Aircraft Design and Performance Tool Connectivity with AEDT

Project 12

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ASCENT Advisory Committee Meeting
October 13, 2015
Seattle, WA

ASCENT
AVIATION SUSTAINABILITY CENTER

Outline

- Summary of Project 12
- Final output & status
- Conclusions & References

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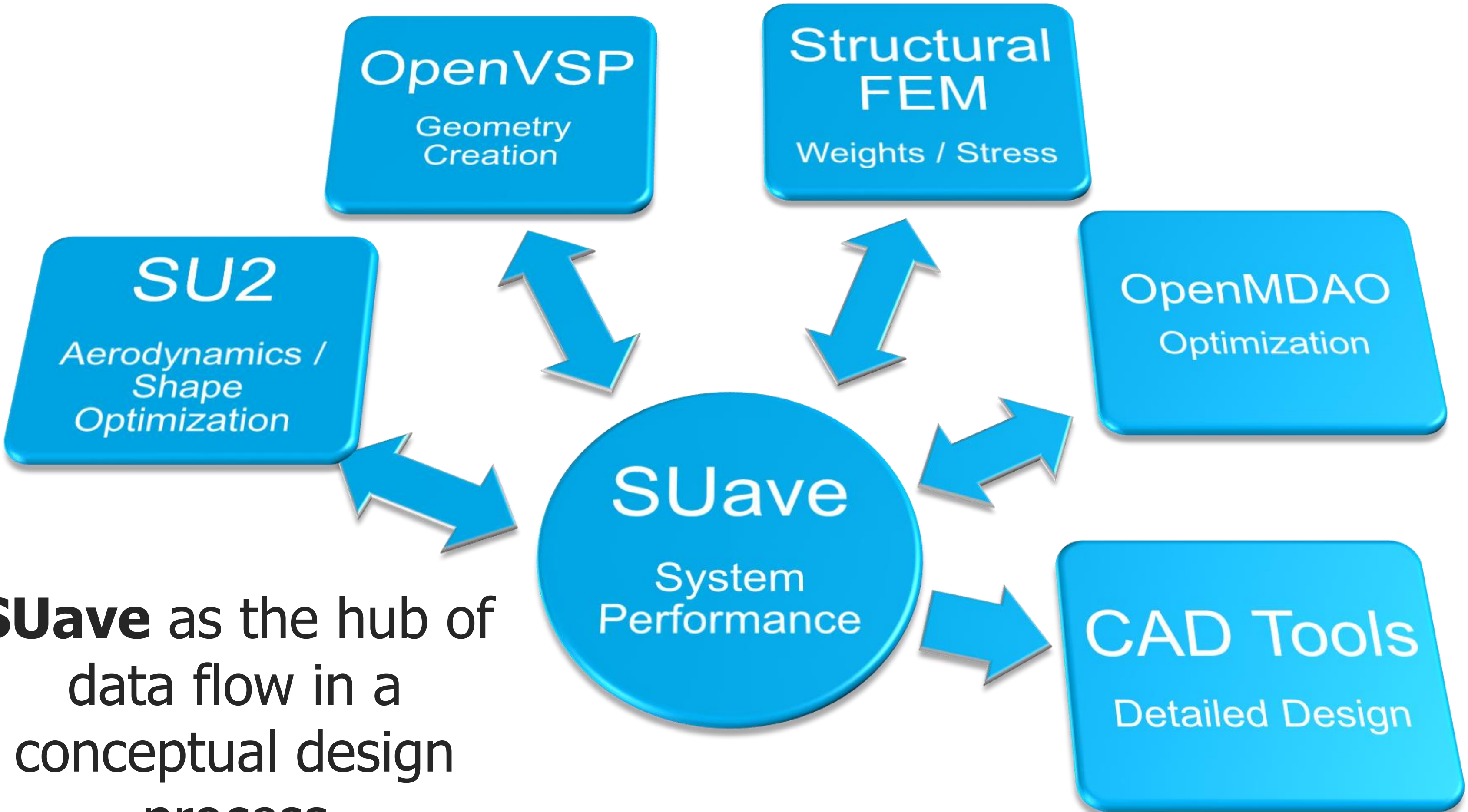
Overview

