Mathematical Modeling Part III

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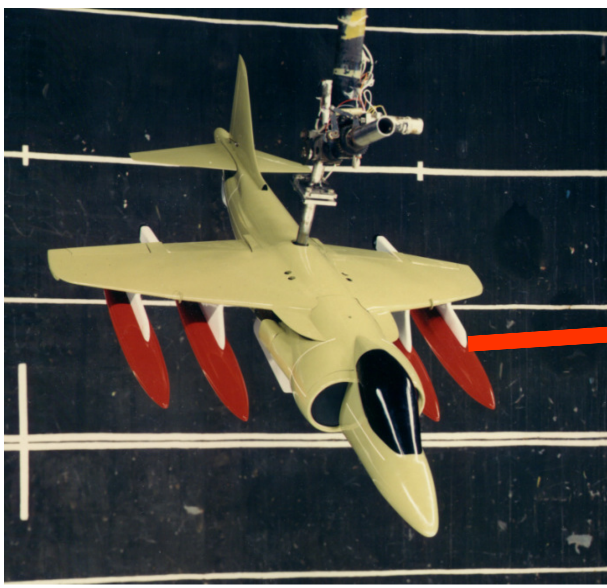


Objectives

- Provide an introduction to tools used in the flight modeling industry and present practical applications of such tools
- Use real-world case studies to illustrate the complexity that can be involved in the modeling of flight dynamics and performance.

Agenda

- Flight Modeling Tools
  - Data Manipulation
  - Simulation
- Case Studies
  - Military Trainer Configuration
  - Advanced Flight Modeling for Stall and Upset
    - Commercial Pilot Training

Flight Modeling Tools

- Data Manipulation Tools
  - Data Import
    - Ability to easily read data from a variety of sources
  - Data Visualization
    - Ability to see the data
      - Graphical or tabular
  - Data Sorting and Math Operations
    - Data array manipulation
  - Data Export
    - Ability to save data in different, usable, formats

Flight Modeling Tools

- Examples of Manipulation Tools
  - MicroSoft Excel (Commercial - www.microsoft.com)
    - Spreadsheet based
    - Macro capability
  - Matlab (Commercial - www.mathworks.com)
    - Powerful scientific programming environment
    - Many specialized tools
    - Script based
  - Numbers of Proprietary Tools
  - Parameter Identification Tools

Flight Modeling Tools

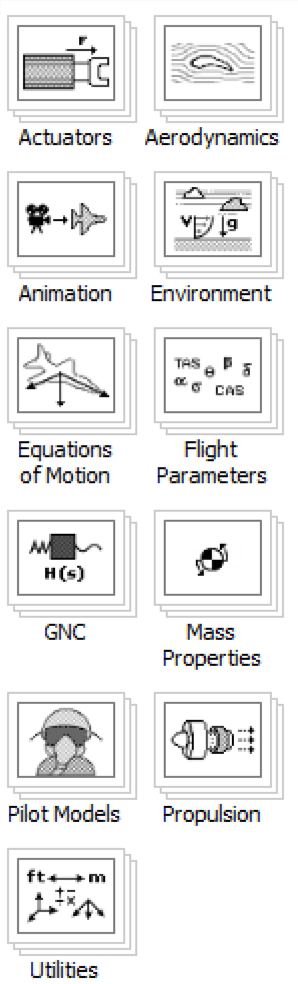
- Examples of Parameter Identification Tools
  - System Identification Programs for AirCraft (SIDPAC)
    - MATLAB based PID toolset
      - Equation error and output error tools, time and frequency domain.
      - RTPID
    - AIAA Published Book (www.aiaa.org)
      - Authors Morrelli and Klein
  - Comprehensive Identification from FrEquency Responses (CIFER)
    - Frequency domain system identification
    - AIAA Published Book (www.aiaa.org)
      - Aircraft and Rotorcraft System Identification, Tischler and Remple

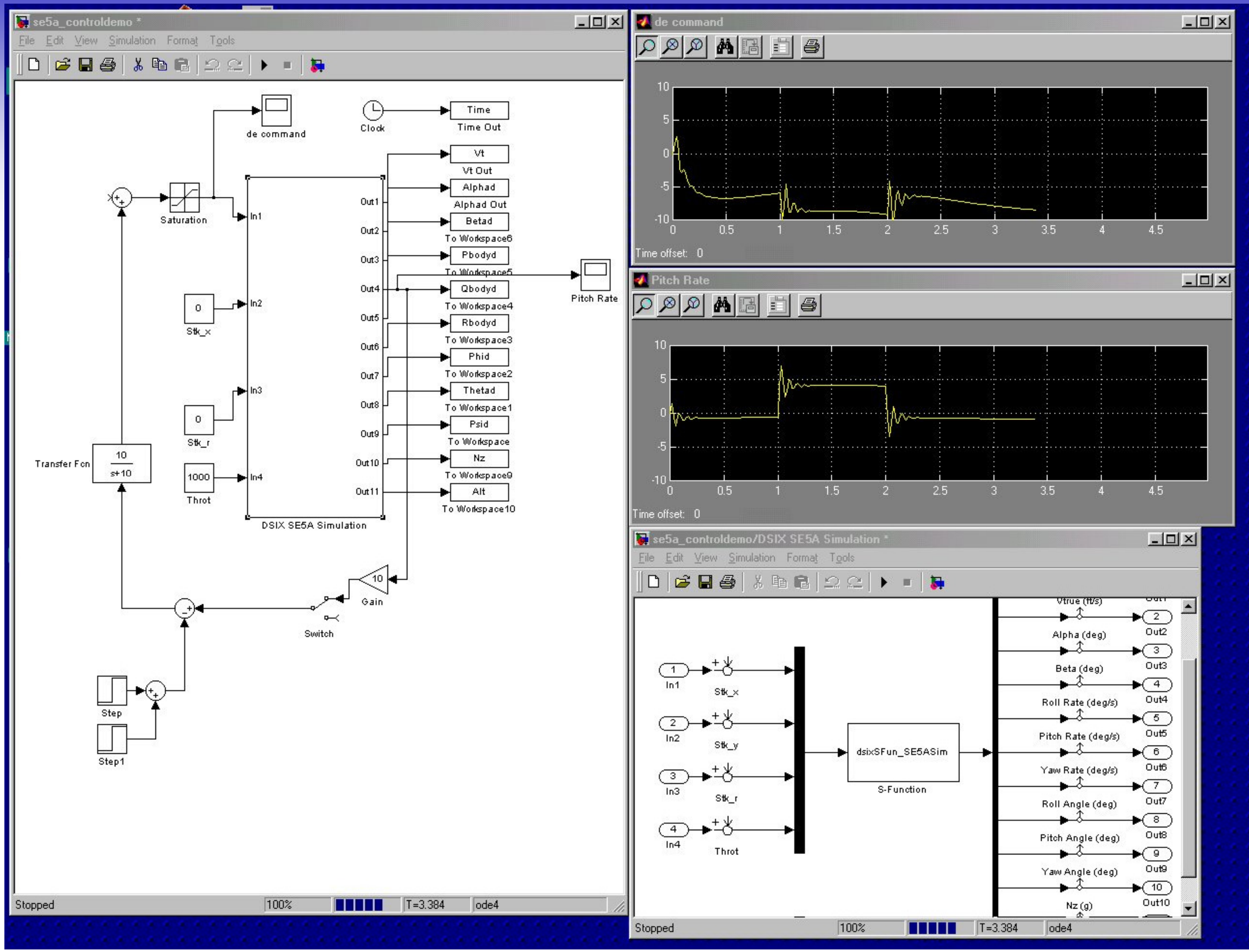
Flight Modeling Tools

- Simulation Tools
  - Reconfigurability
    - Host different models
    - Flexible structure
  - Run Time Flexibility
    - Batch simulation
    - Real-time simulation
    - Overdrive capability
  - Results Analysis
    - Data visualization
    - Data export

Flight Modeling Tools

- Examples of Simulation Tools
  - Simulink and Real Time Work Shop (Commercial – Multi-Platform www.mathworks.com)
    - Graphical interface
    - Non-real time
    - Seamless with Matlab
  - Aerospace Blockset for Simulink
    - Comprehensive function set
      - EOM 3-DOF 6-DOF
      - Aerodynamics
      - Environment
      - GNC
      - Propulsion

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Pitch Angle (deg)
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Flight Modeling Tools

- Examples of Simulation Tools
  - CASTLE (USNAVY – Multi-Platform)
    - Real-time or Batch
    - Hardware interface with manned sim lab
    - PID Tools (IDEAS)
  - D-Six (Commercial – PC-Based www.bihrle.com)
    - Real-time or Batch – Reconfigurable - Hardware interfaces
    - MATLAB/Simulink Interfaces – RTW Target

