FLIGHT TEST RESULTS OF THE CONTROLLED FLIGHT INTO TERRAIN AVOIDANCE MANEUVER IN FLY-BY-WIRE TRANSPORTS

Air Line Pilots Association

Airworthiness Performance Evaluation and Certification Committee

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I. Abstract

Controlled Flight into Terrain (CFIT) is the leading causes of aviation accidents.[1]

A test program was developed to compare the CFIT maneuver performance capabilities of aircraft with hard versus soft Fly-By-Wire (FBW) flight control systems. To obtain this data, simulated CFIT avoidance maneuvers utilizing a Boeing 777-300 and an Airbus A330-200 were performed. These tests were performed at the Boeing Flight Test Facility in Seattle, Washington and the Airbus Flight Test Facility at Toulouse, France.

This flight test had a two-fold purpose. The first was to evaluate the effectiveness and appropriateness of a recovery technique that was developed for convention aircraft without regard for the flight envelope protections incorporated in modern FBW aircraft. The second purpose was to develop and/or evaluate CFIT escape maneuvers that utilize the maximum capability of the aircraft afforded by the protections incorporated in their respective FBW flight control systems.

As a direct result of this flight-test activity, one major US operator of Airbus aircraft (United Airlines) has changed the CFIT escape maneuver for these aircraft.

II. Introduction

A. Purpose of Flight Test

- To evaluate the effectiveness and appropriateness of a recovery technique that was developed for convention aircraft without regard for the flight envelope protections incorporated in modern FBW aircraft.

[1] CFIT Training Aid, section 3 page 3.3.

- To evaluate and/or develop CFIT escape maneuvers that utilize the maximum capability of the aircraft afforded by the protections incorporated in their respective FBW flight control systems.

B. Ground Proximity Warning Systems

Transport aircraft are equipped with a variety of Ground Proximity Warning Systems (GPWS). These systems will usually, depending upon sophistication, warn the flight crew 5 to 60 seconds before impact. The most advanced system is the Enhanced GPWS that uses a terrain data base and compares current aircraft position to known terrain hazards, contained in an onboard database. This system can provide a full 60 seconds of warning before terrain impact.

C. CFIT Escape Maneuvers

A CFIT escape maneuver is usually performed in response to a GPWS warning and is a procedure designed to remove an aircraft from a pending terrain contact in an expedient manner. This maneuver is designed to remove the aircraft from harm by the use of maximum or near maximum aircraft aerodynamic performance. Typically, the aircraft is in a descent. Upon receiving a terrain warning, the pitch is increased to a value between 15 and 20 degrees nose up until the stick shaker activates or maximum Angle-of-Attack (AOA) is reached. This maneuver can be initiated anywhere from a clean cruise descent (280 to 300 KIAS), to a fully configured condition at approach speed.

An industry task force has recommended the following general GPWS Terrain Warning (CFIT) Escape maneuver.[2]

- React immediately to a GPWS warning
- Positively apply maximum thrust and rotate to the appropriate pitch attitude for your airplane.
- Pull up with wings level to ensure maximum airplane performance.
- Always respect the stick shaker.

The task force report goes on to say:

Studies show that there is little difference in performance between a pull-up rate of 3 degrees/second and 4 degrees/second. Because of this, it is recommended that the standard pull-up rate is 3 degrees/second. [3]

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[2] Industry task force. Appendix 4-D, section 4-D.1
[3] Industry task force. Appendix 4-D, section 4-D.1.1

1. AIRCRAFT WITH CONVENTIONAL FLIGHT CONTROLS

The typical CFIT escape maneuver for an aircraft with conventional flight controls, requires the pilot to select TOGA thrust, rotate at a smooth rate of 3 degrees per second (to avoid overstressing or stalling the aircraft) to a pitch attitude of between 15 to 20 degrees nose up. This pitch attitude is maintained until the stick shaker activates or terrain clearance is assured. The stick shaker represents optimum AOA and must be respected to effect recovery. Due to speed and thrust changes, with the resultant variable and usually out of trim stick forces; flying the stick shaker activation angle to maintain optimum AOA, can be quite difficult.

2. FBW AIRCRAFT WITH "HARD" PROTECTION FEATURES

Airbus incorporates "hard" limits in the design of their FBW flight control system. Hard limits prevent the pilot from exceeding the designed flight envelope of the aircraft. That is, the aircraft may not be stalled, over-banked, over-stressed, or over-sped. In other words, the designed aircraft envelope is maintained and protected.

The Airbus design allows the pilot to obtain, in a repeatable fashion, a high level of aircraft performance. However, the pilot may be prevented from obtaining maximum aircraft aerodynamic performance.