- Background:
  - AEDT is beginning to be used by a broader base of users
  - AEDT has connectivity to a number of aircraft databases and conceptual design tools
  - FAA was interested in enhancing the variety of external performance tools that can supply information about current and future aircraft to AEDT
- Objectives:
  - Create an output module for SUave (Stanford University aerospace vehicle environment) so that every aircraft that can be modeled in SUAVE can be provided to AEDT for direct use
  - Create a database of existing and new (on the drawing board) designs
  - Demonstrate the process of introducing an advanced technology aircraft

Technical Approach

- **SUave**: Stanford University Aerospace Vehicle Environment
- A central hub for conceptual design for aerospace vehicles
  - Flexible, extensible, easy-to-use environment for mission analysis
  - No explicit dependence on traditional sizing / analysis methods
  - Incorporates arbitrary levels of fidelity in analysis and geometry
  - Communicate with existing geometry tools, including OpenVSP, CAD, etc.
- Completely flexible power & propulsion network, supporting any combination of electrical, chemical, or other systems
- Communicates semi-automatically with ADL's CFD / shape optimization suite, SU2 (su2.stanford.edu)
- Acts as an API (Python) which can be driven from any optimizer (e.g. OpenMDAO) or design suite
- Partnering with Embraer (and others) for continued development: open source philosophy

Software Tools



SUave as the hub of data flow in a conceptual design process

Details of Approach

Primary Objective: Create an output module in SUAVE that will allow any vehicle generated in SUAVE to be implemented directly in AEDT.

Approach:

1. Create regression modules that allow the coefficients used in AEDT models, for both BADA and ANP, to be estimated using SUAVE performance data
2. Develop code to build AEDT point profiles using SUAVE data, allowing for more flexibility and accuracy in representing SUAVE trajectories
3. Demonstrate / verify that generated coefficients produce flight paths accurately using provided fitting equations
4. Create module to run regressions, collect results, and output data in a file that can be directly imported by AEDT
5. Demonstrate / verify missions within AEDT

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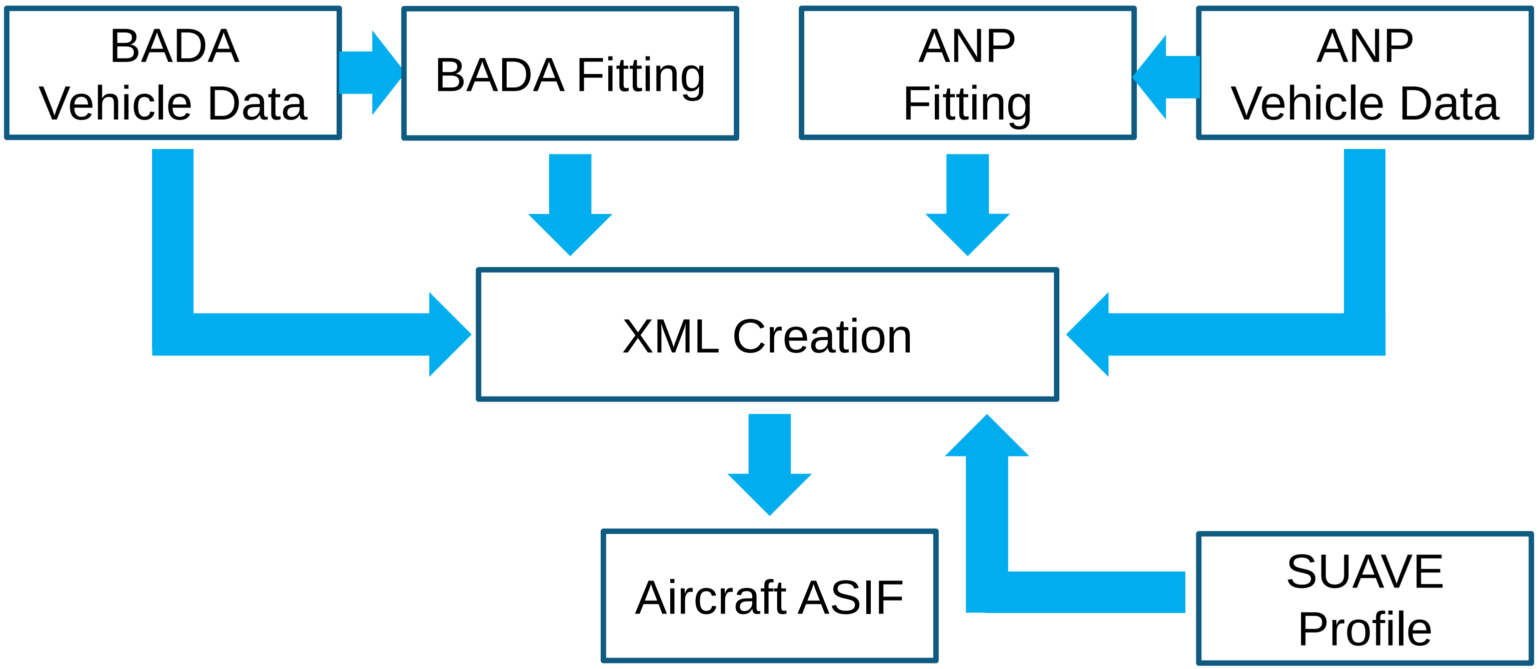
Module Structure



