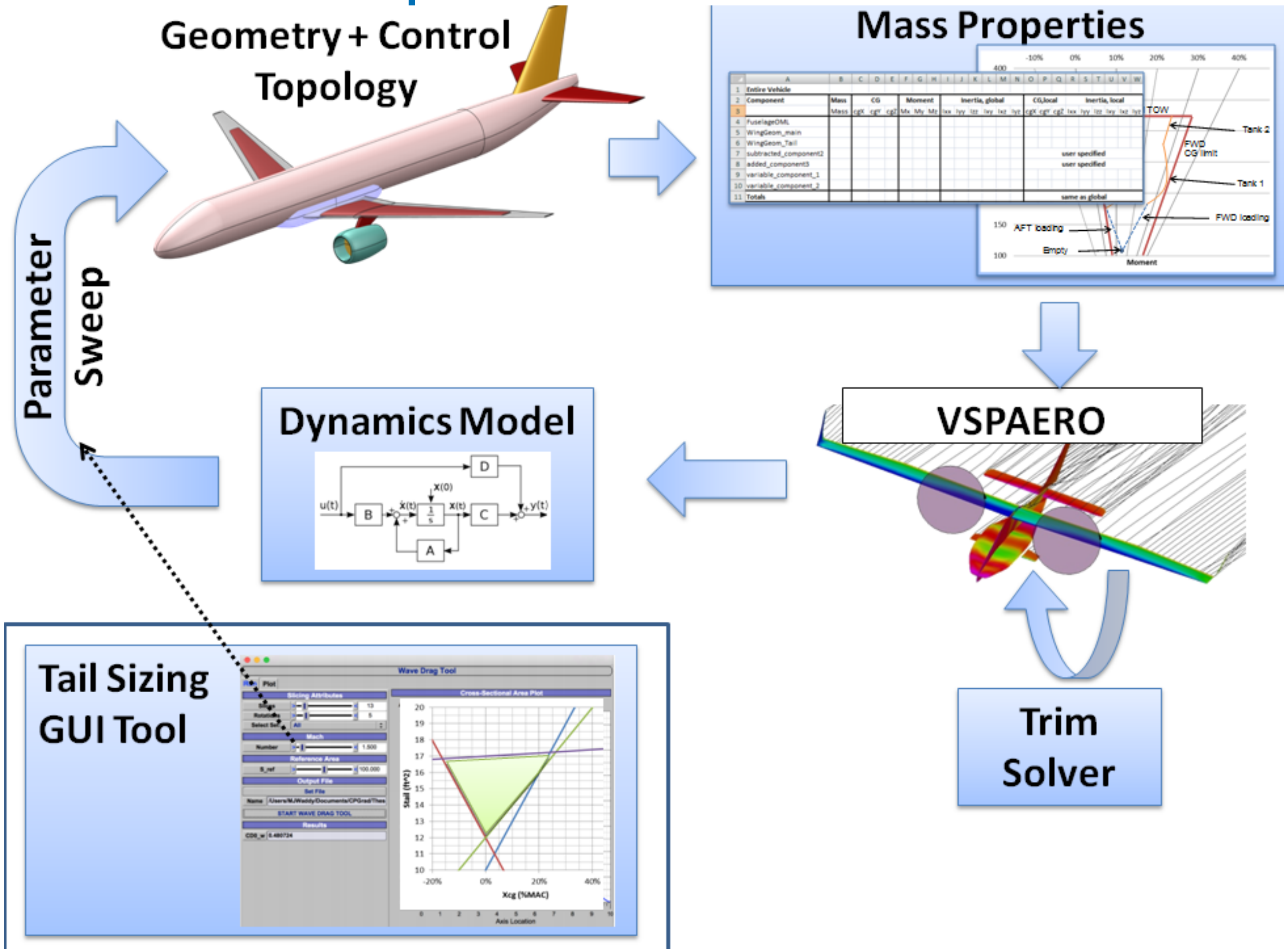
# NASA 2016 SBIR PHASE I

## Physics-Based Conceptual Design Flying Qualities Analysis using OpenVSP and VSPAERO




**Presented by:**

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Empirical Systems Aerospace, Inc.

# Agenda

- Introduction
  - Team Members
  - SBIR Topic
  - Proposal & Technical Objectives
- Task Overview & Status
- Conclusion
- Questions?