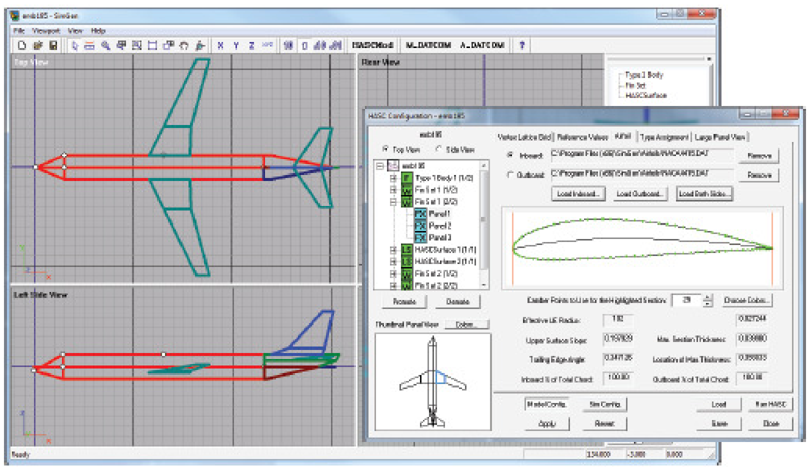
Flight Modeling Tools

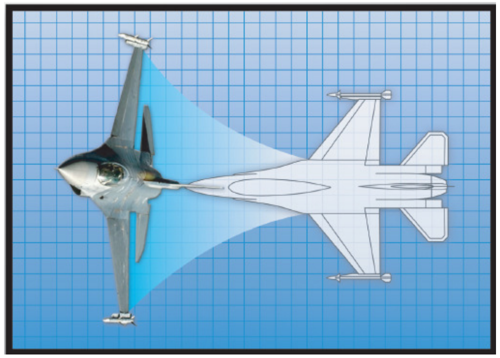
- Examples of Simulation Tools
  - FLSIM & HELISIM (www.presagis.com/products/engenuity)
    - Fixed-wing and Rotor-wing flight and system simulation
  - FlightViz (Commercial - www.simauthor.com)
    - Primarily visualization and playback
  - Flightlab (Advanced Rotorcraft Technology, www.flightlab.com
    - Helicoptor simulation tools
  - FlightGear (www.flightgear.org)
    - "**FlightGear** flight simulator project is an open-source, multi-platform, cooperative flight simulator development project"

Flight Modeling Tools

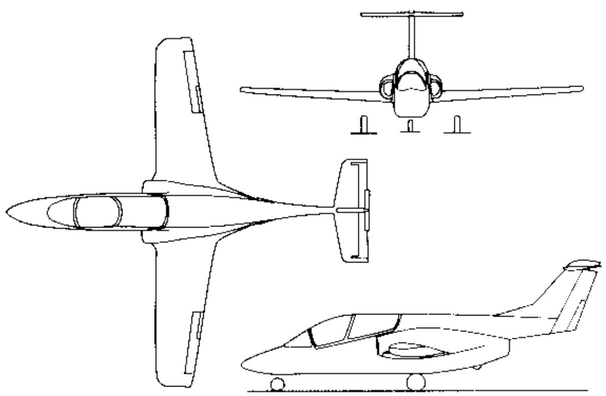
– X-Plane (www.xplane.com)
  - PC based simulator that uses computation aerodynamics (strip-method)

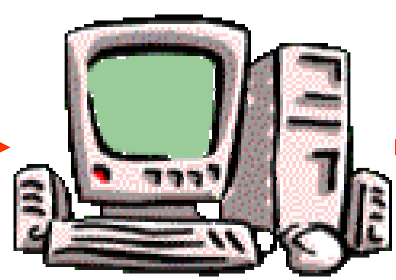
– SimGen (www.bihrle.com)
  - PC-Based tool for the development of aerodynamic databases from HASC95(vortex latice) and Missile DATCOM.





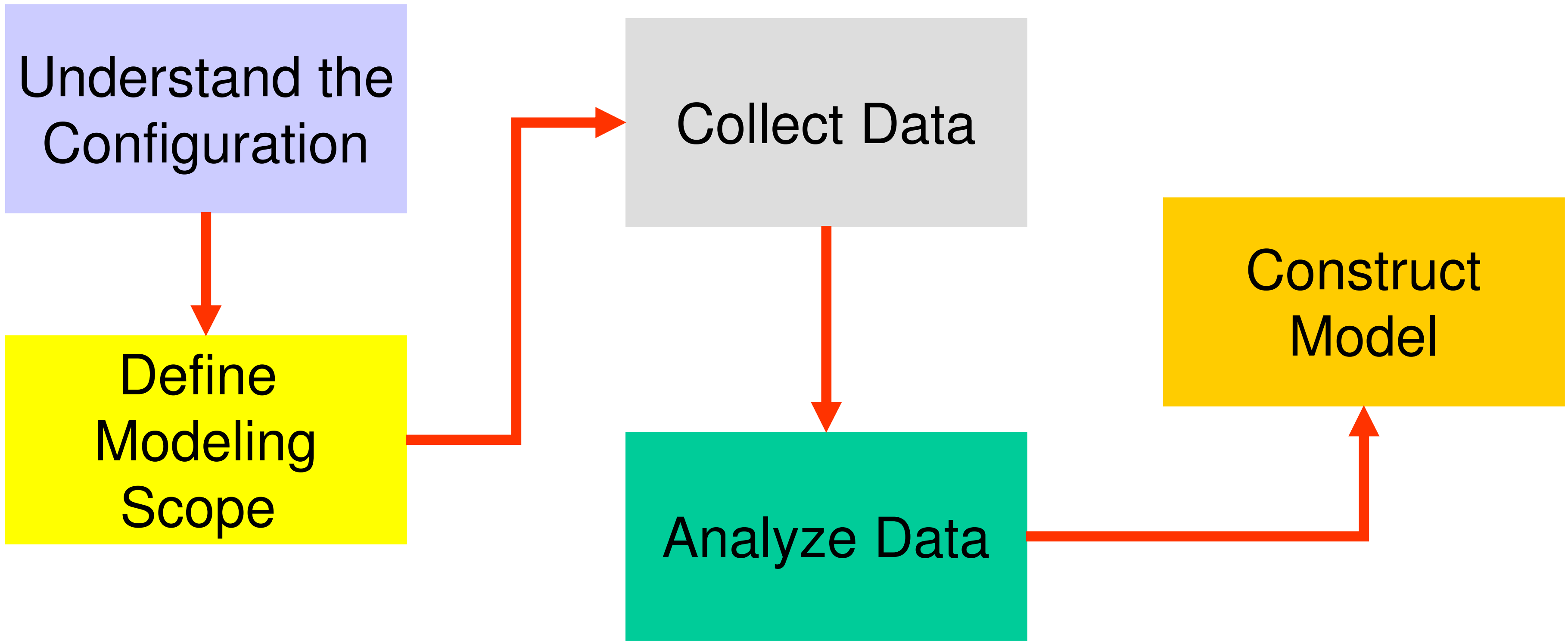
Case Study I:
Military Trainer Configuration





Case Study I: Military Trainer Configuration

- Approach to Flight Modeling Challenge



Case Study I: Military Trainer Configuration

- Understand the Configuration
  - Establish basic model functionality

What is its role?...Military?

Does it carry stores?

Propeller or jet?...how many?

Does a similar aircraft exist?

How many control surfaces?

Does it fly supersonic?

Cause & Effect

↓

Effect = f (Cause)

