Academic Upset Prevention and Recovery Training – The Highlights

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December, 2016
Top Points

• An ounce of prevention is worth a pound of cure

• Reducing angle-of-attack is THE most important pilot action in an upset

• Pilot upset training in simulators must account for their limitations
Outline

• Upset accidents and incidents
• New regulations and guidance
• Definitions
• Aerodynamics
  – Trim
  – Dihedral effect
  – Speed stability
  – Performance considerations
  – Roll stability
Outline, continued

• Stalls
• Upsets without stall
• Loss of reliable airspeed
• Instructor operating station
Upset Accidents and Incidents

Fatalities by CICTT Aviation Occurrence Categories

- LOC-I
- RE (Landing) + ARC + USOS
- CFTT
- SCF-PP
- MAC
- WSTRW
- UNK
- RE (Takeoff)
- RAMP
- F-NI
- OTHR
- RI-VAP

- External fatalities (total 105)
- Onboard fatalities (total 3,191)

ARC: Abnormal Runway Contact
CFIT: Controlled Flight Into or Toward Terrain
F-NI: Fire/Smoke (Non-Impact)
LOC-I: Loss of Control—In Flight
MAC: Midair/Near Midair Collision
OTH: Other
RAMP: Ground Handling
RE: Runway Excursion (Takeoff or Landing)
RI-VAP: Runway Incursion—Vehicle, Aircraft, or Person
SCF-PP: System/Component Failure or Malfunction (Powerplant)
UNK: Unknown or Undetermined
USOS: Undershoot/Overshoot
WSTRW: Wind Shear or Thunderstorm

Total fatal accidents (85 total)
Upset Accidents and Incidents

Loss-of-control incidents
1996-2002

- Wake turbulence: 72 incidents
- Severe weather: 54 incidents
- Autopilot: 47 incidents
- Windshear: 42 incidents
- Aircraft icing: 34 incidents
- Flaps: 33 incidents
- Aileron: 20 incidents
- Rudder: 17 incidents
- Yaw damper: 10 incidents
- Microburst: 6 incidents

Wake severe weather
Upset Accidents and Incidents

Loss-of-control incidents
1996-2002

- Wake turbulence: 72
- Severe weather: 54
- Autopilot: 47
- Windshear: 42
- Aircraft icing: 34
- Flaps: 33
- Aileron: 20
- Rudder: 17
- Yaw Damper: 10
- Microburst: 6

Loss-of-control accidents
1993-2007

- Undetermined
- Stall
- Other
- Atmospheric disturbance
- Contaminated airfoil
- Disorientation
- Flight control

Wake, Severe weather
Upset Accidents and Incidents

Catastrophic upsets are still rare

$49 \times 10^{-9}$ catastrophic upsets/flight hour
Upset Accidents and Incidents

BREAKING NEWS
STATE POLICE: ALL 48 ABOARD FLIGHT 3407 KILLED IN CRASH
Upset Accidents and Incidents
Why?

Lack of attention
Lack of understanding
Lack of proper response
Upset Accidents and Incidents
Why?

- Lack of attention
- Lack of understanding
- Lack of proper response

Most effective solution

Attention

Understanding

Proper response

Easiest to teach and learn
New regulations

• §121.423 – Pilot Extended Envelope Training
  – Extended envelope training must include
    • Manually controlled slow flight
    • Manually controlled loss of reliable airspeed
    • Manually controlled instrument departure and arrival
    • Upset recovery maneuvers
    • Recovery from bounced landing
  – Instructor-guided hands-on experience from full stall and stick pusher activation, if equipped
  – Have to use a Level C, or higher, simulator
  – All maneuvers every 2 years, except bounced landings (every 3 years)
New regulations

• Part 60...modify simulators to
  – Improve aerodynamics past stall warning through post-stall
  – Add icing physics instead of only end effects like stall speed increase
  – Upgrade instructor operating station to help instructors understand simulator limitations
New regulations