The procedure for the CFIT escape maneuver in the Airbus aircraft as recommended by Airbus, is for the pilot to pull full back on the stick and apply TOGA thrust. Speed brakes if extended, will automatically retract.

Control laws either stabilize the AOA at an optimum value or adjust pitch rate to obtain maximum allowed g. With the Airbus CFIT escape maneuver pilots can quickly, easily, and repeatably achieve the maximum level of performance allowed by the envelope limiting system. This ease of handling might, in certain cases, result in optimum CFIT escape performance, even though full aerodynamic performance may not be achieved.

3. FBW AIRCRAFT WITH "SOFT" PROTECTION FEATURES

Boeing incorporates "soft" limits in the design of their FBW flight control system. Soft limits "suggest" and warn when a limit is being approached by increased stick forces and by introducing aural and visual warnings. With soft limits the pilot is warned, but then allowed to stall, over-bank, over-stress or over-speed the aircraft, if necessary or desired.

In a CFIT escape maneuver with the 777, the Boeing recommended procedure (simplified) is for the pilot to immediately select maximum thrust, rotate aggressively to 20 of pitch, and retract the speed brakes.

In all cases, the pitch attitude that results in intermittent stick shaker or initial buffet is the upper pitch attitude limit. When the flaps are not up or at slow speeds with the flaps up, the pitch limit indicator (PLI) provides a visual reference of the pitch attitude limit). Follow flight director TO/ GA guidance if available.[4].

With the Boeing 777 FBW design, maintaining the PLI is less difficult than for conventional aircraft. On most conventional aircraft, the stick forces can be quite high. On the 777 the pilot directly controls pitch attitude and pitch rate. High pitch rates can be attained by the pilot to quickly and precisely place the aircraft at optimum AOA. Although easier than for conventional aircraft, accurately maintaining the PLI still requires a reasonable degree of pilot technique. If ground contact is imminent the pilot can obtain the full aerodynamic performance of the aircraft. High stick forces are required to pull the aircraft into a stall; but the pilot receives numerous warnings and indications of the stall condition. Other than a ramp up of stick force there is not indication that the aircraft's g limit has been reached or exceeded. The authority to obtain maximum g is only limited by the feel system and control power. With this design the pilot is allowed to obtain the maximum aerodynamic capability of the aircraft.

III. Test Plan

A. Test Articles/Locations

For the purpose of this investigation, two aircraft representing the FBW flight control design philosophies under investigation were chosen. The first flight evaluation was conducted using a Boeing 777-300 aircraft at the Boeing flight test facility at Seattle, Washington. The aircraft flight test program was preceded by a work up in a B-777 engineering simulator. The second flight evaluation was conducted using an Airbus A-330-200 aircraft at the Airbus flight test facility in Toulouse, France. This aircraft flight test program was also preceded by a work up in an Airbus A-330 engineering simulator.

Both aircraft were operated at a mid CG with a takeoff weight that would permit the approach CFIT avoidance recovery maneuvers to be preformed at the respective aircraft maximum landing weights.

1. Airbus A-330-200

The A330-200 is a slightly shortened version of the original A330-300. The A330-200 is designed for a typical range of 6,450 nautical miles with a three class passenger load of 381. Normal cruise for the aircraft is .83 to .84 mach with a Mmo of .86 mach. The A330-200 is 193.5 feet long (15.3 feet shorter than the A330-300), 197.8 feet from wing tip to wingtip, and 58.7 feet high. Because of the shorter fuselage, the rudder on the A330-200 needed to be slightly larger (3.5 feet taller). The maximum takeoff gross weight of the A330-200 is 507,100 pounds. For our flight, we weighed 402,600 pounds, just above the maximum landing weight of 396,800 pounds. Our fuel load was 134,000 pounds, with a maximum fuel capacity of 250,000 pounds (36,740 US gallons). The two PW 4168 engines are rated at 68,000 pounds of thrust each.

[4] Boeing 777 Operations Manual, Non-Normal Maneuvers, NNM1.3, February 10, 1995.

The FBW flight control system utilized in the Airbus design prevents the pilot from stalling the aircraft (an AOA margin is maintained). The aircraft can not be commanded to exceed +2.5 gs or –1 g clean, or +2.0 or 0.0 gs with the flaps extended. The pitch attitude is limited to 30 degrees nose up to 15 degrees nose low. The bank angle is limited to 67 degrees. If the side stick is held full foreword, the speed will stabilize at Vmo +16 knots and Mmo + .04 Mach. The protections can be lost through multiple system failures but, there is no approved or readily discernable method for the pilot to over-ride the flight envelope protections.