Case Study I: Military Trainer Configuration

- Define Modeling Scope
  - Establish bounds and the type of model to be created

Engineering

OR

Training

Real-Time

OR

Non-RealTime

Partial Envelope

OR

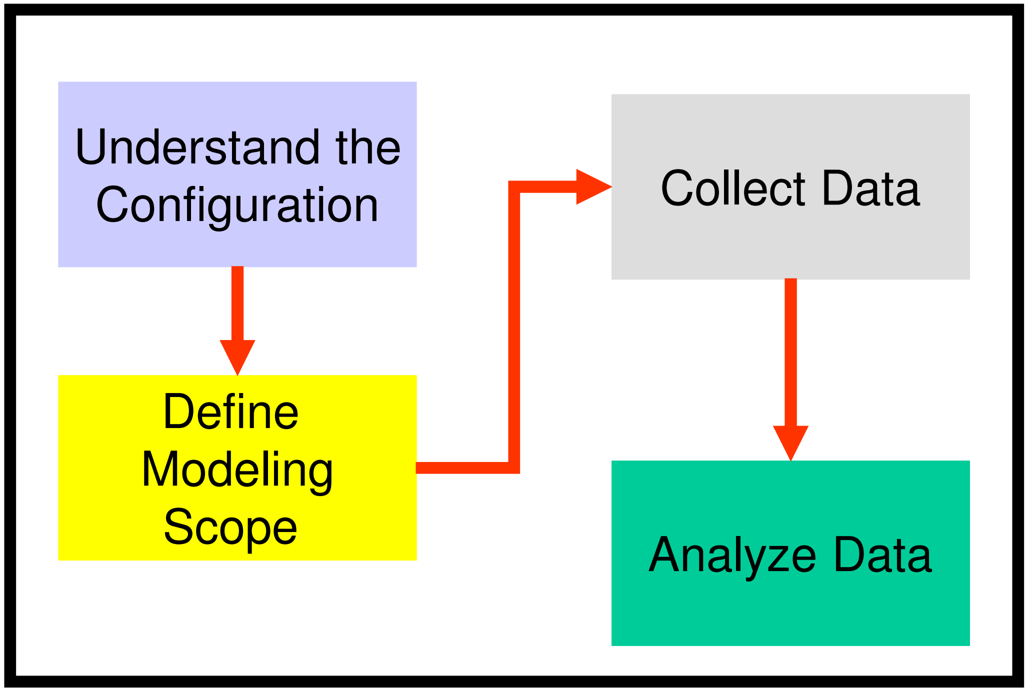
Full Envelope

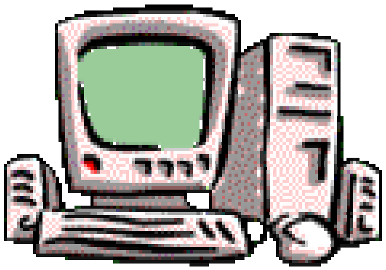
Case Study I: Military Trainer Configuration

- Collect Data
  - Define types of data required
    - Static, Dynamic, Pressure, Flight, etc.
  - Identify data sources
    - Wind-tunnel, CFD, DATCOM, Flight Test
    - Old simulations
  - Collect data
- Analyze Data
  - See what you’ve got
  - Determine what to use and how to use it

Case Study I: Military Trainer Configuration

- Construct the Model
  - Use all information gathered to build model
  - Apply manipulation and sim tools



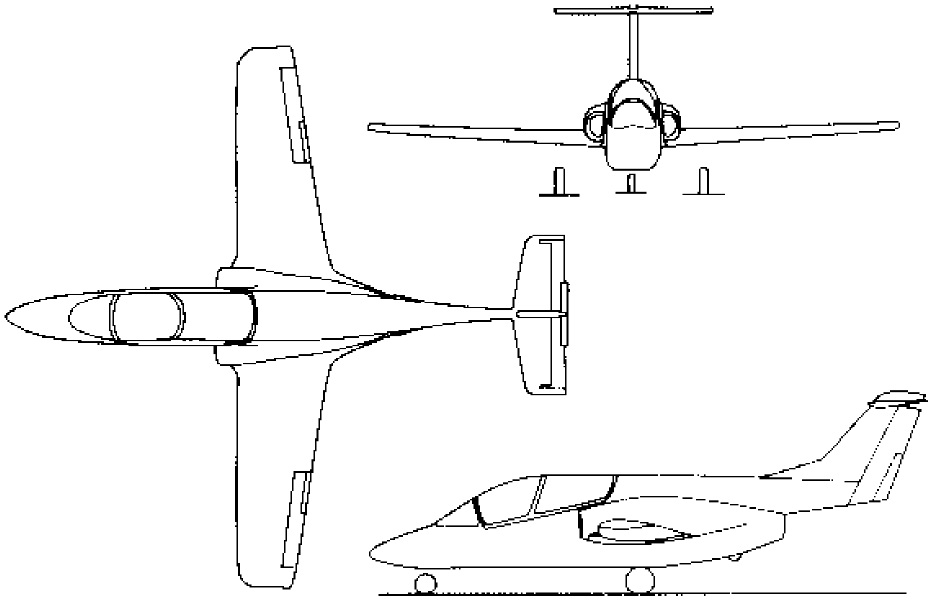


Case Study I: Military Trainer Configuration

- Application: Configuration and Scope
  - Joint Primary Training System (JPATS) Competitor
  - JPATS Program Required Specific Airplane Stall/Spin Characteristics
  - Flight Model was to Accurately Predict Stall and Post-Stall Flight Dynamics
  - Simulation to be used before 1st Flight
    - Maneuver analysis for flight-test planning
    - Pilot familiarization prior to flight

Case Study I: Military Trainer Configuration

- Application: Configuration and Scope
  - Single-engine jet trainer
  - Conventional controls and surfaces



Case Study I: Military Trainer Configuration

- Application: Collect Data
  - Data required
    - Static and dynamic forces and moments
    - Effects of surface deflections
    - Effects of aircraft state
  - Data sources
    - Existing wind-tunnel data
    - Existing simulation models
    - New wind-tunnel data

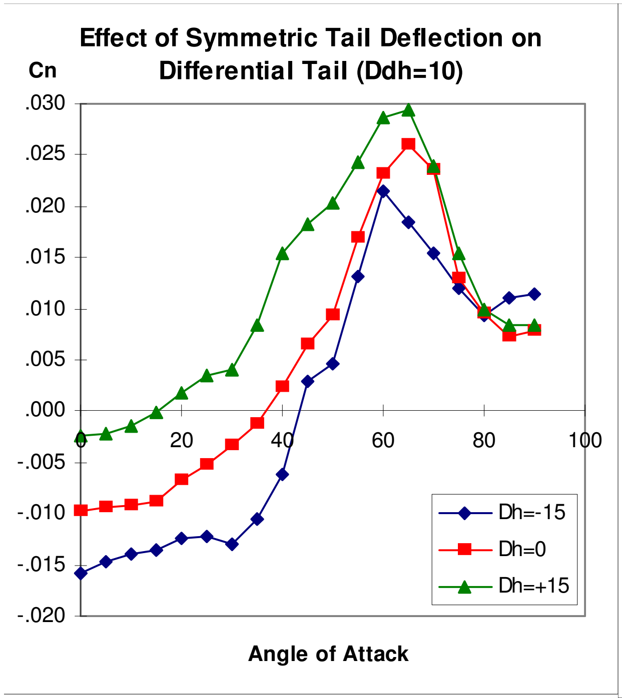
Case Study I: Military Trainer Configuration

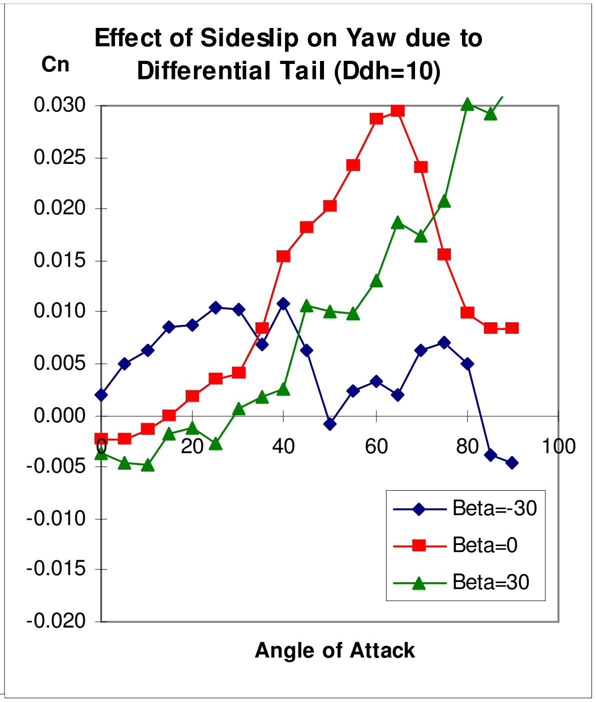
- Application: Collect Data
  - New wind-tunnel tests complementary to existing data (fill holes in data set)

Wind Tunnel	Data Range	Application in Aerodynamic Model
CONVAIR 7 X 10	-10 to 60°α, ±30°β	Static stability of baseline Control effectiveness Config. modification
Rockwell Trisonic	0 to 15°α	Static stability of baseline Mach effects
Bihrle Applied Research LAMP	Static & Rotary: -30 to 90°α, ±30°β	Static stability of baseline Control effectiveness Rotary (wind axis damping) effects Config. Modification
	Forced Oscillation: 0 to 90°α, 0°β	Body-axis roll & yaw damping Config. modification (ventral fins, strakes, etc.)