• For ALL pilots (in part 121 operations)
  – Extended envelope training compliance by March 12, 2019 for initial, upgrade, transition, or requalification training
  – Extended envelope training compliance by March 31, 2020 for recurrent training
New guidance

AC 120-109A

Advisory Circular

Subject: Stall Prevention and Recovery Training
Date: 11/24/15
AC No: 120-109A
Initiated by: AFS-200
Change:

This advisory circular (AC) provides guidance for training, testing, and checking pilots to ensure correct responses to impending and full stalls. For air carriers, Title 14 of the Code of Federal Regulations (14 CFR) part 121 contains the applicable regulatory requirements. Although this AC is directed to part 121 air carriers, the Federal Aviation Administration (FAA) encourages all air carriers, airplane operators, pilot schools, and training centers to use this guidance for stall prevention training, testing, and checking. This guidance was created for operators of transport category airplanes; however, many of the principles apply to all airplanes. The content was developed based on a review of recommended practices developed by major airplane manufacturers, labor organizations, air carriers, training organizations, simulator manufacturers, and industry representative organizations.

This AC includes the following core principles:

- Reducing angle of attack (AOA) is the most important pilot action in recovering from an impending or full stall.
- Pilot training should emphasize teaching the same recovery technique for impending stalls and full stalls.
- Evaluation criteria for a recovery from an impending stall should not include a predetermined value for altitude loss. Instead, criteria should consider the multitude of external and internal variables that affect the recovery altitude.
- Once the stall recovery procedure is mastered by maneuver-based training, stall prevention training should include realistic scenarios that could be encountered in operational conditions, including impending stalls with the autopilot engaged at high altitudes.
- Full stall training is an instructor-guided, hands-on experience applying the stall recovery procedure and will allow the pilot to experience the associated flight dynamics from stall onset through the recovery.

This revision of AC 120-109 reflects new part 121 regulatory terms and incorporates the full stall training requirement of Public Law 111-216. Considerable evaluation of the full flight simulator (FFS) must occur before conducting full stall training in simulation. Reference Appendix 5 for FFS evaluation considerations.

John S. Duncan
Director, Flight Standards Service

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AC 120-111

Advisory Circular

Subject: Upset Prevention and Recovery Training
Date: 
AC No: 120-UPRT
Initiated by: AFS-200
Change:

This advisory circular (AC) describes the philosophy and recommended training for airplane Upset Prevention and Recovery Training (UPRT). The goal of this AC is to provide recommended practices and guidance for academic and flight simulation training device (FSTD) training for pilots to prevent developing upset conditions and ensure correct and consistent recovery responses to upsets. The AC was created from recommended practices developed by major airplane manufacturers, labor organizations, air carriers, training organizations, simulator manufacturers, and industry representative organizations. This AC provides guidance to Title 14 of the Code of Federal Regulations (14 CFR) part 121 air carriers implementing the regulatory requirements of §§ 121.419, 121.423, 121.424, and 121.427. Although this AC is directed to air carriers to implement part 121 regulations, the FAA encourages all airplane operators, pilot schools, and training centers to implement UPRT and to use the guidance contained in this AC, as applicable to the type of airplane in which training is conducted.

Although a stall is categorized as an upset, this AC does not cover stall prevention and recovery training. This training, which includes the requirement for full stall training, is contained in the current edition of AC 120-109, Stall Prevention and Recovery Training.

Core principles of this AC include:

- Enhanced instructor training on the limitations of simulation.
- Comprehensive pilot academic training on aerodynamics.
- Early recognition of divergence from intended flight path.
- Upset prevention through improvements in manual handling skills.
- Progressive intervention strategies for the pilot monitoring.

CAUTION: Prior to commencing UPRT, air carriers should review and implement Guidance Bulletin 11-05, FSTD Evaluation Recommendations for Upset Recovery Training Maneuvers to ensure FSTDs are specifically evaluated for UPRT maneuvers. Otherwise, negative transfer of training could occur.

