity).

The units for all length inputs are inches and pounds for weights.

The first time this form is viewed, the inputs will be derived from the geometry entered for the body and fins. After changes are made, the data needs to be modified manually. Components can be moved, added, or removed from a pop-up menu viewed by right-clicking on the first column in the row.

Finsets are originally derived from the inputs on the FinSet page. For Moment of Inertia calculations, the panels must either be horizontal or vertical. Fins can be

Figure 8. Mass properties estimator screen