- Vehicle Data
  - Vehicle setup
  - Mission setup
  - BADA or ANP specific data

New engine data and resulting noise profiles are not yet included.

ANP Modeling

- Below 10,000 ft above field elevation, AEDT uses a separate modeling process considered more accurate than BADA
- The ANP model uses two equations to determine fuel flow in the terminal area
  - Linear equation for departure, nonlinear for approach
  - Equations are solved using a nonlinear least squares curve fitting tool
- Model determined for two flap positions and fitting segments are based on segments described in a related paper[1]
- The SUAVE point profile provides thrust values, so while thrust coefficients are computed they are not required

$$f_{n_{dep}} = (K_1 + K_2 M + K_3 h_{MSL} + K_4 F_n \,/\, \delta)\sqrt{\theta} F_n$$

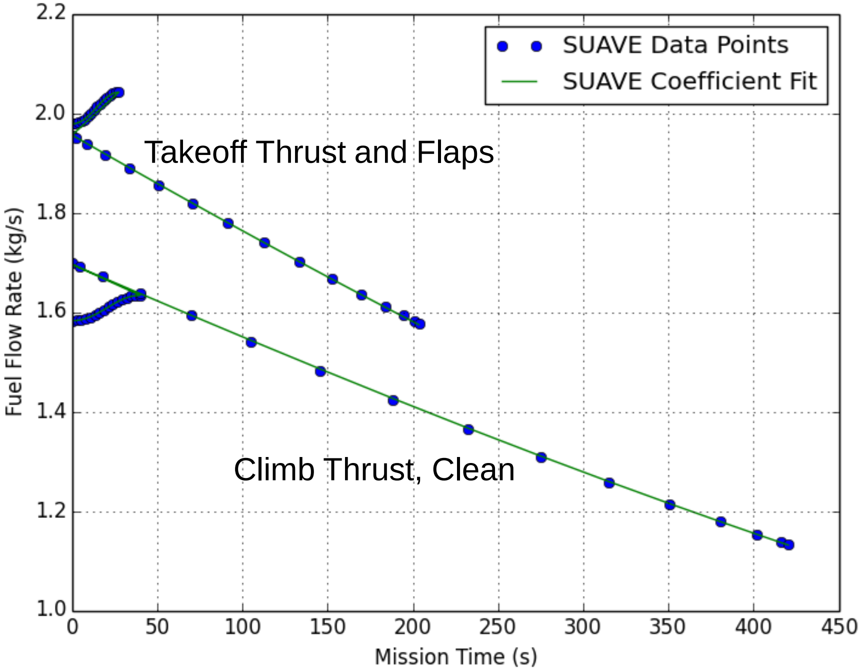
$$f_{n_{arr}} = \left(\alpha + \beta_1 M + \beta_2 e^{-\left(\frac{\beta_3 F_n/\delta}{F_{n_0}}\right)}\right)\sqrt{\theta} F_n$$

[1]Senzig, Fleming, Iovinelli, "Modeling of Terminal-Area Airplane Fuel Consumption." Journal of Aircraft.