Case Study I: Military Trainer Configuration

- Application: Collect Data
  - Data analysis
    - Showed need for nonlinear functionality

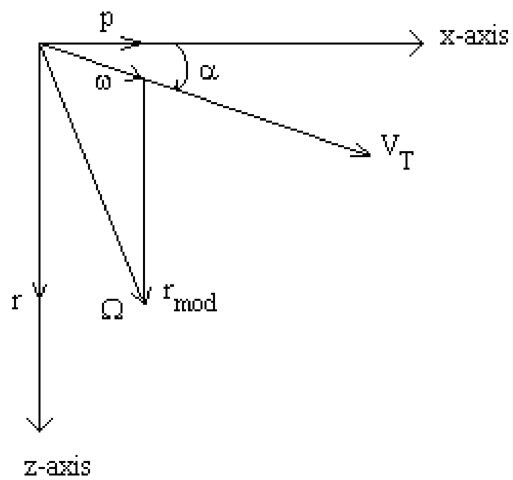




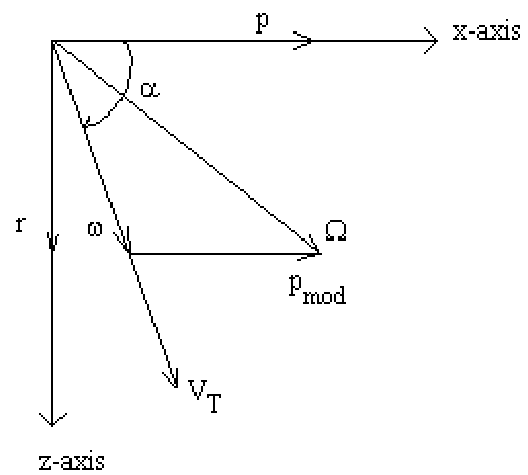
Case Study I:
Military Trainer Configuration

- Application: Construct Model
  - Abandoned conventional linear implementation
  - Use of measured aerodynamics damping data
    - DATCOM and other analytical sources often used
  - Advanced data mechanization applied

Dynamic Maneuver



Spin Condition



Case Study I:
Military Trainer Configuration

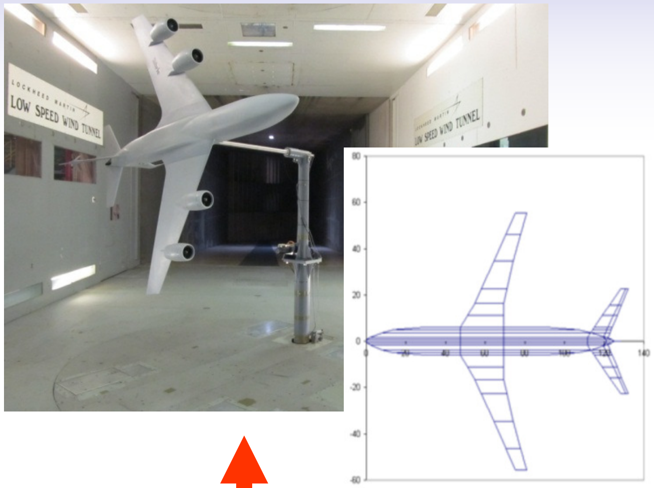
- Application: Construct Model
  - Resulting Aerodynamics Model Structure
    - Coefficient buildup
    - Nonlinear, Multi-dimensional Data

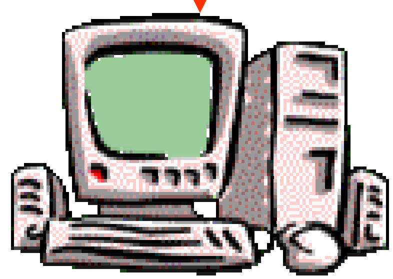
$$
\begin{aligned}
C_{n_{Tot}} &= C_{n_{Basic}}\left(\alpha,\beta,M\right)+\Delta C_{n_{Aileron}}\left(\alpha,\beta,\delta_{aileron},M\right)\\
&+\Delta C_{n_{Rudder}}\left(\alpha,\beta,\delta_{Rudder},M\right)\\
&+\Delta C_{n_p}\left(\alpha,\frac{pb}{2v}\right)\frac{p_{\mathrm{mod}}b}{2v}+\Delta C_{n_r}\left(\alpha,\frac{rb}{2v}\right)\frac{r_{\mathrm{mod}}b}{2v}\\
&+\Delta C_{n_{Rotation}}\left(\alpha,\frac{\Omega b\,sign(\beta)}{2v},|\beta|\right)sign(\beta)
\end{aligned}
$$

Case Study I: Summary
Military Trainer Configuration

- Sound Modeling Approach
  - Gather information and use it wisely
- Fear Neither Simplicity or Complexity
  - Choose the model structure that gets the job done…correctly
- Stall and Post Stall Flight Can be Modeled
  - Analytical (DATCOM, CFD) data has limitations
    - Low AOA assumptions
    - CFD can be expensive in $$$ and computations
    - Modern test techniques for data collection exist

Case Study II: Advanced Modeling for Stall and Upset



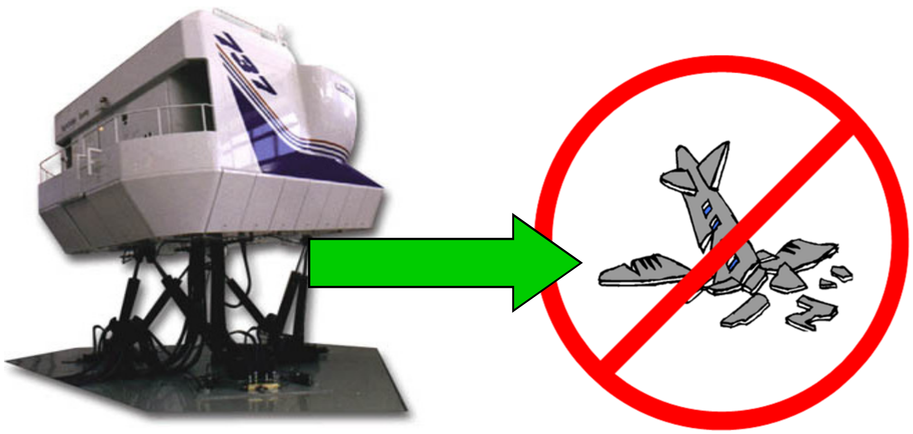



NATIONAL TRANSPORTATION SAFETY BOARD
NTSB
National Transportation Safety Board
Office of Research and Engineering
Flightpath
Loss of Control on Approach
Colgan Air, Inc., Operating as
Continental Connection Flight 3407
Bombardier DHC-8-400, N200WQ
Clarence Center, New York
February 12, 2009
DCA09MA027
Board Meeting

Introduction

- The need for the ability to better train for upsets using ground-based simulators is well established
  - Accident Reports
    - Continental Connection Flight 3407 (Colgan)
    - Air France Flight 447
  - Government/Industry Workgroups
    - ICATEE, SUPRA, LOCART
  - Publications and Presentations
    - AIAA, RAeS, NASA
  - **PUBLIC LAW 111-216**
    - **14 CFR Part 121,**
      - **Docket No.: FAA-2008-0677;**
      - **Amdt. No. 121-366 Final Rule**
      - **05 November 2013**

