RECENT AERO MODELING RECOMMENDATIONS FOR UPSET TRAINING SIMULATIONS

The ICATEE Perspective

Presented to SUPRA

NLR Amsterdam

9 Feb, 2011

BACKGROUND

- Aerodynamic modeling is an important R&T topic for ICATEE
- Modeling recommendations in progress
- Training matrix is primary driver for modeling recommendations
- Recommendations for model certification standards in progress
  - Representative
  - Advanced

Improvements to FSTD Aerodynamic Stall Models

International Committee for Aviation Training in Extended Envelopes
ICATEE

London Meeting - June 7-8, 2009

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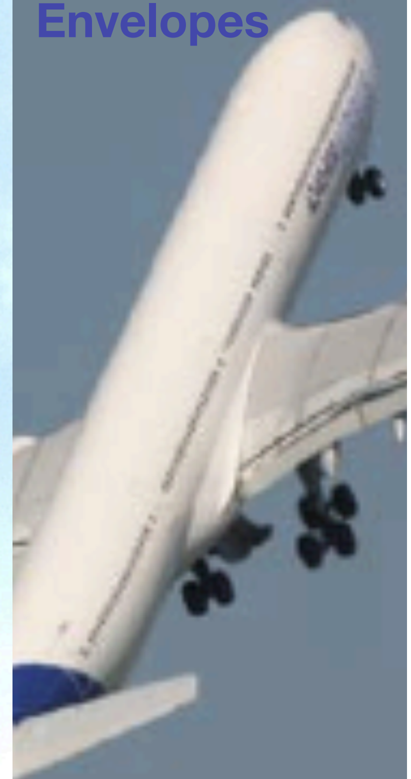


Flight Simulation Group - Royal Aeronautical Society
London, UK

Overview

- Important stall model features
- How do Level D qualified FSTD's Compare?
- Options for stall model improvements
- Data for stall models
- Validation approaches
- Retrofitting stall model improvements
- Dedicated FSTD's for stall training
- Summary

Objective is to get feedback on stall model features & fidelity to meet training requirement

