Stalling Transport Aircraft

joint Airbus-Boeing presentation

SFTE – International Symposium
Ft. Worth, Texas
29 October, 2013

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Stall Definition and Requirements

Engineering Preparations

Crew Briefing

Test Conduct

Future Stalls

Summary & Conclusions
Agenda/Outline

- Stall Definition and Requirements
- Engineering Preparations
- Crew Briefing
- Test Conduct
- Future Stalls
- Summary & Conclusions
Stall definition and Requirements

- In the frame of a new transport aircraft test campaign stalls are performed with the following targets:
  - Flight envelope opening
  - Optimization of aerodynamic configurations to get a good compromise between low and high speeds
  - Aerodynamic identification of the aircraft (\(C_{l\alpha}\) curve of all aerodynamic configurations)
  - Determination of the stall speeds (Vs1g) on which a lot of speeds are based (V2, VFTO, VREF...)
  - Local changes in Angle-Of-Attack (AOA) at the horizontal tail
  - Horizontal tail loads
  - Certification tests
A stall is defined as the point when maximum aerodynamic lift is achieved. Further increases in AOA beyond the point of stall cause a reduction in lift.

Based on $C_l_{\text{MAX}}$ determination, the $V_{s1g}$ is defined as the minimum speed at which the aircraft can generate enough lift to maintain a 1g flight condition.
Stall definition and Requirements

- **Ground effect**
  
  Lift levels vary as the airplane approaches the ground. The proximity to the ground causes a "cushion" effect providing additional lift at the same AOA near the ground. There is, however, a reduction in maximum lift available in full ground effect.
Agenda/Outline

• Stall Definition and Requirements
• Engineering Preparations
• Crew Briefing
• Test Conduct
• Future Stalls
• Summary & Conclusions
• Initial predictive data obtained from wind tunnel testing
• Simulation database and math-model assembled based on this data
• Extensive predictions made of flight characteristics to look for unacceptable trends
• Pilot-in-loop simulation handling qualities evaluations during design phase can drive airplane changes
• Flight test rehearsals also conducted in company simulators shortly before flight testing
• Simulators have proved very useful for normal flight envelope evaluations up to the point of stall
• Post-stall, simulation capability is problematic
Instrumentation preparations

- Thousands or perhaps tens of thousands of channels of data – both from analog sources and digital bus traffic
- Special displays for pilot data cueing
Engineering Preparations

- Tail Loads Monitoring
Engineering Preparations

- Trailing fin cone static source
- Horizontal Tail AOA probe
Engineering Preparations

– Flow cones
Engineering Preparations

- Flow cones
Engineering Preparations

- Flight Test Pitot probe

- Artificial Ice shapes
Engineering Preparations

- Flight Test Engineer data station
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Crew Briefing - Roles & Responsibilities

• Flight Test Engineer
  – Acts as Test Director
  – Preflight planning
  – Stall boundary definition
  – Configures the Flight Test Instrumentation
  – Closely monitors AOA and Sideslip angle
  – Calls “Break” when Cl and Nz begin to drop
  – Calls “Recover” if any parameter reaches the pre-briefed limit

• Test Pilots
  – Insure the airplane is in the proper trim condition
  – Decelerate to the stall without spoiler extension
  – Recover for unpredicted motions, “Break”, or “Recover”
Crew Briefing – Approach to Stall

- **Duties of the Pilot Monitoring as AOA Increases**
  - Checks Configuration and Trim setting
  - Crosschecks Airspeed with expected AOA
  - Verbally calls out AOA to the Pilot Flying
  - Calls “Recover” if Alpha Exceeds the AOA target
  - Monitors Sideslip
  - Monitors spoilers on the flight control systems page

- **Duties of the Pilot Monitoring During Recovery**
  - Verifies AOA decreasing
  - Monitors Sideslip
  - Verifies auto trim function (if required)
  - Monitors Airspeed and Protects the Configuration
  - Backup Pilot Flying for Thrust and Speed Brake usage
Crew Briefing - Stall Recovery

- Fly into the stall - Fly out of the stall
  - Stalled wake of the wing can impose high horizontal tail loads
- At the “Break” callout, smoothly reduce AOA
  - Altitude is of secondary importance to the reduction of AOA
  - Expected altitude loss will be 1500 – 2500 ft
- If a wing drops at the stall or during recovery:
  - Avoid using rudder
  - Recover to wings level with ailerons as AOA decreases
- Carefully monitor AOA during recovery
  - Nose-up pitch tendency above trim speed
  - Nose-up pitching moment due to engine thrust
Crew Briefing – Turning Stall Recovery

• A sequential two step approach works best
  – First lower the nose with elevator (full elevator and pitch trim may be needed)
  – As airspeed builds-up smoothly roll back to the horizon

• A dual axis recovery (simultaneous use of pitch and roll)
  – Not desired
  – Ailerons and spoilers may not be effective above $C_l^{\text{MAX}}$
  – Increases tail loads
  – Delays recovery
Crew Briefing – Turning Stall Recovery