2. Boeing B-777-300

The 777-300 is a 33 foot stretch of the 777-200, allowing it to carry 20% more passengers. The maximum take off weight of the –300 is 660,000 with 98,000 pound thrust engines, and maximum landing weight is 524,000 pounds.

The 777-300 has a wheel base of 102 feet and 5 inches, as compared to the 777-200 with a wheel base of 84 feet 11 inches, and the 747-400 with a wheel base of 84 feet 0 inches.

The 777-300 is 242 feet 4 inches long, has a wingspan of 199 feet 11 inches, and a tail height of 60 feet 8 inches. The –300 is designed to carry 350 passengers in a tri-class configuration, with a range of approximately 6500 nautical miles.

For our flight evaluation, we flew the number one 777-300, which has accumulated approximately 500 flight test hours. The aircraft weighed 501,000 pounds, of which 163,500 pounds was fuel. The Rolls-Royce Trent 892 engines were rated at 90,000 pounds of thrust.

The aircraft utilizes a FBW flight control design that does not restrict the pilot from stalling, over-banking, or obtaining the full aerodynamic g capability. The aerodynamic g capability of the 777 can exceed 4 gs under certain conditions of aircraft loading and CG position.

B. Maneuvers/Test Points

1. Simulated CFIT escape maneuvers flown at maximum landing weight and at an approach speed of Vref +5 knots, gear down and flaps at maximum landing setting, at a descent rate of 1500 fpm.
2. Simulated CFIT escape maneuvers flown at typical enroute descent speeds (250 and 300 KIAS as permissible), clean configuration, and a descent rate of 1500 fpm.
3. Aircraft fully instrument and capable of recording at a minimum: α, pitch and Q (pitch rate), NZ, VC, H, and g.
4. Maneuvers to be flown with a smooth pitch rate (target 3 degrees/sec) to a pitch attitude of 17 degrees.
5. Maneuvers repeated with an aggressive (soft protections) respecting the PLI, or full back stick (hard protections).

C. Test Methods

Ron Rogers, APEC Chairman, and three other members of the APEC Committee conducted the 777-300 flight evaluation. The same individuals with the exception of Steve Stowe who was not available, conducted the Airbus A330-200 evaluation. Ron Rogers is a Captain for United Airlines on the A-320. Steve Stowe is a B767 first officer for Delta and a former USAF test pilot. He headed the F-15 Strike Eagle program, and was Vice Commandant of the USAF Test Pilot School. Terry Lutz is an A320 first officer for Northwest, a former USAF Test Pilot School Instructor, and a former project pilot for Calspan Corporation. Joe Kohler is a B747 captain for Northwest and a long time committee member. None of the evaluation pilots were typed in either the B-777 or the A-330 although all the A330-200 evaluators had A-320 type ratings and considerable operational experience in the aircraft.

In preparation for the flight evaluations, work up sessions and test card validations were performed in the respective engineering simulators. Extensive flight evaluations (over 2 hours in the A-330-200 to almost 5 hours in the B-777-300) were conducted in both aircraft. Both the engineering simulators and the test aircraft had extensive data collection capabilities.

IV. Discussion of Results

A. Airbus A330-200

The simulator evaluation was begun with an extensive series of CFIT recovery maneuvers. The objectives were to find what might be the optimum recovery technique, to determine the result of over or under controlling the recovery, and to determine the minimum altitude loss during the recovery. Runs were accomplished in the PA (power approach; gear down and full flaps, except as noted), and Clean (gear and flaps up) configurations, all from a 1500 fpm descent. Recovery was initiated from a callout from the First Officer occurring at 10,000’, with preparatory calls at 200’ and 100’ above the recovery altitude.

AIRCRAFT TEST CARD

Capt Rogers

1. Ground ops and engine start
2. Taxi and ground handling evaluation
3. Normal takeoff at Flex power setting
4. Normal climb to 12,000'
5. CFIT maneuver sequence

Run #	Speed	Config	Max pitch	Pitch rate	Notes
1.	143	Full/Dn	17.5 deg	4 deg/sec	
2.	Repeat			4 deg/sec	
3.	143	Full/Dn	26.0 deg		Full back stick to alpha floor
4.	Repeat				3 deg/sec
5.	170	2/Up	17.5 deg	3 deg/sec	Full speed brakes at entry
6.	170	2/Up	29.0 deg		Full back stick to alpha floor
7.	Repeat				
8.	170	2/Up			Full speed brakes, Full back stick, 1.6g on cockpit meter
9.	254	Clean		3 deg/sec	TOGA
10.	254	Clean		31.0 deg	TOGA/Full back stick/1.8g

