Submission to the

National Transportation Safety Board

For the

American Airlines Flight 587
Belle Harbor, New York
November 12, 2001

Accident Investigation

AIRBUS S.A.S

INTRODUCTION

In accordance with NTSB rules, Airbus submits this report on the investigation of the accident involving American Airlines Flight 587 (AA 587) that occurred shortly after takeoff from John F. Kennedy International Airport on November 12, 2001 during a scheduled flight to Santo Domingo, Dominican Republic. The aircraft involved was an Airbus A300B4-605R, Manufacturer Serial Number MSN: 420. The aircraft was destroyed by impact forces, and all 260 persons on board, and 5 residents of Belle Harbor, New York were fatally injured in the accident.

Airbus is acting as a technical advisor to the Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile –B.E.A- in this investigation.

Submission Abstract

- The content of this submission is based on factual information gathered during this investigation, Airbus expertise on the A300B4-605R aircraft, Airbus experience accumulated over more than 16 Million Flight hours on the A300-600 and A310 aircraft by worldwide operators, reported in-service events, and the latest analytical tools available.

- The A300B4-605R aircraft model, its flight control systems and its structure meet or exceed all certifications requirement applicable at the time of certification.

- All the work performed during the AA587 investigation, has demonstrated that there was neither aircraft systems failure nor aircraft structural flaws involved in this accident. All systems and structures behaved as per design. Structural tests and analysis performed since the accident demonstrate that the level of loads achieved during AA587 flight was at the level of the rupture loads achieved during the certification fin rupture test made in 1986, i.e., 1.947 x Limit Loads (well above the certification requirement).

- Extremely high external loads were developed on the accident aircraft due to the repetitive, alternating, aggressive stop-to-stop pilot inputs on rudder pedals. The flying pilot exerted pedal forces far above the maximum force level required to achieve full rudder deflection on any commercial transport category aircraft flying today.

- The A300B4-605R rudder system characteristics –pedal forces and displacement– comply with the Certification requirements and were evaluated by the Airworthiness Authorities in particular during the aircraft flight handling qualities evaluation, where necessary rudder inputs are performed to demonstrate the adequacy of the rudder system for its intended use. Obviously such evaluations are performed in flight and take into consideration the aircraft response to flight controls inputs. These characteristics were found adequate and certified by the Authorities. In addition no adverse comments were received from the operators after more than 16 million flight hours.

- As expressed several times by Airbus, the adequacy of such system cannot be fully assessed without taking into account the aircraft response to various pilot inputs since this is the primary source of feedback used by pilots to determine the overall adequacy of the global system, including the rudder system characteristics, the pilot inputs, and the resulting aircraft response. It is not possible to draw valid conclusions about the adequacy of a flight control system by examining data tables or by evaluation in a simulator in which the accelerations experienced by the pilot in a real aircraft are not adequately represented.

- There have been four events involving high lateral loads reported since A300B4-600 entry into service (including this accident). They all involved the same operator, American Airlines. On the A310 fleet which has the same rudder system design, there have been two high load events due to crew actions after the initiation of temporary aircraft loss of control, and one most probably due to crew input on rudder pedals after they had commanded the rudder trim to its maximum position in the opposite direction.

- In May 1997, a non-fatal accident involving similar rudder pedals inputs and consequently very high fin loads occurred on another A300B4-605R aircraft operated by American Airlines (AA Flight 903). It is one of the four events mentioned above. This accident prompted an unprecedented letter co-signed by the three major airframe manufacturers, including Airbus, and by a representative from the FAA to warn American Airlines of the danger of (1) advocating the use of rudder for roll control in its training "Advanced Aircraft Maneuvering Program"(AAMP) and (2) the inherent danger of "negative training" posed by using simulators incapable of providing realistic feedback to train these upset recovery maneuvers. These explicit warnings, as well as the proper techniques to be used were then announced and repeated in several publications and presentations such as the Airbus submission in the AA 903 investigation and also in the industry publication entitled "*Upset Recovery Training Aid*" published in 1998 by Airbus and other manufacturers. Furthermore, the NTSB report properly identified the cause of this event: "*the flight crew's failure to maintain adequate airspeed during level off which led to an inadvertent stall, and their subsequent failure to use proper stall recovery techniques*" (emphasis added). NTSB Public docket document ID N° 266610 clearly demonstrates that American Airlines fully understood the cause of this accident and knew far before the AA587 accident about the danger of the rudder use theories developed in the AAMP. The AA 587 accident has exactly the same root cause--use of improper recovery techniques as taught in the AAMP--and which are in contradiction with the guidance provided by the Industry Training Aid and generally accepted principles of airmanship.

- In the frame of AA587 investigation it has been clearly identified that the parts of the AAMP training program dealing with rudder use was wrong and, dangerous as unfortunately demonstrated by this accident and by the accident involving AA903.

- Due to simulator limitations (including very poor ability to generate lateral accelerations), the use of full flight simulators for upset recovery training is potentially highly misleading. To greatly compound the problem, the changes introduced on the simulator by American Airlines without Airbus approval effectively nulled *all* roll control inputs for a limited, but critical, period of time when activated by the instructor for wake vortex recovery training, "forcing" the pilot to use full or nearly full rudder. Both elements (simulator limitations and modification) resulted in "negative training" leaving pilots with a false sense of confidence in the improper recovery techniques as taught.

- The net effect of these fundamental simulator limitations and the modification was that when the flying pilot in AA587 used full rudder to aid in what he perceived to be an imminent roll upset due to a wake vortex, **(exactly as he was taught to do in AAMP)**, the dynamic response of the aircraft was dramatically different from what he had previously experienced in the simulator. This surprise factor is believed to have so startled the flying pilot that all subsequent flight control inputs were basically stop-to-stop in a mistaken attempt to recover from what he believed were external influences upon the aircraft. It is important to note that throughout the AA587 accident sequence the flying pilot did exactly as he was trained to do, with predictable, fatal consequences.

- The chain of events leading to the accident can be summarized as follows:
    - AAMP over-emphasized the potential effect of wake vortex on a large transport category aircraft.
    - AAMP wrongly presented the rudder as a primary roll control surface.
    - American Airlines inappropriately handled the warning letter sent by the three major manufacturers, including Airbus and the FAA.
    - AAMP training performed on an in-house modified simulator, led pilots to apply full, or almost full, control wheel and rudder inputs for wake vortex recovery.
    - The AA 587 crew was cautioned by the JFK tower about wake turbulence (like in AAMP scenario). This started to alert the First Officer on potential wake vortex encounter.
    - AA 587 experienced a first wake encounter, and the crew properly identified it as such. This reinforced the previous alert and increased his anticipation of potential wake vortex upset.
    - Like in the AAMP scenario, AA 587 went through the second wake encounter while the aircraft was already banked in a commanded turn.

  - The AA 587 First Officer immediately reacted as taught in AAMP, by making full control wheel and rudder inputs.
  - The resultant aircraft accelerations were very high (unlike those experienced in the simulator with the AAMP scenario), and thus startled the First Officer, who then applied cyclic, stop-to-stop inputs to the rudder pedals, and on the control wheel in response of what he mistakenly believed would be the aircraft reaction to an encounter with a wake vortex.
  - The resulting sideslip build-up led to the development of loads on the fin structure, above the ultimate loads, finally leading to the fin separation.

- Since the accident, Airbus has issued several updates of its operational documentation (Aircraft Flight Manual and Flight Crew Operating Manual) to address the NTSB recommendations A-02-01 and -02 and to clarify a few points such as the definition of V_A.

- Airbus updated the A300B4-605R Maintenance Manual in June 2002 to include additional aircraft inspection criteria in case of high lateral accelerations. This is linked to NTSB recommendations A-03-41 through –44.

- Airbus has proposed a joint Industry meeting to properly address NTSB recommendations A-03-48 through -50 and FAA concerns on DFDR requirements.

- Airbus proposes five additional recommendations for consideration by the NTSB that address issues raised by this accident. These include (1) a revision of the definition of Va that is required in the Aircraft Flight Manual; (2) certification requirements for new aircraft designs; (3) aircraft manufacturer involvement in training program development and approvals; (4) dissemination of information regarding the limitations of training simulators for upset recovery training; and (5) regulatory oversight and manufacturer involvement in modifications to operator training simulators.

CONTENTS

1. FACTUAL INFORMATION

1.1 History of Flight

American Airlines flight 587 (AA 587) took off from John F. Kennedy International Airport at approximately 09.12am local time on November 12, 2001 for a scheduled flight to Santo Domingo, Dominican Republic. The aircraft involved was an A300B4-605R Manufacturer Serial Number MSN 420, N14053, which had been delivered to American Airlines July 12, 1988. It had accumulated approximately 37500 Flight Hours and 14934 Flight Cycles at the time of the accident. When it left the gate, there were no open items on the aircraft logbook. Around 105 seconds after take off, the aircraft impacted the ground and was destroyed by impact forces.

1.2 Injuries to persons

All 260 persons on board and 5 residents of Belle Harbor, New York were fatally injured in the accident.

1.3 Damage to the aircraft

The aircraft rudder (in several pieces) and the entire fin were retrieved from Jamaica Bay. Some post accident damage occurred on those parts during recovery actions. On land, both engines were retrieved separated from the main wreckage. The main wreckage location contained virtually all of the remaining parts of the aircraft

1.4 Other damage

On ground several houses were destroyed or severely damaged by the impact and/or post-impact fire.

1.5 Personnel information

Information relative to the Captain and the First Officer are included in the NTSB factual report. There is no evidence for either crew member of any involvement in activities such as aerobatic or glider flying that would have implied a specific use of rudder control different from that required for transport category aircraft.