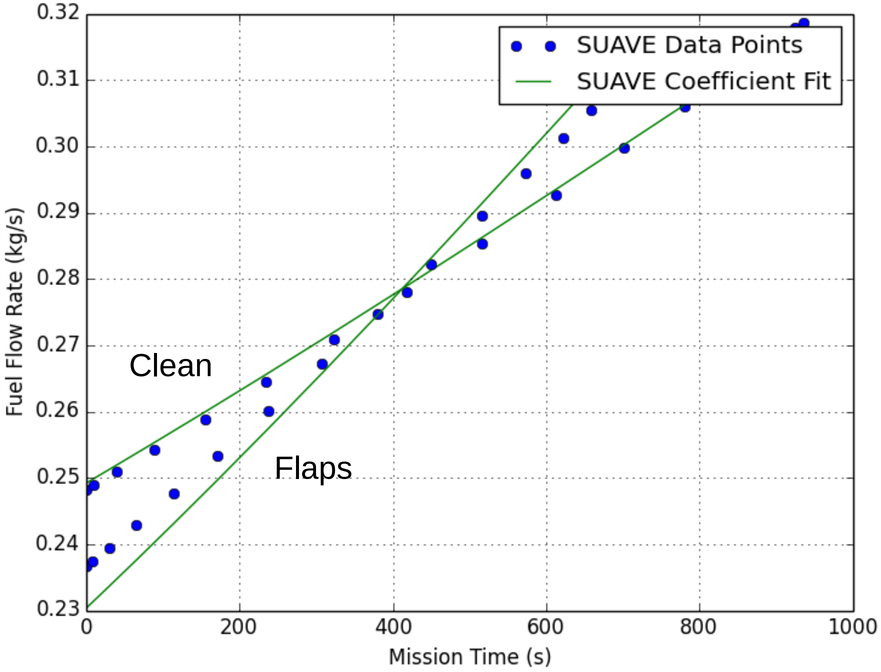
ANP Modeling Coefficient Results

- Two segments for each climb type (takeoff and climb)
  - Acceleration from 170 kts to 250 kts
  - Constant equivalent airspeed climb
- One segment for each descent configuration
  - Constant equivalent airspeed descent

Climb



Descent



BADA Modeling

- Procedure from EUROCONTROL manual is followed for BADA modeling
  - Coefficients are transformed with a given procedure to provide linear equations
- Currently BADA3: anticipate an update in the future
- Performance modeling guide calls for at least 17 segment types with varying masses and speeds
  - 9 ISA climb segments
  - 3 nonISA climb segments
  - 4 descent segments
  - 1 cruise segment
- Climb and descent segments are at constant equivalent airspeed
- Rate of climb and fuel flow are key fitting data
  - Relevant coefficients determined by engine type

$$T_i = t_7\left(t_0 - t_1 h_i + t_2\frac{1}{TAS_i} - t_3\frac{h_i}{TAS_i} + t_4 h_i^2\right)(t_5\Delta T_{ISA} + t_6)$$

$$D_i = \left(d_0\rho_i TAS_i^2 + d_2\frac{m_i^2}{\rho_i TAS_i^2\cos^2\gamma_i}\right)(1 + d_{16}M_i^{16})$$