FO Lutz

6. Evaluate Dual Input modifications
7. Check roll mode time constant
8. Maximum aircraft performance capability
   - Pull and roll simultaneously (11,000', Flaps 3, 145KIAS, 392,000 lbs)
   - Pull to 10 degrees nose high, then maximum pitch and roll commands (Gear down, Flaps 3)
   - Pull to alpha protections, then apply maximum roll command

9. Simulated engine failure, evaluate aircraft protections

Capt Kohler

10. Approach to stall (15,000', Flaps 1+F, Idle power)
11. Approach to stall (15,000', Gear Down, Flaps Full
12. Normal enroute descent
13. Normal landing (Flaps Full, 500' lateral offset on final, maneuver at 500' agl)
14. Simulated engine failure at V1
15. Single engine approach (Flaps 3)
16. Single engine go-around on short final

FO Lutz

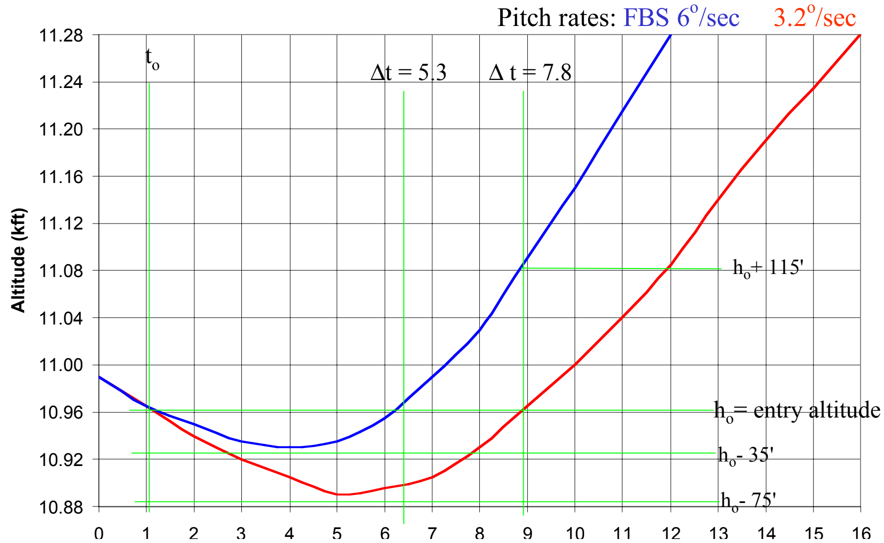
17. Normal landing (Flaps Full, 500’ lateral offset on final, maneuver at 500’ agl)
18. Simulated engine failure at V1
19. Two engine, Direct Law, Flaps 3, manual thrust landing

Capt Rogers

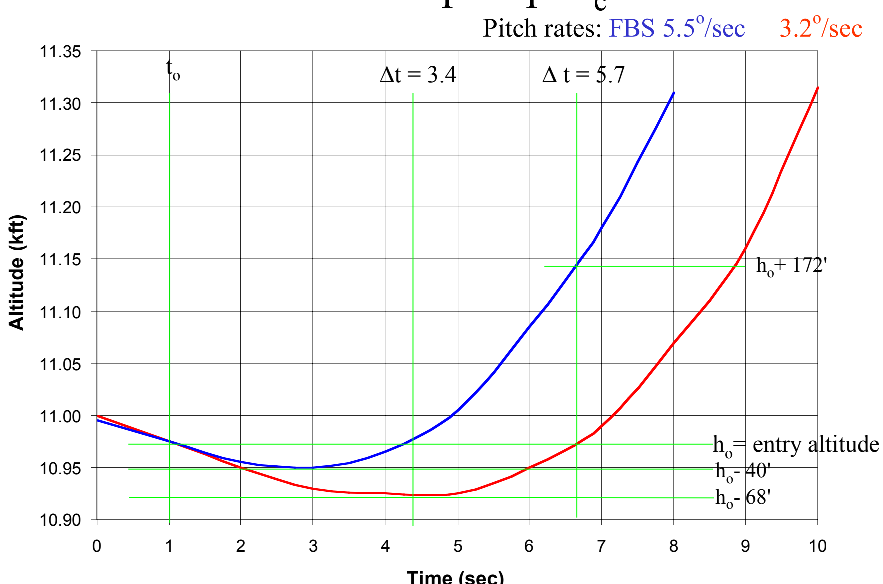
20. Normal landing (Flaps Full, 500’ lateral offset on final, maneuver at 500’ agl)
21. Simulated engine failure at V1
22. Single engine, Direct Law, Flaps 3 landing
23. Full reverse on the good engine during roll out