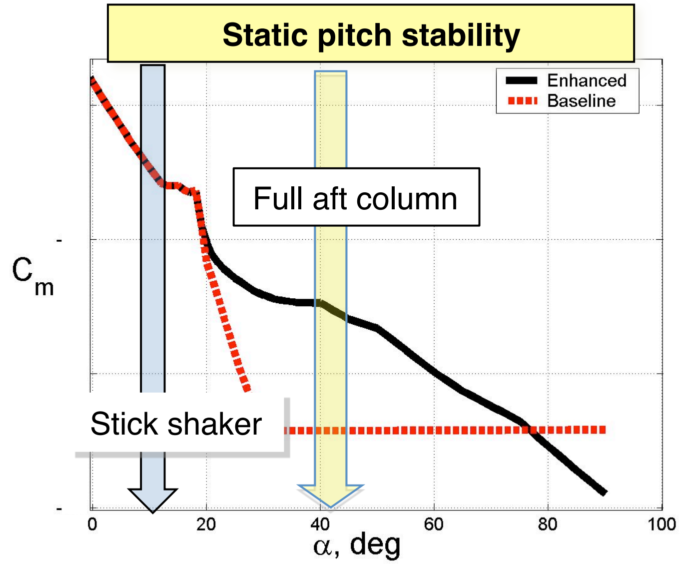
IMPORTANT STALL MODEL FEATURES

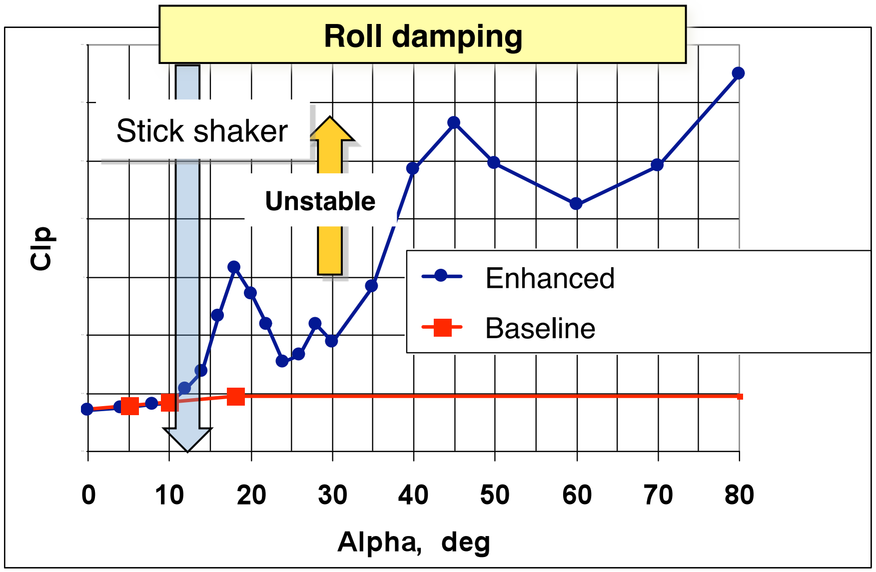
- Handling qualities
  - Degradation in static/dynamic lateral-directional stability
  - Degradation in control response (pitch, roll, yaw)
  - Roll-off requiring significant wheel deflection to counter (primarily aero roll asymmetries)
  - Apparent randomness or non-repeatability
  - Changes in pitch response
    - Perceived pitch instability (e.g. pitch up, pitch break)
    - Degradation in pitch control (elevator effectiveness)
  - Yaw divergence due to loss of directional stability
- Relevant flow physics
  - Downwash on horizontal tail
  - Wing flow separation
  - Aft tail immersion in wing wake
  - Impingement of forebody flow/vortices on aft fuselage/tail, UNSTEADY EFFECTS
  - Aerodynamic asymmetries, (e.g. asymmetric wing stall)
  - Other?
- Cues
  - Stick shaker
  - Buffet (initial, deterrent)
  - Noise

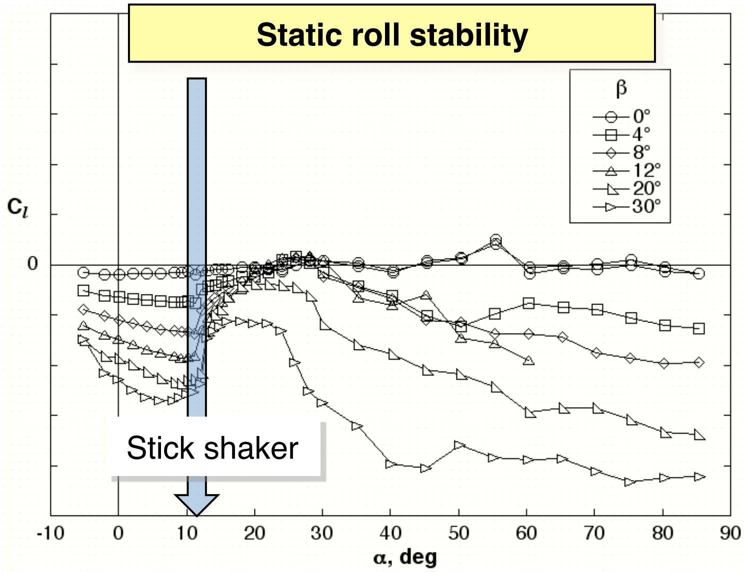
TYPICAL STALL CHARACTERISTICS vs AOA

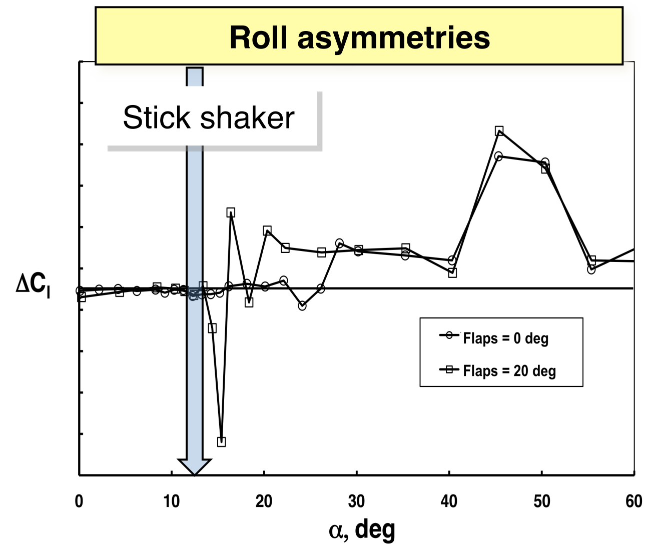
Features	Angle of Attack				
	Stall warning system	Incipient stall	Stall ID (near C_{Lmax})	Post stall	Maximum
Typical AOA	α_{CLmax} - 4°	α_{CLmax} - 2°	α_{CLmax}	α_{CLmax} + 2°	> α_{CLmax} + 3° (varies with CG)
Handling qualities	Nominal	• Control response degradation • Roll-off • Perceived changes in lat-dir stability	Change in pitch stability	Yaw divergence	• Oscillatory departure modes • Large sideslip
Flow physics	Nominal	• Initial wing flow separation • Downwash effects • Asymmetric stall	• Immersion of tail in wing wake • Asymmetric stall	Forebody flow impingement	Fully separated flow
Cues	Shaker, pusher, etc	• Buffet onset • Noise	• Deterrent buffet • Noise	• Deterrent buffet • Noise	