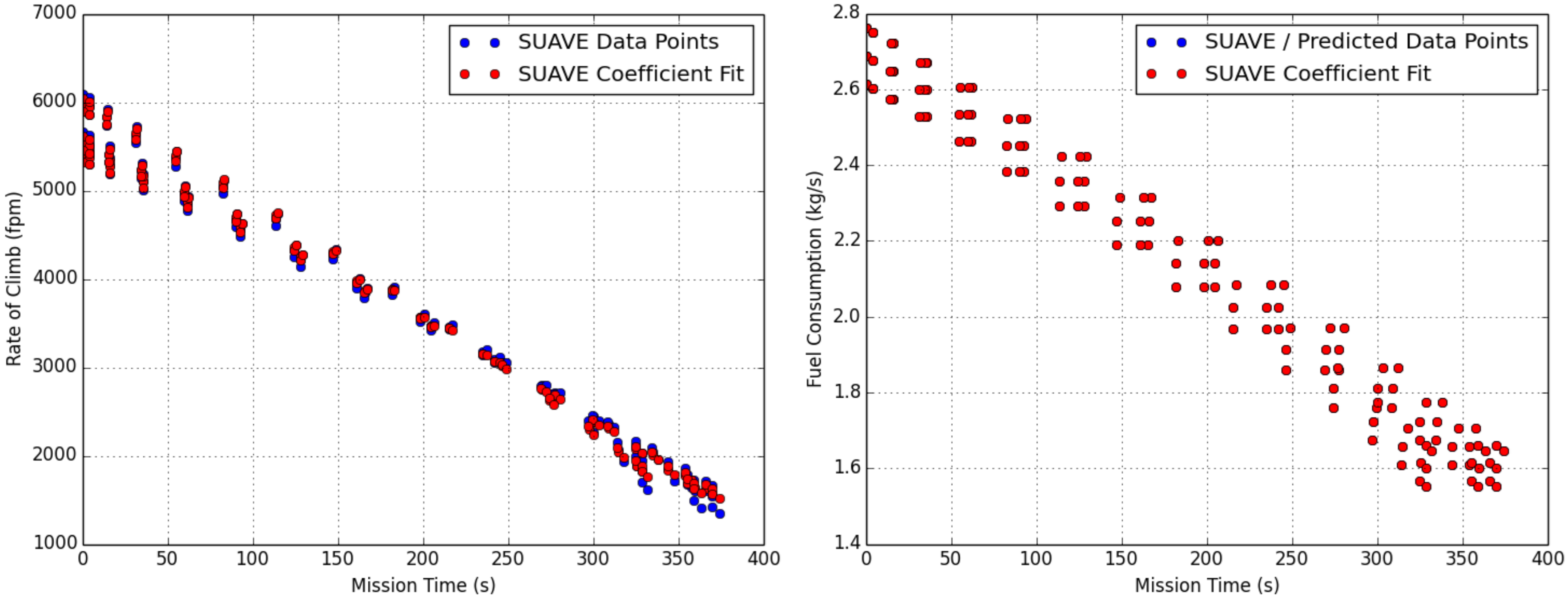
$$\Rightarrow \quad ROC_i = k_4(T_i - D_i)\frac{TAS_i}{m_i g}ESF_i$$

$$F = f_5[f_0 - f_1 h + (f_2 + f_3 V_{TAS} - f_4 V_{TAS}^2)T]$$

BADA Modeling Coefficient Results

- Above 10,000 ft above field elevation, AEDT uses BADA values
- Climb rate and fuel flow rate are primary fitted values
  - ISA climb segments shown below
- Linear coefficients are recalculated in the SUAVE module to provide traditional BADA coefficients