# Intro – Team Members

ESAero Development Team
- Nick Brake – PI
- Ben Schiltgen
- Rob McDonald
- Bryan Schmidt
- Justin Gravett
- Andrew Gibson

NASA
- Erik Olson – TM

# Intro – SBIR Topic

SBIR Topic: A1.05 Physics-Based Computational Tools - Stability and Control/High Lift Design Tools

[Excerpt]
For FY2016, specific capabilities are being sought in the following areas:
…

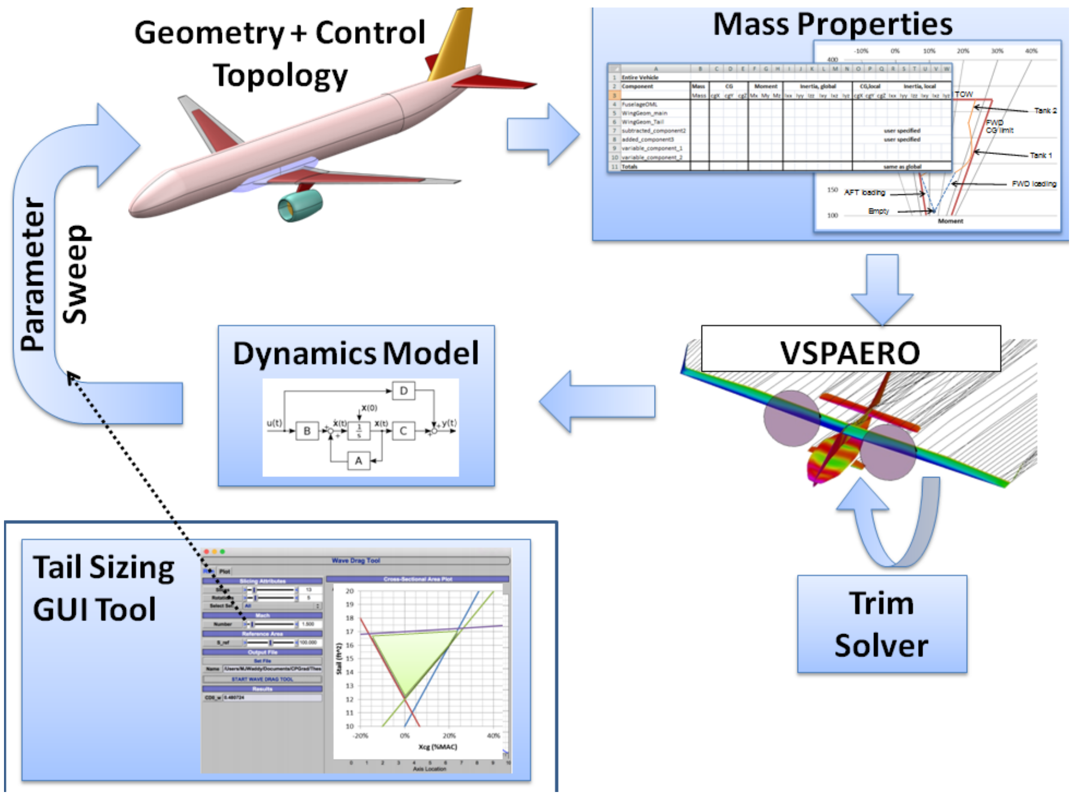
- Methods for **analysis of aircraft static and dynamic stability characteristics** suitable for unconventional aircraft.
  - **Physics-based sizing of tails and control surfaces** that is more sensitive to aircraft design parameters than traditional tail volume coefficients.
  - **Calculation of mass moments of inertia** for the complete aircraft system **throughout the full mission**.
  - Simulation of the dynamics of unconventional aircraft configurations with tight coupling of propulsion and aerodynamics characteristics, including evaluation of active control systems.
  - Definition of handling qualities for unmanned aerial systems.

The desired capabilities are **physics-based methods that are of higher order than traditional empirical methods** , but can be applied in the conceptual design phase with limited requirements on the availability of detailed design information

# Intro – Proposal & Tech. Objectives

Proposal:

Tool suite enhancements to enable rapid physics based handling qualities assesements through an efficient workflow