John S. Duncan
Director, Flight Standards Service
Definitions

- **Upset**, [v., adj. uhp-set; n. uhp-set]:
  - Unintentionally exceeding parameters normally experienced in line operations or training:
    - Pitch > 25 degs nose up or > 10 degs nose down
    - Bank > 45 degs
    - Within above, but at airspeeds inappropriate for the conditions
Definitions

• Full stall condition – any one, or combination, of the following:
  – A nose-down pitch that cannot be readily arrested, which may be accompanied by an uncommanded rolling motion
  – Buffeting of a magnitude and severity that is a strong and effective deterrent to further increase in angle of attack
  – The pitch control reaches the aft stop for 2 sec and no further increase in pitch attitude occurs when the control is held full aft, which can lead to an excessive descent rate
  – Activation of a stall identification device (e.g., stick pusher)

Adapted from part 25.201
Definitions

• Stall characteristics
  – must be able to produce, and correct, roll and yaw up to the stall
  – no abnormal pitching
  – for wings level stalls, the amount of roll between stall and completion of recovery < 20 degs
  – for turning stalls, roll during recovery must not be more than
    • 60 degs in direction of stall, or 30 degs in opposite direction, if deceleration is 1 kt/sec or less
    • 90 degs in direction of stall, or 60 degs in opposite direction, if deceleration is more than 1 kt/sec

Adapted from part 25.203
Aerodynamics

- Load factor $= \frac{L}{W}$
Aerodynamics

- Load factor = $\frac{L}{W}$

![Diagram showing load factor calculations at different altitudes.](image)
Aerodynamics

- Load factor = \( \frac{L}{W} \)
Aerodynamics

- Load factor = $\frac{L}{W}$

F = ma
Aerodynamics

- Load factor = \( \frac{L}{W} \)

\[ F = ma \]

\[ L - W \]
Aerodynamics

- Load factor = \( \frac{L}{W} \)

\[ F = ma \]

\[ L - W \]

Velocity getting bigger or smaller

Velocity changing direction
Aerodynamics

- Load factor = \( \frac{L}{W} \)

\[ F = ma \]

\[ L - W \]

Velocity getting bigger or smaller

Velocity changing direction

= pitch rate \(*\) speed
Aerodynamics

• Load factor = \( \frac{L}{W} \)

F = ma

\( L - W \)

Velocity getting bigger or smaller

Velocity changing direction

= pitch rate * speed

Both can get big at high altitude
Aerodynamics
Aerodynamics

Trim

• Nagoya, 1994 – China Airlines #140
Aerodynamics

Trim

• Nagoya, 1994 – China Airlines #140
• Roselawn, 1994 – American Eagle #4184
• Important to understand potential insidious effects of the trim system in your aircraft (will discuss in simulator)
Aerodynamics

Dihedral effect

• What is it?
Aerodynamics
Dihedral effect

- What is it?

Sideslip causes a side force...might not feel in a simulator
Aerodynamics

Dihedral effect

• What is it?
Aerodynamics

Dihedral effect

• Things to know for commercial transports...

Swept wing increases dihedral effect
Aerodynamics

Dihedral effect

- Things to know for commercial transports...

Swept wing increases dihedral effect

Increasing AoA increases dihedral effect
Aerodynamics

Dihedral effect

• Things to know for commercial transports...

Swept wing increases dihedral effect

Increasing AoA increases dihedral effect

Once you get it going, it’s like a train, it’s hard to stop
Aerodynamics

Stability

• Tendency to return if moved from trim and released
Aerodynamics

Speed stability

Diagram showing the relationship between drag and thrust, with speed instability and stability regions. Key points include:
- Maximum thrust
- Maximum level flight speed
- L/D MAX (minimum drag speed)
- Airspeed axis
Aerodynamics
Performance considerations