1.6 Airplane information

1.6.1 The A300-600 Vertical stabilizer use of composite materials

Composite materials in Airbus aircraft have been introduced in a progressive and cautious step-by-step approach. The initial application was on secondary structure such as fairings and radomes, gaining in-service experience before being used on primary structure. In addition, extensive testing was performed using a build-on-blocks approach that far exceeded certification requirements. The A300-600 composite fin was subjected to load cycling representing 3 times the aircraft maximum number of cycles certified of the aircraft with artificial damages introduced from the beginning of the testing before being loaded up to ultimate loads and eventually to rupture. This final rupture test had demonstrated that the A300-600 composite fin was able to sustain 1.947 times the design Limit Loads (LL), which is significantly above the Ultimate Loads (UL) level required by the certification (UL = 1.5 x LL).

1.6.2 The A300-600 Flight Control system

1.6.2.1 Autopilot

The Autopilot was never engaged during the flight of AA 587. A check of the DFDR data for the previous flights shows that this information was properly recorded and as such confirms the validity of this parameter recording.

1.6.2.2 Operational use of rudder

1.6.2.2.1 Rudder pedals use in flight operations

On civil transport category airplane, the rudder pedal is more a zeroing flight control to compensate for any yaw asymmetry than a primary flight control to create yaw asymmetry as it is on some military fighter aircraft. In flight it has to be used only in case of an engine out condition or during landing for decrab. The rudder turn coordination being automatically done via the yaw damper by the FAC, it is not necessary to add significant rudder input. In the extremely unlikely event of a complete failure of the normal roll control (relying on ailerons and spoilers), the rudder may be used with care to control the roll axis. There are no other technical or operational reasons than the above mentioned ones to use rudder pedals in-flight.

On large transport category aircraft such as the A300B4-605R, roll control authority is adequate, even in the case where upset recovery techniques must be applied. Furthermore, rudder doublets—full stop-to-stop pedal deflections such as those observed in this accident—are not recognized design conditions, nor is there ever an operational need for them in transport category aircraft.

Neither during testing nor in 16 million flight hours of operator in-service experience did Airbus receive even one complaint or criticism of the handling qualities aspect of its design (AA 587 investigation a part).

1.6.2.2.2 Open and closed loop pilot control

Just as automobile drivers apply enough steering wheel or brake input to achieve the desired turning or stopping performance, pilots apply pressure to flight controls to achieve a desired aircraft response. If the response is too small or too slow, the pilot increases the pressure until the desired response is achieved. Conversely, if the response is too large or too fast, the pressure is reduced until the desired response occurs. In the same way, the car driver turns the steering wheel without knowing in advance the exact amount of displacement or force he will apply; he continuously adjusts his input to zero the error between the objective and the actual position taking into account the rate at which he is reaching the objective. This human control behavior is based on experience and training, both in the case of the automobile and for aircraft. Piloting consists of "closed loop" tasks whereby the pilot applies varying pressure to the appropriate flight controls to achieve the aircraft response required to match the actual flight path to the desired flight path. Just like the automobile, the airplane provides the necessary feedback to the pilot so that he or she may continuously adjust control inputs to achieve the desired vehicle response.

1.6.2.3 Rudder control

1.6.2.3.1 System design

The rudder system characteristics (pedal forces and displacements) comply with the Certification requirements and were evaluated by the Certification Authorities (including FAA) in particular during the aircraft flight handling qualities evaluation where necessary rudder pedal inputs are performed to demonstrate the adequacy of the rudder system for its intended use. Obviously such evaluations are performed in flight and take into consideration the aircraft response to flight controls inputs. These characteristics were found adequate and certified by the Authorities. As expressed several times by Airbus, the adequacy of such system cannot be fully assessed without taking into account the aircraft response to pilot inputs. It is important to note that any evaluation of flight control characteristics *must* take into account the dynamic response of the aircraft since this is the primary source of feedback used by pilots to determine the adequacy of any control input. It is simply not possible to draw valid conclusions about the adequacy of a flight control system by examining data tables or by evaluation in a simulator in which the accelerations experienced by the pilot in a real aircraft are not represented.

The rudder maximum displacement was chosen to be able to compensate for an engine out condition with a sufficient maneuverability margin at any speed. It is plus or minus 30 degrees at low speed (below 165 knots) and progressively decreases to plus or minus 3.5 degrees at and above 395 knots for an A300-600 equipped with a composite vertical fin.
The rudder is driven by three servo actuators powered by three independent hydraulic circuits, which are able to move it at 60 degrees per second.

The rudder movements can be controlled by:

a. An action of the crew on the rudder pedals
b. An input from the Auto-pilot Yaw actuator
c. An input from the Yaw damper
d. An input from the rudder trim

1.6.2.3.2 Rudder pedals

The maximum travel of the ruder pedals at low speed (below 165 kts) is plus or minus 4 inches; this is associated with a maximum rudder deflection of 30 degrees. When the aircraft speed increases, the maximum rudder displacement decreases and the amount of pedal displacement decreases accordingly. At around 250 kts the maximum rudder displacement is 9.3 degrees, and the corresponding pedal travel is 1.2 inches. This means a relative displacement of one pilot foot to the other of 2.4 inches at this speed.

In order to minimize any inadvertent crew actions on the rudder pedals, a minimum force of 22 pounds independent of aircraft speed must, by design, be applied on the pedals before any displacement occurs.
To achieve the maximum rudder pedal displacement of 4 inches at low speed, a maximum force of 65 lbs has to be applied. At 250 kts, the rudder displacement is limited to 9.3 degrees and consequently, the rudder pedal displacement is limited to 1.2 inches requiring a force of 32 pounds to reach the stop.

1.6.2.3.3 Yaw damper

The yaw damper primary functions are to damp the Dutch roll (a natural, oscillatory yawing/rolling movement characteristic of swept wing aircraft in flight) and to provide automatic turn coordination. Therefore there is no need for rudder pedal inputs in flight except in case of engine failure or other asymmetric conditions, and crosswind takeoffs and landings. The maximum authority of the yaw damper is approximately a third of the rudder authority. The yaw damper actuator signals are added to those of the pilot, up to the maximum travel allowed by the variable stop lever. Due to this logic, the pilot authority is always greater than the yaw damper authority.

1.6.2.3.4 Rudder Travel Limiter design & operation

The rudder travel limiter is located in the rear section of the aircraft it is a "V" shaped cam activated by an electrical motor which, by closing, limits the possible travel of the servo actuators input control rods. It is located downstream of all rudder controls (pedals, auto pilot, rudder trim, yaw damper). The closing speed of the rudder travel limiter has been selected to cover all aircraft speed gradients within the operational flight domain. As speed increases the rudder travel limiter closes to ensure the appropriate maximum displacement of the rudder in accordance with the actual aircraft speed. In normal flight operations there is never a need to reach the rudder travel stops. However if the rudder control is already on the stop in one direction, applying excessive force on the rudder pedals (above 240 pounds) prevents the actuator from further closing the travel limiter as the aircraft speed continues to increase. In addition the rudder travel limiter ensures that the loads developed by a single, full rudder pedal input followed by a return to the neutral position will remain inside Limit Loads as prescribed by the Certification requirement.

1.6.3 Previous events involving high lateral loads on the vertical stabilizer of the A300-600 and A310 fleet.

In the course of the AA 587 accident investigation, a review of all A300-600 and A310 in-service high load events was performed by Airbus. For that review, Airbus looked at all reported incidents since aircraft entry into service regardless of whether they were due to atmospheric conditions, systems failure or crew inputs.

All events where the fin lateral loads level reached was above the Certification Limit Loads level have been considered as high lateral loads events. The vertical fin attachment lugs of all these aircraft have been inspected using an Ultra sonic NDT procedure. None of these had any damage except the American Airline aircraft that was involved in the AA

903 accident in 1997. For this aircraft it has been assessed recently that the level of loads reached could have been close to the one achieved during AA 587 accident..

Because for the first similar commercial transport category airplane that experienced a vertical stabilizer rupture in-flight (Lauda Air Flight NG004), the origin of the accident was attributed to an un-commanded thrust reverser deployment in climb, Airbus looked at the only case where an A300-600 thrust reverser deployed in-flight. After evaluation of the lateral loads, it appears that this particular case does not fall in the High Loads events category, since the level of lateral loads reached was 14% below the Certification Limit Loads.

Including the AA 587 accident, the A300-600 fleet has experienced a total of 4 "high lateral loads" events. They all occurred on the American Airlines fleet.

On the A310 fleet which shares the same rudder system design, there are 2 "high lateral loads" events (1.55xLL and 1.12 LL) which occurred during aircraft temporary loss of control and one case barely exceeding the Limits Loads level (1.06xLL), where the most probable cause is a crew rudder input after a full rudder trim action in the opposite direction.

1.6.3.1 Interflug event

In 1991 an A310 aircraft, operated by Interflug, executed a missed approach procedure during which the pilot mishandled the flight controls such that the aircraft went into three successive stalls. On each of these three occasions the crew experienced temporary loss of control (aircraft pitch attitude reaching a maximum of 89 degrees and stalling). Also during each recovery aircraft reached very high vertical loads factor. These extreme vertical load factor excursions were a subject of structural concerns, and Airbus Design Offices focused on defining appropriate additional aircraft inspections for structure loaded in the vertical axis. The lateral axis situation was not addressed. Revisiting all Airbus archives shows that there is no document addressing the lateral loads issue; the focus of the investigation by Airbus or any other authorities being exclusively on the vertical axis as far as structure is concerned.