FLIGHT TEST DATA

A330-200 Flaps full, Gear down V_c=145KIAS



A330-200 Gear & Flaps Up V_c=250KIAS



Source: Airbus Flight Test Data

Data Plots	Manevuer	Q (°/Sec)	N_z (G)	V_c (Kts)	Δ T (Sec)	Alt Loss (Ft)	Δ Zp V_s (Ft)
4	F/Dn	3.2	1.38	146	7.8	82	-
3	F/Dn (Fbs)	6.0	1.44	145	5.3	52	115 (4)
9	Clean	3.2	1.76	250	5.7	68	-
10	Clean (Fbs)	5.5	1.83	250	3.4	40	172 (9)

A330-200 AIRCRAFT

The benefit of the FBS recovery for the A330-200 in the approach configuration was quite apparent. The use of the full back stick resulted in only a 35 foot altitude loss below the maneuver entry altitude. Whereas, the 3 degree/second rotation rate recovery resulted in a 75 foot altitude loss. More significantly however, the aircraft using the Full Back Stick (FBS) recovery technique was only below the entry altitude for 5.3 seconds, whereas the 3 deg/sec aircraft was below the entry altitude for 7.8 seconds. But most significant was that at the point where the 3 deg/sec aircraft was just getting back to the entry altitude, the FBS aircraft was 115 feet above the entry altitude.

In the clean descent configuration, altitude loss for the FBS recovery was 40 feet, as opposed to 68 feet. The time below the entry altitude was 3.4 seconds as opposed to 5.7 seconds. And finally, the FBS aircraft was 172 feet above the 3 degree/sec aircraft as it was just getting back to the entry altitude.

Pilot Comments

SIMULATOR - Since the iron bird simulator cab is a non-moving cab, it was difficult to make several repeatable runs at a specific pitch rate, notably 3.0 deg/sec. But what was learned from the CFIT maneuvers was that better, more consistent recoveries were achieved by using the Airbus recommended full aft stick technique. They provided the minimum altitude loss, and the maximum climb rate, while minimizing pilot workload. At the completion of the maneuver flown with full aft stick, there was always the feeling of precise pitch control, even though the airplane was recovering from a maximum performance maneuver. The runs flown using the airline AFM recommended “normal pull up to 17.5 deg”, and climbs to SRS (speed reference system) commands, gave more altitude loss and a slower climb. Additionally, the pilot comments indicate that workload actually increases while trying to precisely hold pitch attitude, and several bobbles and pitch overshoots were noted trying to get there. The time spent trying to precisely maintain a pitch attitude could better be used building situational awareness of position and clearance with terrain.

AIRCRAFT - This extensive series of CFIT avoidance maneuvers indicated to us, even without reducing the data, that in the dark absence of situational awareness, the best possible performance is obtained by using a full back stick technique.

Conclusion

The A320/330 full aft stick CFIT recovery vs 3 deg/sec pull gave better and more consistent performance without any increase in risk of exceeding envelope parameters. No additional or specific pilot training was necessary to perform the full aft stick recovery technique since the FBW design provides excellent pitch rate and g control as well as excellent envelope protection for stall, overstress, or overspeed.

Recommendations

A320/A330/A340 operators should use the manufacturers recommended full aft stick CFIT recovery procedure.

B. Boeing B-777-300

SIMULATOR TEST CARD

Following briefings on the B777-300 flight control system, and CFIT avoidance procedures, 2 hours was spent in the simulator cab. This was done mainly for familiarization with switches and controls, to get a basic feel for dynamics and handling characteristics, and to practice CFIT maneuvers that were to be flown in the airplane the following day.

Several CFIT avoidance maneuvers were flown in the simulator cab. There are no hard limits on angle of attack, load factor, pitch rate, and pitch angle in the B777. The evaluation pilots were able to use both the visual display of terrain, and the EGPWS system to set up the maneuvers, and to execute the avoidance maneuvers. Four entries were flown:

1. clean, 300 kts, idle, 1500 fpm descent, smooth pull up
2. clean, 300 kts, idle, 1500 fpm descent, aggressive pull up
3. Vref+5, flaps 30, 1500 fpm descent, smooth pull up
4. Vref+5, flaps 30, 1500 fpm descent, aggressive pull up

The maneuvers were flown toward the simulation terrain, and recovery initiated when the “Pull-up, Pull-up” aural warning was heard. The smooth pull up was flown several times to evaluated what the actual rate was, comparing pitch rate to the g that was produced

AIRCRAFT TEST CARD

Capt Rogers

1. Taxi
2. Takeoff
3. Normal climb
4. CFIT maneuver evaluation:

With the protections fully demonstrated, an investigation into the performance and pilot techniques necessary to get optimum performance during a CFIT avoidance maneuver was begun. A total of seven maneuvers were flown, with the parameters as follows:

1. clean, 300 kts, 1500 fpm descent	result: 1.5 deg/sec pull, 1.4g
2. clean, 300 kts, 1500 fpm descent	result: 3.5 deg/sec pull, 1.8g
3. clean, 300 kts, 1500 fpm descent	result: 4.9 deg/sec pull, 2.2g
4. clean, 300 kts, 1500 fpm descent	result: 6.0 deg/sec pull, 2.25g
5. flaps 30, 149 kts, 1500 fpm descent	result: 4.8 deg/sec pull, 1.6g
6. flaps 30, 149 kts, 1500 fpm descent	result: 4.0 deg/sec pull, 1.6g
7. flaps 30, 149 kts, 1500 fpm descent	result: 7.6 deg/sec pull, 1.7g

FO Stowe

5. Dynamics eval, 15,000'/250 kts, in Normal and Direct
6. Stalls (clean, PA)
7. Manual override of the autopilot from a trimmed PA configuration

FO Lutz

8. Clean stall
9. Turning stall (flaps 5, 30 degrees bank)
10. Evaluate trim characteristics (effectiveness, precision to hold speed)
11. Dynamics (s.p., phugoid, roll mode time constant, dutch roll), max L/D
12. Descent for landing at Moses Lake
13. Direct law landing, flaps 20
14. Normal landing from a 1200 ft offset, sidestep at 500 ft
15. V1 cut on the go, clean up on downwind

FO Stowe

16. Normal landing, capture 6 degrees after TD
17. Normal landing from 1200 ft offset, flaps 20

Capt Rogers

18. Normal landing from 1200 ft offset, V1 cut on the go

19. SE pattern, landing

Capt Kohler

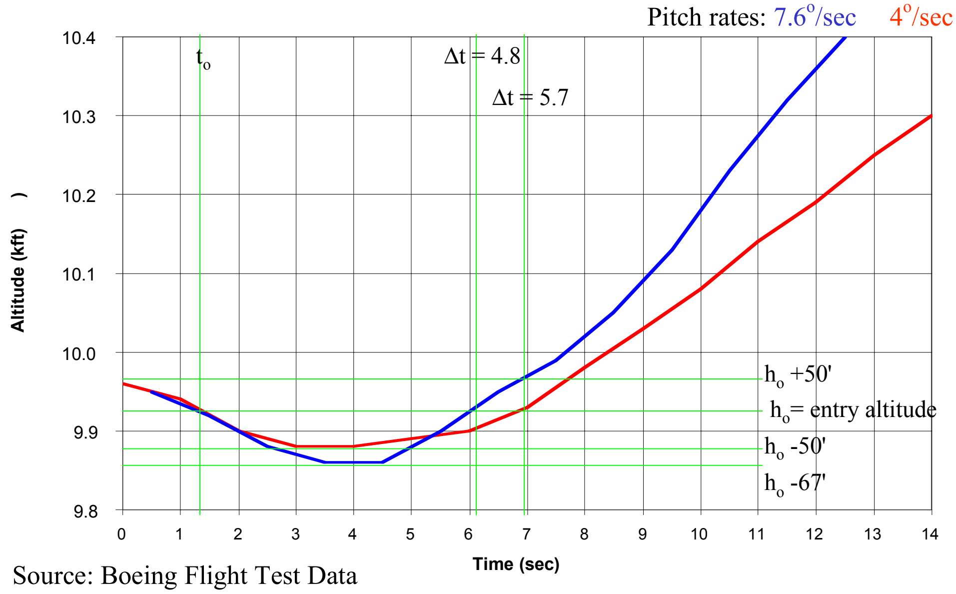
20. Normal full-stop landing, delay TD to Vref-5, full thrust reverse on upwind engine
21. Taxi evaluation on narrow taxiways
22. Normal takeoff, V1 cut on the go, SE pattern and landing
23. Climb to FL 350, accel to .86 mach, evaluate noise
24. Slow to 250 kts at altitude
25. Descent to 11,000 ft in Direct Law