Pilot Tip: If a condition or airspeed decay occurs, take immediate action to recover:
- Reduce bank angle
- Increase thrust – select maximum continuous thrust (MCT) if the aircraft is controlling to a lower limit
- Airspeed continues to deteriorate – Descend
Aerodynamics

Roll stability

Rear View

Lift Coefficient

AoA
Aerodynamics

Roll stability

Rear View

Lift Coefficient

AoA
Aerodynamics

Roll stability

Rear View

Lift Coefficient

AoA
Aerodynamics
Roll stability

Rear View

Lift Coefficient

AoA
Aerodynamics
Roll stability

Rear View

Lift Coefficient

AoA
Aerodynamics
Roll stability

Rear View

Lift Coefficient

AoA
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
Why?
Colgan 3407

Displayed speed margin decreases → Lack of attention

Unstable rolling → Lack of understanding

Unexpected shaker and pusher → Lack of proper response

Pilot pulls

Tries to control roll
Aerodynamics

• Energy
  – What it is
  – Trades and judgment...keeping final state in mind
    • Mental sanity checks useful
      – Knowing roughly how much speed you can bleed configured versus not in straight-and-level and on glidepath
      – Descent rate on path is about groundspeed/2 × 10
        so, 140 kts --> 700 fpm
  – High altitude stall recovery
Stalls

• So, are we really stalling airplanes in the U.S.?
Stalls
So, are we really stalling airplanes in the U.S.?

Colgan
U.S. Law
Sec. 208 – Implementation of NTSB flight crewmember training recommendations

Stall & Stick Pusher Guidance

FAA Reg
Upset Prevention & Recovery Guidance
Stall Prevention & Recovery Guidance
Stalls

So, are we really stalling airplanes in the U.S.?

Colgan
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Stall & Stick Pusher Guidance

FAA Reg
Upset Prevention & Recovery Guidance
Stall Prevention & Recovery Guidance

CRJ 200 stall

Stalls
So, are we really stalling airplanes in the U.S.?

Colgan
U.S. Law
Sec. 208 – Implementation of NTSB flight crewmember training recommendations

2009

2010

2011

2012

2013

2014

2015

2016

CRJ 200 stall

B757 stall

Stall & Stick Pusher Guidance

FAA Reg

Upset Prevention & Recovery Guidance

Stall Prevention & Recovery Guidance
Stalls
So, are we really stalling airplanes in the U.S.?

- **2009**: Colgan
- **2010**: U.S. Law
  - Sec. 208 – Implementation of NTSB flight crewmember training recommendations
- **2011**: Stall & Stick Pusher Guidance
- **2012**: FAA Reg
  - Stall Prevention & Recovery Guidance
- **2013**: CRJ 200 stall
- **2014**: B757 stall
- **2015**: CRJ 700 stall
- **2016**: Stall Prevention & Recovery Guidance
Stalls

• What does a stall fundamentally depend on?
  – Airspeed?
  – Bank angle?
  – Load factor?
  – Altitude?
  – Gross weight?
  – Angle of attack?
  – Mach number?
  – Configuration or contamination (e.g., flap or slat position or ice)?
Stalls

• What does a stall fundamentally depend on?
  — Airspeed
  — Bank angle
  — Load factor
  — Altitude
  — Gross weight
  — Angle of attack
  — Mach number
  — Configuration or contamination (e.g., flap or slat position or ice)
Stalls

Stall warning system*

Angle of attack
Mach
Configuration or contamination

Stick shaker or Airbus “stall stall <cricket>”

* - can be a little more complicated that this...asymmetric flap and thrust bias (flaps down) and a speedbrake input
Angle of attack margin