The operational factors that led to this event were thoroughly investigated by Airbus at that time and remedial actions were launched and modifications introduced to avoid the situation that led to the initiating loss of longitudinal control. It should be noted that none of these operational factors are common with any of the circumstances surrounding AA 587 accident.

After the AA587 accident, lateral loads for the Interflug case were evaluated, and showed that the aircraft reached a maximum lateral loading of 1.55x Limits Loads. It has to be noted that apart from the American Airlines high loads events cases, this Interflug case is the only one having barely exceeded the Ultimate Loads level. Furthermore, this happened during a flight where extreme upset situations were reached.

It has to be strongly highlighted that during all these extreme aircraft upset situations the flight control inputs applied by the crew were performed at a normal rate, far below the control rates seen during the AA587 flight, which never reached an actual aircraft upset situation.

1.6.3.2 AA903 event at Miami in 1997

The American Airlines Flight 903 event occurred on 12 May 1997 near Miami, FL. Hereafter is a short chronological summary of events subsequent to May 12, 1997. The full history with copies of all relative documents has been previously provided to the NTSB.

Airbus first learned of the event on 13 May 1997 in a message from its Field Service Representative based at American Airlines' maintenance and engineering facility in Tulsa. This event was described as severe turbulence with dramatic attitude changes over a short period. The Field Service Representative also noted that the operator had refused to release the DFDR information, at this time.

A load engineering assessment was done leading to specific inspections. There was no finding identified further to these inspections. The exact sequence of events leading to this conclusion is enclosed in appendix 5.6.

Regarding operational considerations of AA 903:

On 12 August 1998, the Airbus submission to the NTSB highlighted the incorrect nature of the flight control inputs saying that stall (warning) recovery techniques which attempt to maintain a nose-high attitude while controlling bank angle with large rudder and wheel inputs result in secondary stalls and large lateral/directional oscillations experienced by AA903. It also said,

> ***"rudder reversals such as those that might be involved in dynamic maneuvers created by using too much rudder in a recovery attempt can lead to structural loads that exceed the design strength of the fin and other associated airframe components."***

On the same day, Airbus sent copies of the entire submission to all other parties to the NTSB investigation and their technical advisors. These parties included the operator, the applicable pilots association, and the FAA.

In the NTSB report concerning AA903, the cause of the accident was correctly identified as,

> "*the flight crew's failure to maintain adequate airspeed during level off which led to an inadvertent stall, and their subsequent failure to use proper stall recovery techniques*" (emphasis added).

NTSB issued recommendations regarding the Airbus A300-600 aircraft.

Since the event, Airbus has developed a number of A300-600 design changes to minimize the risk of a reoccurring event similar to the Flight 903 upset and subsequent recovery. These modifications:

- Introduced speed protection in the FCC, and AP disconnection logic when the airspeed drops below V_{LS} - 10kts. The change was introduced by modification 11900/SB22-2049, which was subsequently mandated by F-DGAC CN 2000-137-305 (B) and FAA AD 2000-23-08.

- Improved the display information by EFIS-SGU modification 12991, which was subsequently mandated by F-DGAC CN 2001-467 (B)
- Changed the "MAN THR" FMA message logic and replication of the message triggering information on the SGU output bus
- Eliminated the SGU reset (and associated PFD display blanking) attitude logic to provide instead a "CHECK ATT" flag on the PFD
- Eliminated the SGU reset (and associated PFD display blanking) speed monitoring logic to provide instead a "SPEED" flag on the PFD.
- To implement in the latest production standard, modifications 12144 (FWC), and 12134 (ECAM SGU), to provide a new ATS auto-throttle OFF Amber ECAM warning triggered in case of auto-throttle disconnection (modification 12144)
- Give priority to stall aural warning over AP OFF aural warning (modification 12144)
- Introduce a new ECAM procedure in case of auto-throttle manual disconnection (modification 12134).

None of these technical issues are common with the circumstances surrounding the AA 587 accident.

In addition Airbus addressed the operational aspects of this accident by:

- Issuing in conjunction with other manufacturers the Upset Recovery Training Aid (see appendix (5.3)
- Publishing a specially dedicated "FAST " magazine (see appendix 5.2)
- Making a formal presentation on Airplane Upset Recovery Training Aid addressing simulators limitations, and proper rudder use during the 10th Performance and Operations Conference in San Francisco (see appendix 5.7), where four representatives from American Airlines were present.

Contrary to AAL testimony during the AA 587 Public Hearing, it is clear that some senior personnel in American Airlines Flight Operations fully understood the real cause of AA903 accident and were fully aware of the danger of the rudder use as advocated in the AAMP well before AA 587 accident. It is further clear that American Airlines' management had been made aware of the limitations of simulators for such training, also well before the AA 587 accident. This is clearly shown by the NTSB Public document ID N° 266610 which is an American Airlines internal memo from the Managing Director of Flight Operations Technical to the Chief Pilot and Vice-President of Flight.

> *"I have grave concerns about some flawed aerodynamic theory and flying techniques that have been presented in the AAMP. Furthermore I believe that these concerns are validated by the recent AA 903 accident.*
>
> ...
>
> *In no uncertain terms pilots are told to use rudders as the primary means of roll control in unusual attitude recoveries involving wind shear events and recovery from high angle-of-attack situations.*
>
> *This is not only wrong, it is exceptionally dangerous.*
>
> ....
>
> *John Cashman, Boeing Chief Test Pilot says that he "vehemently disagrees" with the aggressive use of rudder at high angle-of-attack "it is extremely dangerous and unpredictable". Tom Melody, McDonnell Douglas Chief Test Pilot also has expressed "serious concern and disagreement" about the rudder theories presented in AAMP.*
>
> *Much of the rudder theory and technique described in AAMP was "proven" in our simulators. Our simulators are training devices only, and not engineering simulators. They do not accurately represent flight regimes that are not required for normal training events. A simulator is not an airplane.*
>
> ...

> *I submit that the violent nature of the event was not caused by turbulence, but by excessive rudder inputs by the crew, which is exactly what they were taught by AAMP.*
>
> ...
>
> *I also want to point out that since we are selling or giving this program to other airlines we will be held legally accountable if an accident occurs which can in any way be linked to AAMP, particularly since Boeing and McDonnell Douglas have both expressed disagreement with the high angle of attack theory being advocated.*
>
> ...
>
> *Furthermore, we are presently conducting high angle of attack training in simulators which do not accurately replicate the behavior of the airplane and are very likely to provide a false sense of confidence to our pilots. This is negative training at its worst.*
>
> *I suggest that American Airlines take immediate corrective action to change our training programs and advise our flight crews of the correct nature and danger of rudder inputs at high angle of attack".*

1.7 Meteorological Information

Visual conditions prevailed at the time of the accident. There were no adverse weather conditions at the time of the accident.

1.8 Aids to Navigation

Not relevant

1.9 Communications

Not relevant

1.10 Airport Information

Not relevant

1.11 Air Traffic Control Information

The Control Tower gave a proper notice concerning possible wake encounter due to the preceding aircraft.

1.12 Wake vortex

1.12.1 No history of large aircraft upsets due to wake encounter

Analysis conducted by NASA at the request of the NTSB shows that at the time it was encountered by AA 587, the wake vortex generated by the preceding B747 could have been between 60 and 80 percent of its initial strength, and that there were no linking instabilities, such as Crow Instability, going on at the time. In other words, it was a typical wake vortex with nothing extraordinary or unusual about it.

The available information also clearly shows that there is no known case of a wake vortex causing an upset in a large aircraft, such as an A300B4-605R as dramatically as that depicted in AAMP documentation. Also, according to Airbus knowledge, there are no known studies that show, under the conditions experienced by the accident aircraft, that a 100 second old wake vortex could roll a large aircraft into an upset condition, i.e., beyond 45 degrees.

The Phase I testing in the NASA Ames Vertical Motion Simulator used the DFDR data to back-drive the simulator. This also confirmed that the vortex encounter was similar to a typical encounter in any large transport category aircraft. The first encounter consisted of essentially no aircraft movement in the lateral axis, but there was a sharp bump in the vertical axis. Furthermore, there were no visual or acceleration cues observed in the second encounter that would require a pilot to apply the large and abrupt control wheel and rudder pedal input recorded on the DFDR. After those tests were performed, additional NTSB studies revealed a rolling moment at the onset of the second wake encounter before the initial pilot entry.

These analyses also clearly show that the conclusions in a highly theoretical study entitled "An Engineering Study of the Unsteady

Response of a Jet Transport During a Wake Encounter and the Transitional State of Potential Crow Instability" are not relevant to this accident.

1.12.2 Second wake vortex limited impact

An extensive review of data and a simulation done by the NTSB Aircraft Performance group shows that the wake vortex encounter would not have induced an upset even if the pilot had made no control inputs, i.e., had he flown hands and feet off the controls. From the 20 degrees of bank angle the aircraft had during the turn, it would have reached around 34 degrees bank angle due to the effects of the vortex encounter. This is still far from the 45 degrees of minimum bank angle used to define an aircraft roll upset.

1.13 Flight Recorders

1.13.1 DFDR

It is necessary to have very precise knowledge of the rudder deflection throughout this event to fully understand the observed aircraft motion and accurately determine the aerodynamic loads created by that motion.

The Digital Flight Data Recorder (DFDR) sampling rate for the main flight control surface positions is 2 samples per second. Although this is typical and adequate for most accident/incident investigation, it does not provide the very detailed history of rudder deflections required in the highly dynamic case of AA 587 accident. A higher data rate would be required.