EXAMPLE NON-LINEAR CHARACTERISTICS FOR STALL/UPSET MODELING









Examples of a Level D Simulator Model

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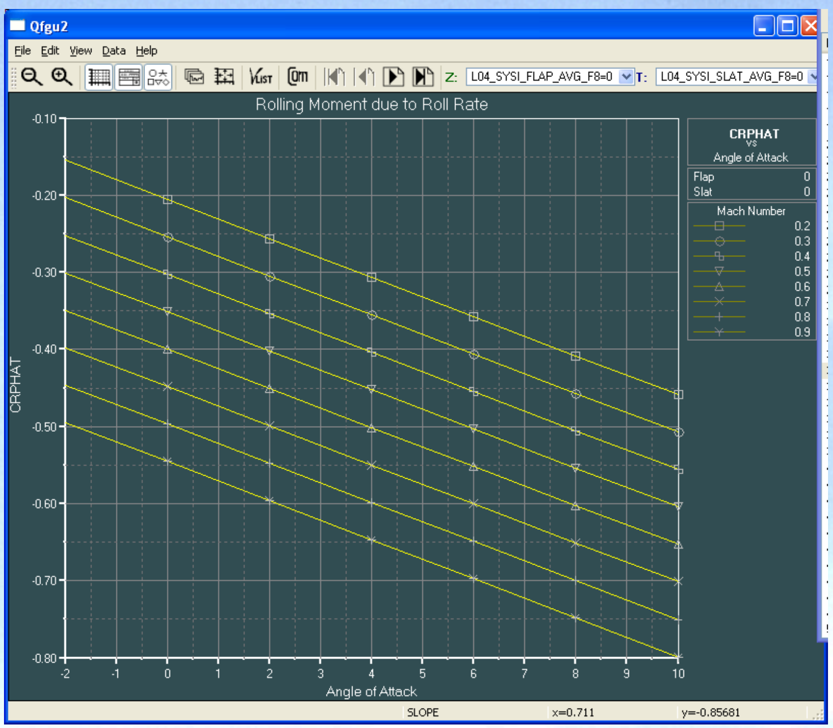
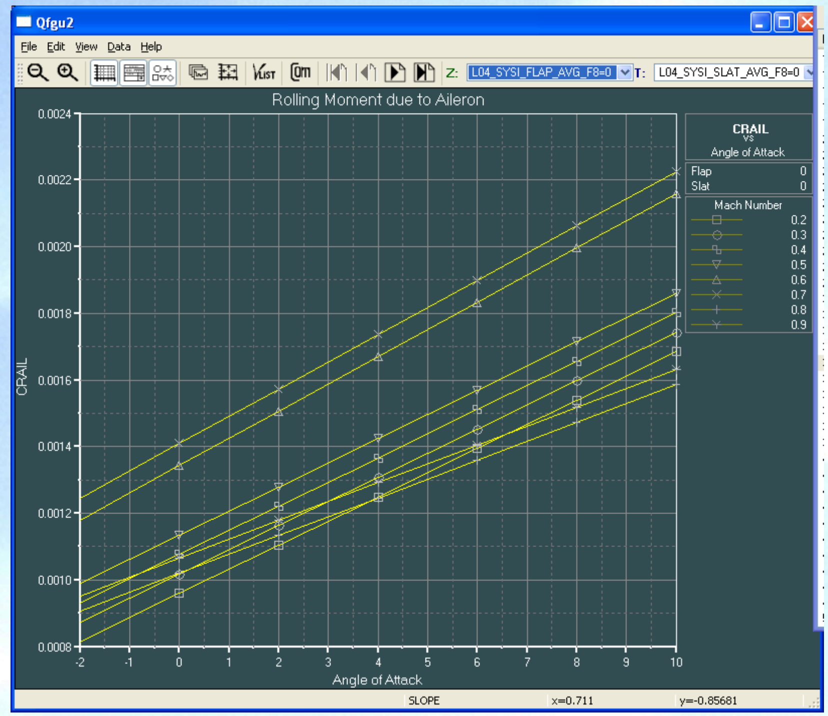
Rolling Moment due to Roll Rate