Capt Rogers

26. Flight on RAT only for hydraulic power
27. Normal landing at Boeing Field

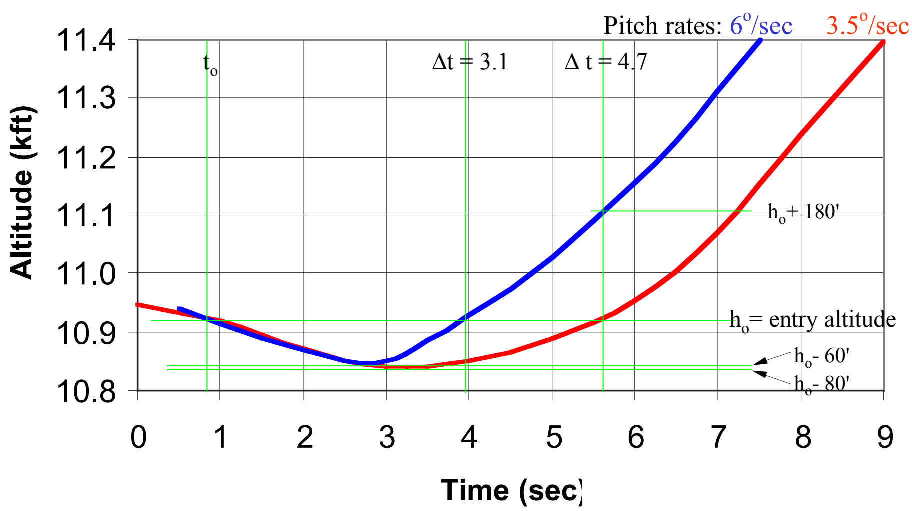
FLIGHT TEST DATA

B777-300 Flaps 30° Gear Down V_c=150 KIAS



Source: Boeing Flight Test Data

B777-300 Gear & Flaps Up - 300 KIAS



Source: Boeing Flight Test Data

Data Plots	Manevuer	Q (°/Sec)	N_z (G)	V_c (Kts)	Δ T (Sec)	Alt Loss (Ft)	Δ Zp V_s (Ft)
15	30F/DN	4.0	1.6	150	5.7	50	-
16	30F/DN®	7.6	1.7	150	4.8	67	50 (15)
11	CLEAN	3.5	1.8	300	4.7	80	-
13	CLEAN®	6.0	2.25	300	3.1	60	140 (11)

777-300 AIRCRAFT

For the B777-300 in the landing configuration, the aircraft with the rapid rotation rate initially performed worse. This was in contrast to the simulator data that showed improved performance. A rapid rotation led to a greater altitude loss during the maneuver, 67 feet versus 50 feet. The exposure time below the entry altitude was still less, 4.8 sec vs 5.7 seconds. But, the aircraft with the rapid rotation was only 50 feet above the aircraft with the normal rotation rate, as it was just returning to the entry altitude**.** The aircraft with the rapid rotation rate did achieve greater altitude gains as the climb continued.

For the enroute descent case, a rapid rotation resulted in a 60 foot altitude loss versus 80 feet for the normal rotation rate. The time below the entry altitude was 3.1 seconds versus 4.7 seconds. And, the aircraft with the rapid rotation rate was 140 feet above the normal rotation rate aircraft as it returned to the entry altitude.

Pilot Comments

SIMULATOR - Pulling smoothly at the standard 3 deg/sec did not produce enough g for maximum performance. Pulling at 6 deg/sec to 20 degrees of pitch provided 1.6g to 2.0g in the simulator. If pull-ups were made more aggressively, pitch attitude would overshoot into the 25 to 30 degree nose high range, and there were several pitch oscillations noted.

AIRCRAFT - Different entry g levels were evaluated, pulling up to a target pitch attitude of 17.5 degrees. At the higher g levels, precisely matching the pitch attitude at 17.5 was difficult, and would often result in a pitch overshoot of 2-3 degrees. The best run appeared to be run 3, where at the end of the run, pitch was exactly at 17.5 degrees, which was right at the pitch limit indicator (PLI), which is the threshold for stick shaker activation. Minimum altitude loss below the pull up altitude (10,000 ‘) was observed to be about 100 feet on run 3. On run 7, a near maximum performance pull up to 30 degrees nose high was executed, activating the stick shaker. The airplane stagnated in climb at 10,900’ and 105 kts with full thrust. While this run gave the maximum initial pitch rate, it bled off energy rapidly, resulting in complete loss of climb performance after a 900’ altitude gain. During all of these maneuvers, maximum thrust was applied at the beginning of the pull up. It nominally took 3-4 seconds for the engines to come to full thrust, which usually occurred at about 15 deg nose during the maneuver.

Conclusions

The evaluation team preferred the flight envelope limiting features ("soft limits") of the B777 design to a "hard limit" design. This was a subjective judgement based on the premise that there may be situations unforeseen by the designers where the pilot might need to achieve full aerodynamic capability as opposed to being software/control law limited.

V. Lessons Learned

A. Simulation

1. The use of an engineering simulator was beneficial in developing recovery techniques and assessing the ability to perform the recovery maneuver without overstressing the aircraft. This was very necessary in the build up phase to avoid or assess the potential for damage to the test aircraft.
2. The use of fixed based simulators did not provide any motion cues and thus was not a true simulation of the dynamics of the aggressive maneuvers being tested or developed. A "quick look" evaluation was performed with a full motion Airbus A-320 and a Boeing 777 simulator at the United Airlines Flight Center, but these simulators did not have the necessary data acquisition capability required for the test program.