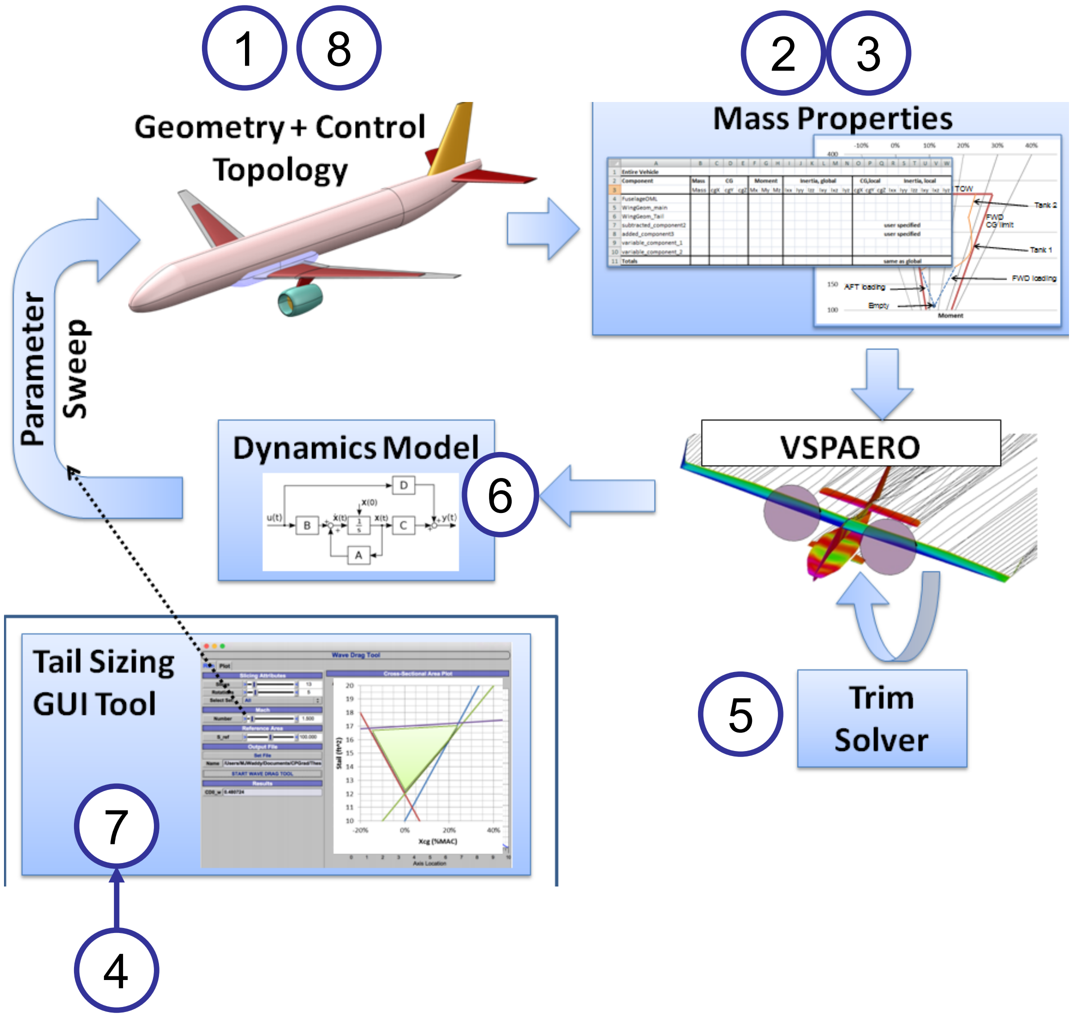



Tech. Objectives:

- Improved vehicle definition (Controls & Mass properties)
- Integrated tool suite for handling qualities with physics based models
- Simple kinematics engine

# Task Overview

1. Improve Sub-Surface Based Control Surfaces
2. Mass Database
3. Mass Properties for Partially Filled Fuel Tanks
4. Interactive Tail Sizing
5. Trim Solver
6. Dynamic Model Synthesis
7. Tail Size Assessment Tool
8. OpenVSP Representation of Simple Kinematic Joints



# Task 1 – Improved Sub-Surface Based Control Surfaces

Objective:

- Improve control surface definition for better representation of real surfaces

Status: IN PROGRESS

- Final integration with VSPAERO

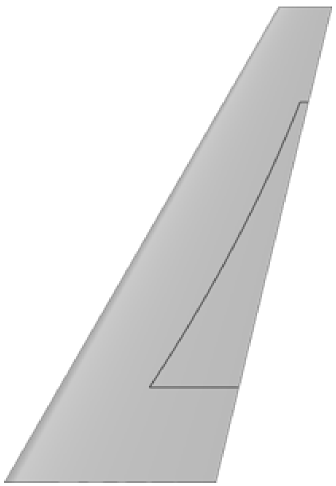


Figure 4. Curved control surface leading edge

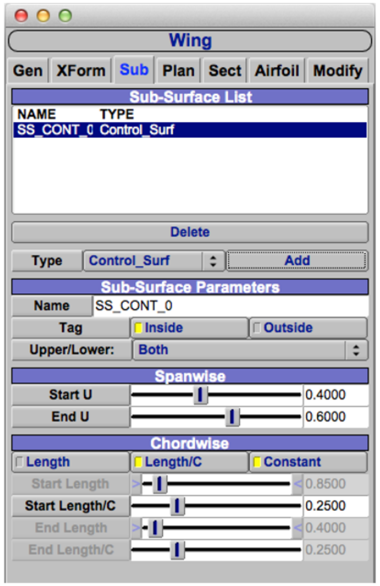
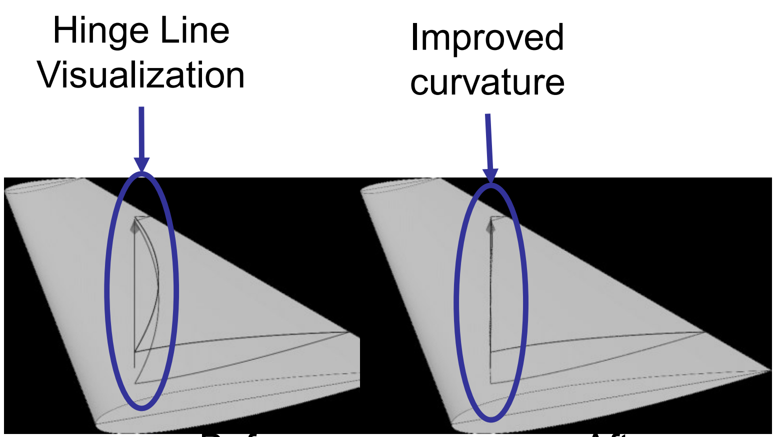
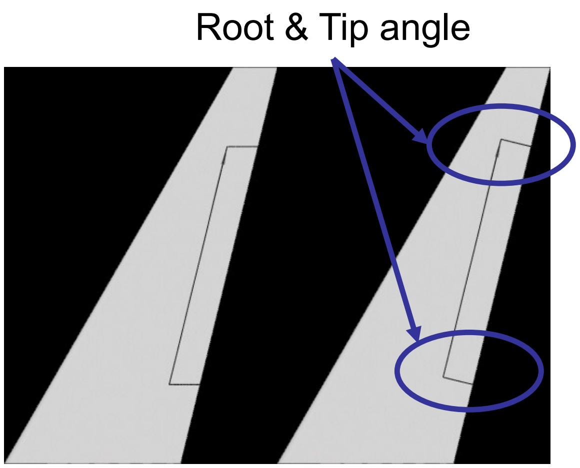



Figure 3. OpenVSP sub-surface GUI for control surface definition




Before After




Before After

# Task 2 – Mass Database Tool

Objective:

- Increase flexibility and accessibility of mass prop. info

Status: IN PROGRESS

- Override properties
- GUI layout
- Data export

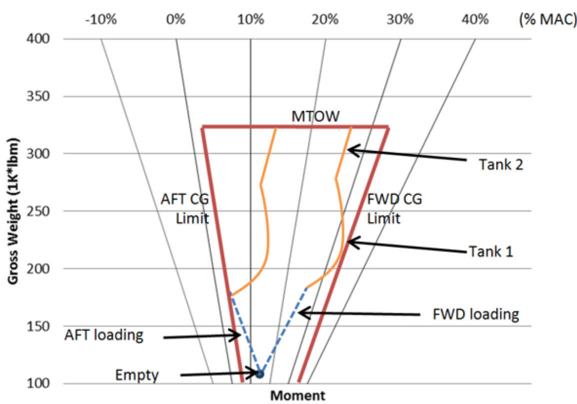



Figure 7. Example CG Potato Chart

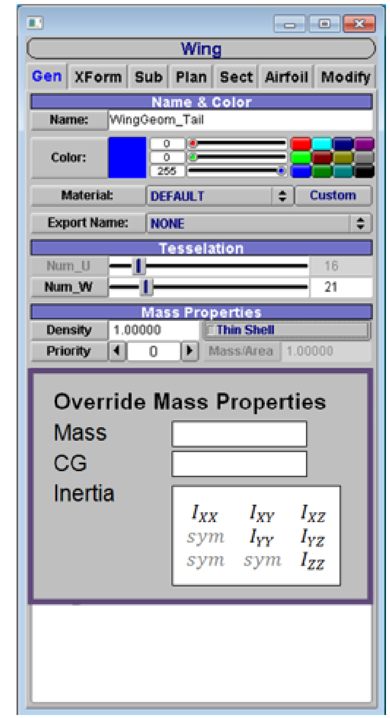
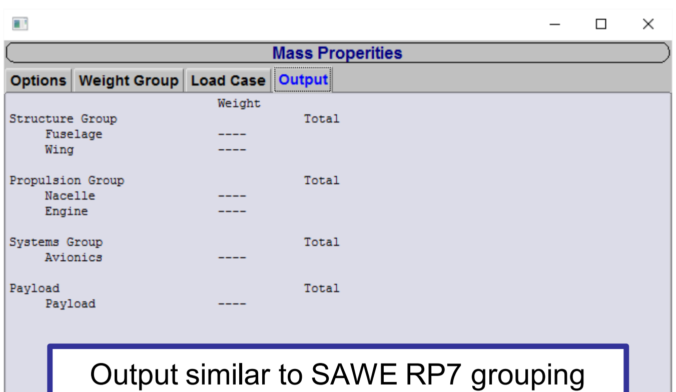



Figure 5. Example generic override




| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z | AA | AB | AC | AD | AE | AF | AG | AH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Entire Vehicle | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Component | Mass | CG | | | Moment | | | Inertia, global | | | | | | CG,local | | | Inertia, local | | | | | | Geometry | | | | | User Input | | | | | |
| 3 | | Mass | cgX | cgY | cgZ | Mx | My | Mz | Ixx | Iyy | Izz | Ixy | Ixz | Iyz | cgX | cgY | cgZ | Ixx | Iyy | Izz | Ixy | Ixz | Iyz | Area | Vol | centX | centY | centZ | Variable | Fill Level? | Override? | Skin Density | Core Density | Qty |
| 4 | FuselageOML | | | | | | | | | | | | | | | | | | | | | | | | | same as CG | | | N | n/a | N | | | 1 |
| 5 | WingGeom_main | | | | | | | | | | | | | | | | | | | | | | | | | same as CG | | | N | n/a | N | | | 1 |
| 6 | WingGeom_Tail | | | | | | | | | | | | | | | | | | | | | | | | | same as CG | | | N | n/a | N | | | 1 |
| 7 | subtracted_component2 | | | | | | | | | | | | | | user specified | | | | | | | | | | | | | | N | n/a | Y | n/a | n/a | -1 |
| 8 | added_component3 | | | | | | | | | | | | | | user specified | | | | | | | | | | | | | | N | n/a | Y | n/a | n/a | 1 |
| 9 | variable_component_1 | | | | | | | | | | | | | | | | | | | | | | | | | | | | Y | 0 | N | | | 1 |
| 10 | variable_component_2 | | | | | | | | | | | | | | | | | | | | | | | | | | | | Y | 0.5 | N | | | 1 |
| 11 | Totals | | | | | | | | | | | | | | same as global | | | | | | | | | | | | | | | | | | | |

Figure 6. Example enhanced GUI display and table output

# Task 3 – Mass Properties for Partially Filled Tanks

Objective:

- Calculate mass propertie impact of fuel tanks

Status: IN PROGRESS

- GUI implementation
- API integration

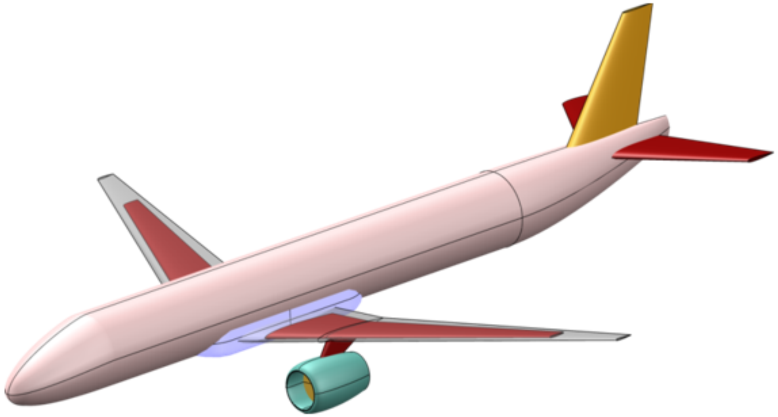


Figure 8. OpenVSP model of a transport aircraft with notional fuel tanks in the wings.