Additionally, the flight control surface positions recorded on the DFDR are not the raw positions of the synchros. The recorded values are the ones displayed to the crew. They are filtered to prevent display flickering.

The required information was nevertheless made available through an iterative process that uses an accurate A300B4-605R handling qualities model. This process generates an assumed flight control surface history that matches throughout the event both the recorded filtered flight control deflections and the aircraft motion parameters. When a suitable match is achieved, this sophisticated analysis process provides the flight control surface positions and wind gradient history that are required to properly evaluate the performance of the rudder system and accurately determine the aerodynamic loads developed.

1.13.2 CVR

1.13.2.1 Aural warnings

Different aural warnings exist, and can be recorded on CVR. It is important to note that before the estimated time of vertical stabilizer separation, no warnings are recorded on the CVR for AA 587. However, after the vertical stabilizer rupture time, several aural warnings are recorded. This demonstrates that the Flight Warning Computer was working properly and that prior to the vertical stabilizer separation no failures associated with an aural warning were present.

1.13.2.2 Wake vortex related comments on CVR

Prior to take off at time 0910:34, the crew is informed by the tower that they may encounter wake turbulence when the controller says, "*caution wake turbulence, there'll be uh, several heavy jets departures over Canarsie momentarily.*"
Later, at time 0911:36 Kennedy tower specifically advised the AA 587 crew, "*American five eighty seven heavy Kennedy tower, caution wake turbulence runway three one left, take position and hold.*"
Before the take off roll begins at time 0913:35.3, the First Officer asked for the Captain's judgment, "*You happy with that distance*? " The Captain replied, "*aah, he's... we'll be all right once we get rollin'. He's supposed to be five miles by the time we're airborne, that's the idea.* "
The First Officer responded, "*so you're happy .lights ?.*"
After the first wake encounter at time 0915:44.7 the Captain commented, " *little wake turbulence, huh ?* ", the First Officer replied, "*...yeah.*"

1.13.2.3 CVR comments and the startle effect

During the second wake encounter at time 0915:54.2 the First Officer asked the Captain in a strained voice for, "*max power.*" Then the Captain questioned the First Officer, " *You all right ?* " to which he replied, " *Yeah, I'm fine.*" At time 0915:57.5 the First Officer again asked the Captain, " *let's go for power please.*"

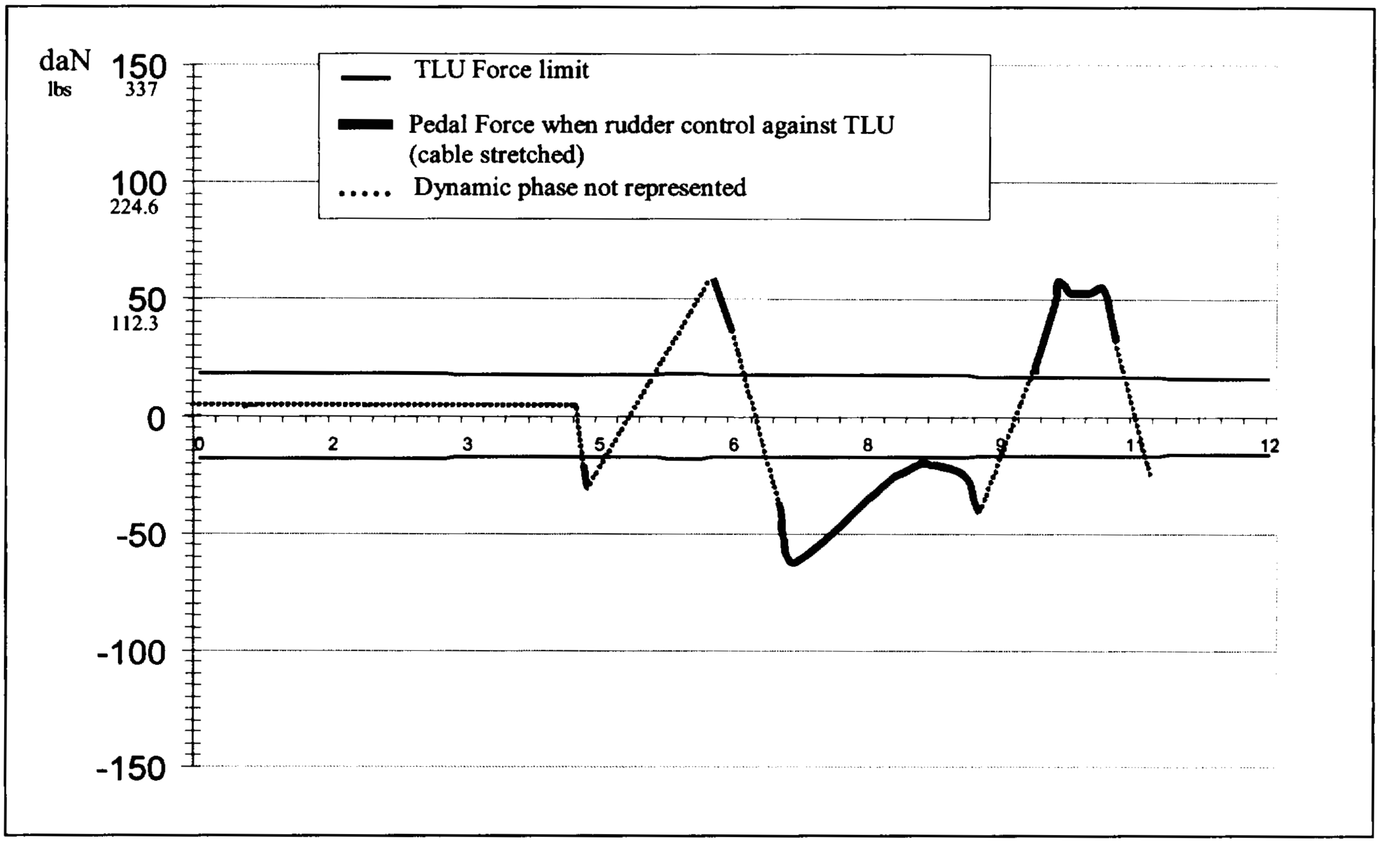
1.13.2.4 CVR spectrum analysis

The CVR spectrum analysis performed did not provide any evidence of aerodynamic flutter during the flight of AA 587.

1.13.2.5 Crew voice characteristics

The analysis of the First Officer voice characteristics shows that the First Officer exerted large physical effort several times during the second encounter (refer to Human Performance speech report).

These physical efforts are confirmed by the amount of force applied on the rudder pedals over time during the second encounter as shown on the following graph from Technical note ref : C27D03017000 V3.



Estimated pedal force derived from the pedal, rudder and yaw damper positions as identified in the TN: 517.0082/2002 "AAL 587 – Handling qualities investigations" and the control system elasticity as measured on production aircraft.

1.14 Wreckage and Impact information

The fin and rudder were retrieved from Jamaica Bay. Further along the aircraft trajectory, both engines were retrieved on the ground separated from the aircraft wings in two different places located a few hundreds meters from the main wreckage site.
Detailed information concerning the wreckage is included in the NTSB Structure group factual reports.

1.15 Medical and Pathological information

Not relevant.

1.16 Fire

There was no evidence of in-flight fire prior to the fin separation.

1.17 Survival aspects

The aircraft impact on the ground was not survivable.

1.18 Tests and research

1.18.1 Tests on composite materials

Extensive non-destructive and destructive testing of the accident aircraft vertical fin and rudder failed to reveal any data that indicated that use of composite material in the primary structure of the vertical fin and rudder was unwise or inappropriate.

These tests have clearly shown that the composite materials, their manufacturing and certification processes, and the in-service inspections used for the A300B4-605R vertical fin assure that all of the certification structural integrity requirements were met. These tests also show that structural integrity was maintained in-service. Furthermore, there were no defects detected during this testing that would invalidate the in-service inspection program recommended by Airbus.

1.18.2 Tests on vertical stabilizer attachment lugs

The tests performed showed consistently that the structural strength of the fin attachment lugs significantly exceeded the design requirements.

1.18.3 Human Performance tests on NASA VMS

A three phase test program was initially defined by the Human Performance Group:
-Phase I: back drive of accident flight
-Phase II: Target Tracking Task
-Phase III: Simulator emulation with A300B4-605R aircraft model

Phase I tests performed using a preliminary reconstruction of data from the DFDR demonstrated the high lateral accelerations the crew was subjected to, unlike in a standard training simulator which is unable to represent those accelerations.

Phase II tests consisted of a tracking task that was not linked to realistic piloting tasks and did not include aircraft response to pilot inputs (e.g., pulling 8 vertical G's to follow the target)

Phase III tests were cancelled by NTSB

1.18.4 Ground tests

Tests were performed on ground on one A300-600 aircraft to measure force on rudder pedals and evaluate rudder system characteristics and associated DFDR recording "signature". These tests also indicated that there was no hydraulic power issue in the accident sequence.
Because these test were performed on the ground, they did not include the aircraft response to flight control inputs, and consequently do not allow a complete assessment of flight control adequacy.

1.19 Organizational and Management information

1.19.1 American airlines AAMP

1.19.1.1 Development of AAMP

During the development of the AAMP, American Airlines gave the opportunity to the major aircraft manufacturers to evaluate their program.

After observing an early AAMP session, the three major airframe manufacturers together with an FAA representative, wrote an unprecedented letter to American Airlines to express their common concerns regarding the rudder use theories developed in the AAMP (refer to paragraph 1.19.1.4).