ICATEE
PREVENT - AVOID - RECOVER
INTERNATIONAL COMMITTEE FOR AVIATION TRAINING IN EXTENDED ENVELOPES

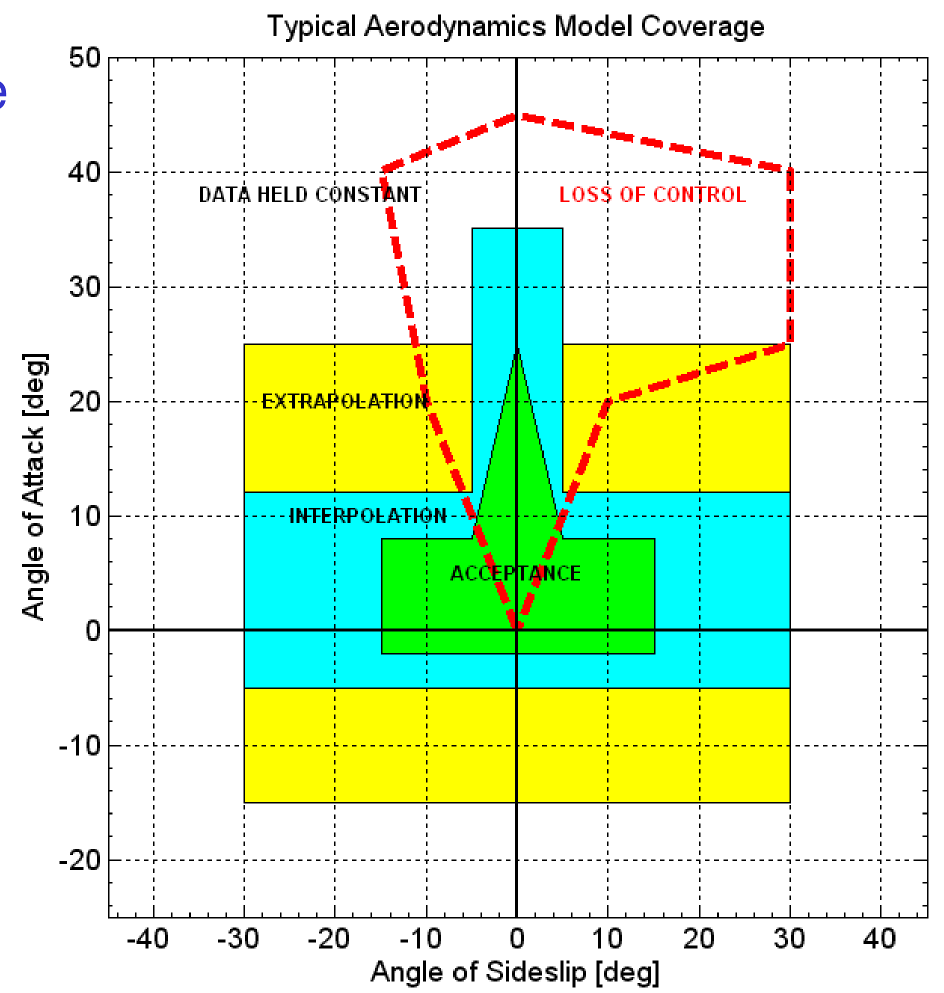


Ground-Based Training

- Existing “Airplane Upset Recovery Training Aid”
  - Focus on Upset and DO NOT include stalls
  - Responsibility of Training Validity Placed on Instructor
    - Simulator Limitations
    - Limited Envelope Coverage
- ICATEE
  - Defined training objectives and tasks for upset and stall
    - Response to global-industry need and US Law (PL111-216)
  - Defined technology requirements needed to meet training objectives.

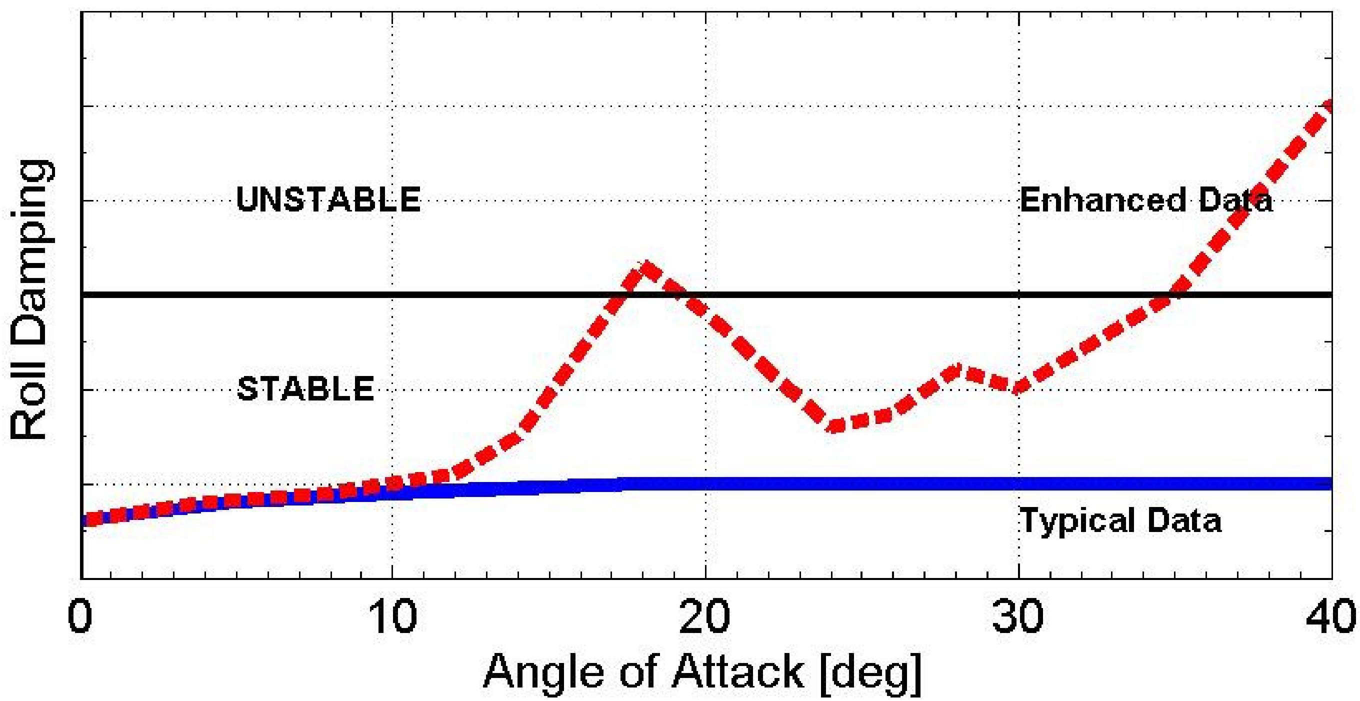
Typical Coverage

- Aerodynamics Model Coverage
  - Very Good Normal Envelope
  - Marginal at Extreme Conditions
  - Inadequate for Comprehensive Training
  - NO FAA/EASA Requirements Beyond Stall
- Control Effects and "Dynamic" Effects
  - Limited Coverage



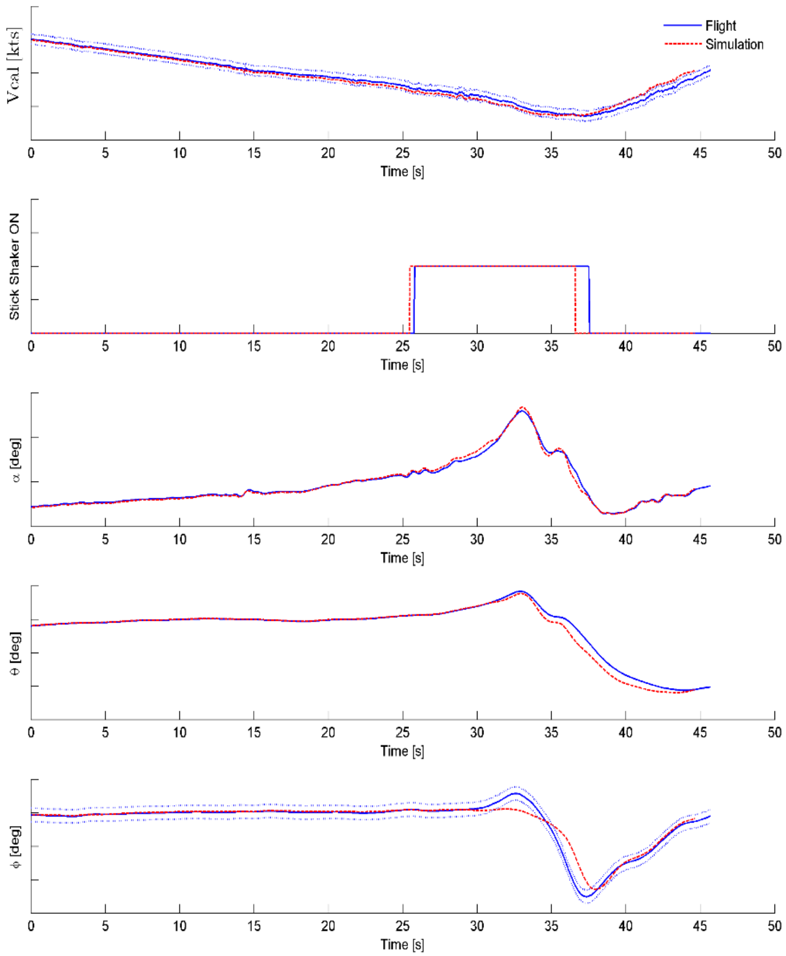
Typical Coverage

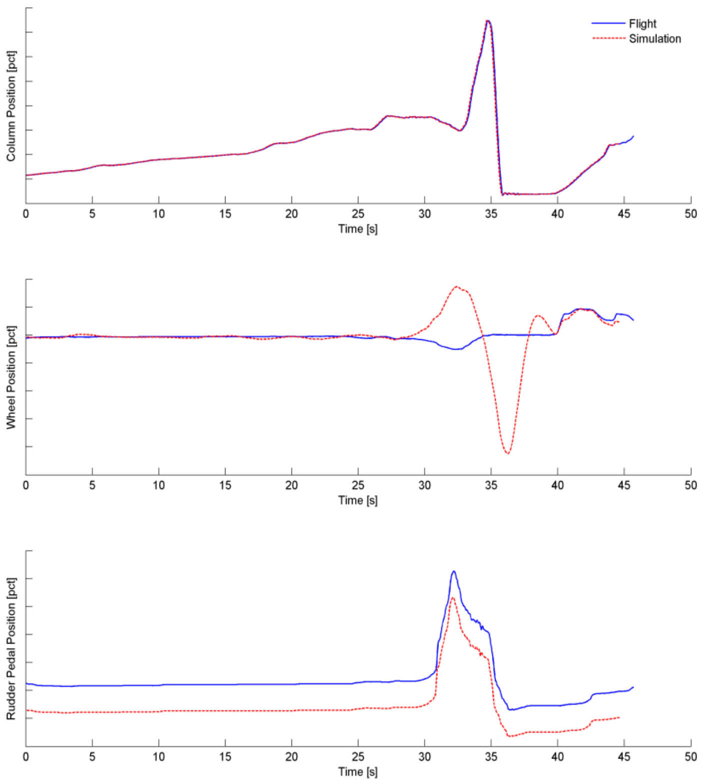
- Example: Roll Damping



Foster, J.V. et al. “Dynamics Modeling and Simulation of Large Transport Airplanes in Upset Conditions,” AIAA-2005-5933.