Rolling Moment due to Aileron



- Degradation in roll damping and roll control authority not modeled
- Limited alpha range

Examples of a Level D Simulator Model

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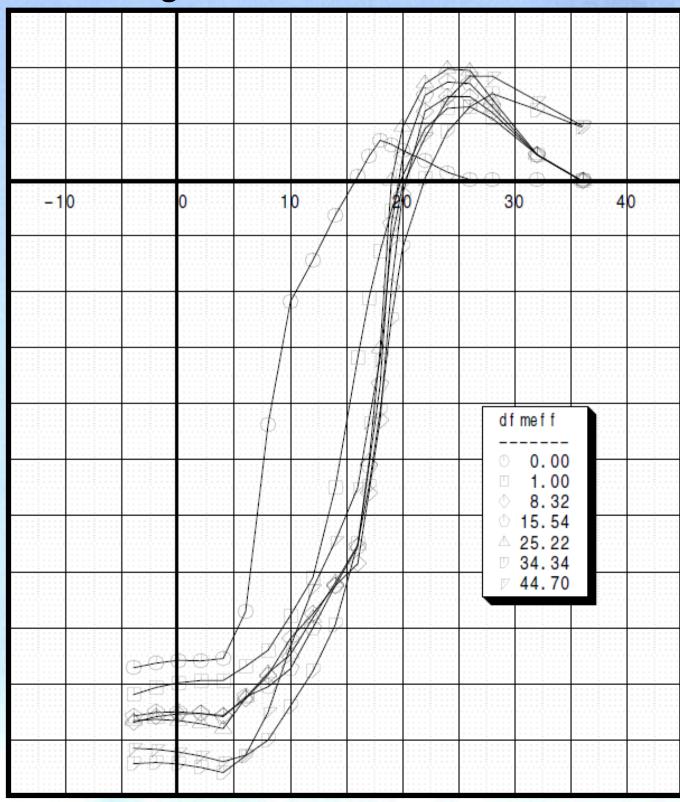
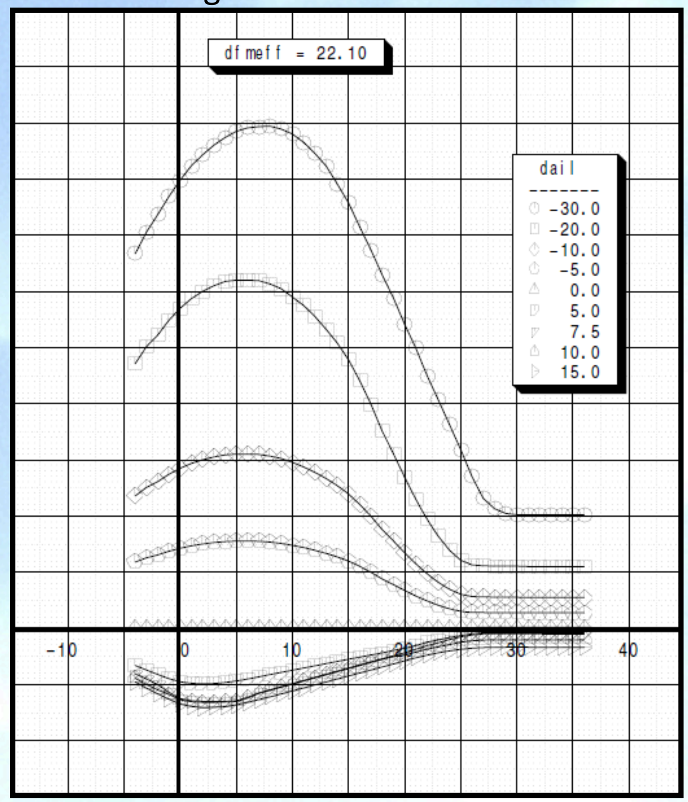
Rolling Moment due to Roll Rate