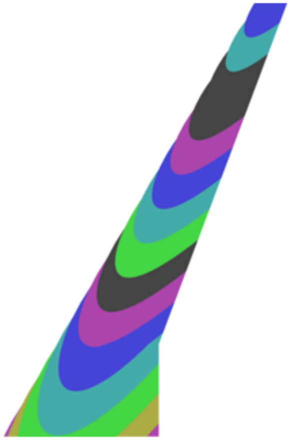


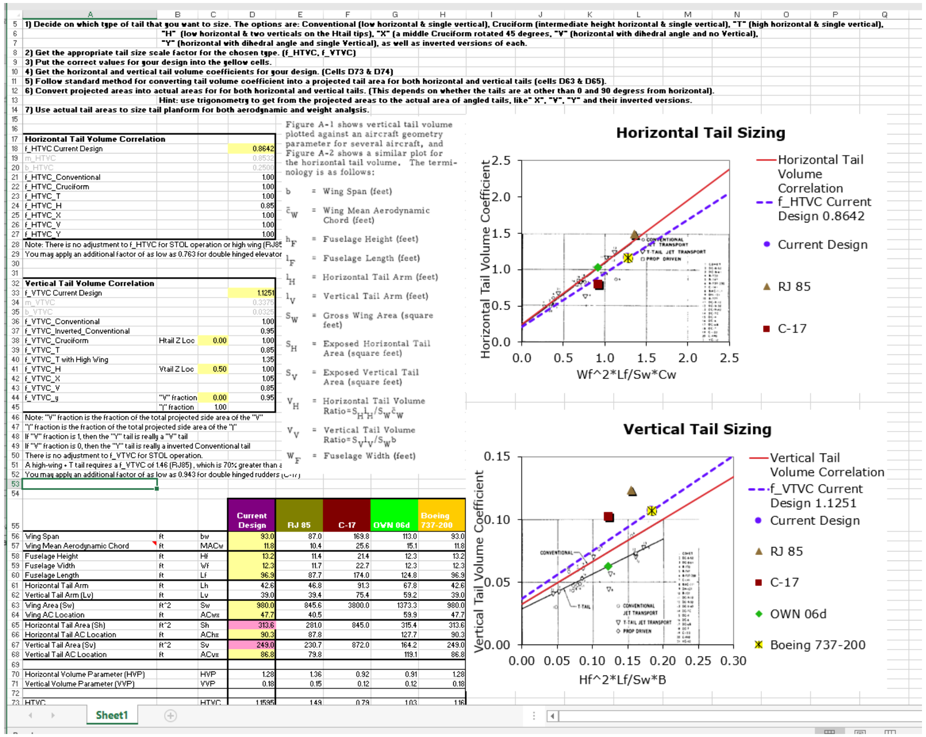
Figure 9. Top-down view of constant-z planes intersecting a wing fuel tank

| | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | S | T | U | V | W | X | Y | Z | AA | AB |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | variable_component_1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 2 | Level | Mass | CG | | | Moment | | | Inertia, global | | | | | | CG,local | | | Inertia, local | | | | | | Geometry | | | | |
| 3 | Level | Mass | cgX | cgY | cgZ | Mx | My | Mz | Ixx | Iyy | Izz | Ixy | Ixz | Iyz | cgX | cgY | cgZ | Ixx | Iyy | Izz | Ixy | Ixz | Iyz | Area | Vol | centX | centY | centZ |
| 4 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 5 | 0.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 6 | 0.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 7 | 0.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 8 | 0.8 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 9 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | variable_component_2 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 12 | Level | Mass | CG | | | Moment | | | Inertia, global | | | | | | CG,local | | | Inertia, local | | | | | | Geometry | | | | |
| 13 | Level | Mass | cgX | cgY | cgZ | Mx | My | Mz | Ixx | Iyy | Izz | Ixy | Ixz | Iyz | cgX | cgY | cgZ | Ixx | Iyy | Izz | Ixy | Ixz | Iyz | Area | Vol | centX | centY | centZ |
| 14 | 0 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 15 | 0.2 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 16 | 0.4 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 17 | 0.6 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 18 | 0.8 | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 19 | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | | |

Figure 10. Example variable mass table export

# Task 4 – Interactive Tail Sizing

Example tail sizing implementation based on SAE 670370
Source: "Betterer_Tail_Volume_Coeff.xlsx", Andy Hahn




Objective:

- Implement tail sizing with real-time visualization based on SAE 670370
- Used as "seed" size for Task 7