AoA margin to stall warning
Angle of attack margin
Stalls

Angle-of-attack

Mach

Configuration or contamination

**Angle-of-attack**
- $C_{L_{\text{MAX}}}$
- Straight Wing: High lift / low speed
- Swept Wing: High speed

**Mach**
- EFFECT OF MACH NUMBER
- Lift vs. Angle of attack: 1 to 2 deg
- Increasing Mach number

**Configuration or contamination**
- Clean
- Ice
- Buffer
- Stick Shaker
- Stick Pusher

**BEA**
- ~ 10° Stall warning threshold in direct or alternate law
- ~ 4°
Stalls

• Physical confusion...
  – Airspeed
    • I have stall speed in my flight manual for different weights. Won’t I be ok if I make sure I fly faster than those?
      – No, those are 1g stall speeds
Stalls

• Physical confusion...
  – Airspeed
    • I have stall speed in my flight manual for different weights. Won’t I be ok if I make sure I fly faster than those?
      – No, those are 1g stall speeds
  – Bank angle
    • Don’t I stall at a lower AoA when banked in a level turn?
      – No, it may seem lower, but that is because you are already at a higher AoA in the turn to get more lift to stay in level flight.
      – Your stall speed goes up because you are already at a higher AoA in the turn, so if you trade speed with AoA to maintain the same lift...you’ll run out of AoA sooner
      – Seems like you can bank less at altitude, because you do not have the excess thrust to balance the additional drag that accompanies the additional lift in the turn
Stalls

• Physical confusion...
  – Load factor
    • Don’t I stall at a lower AoA if I pull g’s?
      – No, it may seem like it, but you’ve increased your AoA to pull the g’s, so you have less margin until you reach the AoA for maximum lift
Stalls

• Physical confusion...
  – Load factor
    • Don’t I stall at a lower AoA if I pull g’s?
      – No, it may seem like it, but you’ve increased your AoA to pull the g’s, so you have less margin until you reach the AoA for maximum lift
  – Altitude
    • Don’t I stall at a lower AoA at altitude?
      – Not if your Mach number doesn’t change with altitude.
Stalls

• Physical confusion...
  – Load factor
    • Don’t I stall at a lower AoA if I pull g’s?
      – No, it may seem like it, but you’ve increased your AoA to pull the g’s, so you have less margin until you reach the AoA for maximum lift
  – Altitude
    • Don’t I stall at a lower AoA at altitude?
      – Not if your Mach number doesn’t change with altitude...but your Mach probably does change, so that is the fundamental parameter
  – Gross weight
    • Don’t I stall at a lower AoA with more weight?
      – No, the wing doesn’t care about how much you weigh
Stalls

Important identification cues...based on earlier stall definition

• Pitch break
• Strong buffet
• Control stop, no more pitch
• Pusher activation
### Stalls

**Recovery template, abridged**

<table>
<thead>
<tr>
<th>Operation</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autopilot and autothrottle</td>
<td>Disconnect</td>
</tr>
<tr>
<td>Nose down pitch control</td>
<td>Apply until stall warning eliminated</td>
</tr>
<tr>
<td>Nose-down pitch trim</td>
<td>As needed</td>
</tr>
<tr>
<td>Bank</td>
<td>Wings level</td>
</tr>
<tr>
<td>Thrust</td>
<td>As needed</td>
</tr>
<tr>
<td>Speed brake/spoilers...</td>
<td>Retract</td>
</tr>
<tr>
<td>Return to desired flightpath</td>
<td></td>
</tr>
</tbody>
</table>

**Procedure developed by**

Boeing, Airbus, Bombardier, ATR and Embraer
Why?
Air Asia 8501

Circuit breaker pulling
In effort to clear repeated failure

Lack of understanding

? – [airplane does not return to normal law... pulls and stalls]

Unstable rolling

Lack of understanding

?