B. Aircraft Flight Test

1. It was difficult to consistently obtain a pitch rate of 3 degrees/second over a variety of airspeeds without considerable practice and finesse (both aircraft have a long moment arm and there is no cockpit indication of pitch rate). The pitch rate attained at higher airspeeds (250 to 300 KIAS) tended to be underestimated by the pilot. The evaluation pilots felt that specifying a pitch rate of 3 degrees/second for line operations without a parameter display is impractical. The motion cues and g onset rates played a very important role in the closed loop performance.
2. Flight time to perform the evaluation was very limited. Because of this, detailed coordination preplanning and performance were required to achieve the test objectives.
3. Some of the coordination was international and this contributed to the communications difficulties. Some final issues could only be raised and resolved face to face and this resulted in some significant, last minute changes to the test card.
4. Flexibility in the test was required since our evaluators had limited control of the aircraft configuration and test cards.
5. Last minute test constraints due to structural safety concerns raised during the flight briefing required last minute modifications to the test cards. Care had to be taken to maintain like maneuver comparisons in spite of last minute maneuver modifications.

C. General

1. Manufacturer and FAA test pilots and purchasing company management pilots have traditionally evaluated most aircraft. The Airline Pilots Association has played more of a minor role in such evaluations until recently. Members of ALPA's APEC Committee have evaluated virtually every transport aircraft in current use or development and bring this broad aircraft knowledge along with considerable operational experience to the evaluation process. As a result of APECs evaluation of the CFIT recovery procedure for FBW aircraft, one major US airline, United Airlines, has changed their CFIT recovery procedure.
2. New aircraft should require an OT&E phase where old procedures are evaluated in light of new technological features. This may prevent the application of outdated Standard Operating Procedures that are not in keeping with the benefits derived from system improvements and advancements, such as FBW flight control systems.

VI. Conclusions/Recommendations

From the data gathered in the evaluation, there was not a distinct advantage of the B777 soft limits vs the A320/330 hard limits for CFIT recovery open loop performance.
However, closed loop evaluations showed that the pilots could achieve more consistent performance results as well as achieve target pull out parameters more quickly in the A320/330 than the B777. Even with the B777 soft limit features, pilots were able to use abrupt pitch inputs without fear of overstress or stall. Both aircraft types offered better handling during CFIT recoveries than conventional aircraft since the FBW design features allowed the pilot more precise control of pitch rate and g onset rate than with conventional flight controls.

RECOMMENDATION: Operators of fleets with a mix of conventional and FBW aircraft should reevaluate the benefits of a fleet standard CFIT recovery procedure vs. a FBW aircraft specific procedure that would provide such aircraft with better performance.

The A320/330 full aft stick CFIT recovery vs 3 deg/sec pull gave better and more consistent performance without any increase in risk of exceeding envelope parameters. No additional or specific pilot training was necessary to perform the full aft stick recovery technique since the FBW design provides excellent pitch rate and g control as well as excellent envelope protection for stall, overstress, or overspeed.

RECOMMENDATION: A320/A330/A340 operators should use the manufacturers recommended full aft stick CFIT recovery procedure.

The evaluation pilots' found that the enhanced flight path control precision and envelope protection features available through FBW design were highly desirable.

RECOMMENDATION: Incorporation of similar FBW design features is highly desirable in future designs.

The evaluation team preferred the flight envelope limiting features ("soft limits") of the B777 design to a "hard limit" design. This was a subjective judgement based on the premise that there may be situations unforeseen by the designers where the pilot might need to achieve full aerodynamic capability as opposed to being software/control law limited.

Another approach may be to incorporate "hard limits" with a pilot override capability such as an "instinctive cut-out" switch. Or alternately, the CFIT recovery capability on the 777 could be enhanced if the aircraft's Primary Flight Computers (PFC) were design to recognize aggressive pilot inputs as a desire for maximum aircraft performance. The PFCs would then provide maximum pitch rate consistent with AOA or g limits (depending on airspeed). If the resultant aircraft performance was not sufficient, the pilot could then pull to the full aerodynamic capability of the aircraft. Additionally, automatic speed brake retraction, in the event of a go around or CFIT escape maneuver, should be provided in the 777 design. This system although somewhat complex mechanically, can be implemented since the PFCs will control any undesired pitch excursions.

RECOMMENDATION: Further research and development should be conducted to optimize flight envelope protection control laws and design features with emphasis on providing pilot override authority.