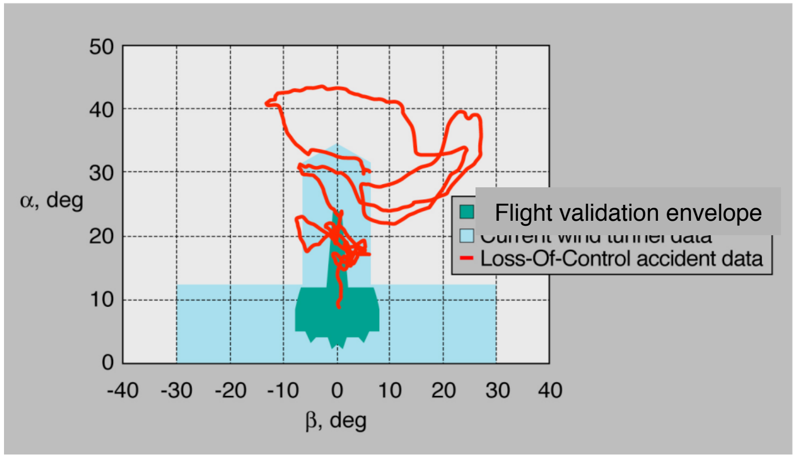
Rolling Moment due to Aileron



Degradation in roll damping and roll control authority <u>are</u> modeled

CURRENT LEVEL D ISSUES

- Data coverage: Stall modeling
  - Some models may not fully cover alpha/beta range (extrapolation may not work)
  - Static terms may have different data range than dynamic terms
- Lack of damping data in stall/post-stall regimes
- Lack of detailed aero asymmetry modeling
- Lack of accurate flap effects at high AOA
- Fidelity varies across simulator fleet



Current simulations not designed for stall or post-stall conditions

Current Level D Issues – Cont'd

- Some OEM models partially model the lateral/ directional features associated with stall
  - E.g. degradation of roll authority and roll damping
  - Not sure how representative models are beyond stall warning
  - Limited validation data is provided
- Some manufacturer-developed simulations partially model these features based on subjective pilot comments
- Not aware of any Level D simulator models in which all features are modeled - especially post stall ID

Current Level D Issues – Motion Buffets

- Buffet onset and amplitudes models provided by OEM
  - Typically based on angle of attack or lift coefficient
- One QTG validation test "Buffet at approach-to-stall"
  Tolerance: Simulator test results must exhibit the overall appearance and trends of the airplane data with at least three (3) of the predominant frequency "spikes" being present within +/- 2 Hz
- Vibration data typically collected for all flap settings
- Buffet amplitudes are often subjectively tuned by the acceptance pilots (except at the QTG test point)
- Motion systems are capable of reproducing buffet amplitudes in the approach to stall