Lack of proper response

Tries to control roll
Upsets without stall

B737-700

B737-500

Cockpit door

Rud trim
Upsets without stall
Upsets without stall
Upsets without stall

Recovery techniques

- Recognize and confirm
- A/P & A/T disconnect
- Push
- Roll
- Power
- Climb

We will go over the fine points in the simulator
Loss of reliable airspeed
Loss of reliable airspeed
Loss of reliable airspeed—AF447

UTC 2:10:15 – Right seat says “We haven’t got a good display of speed”
UTC 2:10:22 – Left seat says “Alternate law protections”
UTC 2:10:27, 28 – Left seat says “Watch your speed, watch your speed”
UTC 2:10:33 – Left seat says “According to all three you are going up so go back down” Right seat “okay”
UTC 2:10:51 – First stall warning
UTC 2:10:56 – Right seat calls and goes to TOGA [Airplane does not have available thrust to help at this point]
UTC 2:11:21 – Left seat says “But we’ve got the engines what’s happening?”
UTC 2:11:32 – Right seat says “I don’t have control of the airplane anymore now”
UTC 2:11:41 – Right seat says “I have the impression we have the speed”
UTC 2:11:42 – Captain enters and says “Er what are you doing?”
UTC 2:11:46 – Left seat says “We lost all control of the aeroplane we don’t understand anything we’ve tried everything”
UTC 2:12:04 – Right seat says “I have the impression that we have some crazy speed no what do you think?”
UTC 2:12:07 – Left seat says “No above all don’t extend” Right seat says ok
UTC 2:12:23 – Captain says “The wings to flat horizon the standby horizon”
UTC 2:12:32 – Captain says “No you climb there you are climbing”…perhaps he is referring to pitch attitude
UTC 2:12:43 – Captain says “it’s impossible”
UTC 2:12:48 – Right seat says “Yeah yeah yeah I’m going down no?”
UTC 2:12:54, 56 – Captain says “Get the wings horizontal” Right seat says “That’s what I am trying to do”
UTC 2:12:58 – Right seat says “I am at the limit with the roll”…then dual input
UTC 2:13:38 – Captain says “careful with the rudder bar there”
UTC 2:13:39: Left seat says “Climb climb climb climb”
UTC 2:13:40-41 – Right seat says “But I’ve been at maxi nose up for awhile”
UTC 2:13:42 – Captain says “No no no don’t climb”
UTC 2:13:43: Left seat says “so go down”
UTC 2:13:45: Left seat says “so give me the controls the control to me controls to me”
UTC 2:14:05: Captain says “watch out you are pitching up there”
UTC 2:14:06: Captain says “you are pitching up” Left seat says “I’m pitching up” Right seat says “Well we need to we are at four thousand feet:
UTC 2:14:16, 17: They get “sink rate and pull up”
UTC 2:14:18: Captain says “Go on pull”
UTC 2:14:23: Right seat says “We’re going to crash. This can’t be true”
UTC 2:14:26: Captain says “10° pitch attitude”
Why?
Air France 447

Left seat: “We’ve lost the the the speeds so... alternate law protections”
Right seat: “We haven’t got a good display... of speed”

Unreliable speed
Intermittent stall warning
High rate of descent
Buffeting

Lack of understanding

“I have the impression that we have some crazy speed”

Unstable rolling

Lack of understanding

Tries to control roll

Lack of proper response

Lack of proper response
Pilot monitoring

See

- “Monitoring Matters,” CAA Paper 2013/02
- “A Practical Guide for Improving Flight Path Monitoring,” FSF
Instructor training

- By law, instructors need additional training...this is the guidance
- From Upset Prevention and Recovery Advisory Circular
  - Limitations of simulator (part 121.414)
  - Instructor operating station
  - History of events
  - Energy management
  - Spatial disorientation
  - Distraction
  - Recognition and recovery strategies
  - Recognition and correction of pilot errors
  - Type-specific characteristics
  - OEM recommendations
  - Operating environment
  - Startle and surprise
  - Assessing proficiency
Instructor operating station
Simulator limitations

- Need to stay within valid training envelope
Simulator limitations

- Need to stay within valid training envelope
- G cues are seriously lacking
Simulator limitations

- Simulator g-limitations
Conclusions

- An ounce of prevention is worth a pound of cure

- Reducing angle-of-attack is THE most important pilot action in an upset

- Pilot upset training in simulators must account for their limitations