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• Rudder normally is not needed
  – Rudder can add high asymmetric loads to the tail
  – For conventional aircraft use the sequential recovery
Crew Briefing - High Mach Stalls

• Determining the point of stall is difficult
  – Low speed and high speed buffet characteristics are different
  – The stall can be determined by the onset of deterrent buffet
  – Rarely would you encounter full aft stick or significant g-break
  – Sometimes a rapid vertical velocity may be the first indication

• Be patient - recovery must be smooth but positive
  – Airspeed builds slowly
  – Expect altitude loss of 5000ft to 7000ft
  – Expect nose-down attitudes of -5 to -10 degrees
  – Nose-down attitude will increase as pitch-up disappears
    ✓ Can be countered somewhat by application of thrust
Crew Briefing - High Mach Stalls

- Additional considerations for recovery
  - As Mach number increases, AOA margin decreases
  - Forward stick must be maintained
  - Pre-mature recovery can cause re-entry to deterrent buffet
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Stalls are performed with the following flight control laws

- **Airbus**
  - “Stall law” is fully proportional version of Direct law
  - Deflections reduced
  - Inhibits spoiler deflection for small roll inputs
  - Aerodynamic anomalies easily detected

- **Boeing (787)**
  - Enhanced Stall Protection law is basically an AOA command law
  - Blended in above the stall warning AOA
  - Limits AOA to just beyond AOA for CLmax
Test Conduct - Pre-Stall Checklist

- Weather Conditions
  - Visible horizon + suitable for stall, recovery, repositioning
- Altitude Block
  - 8,000’ to 14,000’ (avoids mach effects), over flat terrain
- Flight Controls
- Configuration
- Thrust
- Pitch Trim
- Rudder Trim
- Ignition
- Fuel imbalance
- Predicted stall AOA

As briefed
As specified
Established
IDLE
Set for 1.23Vs1g
Set for zero roll
ON (if relevant)
Minimum L/R delta
Briefed
Test Conduct - Stalls in a New Aircraft

- Normally performed at mid-cg
  - A compromise between stability and maneuverability
- Deceleration at 1Kt/sec to the target AOA, Recover
  - Examine recovery characteristics from each target AOA
  - A small amount of additional nose-up trim may be used
  - A small amount of rudder may be used to keep wings level
  - Non-flying pilot monitors spoiler deflection and sideslip angle
- Avoid countering any pitch-up tendency
  - Maintain deceleration rate with less input
  - Avoid high pitch attitudes and rapidly decreasing airspeed
Test Conduct – Buffet Characteristics

- Initial buffet begins a few knots prior to stick shaker/stall warning
- Increases dramatically near the stall AOA
- Deterrent buffet level: Vertical ±1g and Lateral ±0.5g
A330 FL350/M 0.81
Deterrent Buffet + recovery
Test Conduct - Stalls at Forward CG

- Testing begins in CLEAN configuration
  - Horizontal tail AOA carefully measured with increasing flap deflection
- Highest risk case is when fully configured
  - The highest downwash angle from wing to horizontal tail
  - Risk is horizontal tail stall during recovery
- Pushovers performed with increasing AOA
  - Inputs begin small and are gradually increased
  - Progressively increased toward 2/3 stick deflection
  - 2 degrees margin to horizontal tail stall is desired
  - Accounts for ice contamination on the LE of the HTP
Test Conduct - Stalls at Aft CG

• Higher risk factors are:
  – Lateral departure
  – Pitch-up

• Worst case:
  – Nose-down authority to counter nose-up pitching moment with application of TOGA thrust

• Build-up to the stall the same as for first stalls
  – Recovery must be started immediately if limits are exceeded

• With strong pitch-up:
  – Conservatively set the threshold for stall warning
Test Conduct - Stalls for certification in FBW aircraft

- Initially performed at forward CG
- Must be performed in Normal Law
  - In case a stall occurs despite the protections
  - Airbus - Normal Law modified with higher limiting AOA
- For stalls with augmented control laws:
  - C* design attempts to maintain 1g flight
  - Forward stick is necessary for recovery to avoid more nose-up elevator than commanded at the g-break
- Additional stalls performed with degraded control laws
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Future Stalls

• If stall or AOA limiting becomes “standard” and is proven to be highly reliable, will stalls cease being demonstrated?

• What about augmenting Degraded Control Laws?
  – Currently envelope protection/limiting exist only in Normal control laws

• Should the commercial transport industry investigate automated recovery systems (such as the Eurofighter)?

• Are we skilled enough to imagine all possible reasons for airplanes to achieve high AOA environments?
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Summary & Conclusions

- We have...
  - Shown how large company flight test organizations discuss, plan for, and conduct stall flight testing
  - Included insights from both the engineering point of view as well as the test pilot point of view
  - Shown videos of what stall testing is like
  - Discussed questions about the future of transport stall testing
Summary & Conclusions

- We learned much from this cooperative effort
  - Much of what we do is similar
  - The different approaches are intriguing
  - But mostly, when it comes to Flight Test safety, there’s no competition between us

Thank you for your time and attention.