Recommend additional validation tests using existing data

Example of Stall Buffet QTG

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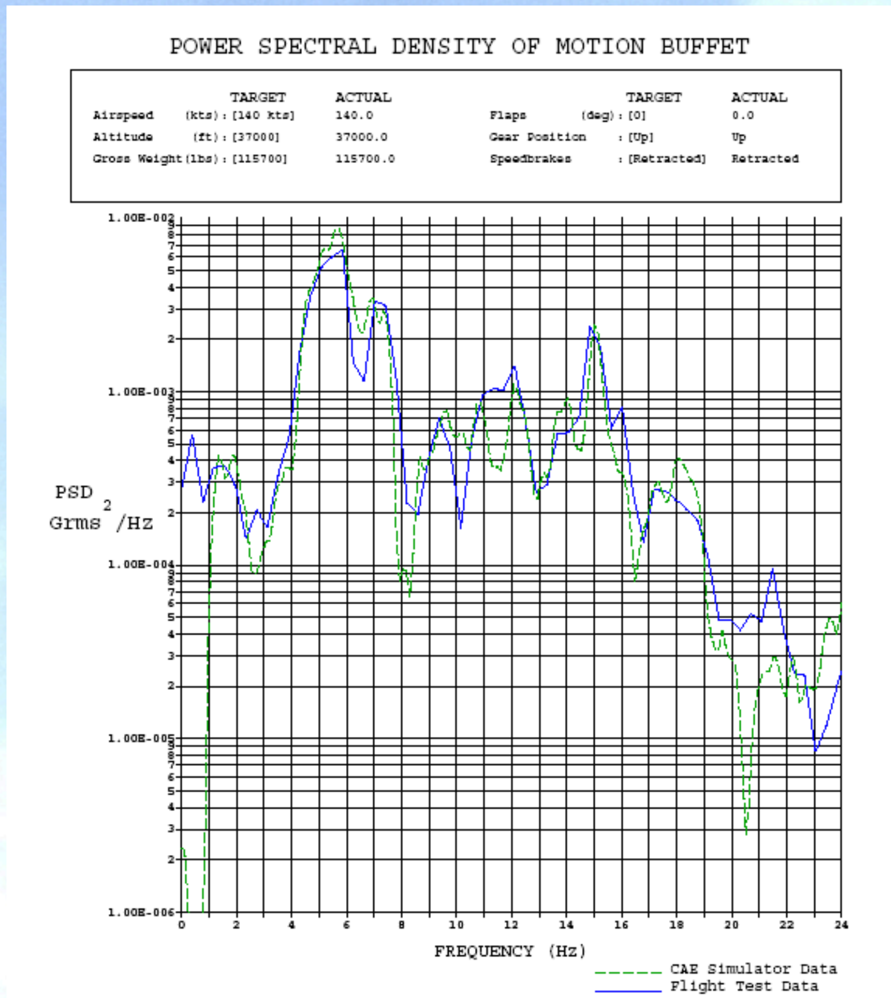

Current Level D Issues – Sound Cues

- Specific sound cues associated with stall are not simulated other than simulator cockpit noises generated by motion buffets
- On some aircraft there are aerodynamic sounds associated with stall in addition to mechanical noise generated by structural vibrations
- No validation data is provided

MODEL FIDELITY OPTIONS

Fidelity	Handling Qualities Features	Data Modifications
Generic (transport)	• Representative stall AOA and column deflection • Generic roll damping/roll-off	• Generic trends of α/β static data • Evaluation and tuning of roll damping • Generic aero roll asymmetry
Class (body, engine, tail)	• Representative stall AOA and column deflection • Generic control response degradation • Generic roll asymmetries • Generic lat/dir damping	• Generic trends of α/β static data • Control response tuning • Aero roll asymmetries model • Tuning of roll/yaw damping
Specific (type)	• Accurate stall AOA • Accurate pitch stability • Control response degradation (all axes) • Non-linear lat/dir damping • Accurate sideslip divergence • Accurate wheel/column deflections	• Full α/β static data (all axes) • Non-linear static control effectiveness data • Non-linear damping data (all axes) • Accurate aero asymmetries model

MODEL UPDATE TRADEOFFS

Configuration	Advantages	Disadvantages	Effort
Generic Through stall ID	• Lowest development cost • Allows demonstration of potential stall behavior • No validation	• No validation • Cannot demonstrate appropriate recovery • Potential for highly unrealistic post stall • Potential for negative training	• Requires adjustment of existing model, may require adding limited data functionality
Class Through Post-stall, Recovery	• Allows reuse of class data for multiple airframes • More representative demonstration of stall behavior • Representative recovery demonstration • Limited class validation	• Uncertainty for specific configuration stall /recovery characteristics • Remaining potential for negative training • Increasing cost for development	• Data acquisition • Flight data validation • Integration and testing of additional coefficient components w/ existing model
Type Specific Through Stall ID ----------------------- **Class** Through post stall/recovery	• Fully representative stall characteristics • Demonstrate recovery • Stall validation w/ aircraft data • Limited data reuse	• Limited uncertainty for post stall recovery • Reduced potential for negative training during recovery • Some aircraft specific development • Cost	• Data acquisition • Flight data validation • Integration and testing of additional coefficient components w/ existing model
Type Specific Through post stall/recovery	• Fully representative throughout flight envelope • Stall validation w/ available aircraft data	• Cost • Aircraft specific development	• Specific configuration data acquisition • Flight data validation • Integration and testing of additional coefficient components w/ existing model

Questions

- What is our definition of stall for modeling recommendations?
  - Do we need to define stall by
    - Range of alpha/beta
    - Stall ID, column position, buffet
  - Do we want to include all definitions of stall ID
    - Pitch break, deterrent buffet, full aft column
- What info do we have for other simulations besides EUR?
- What is current industry approach to modeling aerodynamic asymmetries for stall AOA's
- Can training matrix be mapped into model requirements?