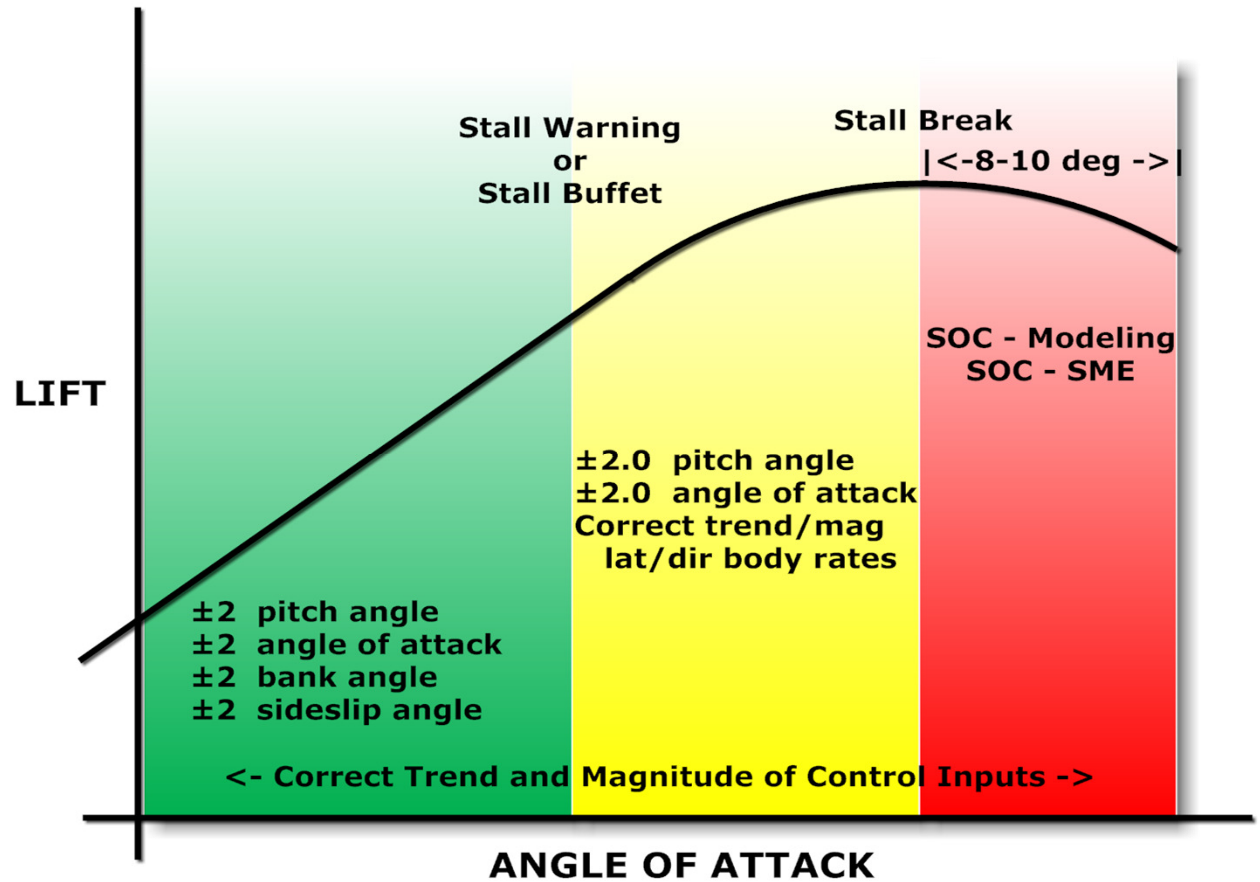
Level-D Qualified Simulation





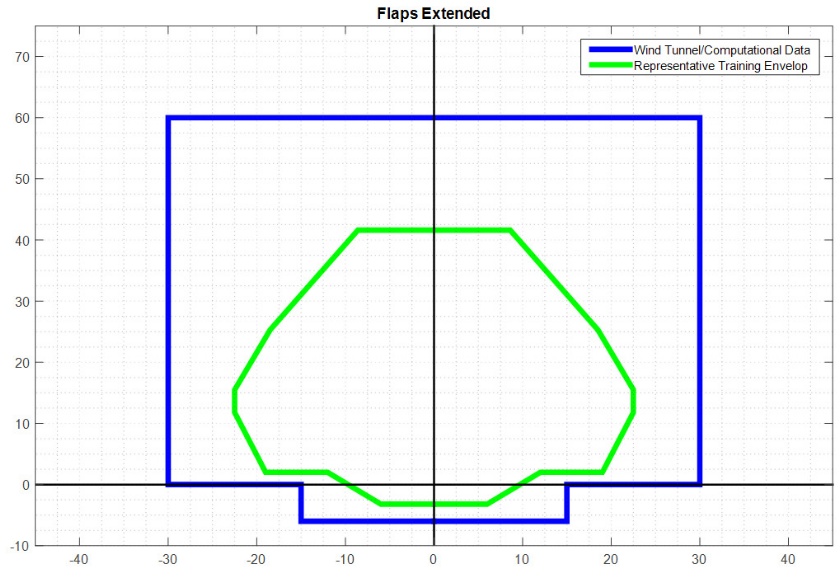
New Requirements FAA 14 CFR Part 60 Change 2 31 March 2016

- New Concept:
  - One Sim Several Fidelity Levels



New Requirements FAA 14 CFR Part 60 Change 2

- Identify sources of data used for the stall modeling
  - Allows use of engineering data
    - Type “Exemplar” Models aka Type “Representative” models
- Map data coverage (simulator limitations)
  - Angle of attack / Angle of Sideslip space
  - Each Flap Setting



- Model at least 8 to 10 degrees past critical angle of attack

New Requirements
FAA 14 CFR Part 60 Change 2

- Features Must be Incorporated as Appropriate
  - Degradation in static/dynamic lateral-directional stability
  - Degradation in control response (pitch, roll, yaw)
  - Uncommanded roll response
  - Roll-off requiring significant control deflection to counter
  - Apparent randomness or non-repeatability
  - Changes in pitch stability
  - Mach effects
  - Stall buffet

Where Will the Stall Model Data Come From?

- **Wind Tunnel test model data**
  + Easily identify all model functionalities
  - Configuration surface data availability, Re effects, cost
- **Flight Extracted model data**
  +"Truth" data
  - Stall flight data availability, data coverage, cost
- **Analytically derived model data**
  + Potential for development with geometric parameters
  - Availability of methods, reasonableness of predictions

Stall/Post-Stall Modeling

- Air Force and Navy Sponsored Work in Stall/Post-Stall (since 1980's)
  - Flight Control Development
  - Flight-Test Support
  - Incident Investigations
  - Training

Stall/Post-Stall Flight

- Characterized by Large Angles of Attack and Sideslip
- Definitions
  - Static Data
    - Data representing classic "Static Stability" and Control
      - Angular-Rate = 0
  - Dynamic Data
    - Data representing non-zero angular rate
      - "Damping"
- Aerodynamics Model
  - Superposition of Static and Dynamic Terms

$$C_{n_{Tot}} = C_{n_{Basic}}(\alpha, \beta, M) + \Delta C_{n_{Aileron}}(\alpha, \beta, \delta_{aileron}, M) + \Delta C_{n_{Rudder}}(\alpha, \beta, \delta_{Rudder}, M)$$