1.19.1.2 Evolution of AAMP

The AAMP classroom material and, later, the video that was sent to all of the operator's pilots, contained improper guidance concerning the use of rudder. This is also consistent with the recollections of Captain Rockliff and former NTSB Board Member Hammerschmidt concerning the emphasis the AAMP placed on rudder use during upset recovery.
During the AAMP discussion of recovery from an inverted nose low attitude, the videotape contains the following comments by the instructor, *"I'm going to tell you to put in 'coordinated rudder', put it fully in, fully, all of it, right now. As many of you know, the rudder in this portion of the roll becomes what acrobatic pilots call Top Rudder". He goes on to say: "When you pull back what goes up? Angle of attack. When angle of attack goes up, what rolls the plane? Rudder. Exactly, and that's rudder all the way in and it whack, it will try to snap roll. That's fine. Just neutralize the rudders real quick".*

After the AA 587 crew took the AAMP training, a very short advisory regarding rudder use was added to the end videotaped version of the AAMP course. The video was then distributed to American Airlines pilots who had taken the course, but with no notice that additional material had been added and with the sole instruction that it should be added to the pilot's library. Even had the change been noted, the video still contains guidance that could lead some pilots to use inappropriate techniques during upset recovery.

The videotape also shows that the AAMP redefined the term "coordinated rudder." The AAMP definition of the term was rudder in the direction of roll. This differs greatly from the industry-wide usage of the term which means the application of sufficient rudder to zero the sideslip generated by adverse yaw from the roll controls, i.e., to "center the ball."

1.19.1.3 Use of roll inhibit logic in AAL training simulators

To introduce a simulated aircraft upset American Airlines modified their training simulator by temporarily inhibiting roll and yaw controls while introducing a large rolling moment, instead of using the classical method of having one pilot close his eyes while the upset is introduced by the non-flying pilot. As a consequence, while trying to recover from the developing upset, pilot inputs on the control wheel and on the rudder pedals have no effect thus leading the pilot to make even larger inputs. During the public hearing, American Airlines testified that it had not consulted the airframe manufacturers regarding this simulator modification (refer to Public Hearing transcript page 468)
It is important to note that after the accident, American Airlines stopped using this method of inducing upsets in simulator (refer to Public Hearing transcript pages: 373 & 374).

1.19.1.4 Boeing / Mc Donnell Douglas / Airbus / FAA letter (see appendix 5.1)

Other aspects of the AAMP training could also have inadvertently produced negative transfer of learning from the simulator to the actual aircraft regarding use of rudder in recovery from wake vortex encounters. This serious concern was highlighted in the joint 1997 letter to American Airlines from representatives of three major aircraft manufacturers, including Airbus, and the FAA.
"*... Artificially manipulating a simulator into an environment that is way beyond valid engineering data creates a potential for negative learning. Current simulator limitations also do not permit the replication of linear and lateral load factors. Using a vortex flow in the simulator to induce an upset is a reasonable approach, however, inhibiting aileron inputs as apparently implemented in your training simulators, until the airplane has rolled through 90 degrees of bank will invariably result in large sideslip angles - probably outside the range of valid aero data. Additionally, without any aileron effectiveness during the first 90 degrees of roll, the pilot will probably use rudder in an attempt to roll the*

airplane erect. This will lead to an increase in sideslip that could invalidate the response of the simulator to any further inputs…"

1.19.1.5 Pilot and First Officer experience with AAMP

Pilot and First Officer experience with AAMP is fully documented in the NTSB Public Docket document ID Number: 266639. It is important to note that the First Officer attended AAMP ground school in March 1997, and went to recurrent training on the B727 that included AAMP simulator training on upset recovery in November 1997. The AAMP video was distributed to American Airlines pilots on December 1997.

1.19.1.6 Other operators participations in AAMP

During the AA 587 Public Hearing, American Airlines stated that AAMP was prepared with the involvement of other airlines and that once completed, it was provided to other airlines.

1.19.2 Airbus communications regarding Upset Training

1.19.2.1 Airbus / Boeing Industry Training aid (see appendix 5.3)

Airbus develops training programs to assist all operators of its aircraft in training the initial cadre of airmen in preparation for initial revenue service. These recommended training programs are also used as a guide for operators in developing their own training requirements. In some cases, Airbus conducts all training for the operators, especially for those with only a few aircraft. Additionally, Airbus develops training programs for special operations, such as ETOPS, and special emphasis items, such as Upset Recovery Training.

For upset recovery in situations such as a wake vortex encounter, the Airbus Upset Recovery training program emphasizes that normal roll controls should be used first and that rudder should only be used to induce roll after application of full roll control has failed to produce the required aircraft response.

In situations like those encountered by AA 587, this training also emphasizes that inappropriate use of rudder, such as using too much rudder in a recovery attempt, can lead to structural loads that exceed the design strength of the fin and other associated airframe components.

1.19.2.2 Airbus submission to NTSB on AA903(see appendix 5.4)

In its submission sent to the NTSB and to all parties involved in this investigation, Airbus made clear statements and provided warning about the danger of such improper rudder use, *"Although a simple rule about rudder usage cannot be stated, an appropriate standard is to first use full aileron control. Then, if the aircraft is not responding, use rudder as necessary to obtain the desired airplane response. Momentary actuation of spoilers during roll does not significantly increase drag.*
Sideslip angle is a crucial parameter during a recovery maneuver. This is probably not well understood by many line pilots, but it has a significant impact on an airplane's stability and control. Large or abrupt rudder usage at high angles of attack can rapidly create sideslip angles and can lead to rapid loss of controlled flight. ***Rudder reversals such as those that might be involved in dynamic maneuvers created by using too much rudder in a recovery attempt can lead to structural loads that exceed the design strength of the fin and other associated airframe components*** *(emphasis added). The hazards of inappropriate use of rudder during a windshear encounter, wake turbulence recovery, or recovery from low airspeed at high angle of attack (e.g.: stick shaker) should also be included in any Unusual Attitude Recovery discussion. "*

1.19.2.3 Airbus Operational Conference in 1998 (see appendix 5.7)

Airbus again warned operators about the danger of excessive rudder use and about the limitations of simulators. Four representatives from American Airlines attended this Conference.

1.19.2.4 Airbus " FAST " magazine (see appendix 5.2)

Through two separate issues of a widely circulated magazine, in 1998 and in 1999 Airbus again informed all operators about the proper upset recovery techniques and the necessary cautions about rudder use.

1.19.3 NTSB report on AA903 (see appendix 5.5)

In its report, the NTSB clearly and correctly identified the cause of the accident and informed American Airlines accordingly, "*...failure of the crew to monitor the speed, and use of improper stall recovery techniques.*"

1.20 Additional information

1.20.1 Certification requirements for Transport Aircraft vertical stabilizer

1.21 The Yawing maneuver

FAR§ 25.351 defines the yawing conditions for certification purposes in terms of maneuvering and lateral gusts.
For maneuvering conditions, the regulation states, "*at speeds from V_{MC} to V_A, the following maneuvers must be considered. In computing the tail loads, the yawing velocity may be assumed to be zero:*

1/ With the airplane in unaccelerated flight at zero yaw, it is assumed that the rudder control is suddenly displaced to the maximum deflection, as limited by the control stops or by a 300 lbs rudder pedal force, whichever is less.
2/ With the rudder deflected as specified in 1/, it is assumed that the airplane yaws to the resulting sideslip angle.
3/ With the airplane yawed to the static sideslip angle corresponding to the rudder deflection specified in 1/, it is assumed that the rudder is returned to neutral."

This FAR 25-351 requirement is amended by DGAC/LBA CC CC6 which states that, "*Yaw maneuvers must be analyzed for all speeds between V_{MC} and V_D.*"

1.21.1.1 Design maneuvering speed

Examination of all available information shows that there could be some major misconceptions concerning Design Maneuvering Speed (V_A) within a portion of the pilot community. V_A is a design speed not an operational one. The misconception has likely evolved from the FAA mandated wording in Airplane Flight Manuals (AFM) and the additional guidance information contained in FAA Advisory Circular (AC) 61-23, Pilots Handbook of Aeronautical Knowledge.

The FAA mandated wording in the AFM states "*Maximum Design Maneuvering Speed (V_A): Full application of rudder and aileron controls, as well as maneuvers that involve angles of attack near the stall, should be confined to speeds below V_A.*"

This mandatory AFM wording does not clearly reflect the purpose of V_A and its restrictions, which could lead some pilots to conclude that there are no restrictions to manipulating the flight controls (including the use of rudder reversals) when operating at or below V_A. A portion of the wording in AC 61-23 makes the purpose of V_A and its restrictions even less clear. This wording states that:

"*Design maneuvering speed is a valuable reference point for the pilot. When operating below this speed, a damaging flight load should not be produced because the airplane should stall before the load becomes excessive. Any combination of flight control usage, including full deflection of the controls, or gust loads created by turbulence should not create an excessive air load if the airplane is operated below maneuvering speed.*"

This issue is further complicated by the fact that the "Operational Maneuvering Speed" used on every flight is not based on the same principle as the "Design Maneuvering Speed." For example, for an A300B4-605R, at the weight and configuration of flight AA 587 the Operational Maneuvering Speed, (known as "Green Dot") was 210 knots, while the Design Maneuvering Speed was about 270 knots.

2 ANALYSIS

2.1 Reconstruction of aircraft performance from DFDR data

2.1.1 DFDR sampling and filtering

The following highlights the objectives of the sophisticated analytic process used for this investigation.