ISA Climb Fitting – Rate of Climb and Fuel Flow

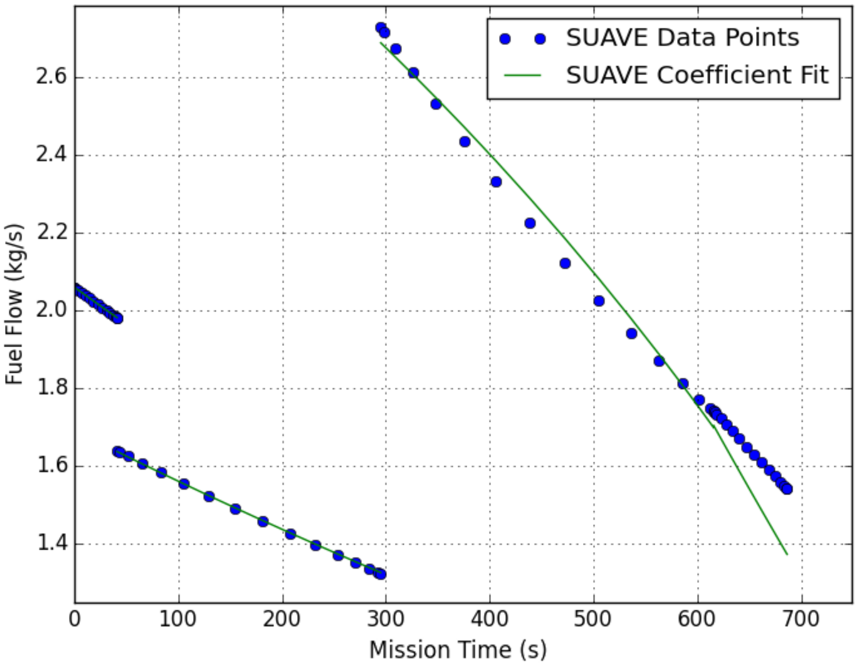


SUAVE Test Mission Results

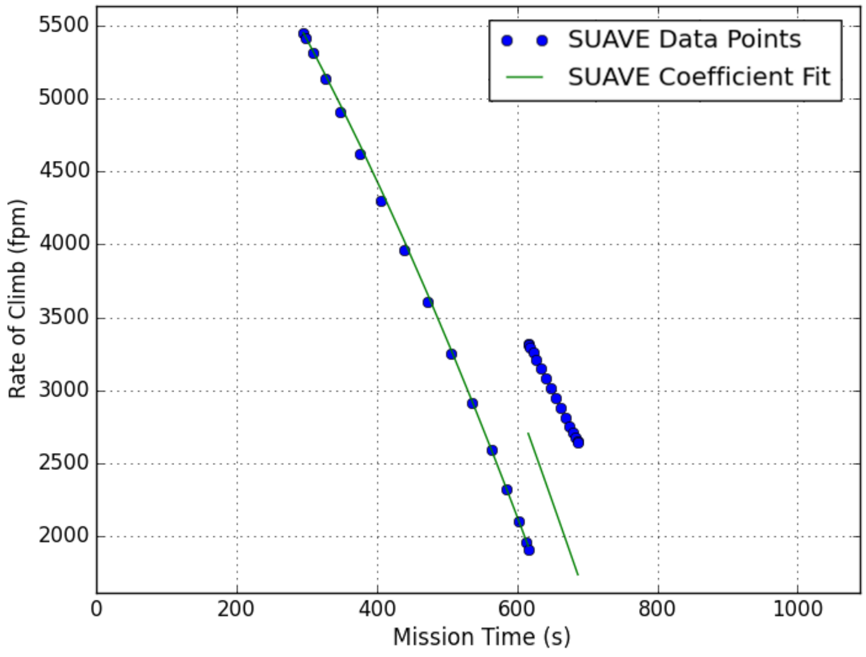
- Full SUAVE mission created with similar characteristics
- SUAVE point profile built with generator to be used for AEDT
- Coefficients loaded from fitting programs and used with profile
- Results match closely. Minor discrepancies being investigated / resolved.
  - An exception are differences in constant Mach BADA segments, which are expected as this is not part of the BADA modeling procedure. This is noticeable in the climb phase climb rate, as shown.