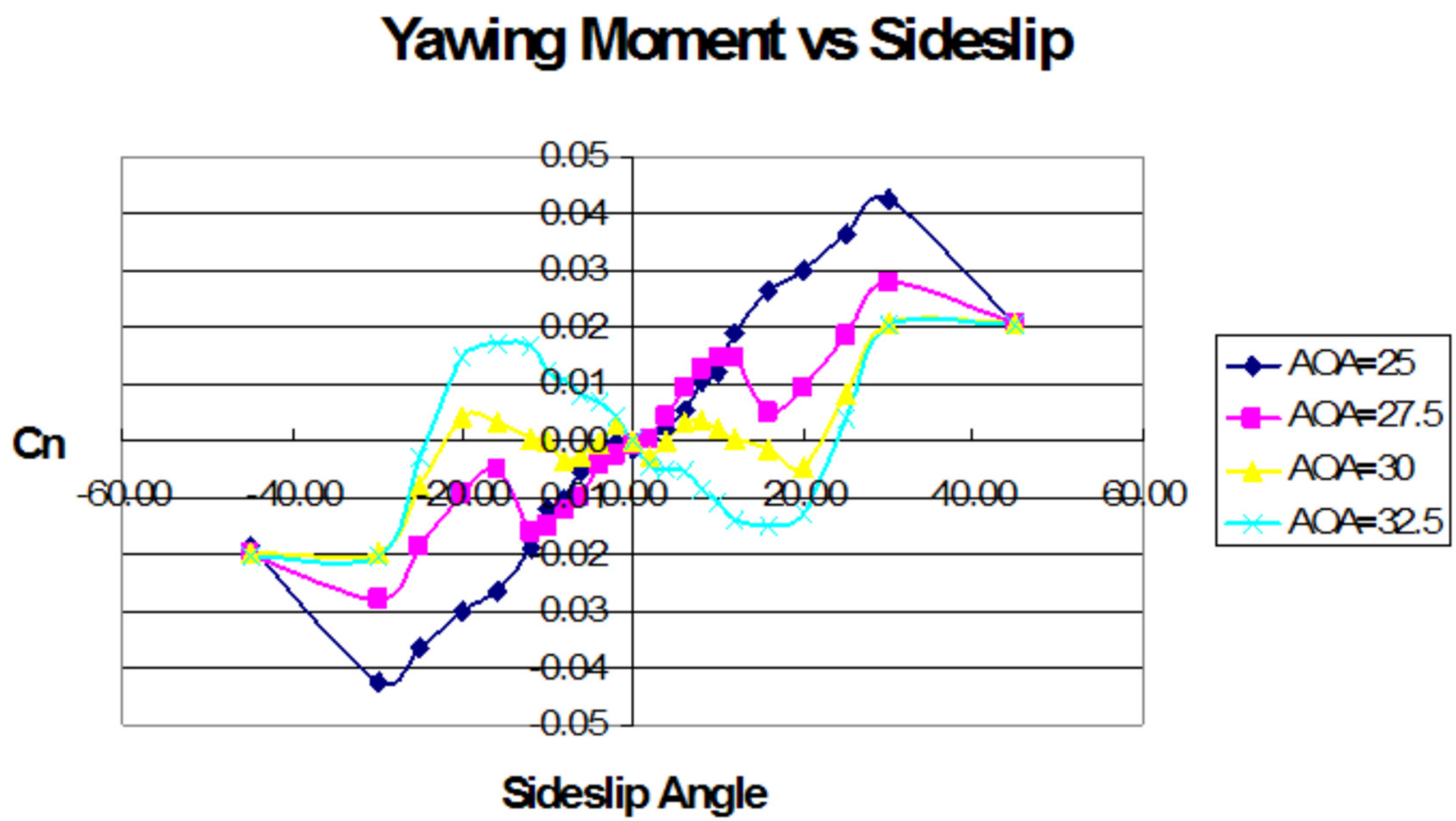
$$\left.\begin{array}{l} + \Delta C_{n_p}\left(\alpha, \frac{pb}{2v}\right)\frac{p_{\text{mod}} b}{2v} + \Delta C_{n_r}\left(\alpha, \frac{rb}{2v}\right)\frac{r_{\text{mod}} b}{2v} \\ + \Delta C_{n_{Rotation}}\left(\alpha, \frac{\Omega b sign(\beta)}{2v}, |\beta|\right) sign(\beta) \end{array}\right\} \text{Dynamic Terms}$$

Stall/Post-Stall Modeling

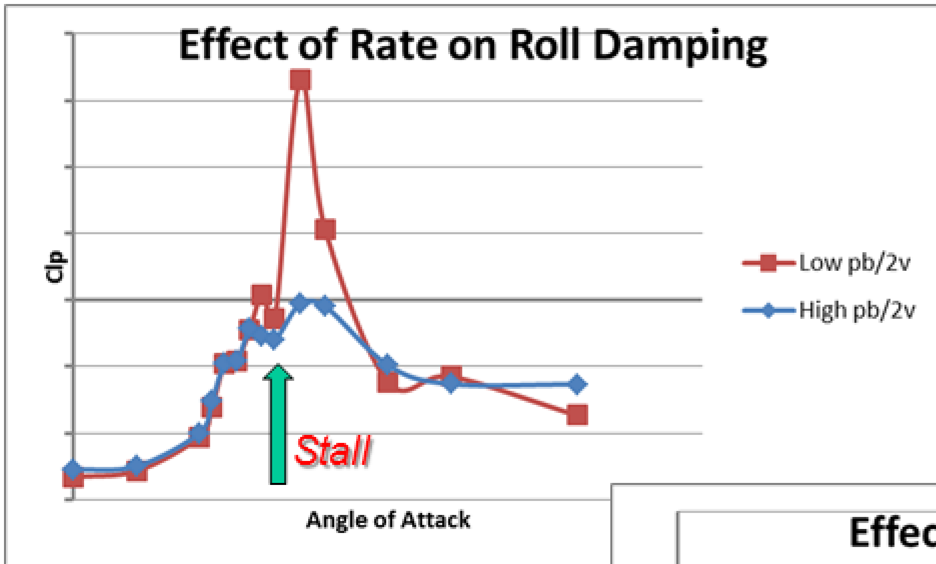
- Static Data
  - Focus of a number of efforts was on collection and implementation of data at and past stall
    - < -90 to >+90 degrees angle of attack
    - <-45 to >45 degree angle of sideslip
    - Control Effects across the ranges
  - Most data were collected from Wind-Tunnel tests
  - Work resulted in extended use of nonlinear data in aerodynamics models
    - Table driven implementations
    - Expanded functionality
      - 4+ dimensions

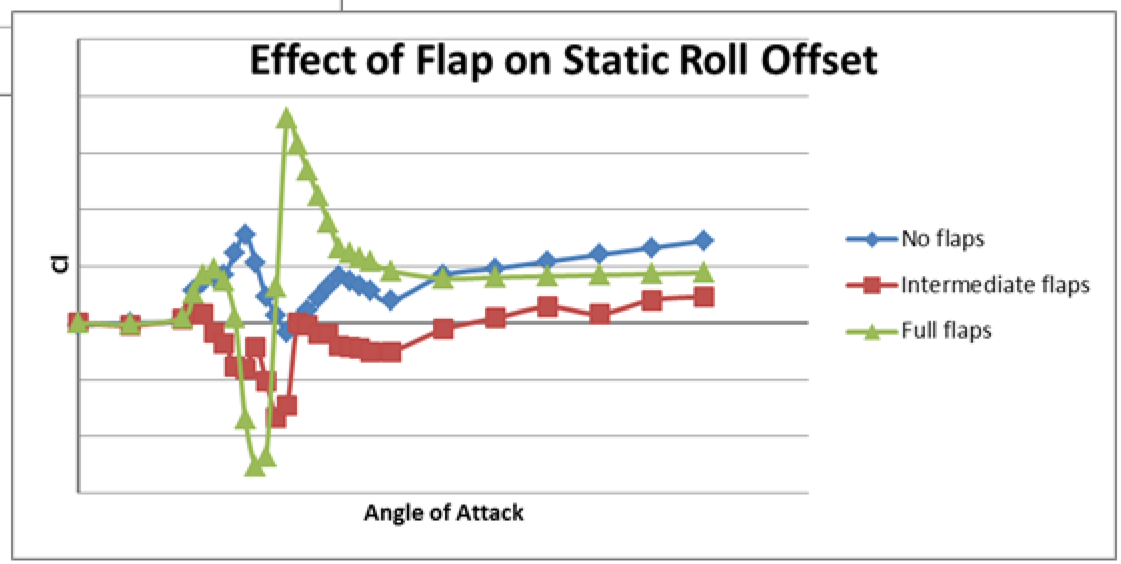
Stall/Post-Stall Modeling

- Example: Static Directional Stability



Wind Tunnel Data Source





Flight Test Data Source

- Traditional flight I.D. uses linearized buildup

e.g. $Cl = Cl(\propto, \delta flap) * \beta + \Delta Cl\delta a \; * \delta a + Clp * \frac{pb}{2V} + Clr * \frac{rb}{2v}$