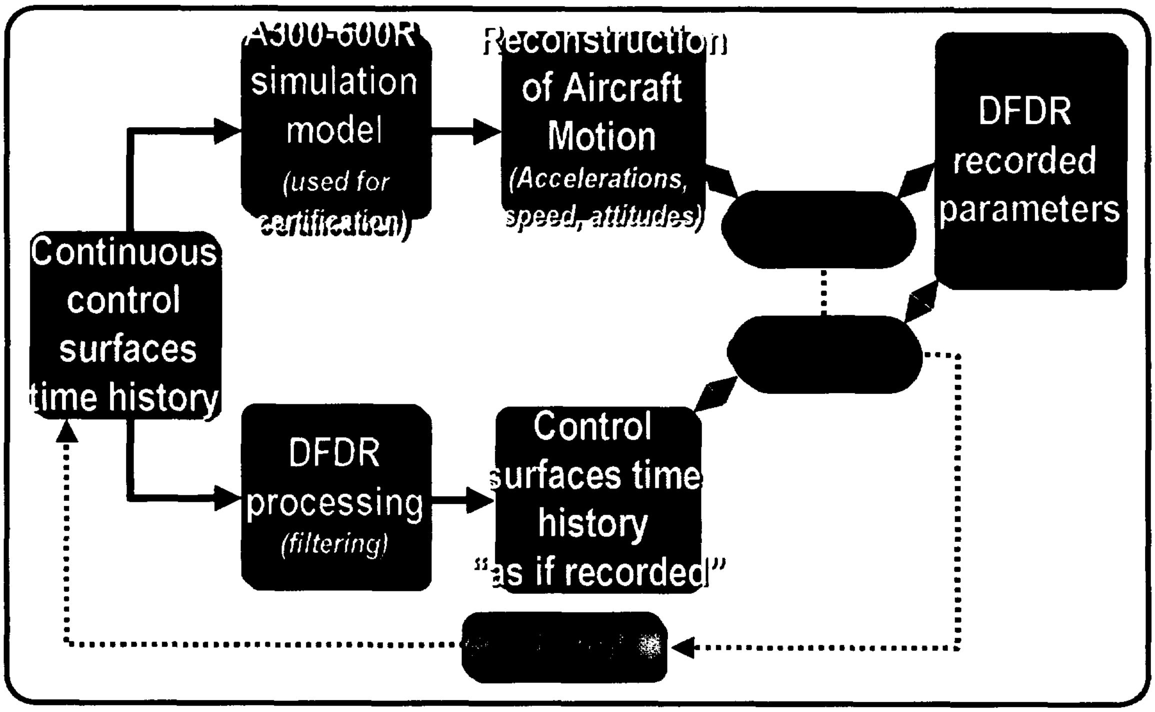
- The first objective was to compare the aircraft motion as it is recorded on the DFDR with a computed motion of the A300B4-605R simulation model.

- The second objective was to reconstruct a continuous time history of all control surface positions, including those between the recorded data samples. High quality analysis of the AA 587 accident requires, continuous curves to be produced, because the data on the DFDR are only recorded at their sampling period, which for most of the control surfaces is two samples per second.

- The third objective of this simulation analysis was to derive the wind profile during the event.

- The last objective was to use the simulation model to compute the parameters that are not recorded on the DFDR but that are a necessary to understand the development of flight loads. For example, there is no sideslip vane on large transport category aircraft, and therefore sideslip is not recorded on the DFDR. Thus we have to deduce the sideslip by other means. Another example are the rotation rates, which are also not directly recorded on the DFDR.

This process is illustrated in the diagram, which follows.



This process is more consistent, more comprehensive and a better alternative than:
-derivation of rudder deflection by interpolation/de-filtering, and
-derivation of rotation rates by computing the derivatives of recorded angles since this later process may be affected by "numerical noise."

2.1.2 Ny and Handling Qualities modeling

Airbus used flight mechanics model analysis to derive a sideslip history by simulation of aircraft response. In addition, a second method that is completely independent of the flight mechanics model was used. This method computes sideslip through a direct derivation of the recorded aircraft movements and an integration of the lateral acceleration. This second process is frequently called a kinetic Ny integration mathematical method.

In summary, Airbus used two different methods and the results of the two methods were cross-checked against each other for the main parameters that were relevant for the load analysis (e.g., the side slip time history). These processes are described in Appendix 5.8.

These comparisons between the DFDR recorded parameters and the aircraft motion derived from the simulation are in good agreement, which means that the aircraft model and the aircraft involved in Flight 587 behaved in similar ways. Consequently almost all the lateral motions of Flight 587 can be accounted for by the roll and yaw surface deflection.

2.2 Chain of events leading to the accident

- The AAMP booklet shows in a clear drawing a greatly exaggerated view (aircraft shown inverted) of the possible effect of a wake vortex on a large transport category aircraft. This misleads the pilots to believe that they can anticipate very large upset on an A300B4-605R due to wake vortex. As mentioned earlier there has never been an upset of this magnitude in an aircraft of this type.

- The AAMP emphasis on rudder use in wake vortex upset recovery ("*coordinate rudder all the way in, …*") led crews to believe that the rudder should also be used as a primary roll control. This is in direct contradiction with the Industry Upset Recovery Training Aid.

- The warning letter sent by the three major manufacturers and the FAA was inappropriately handled by American Airlines. This was despite the fact that AAL received almost identical concerns expressed in the internal memo from its own Operations Management (see appendix 5.9). The advisory concerning rudder use that was incorporated at the end of the AAMP video is weak compared to the more "entertaining" parts that preceded it, and was also not properly highlighted in the cover letter. Furthermore, it is likely that the crew involved in the AA 587 accident never saw those additions, based on the chronology of events developed by the NTSB.

- As shown in the report of the NTSB Human Performance group exercise performed on the training simulator, AAMP training (including the video, instructor briefings, and the modified simulator) resulted in all pilots from the group applying full control wheel, and nearly full rudder inputs, upon their first encounter with the AAMP wake vortex scenario on the modified simulator.

- ATC caution about possible wake turbulence

  Prior to take off at time 0910:34, the crew heard from the tower that they may encounter wake turbulence, " *caution wake turbulence, there'll be uh, several heavy jets departures over Canarsie momentarily*".

  Later, at time 0911:36 JFK tower specifically advised AA 587 crew, "*American five eighty seven heavy Kennedy tower, caution wake turbulence runway three one left, take position and hold.*"

  Before the take off roll at time 0913:35.3, the co-pilot asked for the Captain's judgment, "*You happy with that distance* ? " The Captain replied: "*aah, he's... we'll be all right once we get rollin'. He's supposed to be five miles by the time we're airborne, that's the idea.* "

  The co-pilot responded, "*so you're happy.*"

  This exchange shows that the co-pilot was not comfortable with the proposed separation and deferred to the judgment of the Captain.

  At this time the co-pilot was mentally prepared to experience a wake encounter. This scenario was identical to the one used in AAMP.

- Encounter with first wake vortex

  While climbing through about 1500 feet, at approximately 0915:38, there is a rattling noise on the CVR that corresponds to the first wake vortex encounter. From conversations prior to takeoff, the First Officer had anticipated the potential for such an encounter.

  The first encounter consisted of essentially no aircraft reaction in the lateral axis, however there was a bump in the vertical axis. Flight data shows that AA 587 encountered a fairly typical wake vortex that did not create any significant visual or motion cues, or changes in aircraft performance that would have required the pilot to make large and abrupt control movements. The aircraft flew wings level through this first encounter without incident and with only alternate left/right control wheel inputs from the co-pilot. There were no inputs on rudder pedals.

  After the first wake encounter at time 0915:44.7 the Captain commented, "*little wake turbulence, huh*? ", and the co-pilot replied, "*...yeah.*"

This first encounter most probably increased the co-pilot's anticipation of potential wake turbulence and brought back to his "working memory" the upset recovery actions taught by AAMP.
Flight 587 encountered a fairly typical wake vortex. It is important to note that this first encounter occurred while the aircraft was flying with its wings level.

- Encounter with second wake vortex

At the onset of the second encounter, the aircraft was in a commanded left turn of 20 degree bank, similar to the AAMP scenario used to train wake vortex upset recovery, and was at 240 kts, also similar to the AAMP scenario.

Almost immediately, the First Officer applied what apparently was a conditioned upset recovery response, even though the aircraft was not actually in an upset situation. He used full right control wheel and full right rudder, in the same direction just as taught by the AAMP for wake vortex upset recovery. These combined inputs generated a large lateral acceleration felt in the cockpit, of a magnitude far greater than that perceived in the simulator during the AAMP training. This large lateral acceleration, totally un-expected by the First Officer, probably triggered the subsequent reversal of inputs.

During these unnecessary upset recovery actions, the First Officer aggressively applied a series of excessive inputs, both in terms of rate and magnitude, to the roll and rudder controls. Three rapid, nearly full roll inputs and three full rudder reversals were applied all within three seconds. After the third rudder reversal, the First Officer continued to apply full right rudder for a short period of time. At approximately 0915:54, he asked in a strained voice for max power.

Less than one second later, at 0915:55, the Captain asked if the First Officer was "all right" and he responded that he "was fine". This answer clearly shows that he had no concerns about the aircraft flight controls; otherwise he would have said so. Most probably he was convinced that the aircraft movements were due to the wake encounter. He believed from AAMP that the aircraft might go beyond 90° of bank unless he applied full rudder as taught. Due to this negative training, he most probably never realized that the aircraft movements and accelerations were simply due to his own control inputs. Despite this highly unusual situation, the Captain did not take over aircraft control.