Climb Phase

Fuel Flow



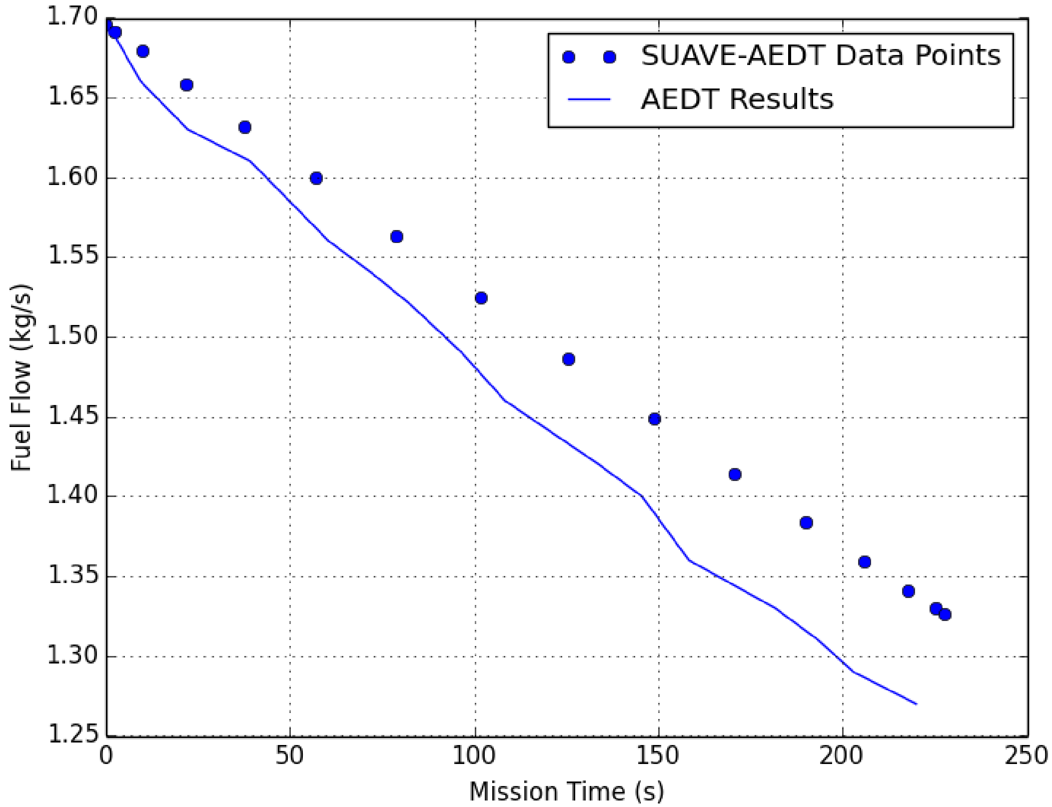
BADA Climb Rate



AEDT Import Results / Verification

- Some results nearly match predicted values, though reasons for not matching exactly are unclear
- Discussion with AEDT development team likely necessary to minimize differences (approx. 3%)

ANP Climb Fuel Flow



Task 3: Advanced Technology Aircraft Modeling

- Showcase SUave-AEDT connection by designing and incorporating an advanced aircraft model.
- Currently focusing on high-span vehicle – strut-braced, slightly reduced cruise Mach, optimum altitude, ultra-high bypass ratio engines, significant laminar flow. Representative of possible next-generation SA.
- Utilize both high-fidelity aerodynamics (SU2) and high-fidelity structural weight estimation (NASTRAN-based).
- Completed design study and created AEDT input files. Currently flying aircraft through AEDT missions

Renderings of Boeing N+3 SA Concepts

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Conclusions

- Module created to convert SUAVE vehicle to XML files that can be imported in AEDT
  - File structure built to allow independent modification of vehicle files, fitting procedure, and operational profiles
- Generated coefficients match SUAVE data
  - Indicates that model can accurately provide a trajectory based on SUAVE values
- AEDT results nearly fully consistent with provided equations
  - Further discussion with AEDT development group needed to address remaining differences
- pySUAVE-AEDT module now available (see http://github.com/suavecode) and will be maintained as part of the SUAVE distribution for future use
- Library of SUAVE aircraft available, including advanced vehicle example

Collaborations

- Volpe / AEDT
- Eurocontrol
- Industry: Embraer, RAND, Boeing
- Academia: BYU, Delft University
- ICCT

References

- http://github.com/suavecode , SUave (Stanford University Aerospace Vehicle Environment) Main Site. As of October 2015.
- **T. Lukaczyk, A. Wendorff, E. Botero, T. MacDonald, T. Momose, A. Variyar, J. M. Vegh, M. Colonno, T. Economon, J. J. Alonso, T. Orra, C. Ilario, "SUAVE: An Open-Source Environment for Multi-Fidelity Conceptual Vehicle Design", 16th AIAA Multidisciplinary Analysis and Optimization Conference, Dallas, TX, June 2015.**
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Acknowledgements

- SUave is being made possible through the effort of a number of graduate students, staff, and collaborators:
  - Main developers: Trent Lukaczyk, Anil Variyar, Michael Vegh, Andrew Wendorff, Emilio Botero, Tim Momose, Michael Colonno, Tom Economon
  - Test Cases and V & V: Jeff Sinsay (AFDD), Emilio Botero, Tim McDonald, Tim Momose
  - Collaborators: Carlos Ilario de Silva and Tarik Orra (Conceptual Design Group, Embraer), Winfried Wilcke (IBM Battery 500 Project), Glenn Driscoll and Bruce Gamble (American Superconductor), Mark Gyunn (NASA), Michael Buonanno (Lockheed ADP)