QTG Stall Validation Tests

- Two cases: 2nd segment climb and approach or landing
- Entry at idle thrust and wings level (1g)
- Time history for full stall and initiation of stall recovery but sometimes limited to stick pusher
- Tolerance:
  - ±3 kt airspeed for initial buffet, stall warning, and stall speeds
  - ±2° roll angle for speeds greater than stick shaker or initial buffet.

Limited data for lateral/directional and post stall ID features

QTG Stall Validation Tests

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- Are additional objective cases needed?
- If there is a emphasis on Flaps Up stall-avoidance/stall-recovery training should the Flaps Up stall objective test found in the IATA Document be added?

9	Stick Shaker, Airframe Buffet, Stall Speeds	2nd Segment Climb *Cruise* and Approach or Landing	Stall warning signal should be recorded and must occur in the proper relation to stall. Airplanes exhibiting a sudden pitch attitude change or "g break" must demonstrate this characteristic. Airplanes with reversible flight control systems must also plot Stick/Column Force. *Note: The intent of this test is to collect 1.0g stall data (including cruise configuration).* CCA: Test in Normal AND Non-normal control state.

IATA FLIGHT SIMULATOR DESIGN & PERFORMANCE DATA REQUIREMENTS

QTG Stall Validation Tests

- What about Lateral/Directional characteristics?

- Propose adding an objective test for Turning Flight Stalls
  - Should be available from certification testing (need to waive mid weight/mid CG requirement)
  - Depending on aircraft control law the test could include non-zero values for wheel, rudder, sideslip and yaw rate through stall
- Tolerances:
  - TBD

Turning Flight Stall – Example match

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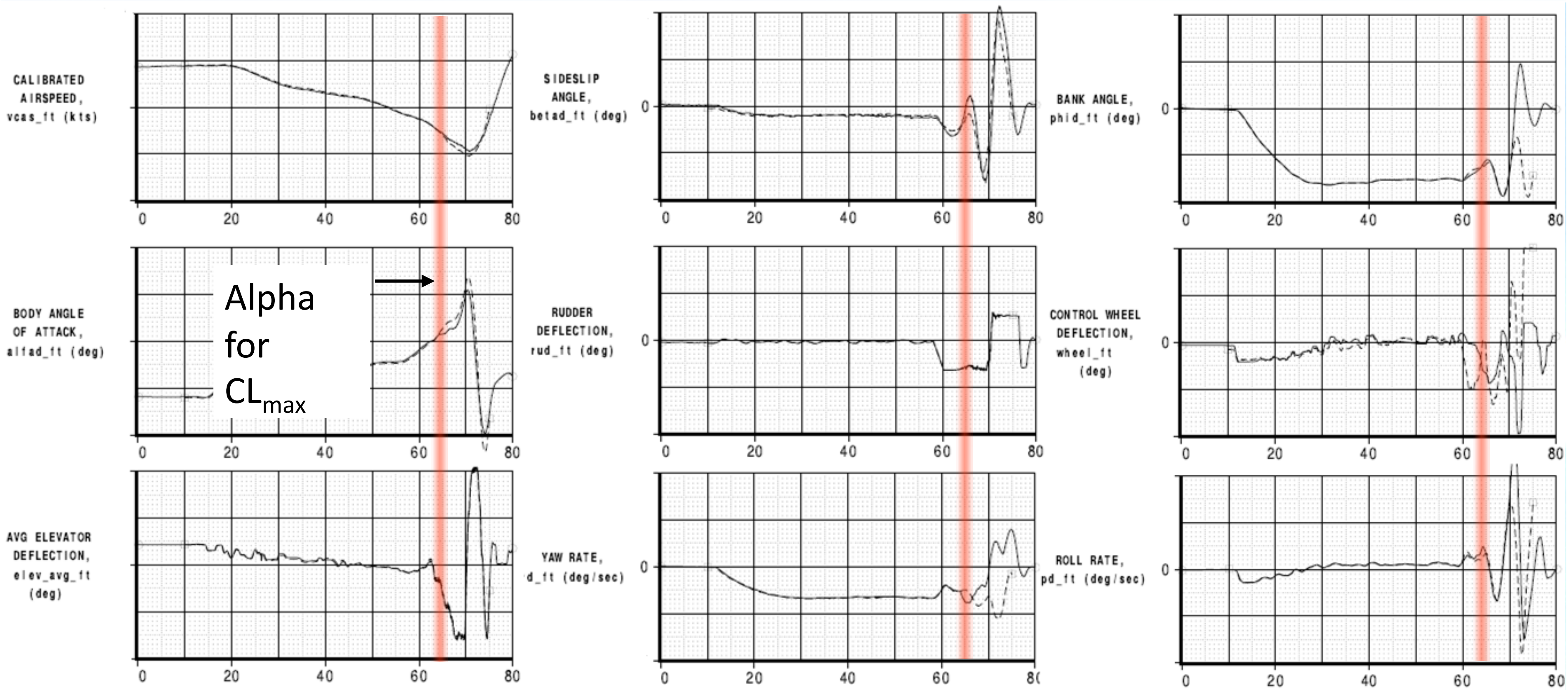