About one second later, the First Officer initiated the fourth reversal of the roll and rudder controls, by rapidly applying nearly full roll input and full left rudder. At approximately 0915:56, the Captain calls out to the First Officer to "hang on to it, hang on to it" and the First Officer responded at approximately 0915:57.5 by once again asking for "power please."

The fourth control input reversal was quickly followed by a fifth rapid reversal of the controls with nearly full right roll input and full right rudder. At approximately the time that the rudder reaches maximum deflection around 0915:58.5, a loud bang is heard on the CVR, most likely indicating vertical fin separation. The flight data recording ended shortly thereafter. Subsequent to the separation of the vertical fin from the aircraft, the rudder separated from the fin and both engine/pylon assemblies separated from the aircraft.

It is significant to note that there were no system warnings prior to separation of the vertical fin. This indicates that all aircraft systems were functioning normally up to this point. There were also no flight crew comments that indicated that the flight crew was having any difficulties with operating the flight controls (i.e., no jammed or inoperative flight controls, and no comments about any over sensitivity in aircraft response).

The reason the first officer made the large roll and rudder pedal inputs cannot be conclusively determined from a review of the DFDR aircraft performance parameters and Cockpit Voice Recorder transcript, nor from the accident reconstruction flights conducted in the NASA Ames Vertical Motion Simulator. However, the latest simulations performed by the NTSB show that the aircraft was in a 20 degree bank with the vertical load factor significantly decreasing and with a rolling moment which would have induced additional roll to the aircraft. **There is no technical or operational reason to apply such inputs, which leads us to conclude that they were pre-conditioned by his AAMP training.**

The extraordinary control inputs recorded on the DFDR were not necessary; the wake vortex encounter would not have induced an upset even if the pilot had made no control inputs. According to the NTSB simulation, the wake vortex would have taken the aircraft from a 20° to 34° bank angle, still far from the 45° threshold that defines an upset situation. This is very far from the 110 degree upset that American Airlines pilots typically achieved in the simulator.

It is also very significant to note that the flight crew thought that the aircraft was still in the wake vortex, or in some atmospheric perturbation more that 9 seconds after the vertical fin had separated. At 0916:07.5 the First Officer called out "*what are we into *, we're still stuck in it*" and at 0916:12.8 the Captain called out "*get out of it, get out of it.*" These comments indicate that the crew believed that the aircraft movements were due to an external cause. The CVR recording ended approximately 2 seconds later at 0916:14.8 and impact occurred shortly thereafter.

2.3 First Officer use of rudder

2.3.1 First Officer experience on A300B4-605R rudder

Pilots experience the breakout force and pedal travel forces during each taxi and takeoff and landing. These forces do not change with airspeed.

Additionally, during the flight control checks during taxi, the flight crew routinely experiences the low speed rudder travel limiter and rudder pedal displacement stop. Also, during initial and recurrent simulator training for engine failures during takeoff, pilots routinely experience the rudder travel characteristics, frequently up to speeds on the order of 220 to 250 knots.

This means that the pilots also experience the high-speed rudder travel characteristics.

This means that any pilot with flight experience in the A300B4-605R is fully aware of its rudder pedal force and rudder travel characteristics. Therefore, Airbus concludes that the First Officer, who had extensive flight experience in the A300-605R, was fully cognizant of these rudder system characteristics.

One other observed factor supports the conclusion that the flying pilot was deliberately using full rudder during this misperceived "upset." Not only did he use full rudder repeatedly, but he also used repeated full roll control. It cannot be argued that he was somehow misled by overly light pedal forces and too small displacements, since he was applying exactly the same control behavior in the roll axis as well. In short, it is abundantly clear that the copilot of AA 587 was doing just what American Airlines Management's Captain Railsback said of the crew of AA 903 in his 1997 memo —they were doing exactly as they were taught by AAMP, which was a well-intentioned but seriously flawed effort to aid pilots to recover from upset situations.

In any event, it is critically important to understand that the most important aspect for evaluating rudder system design is that pilots do not fly aircraft by making arbitrary control inputs or by trying to achieve a certain predetermined displacement of the flight controls. Instead, they apply inputs based on desired aircraft performance objectives and the aircraft response.

2.3.2 No operational requirements for the kind of pilot inputs observed

As previously discussed, in much the same way as a person drives a car, pilots apply pressure to the flight controls to achieve a desired aircraft response. If the response is too small or too slow, the pilot increases the pressure until the desired response is achieved. Conversely, if the response is too large or too fast, the pressure is reduced until the desired response occurs. In the same way, the driver turns the steering wheel without knowing in advance the exact amount of angle or force he will apply. He continuously adjusts his input to null the error between the desired and the actual response of the car, and the rate at which he is reaching the objective. This behavior is based on experience and training. Piloting consists of "closed loop" tasks whereby the pilot applies varying inputs to the appropriate flight controls to achieve the aircraft response required to match the actual flight path to the desired flight path.

Based on the observed characteristics of the wake vortex encountered by AA 587, there was never a requirement for control inputs of the magnitude and rate made by the first officer. In fact, operationally, there is *never* a requirement for such control activity in a civil transport airplane—these aircraft should *always* be flown "closed loop" because the aircraft will always provide the necessary feedback to the pilot to determine how much aileron or how much rudder is enough.

2.4 Performance of rudder control system

2.4.1 No evidence of Flight Control system failures

During this investigation the rudder pedal breakout force, rudder pedal displacement forces, maximum rudder pedal displacement, and the rudder travel limiter were analyzed. Analysis reveals that the rudder system performed its intended function, without any failures prior to separation of the vertical fin. Analysis also shows that the rudder pedal force/displacement and the rudder travel limitations are consistent with the design characteristics of modern transport category airplanes.

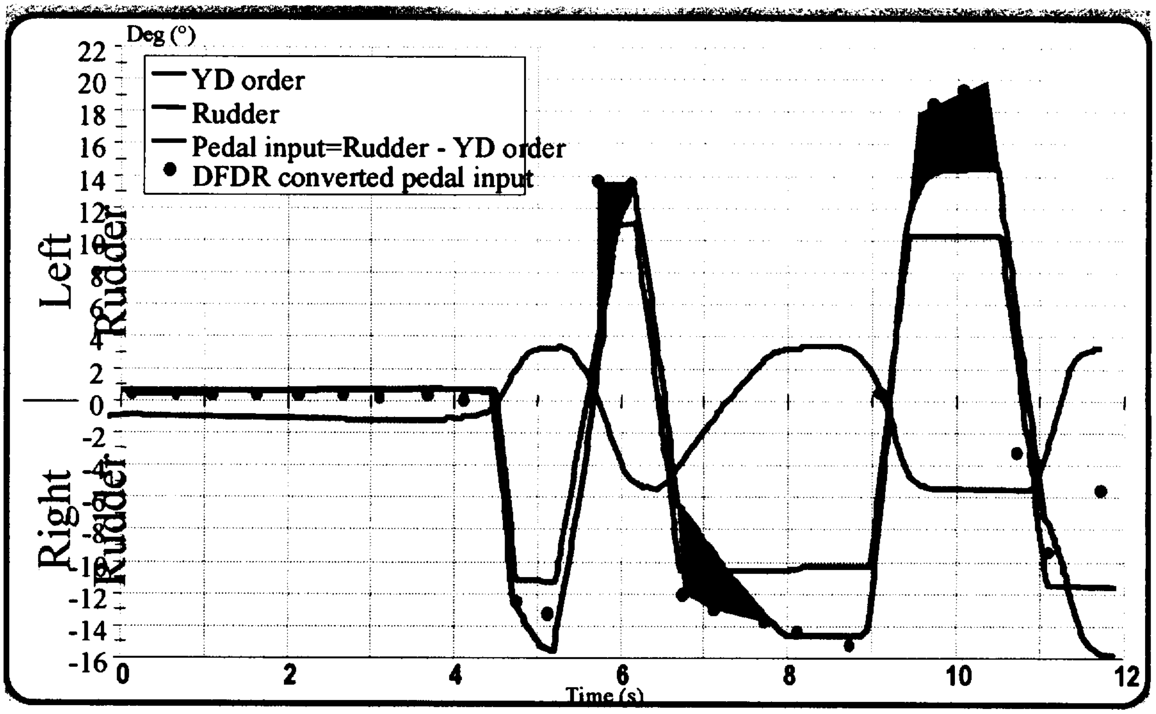
Aircraft performance analysis revealed that the aircraft's response to the flight control inputs was aerodynamically correct. There were no failures in any aircraft systems prior to the vertical stabilizer rupture indicated by this performance analysis.

Airbus has also determined that there are no possible flight control system failures that could have caused the large rudder and rudder pedals movements recorded by the Digital Flight Data Recorder (DFDR) during the 30 seconds period prior to fracture of the vertical fin. Additionally, Airbus has determined that there were no failures in any aircraft systems prior to fracture of the vertical fin. All flight control surface movements noted in this accident resulted from pilot inputs.