- Stall I.D. typically cannot assume linear functionality

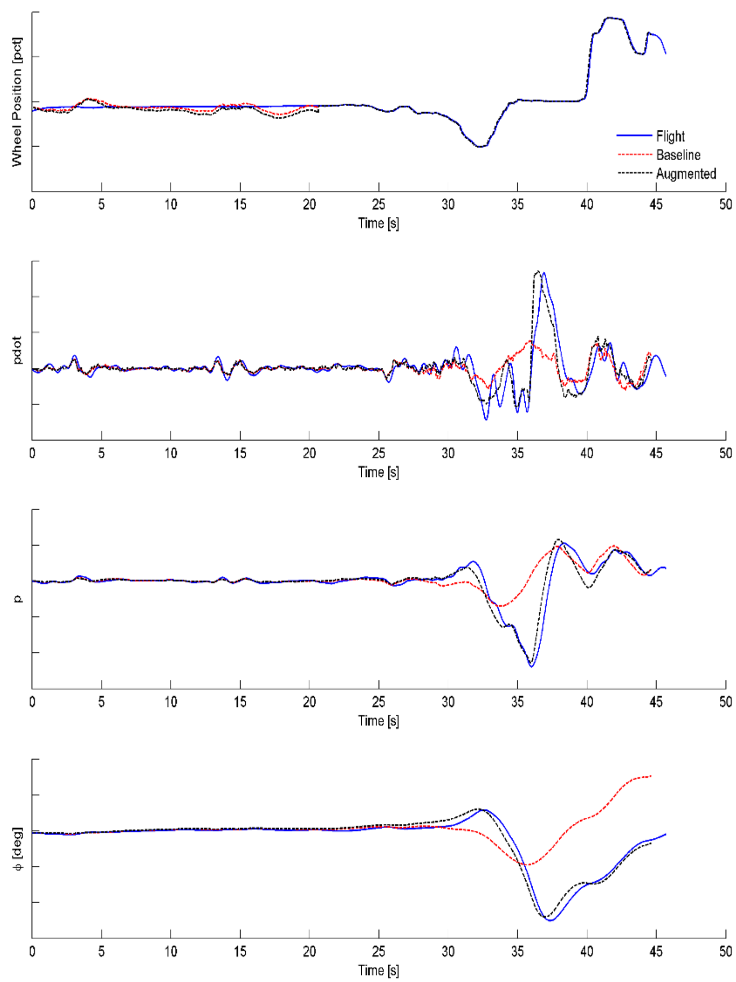
e.g. $Cl = Cl(\propto, \beta, \delta flap) + \Delta Cl\delta a(\alpha, \delta a) + Clp(\alpha, \frac{pb}{2V}, \delta flap) + Clr(\alpha, \frac{rb}{2v}, \delta flap)$

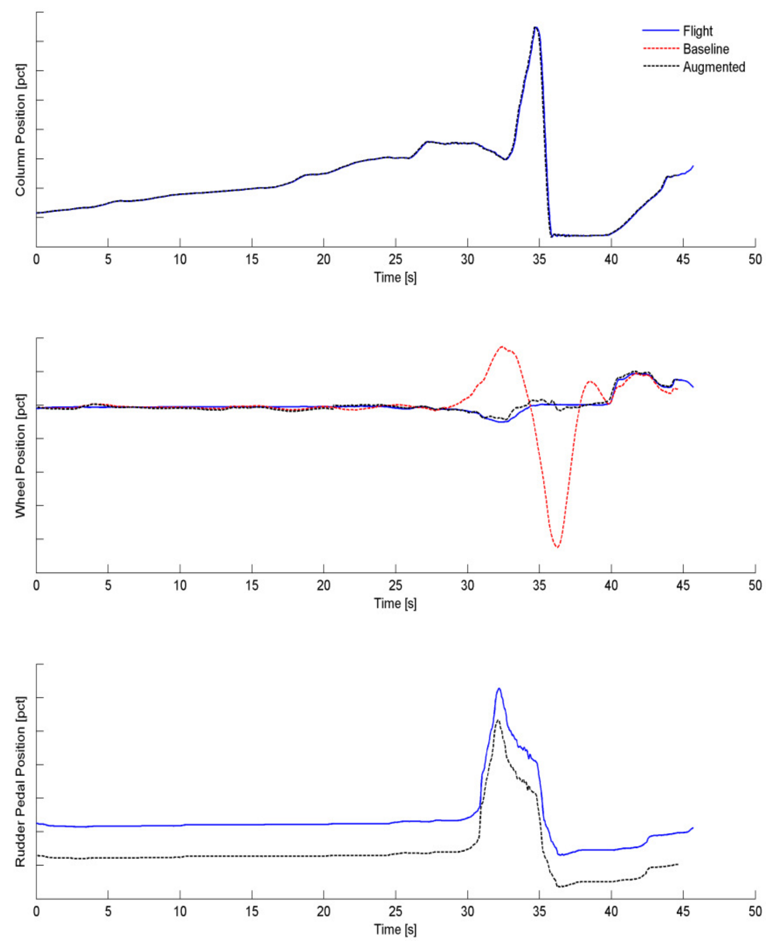
More data to identify non-linear relationships

-- and/or --

A priori recognition of data characteristics

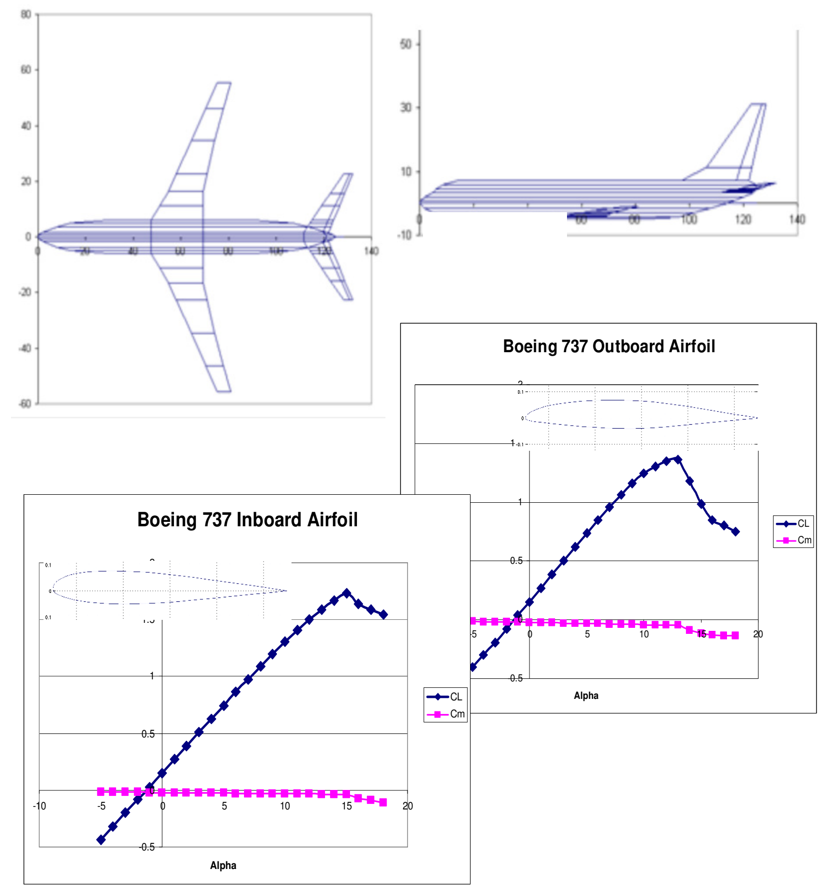
Enhanced Level-D Model





Analytic Data Source

- Hybrid example:
  - Initial stall - immediate post stall analysis
    - Input panel model from 3-view
    - Highly modified Vortex Lattice
    - Kirchoff analysis to predict forces and moments through stalled region
      - Test data or predictive methods for 2-D airfoil data through fully stalled
  - Post stall analysis
    - Uses modified Strip method
    - Accounting for vortex lift
    - User specified predictive database



Stall-Post Stall Modeling

- FAA sponsored research on developing processes for developing “Type-Representative Models” in the stall and post-stall flight regime
  - Computational/predictive methods
  - Wind-tunnel based methods
  - SME expertise

In Your Notes…

– "Aerodynamics Modeling for Training on the Edge of the Flight Envelope."
  - Authors: Gingras and Ralston
– "Improvement of Stall-Regime Aerodynamics Modeling for Aircraft Training Simulations"
  - Authors: Gingras, Ralston, and Wilkening
– "Flight Simulator Augmentation for Stall and Upset Training"
  - Authors: Gingras, Ralston, Oltman, Wilkening, Watts, and Derochers

Mathematical Modeling Part II
PARTING THOUGHTS

- Modeling tools exist that make the modeling engineer's life easier
  - Save time and money
- Simulation tools exist that allow engineers to rapidly develop and evaluate models
  - Save time and money
- Before development, understand how the model will be used
  - Control-Law Design, Training Etc.
- Take the time to do it correctly
  - Save time and money…in the long term

QUESTIONS?