Match driven with flight test elevator & rudder

Math pilot on wheel

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Other Flight Test Data

- For a first of model and under today's regulatory requirements, stalls would be performed at:
  - Forward and aft cg
  - Idle and FAR power
  - Wings level and turning flight
  - Normal (1 kt/sec) and accelerated (3 kt/sec)
  - Normal and degraded control law modes
  - Speedbrakes up and down
  - Natural or artificial ice
  - Multiple altitudes
    (including a flaps up stall at maximum operating altitude)

Validating Stall Model Improvements

- Potential validation approaches for simulator qualification:
  - Subjective evaluation:
    - Experienced test pilot familiar with aircraft and training need
  - Matching time histories:
    - objective tolerances
    - good test for recurrent evaluation
    - Data probably insufficient to validate all features
    - Challenge matching long duration test with divergent behavior
  - Coefficient matching
    - Validates accuracy of database
    - Alternative to time histories

Validation approach will depend on features modeled and available data

RETROFITTING STALL MODEL IMPROVEMENTS

- Large number of qualified FFS
  - Globally: ~1100 FFS qualified to Level C and D (800)
  - FAA: ~ 625 FFS qualified to Level C and D
- Adding stall improvements should be straightforward and not affect rest of envelope
  - Stall and VMCA only QTG cases affected
  - In some cases patches in code add to update effort
- Non-recurring development per aircraft type will depend on features modeled and data used
  - ~ 100 different aircraft types
- Recurring effort per simulator will depend on model complexity and volume
  - Initial estimate of possible range: $25K - $100K per device (TBD)

Dedicated Simulators for Stall Training

- Conduct stall training only on specific FSTDs
- Alternative to retrofitting all simulators
- Aspects to consider:
  - What is the number (ratio) of dedicated devices required to supporting training
  - Logistics and costs of scheduling training on separate devices
  - Are generic, class or type specific stall features required
- May be attractive for lower volume aircraft types

Clarify the Training Requirement

- Training needs will drive model fidelity requirements
  - Envelope (alpha, sideslip, angular rates, configurations, etc)
  - Buffet, sound, etc
  - Generic response versus type specific response
- Can specific training maneuvers be defined?
- Can the maximum alpha envelope be defined?
- Would proof-of-concept model be useful?

Summary

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- Update of aerodynamic damping models can increase/improve stall dynamics
    - Should be approached with caution due to risk of unintended consequences
    - Manipulation alone can lead to inaccurate response
- Existing flight test data can greatly improve stall representation
    - Access additional manufacturer data, revise stall tolerance req.
- Extending data post stall will provide greatest training benefit
    - Allows misapplied control representation
    - Limits exposure to potential neg. training, “bounding” model
    - “Class” data post stall may be most cost effective
- Additional cueing (e.g., motion, sound) improvements can further enhance training
- Training community feedback needed to identify training requirements, desires to bound sim update requirements