Status: IN PROGRESS

- GUI development & layout
- Algorithm implementation
  - SAE 670370 Fuselage Configuration Studies by J. Morris & D. M. Ashford of Douglas Aircraft

# Task 5 – Trim Solver

Objective:

- Calculate flight state and control deflection to satisfy simple user defined constraints
- Replicate AVL trim solver

Status: NOT STARTED

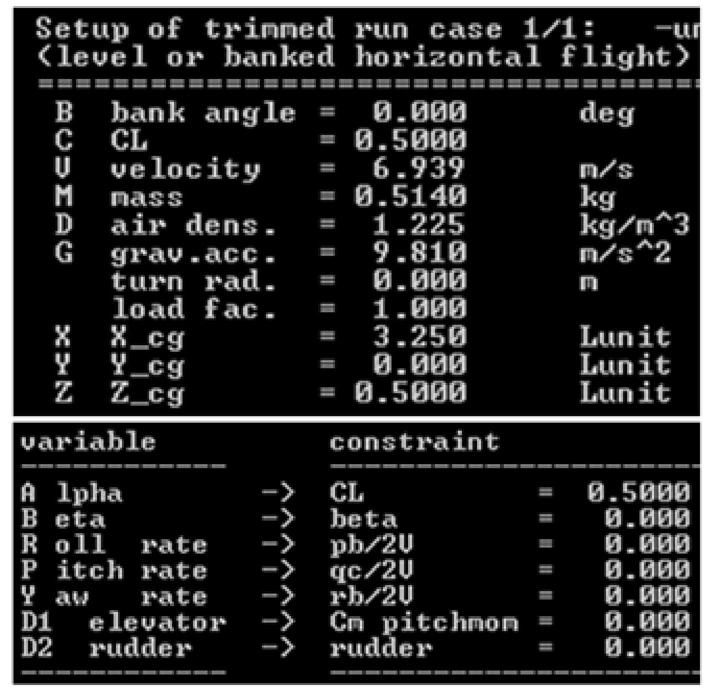
Pre-requisites:

- VSPAERO control derivatives

$$\delta_{surface,i} = B * u$$

$$B = \begin{bmatrix} b_{1,1} & \cdots & b_{1,j} \\ \vdots & \ddots & \vdots \\ b_{i,1} & \cdots & b_{i,j} \end{bmatrix}$$

**Equation 1. Mixing matrix for control allocation**



```
Setup of trimmed run case 1/1:   -ur
(level or banked horizontal flight)
=========================================
 B   bank angle  =  0.000       deg
 C   CL          = 0.5000
 V   velocity    =  6.939       m/s
 M   mass        = 0.5140       kg
 D   air dens.   =  1.225       kg/m^3
 G   grav.acc.   =  9.810       m/s^2
     turn rad.   =  0.000       m
     load fac.   =  1.000
 X   X_cg        =  3.250       Lunit
 Y   Y_cg        =  0.000       Lunit
 Z   Z_cg        = 0.5000       Lunit

variable                constraint
------------            ----------------------
A lpha         ->       CL              =  0.5000
B eta          ->       beta            =   0.000
R oll   rate   ->       pb/2V           =   0.000
P itch  rate   ->       qc/2V           =   0.000
Y aw    rate   ->       rb/2V           =   0.000
D1  elevator   ->       Cm pitchmom     =   0.000
D2  rudder     ->       rudder          =   0.000
------------            ----------------------
```

**Figure 12. Example UI for trimmed flight condition from AVL**

# Task 6 – Dynamic Model Synthesis

Objective:

- Increase accessibility of aircraft dynamics characteristics

Status: NOT STARTED

Pre-requisites:

- VSPAERO control derivatives
- Task 5 – Trim solver

**State Space Dynamics Model**

$$\dot{X} = [A] * X + [B] * U$$

$$X = [u, w, q, \theta, v, p, r, \phi, x, y, z, \psi]^T$$
$$A = [system\ dynamic\ matrix]$$
$$B = [control\ input\ matrix]$$
$$U = [control\ vector]$$

**Table 1. Example additional flying qualities parameter output**

| Parameter | Equation | Description |
|---|---|---|
| [redacted] | | |
| **φ/β effect** | $\frac{\phi}{\beta} = \frac{\lvert e_\phi \rvert_{DR}}{\lvert e_\beta \rvert_{DR}}$ | Measures the degree of rolling response in the Dutch roll mode. Ratio of magnitude of φ and β eigenvectors of dutch role mode<br>Large value: DR mode is primarily rolling<br>Small value: DR mode is primarily yawing |

# Task 7 – Tail Sizing Assessment Tool

Objective:

- Visualize impact of tail size parameters

Status: NOT STARTED

Pre-requisites:

- Task 5 – Trim Solver
- Task 6 – Dynamic Mo Synthesis

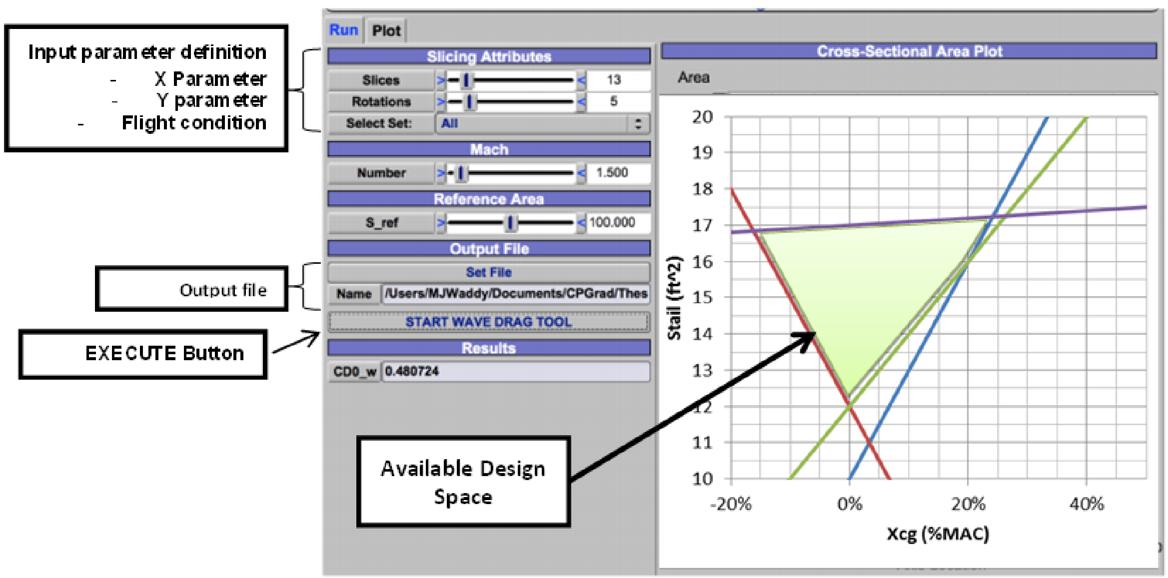



Figure 14. Example Tail Size Assessment Tool GUI layout

# Task 8 – Simple Kinematic Joints

Objective:

- Increase usability for modelir control surfaces, high lift devices, landing gear

Status: RELEASED v3.9.0

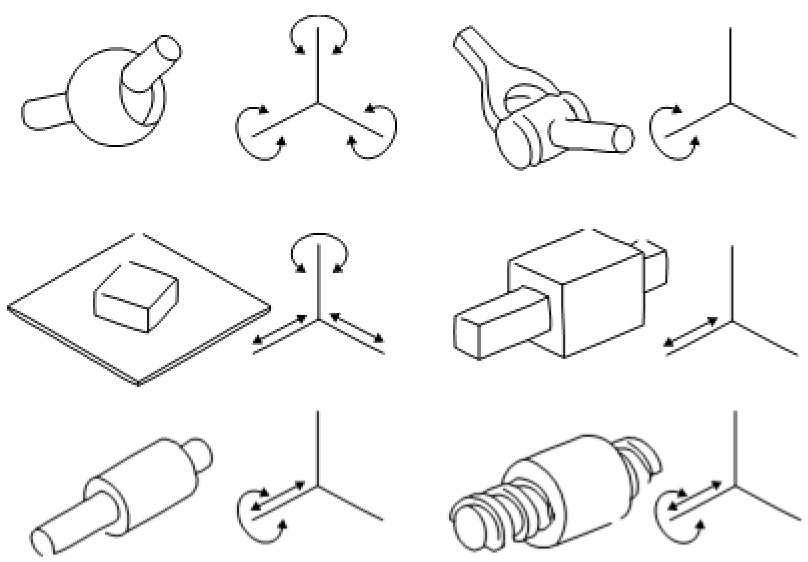


Figure 15. Symbolic representation of six lower order kinematic pairs.

# Questions?

# Contact Information

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