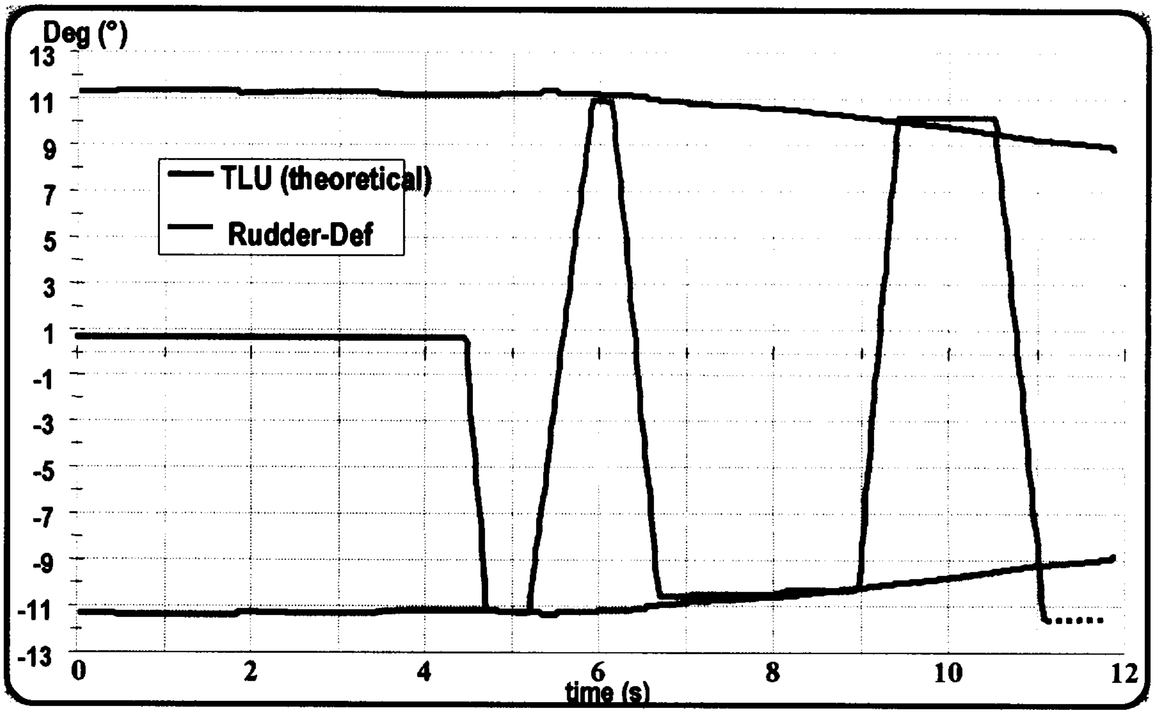
In order to minimize the probability of inadvertent crew actions on the rudder pedals, by design, a minimum force of 22 pounds must be applied on the pedals before any displacement occurs. This breakout force also ensures positive centering of the rudder pedals when foot pressure is released. Despite this design feature, a few incidents have still happened such as during the AA 934 Flight on 28 October 2002.
It is critically important to note that the pilot routinely experiences the breakout force and pedal travel forces during each pre-flight control check (up to the pedal stop), during taxi, takeoff and landing ground roll. These forces do not change with airspeed.
Also, during initial and recurrent simulator training for engine failures during takeoff, the pilot routinely experiences the aircraft response (at least in terms of visual cues) to required rudder pedal inputs, frequently up to speeds on the order of 220 to 250 knots.

The comparison between the reconstructed continuous time history rudder deflection and the design criteria for the Rudder Travel Limiter shows that the latter performed as anticipated during Flight 587.

In the A300B4-605R design, rudder deflection results from the addition of the rudder pedal order and the Yaw Damper order, limited by the TLU. During the second vortex encounter where the pilot made very large rudder inputs, there were two instances where the rudder pedal deflections were greater than required to hold the rudder against the Rudder Travel Limiter. This difference is due to mechanical elasticity in the linkage due to the very high forces that were applied to the rudder pedals. This difference also indicates that the observed rudder motion was neither due to abnormal system behavior nor to a system failure back-driving the rudder pedals.



These very high pedal forces (up to 140 lbs) also prevented the Rudder Travel Limiter from fully matching the theoretical limit as a function of Vc. The end result was that, just prior to separation of the vertical fin, the rudder deflection exceeded the design limits for that airspeed, on two brief occasions.



The Travel Limit Unit (TLU) is driven by an electrical motor. This electric motor moves the variable stop to reduce the maximum rudder deflection as speed increases. However, when very high forces are applied on the pedal (around 240 pounds), the electric motor cannot move the variable stop further in the closing direction. If this occurs while aircraft speed is increasing, it is possible for the rudder deflection to exceed the desired limits. This phenomenon was most probably present during both exceedances shown on the previous chart.

In addition when subject to high forces, the variable stop can be slightly deformed, thus allowing an additional small rudder deflection (maximum 0.7 degree). It is important to keep in mind that by design, the rudder authority is as such that there is no operational need to ever apply rudder pedal input up to the rudder stop in flight.

The main factor that may explain the exceedance is that, just prior to fin separation, the TLU held the lower end of the servo-actuators input control rod inside of the fuselage while the fin was bending. This would place enough tension on the control rod to allow for about 2.6 millimeters (0,1 inch) of additional relative displacement of the servo-actuator input lever equivalent to an additional rudder travel of 1.1

degree. This amount of displacement would explain the difference observed between the TLU and the estimated rudder position.

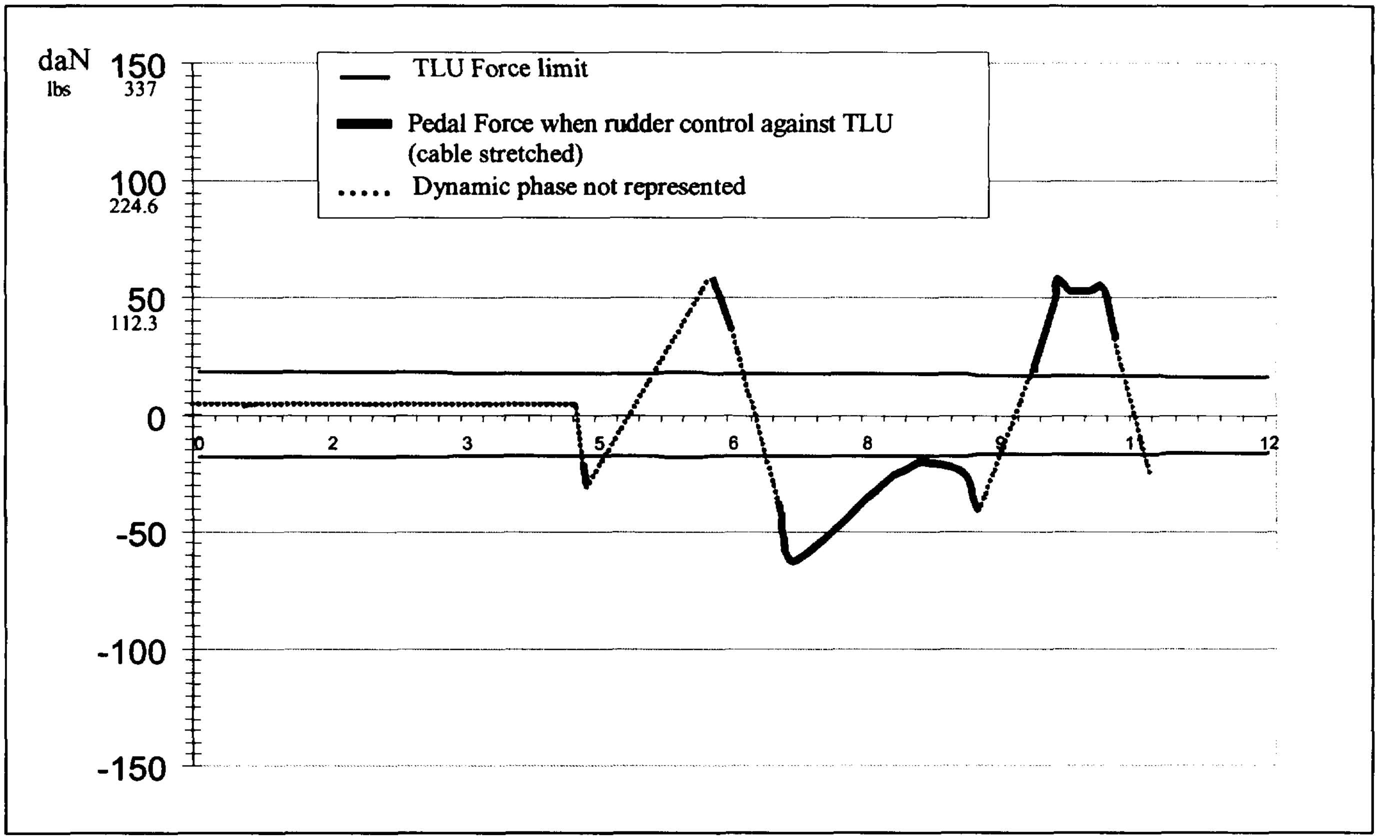
For a full understanding of the observed rudder positions, it is necessary to realize two things. The first is that the order coming from the rudder pedals will be added to the order coming from the yaw damper and the sum of these orders is limited by the TLU. When the rudder is on the stop, the rudder pedal order plus the yaw damper order will always equal the TLU position.

The second thing to remember is that there is a mechanical linkage between the rudder pedals, and the place where the rudder pedals input is summed with the yaw damper (at the rear of the fuselage). Because this is a mechanical linkage, it has a certain amount of elasticity, when high forces are applied. Therefore, when the rudder pedals are deflected far enough to bring the rudder to the stop, they can be deflected a bit more by applying much higher forces. In this case, the rudder will not deflect any further, because it is limited by the stop, but the pedals will move due to elasticity in the mechanical linkage. If this occurs, the rudder pedal position as recorded on the DFDR would be higher than the rudder pedal position theoretically corresponding to the actual rudder deflection corrected by the yaw damper. This elasticity is basic behavior for any mechanical linkage. These effects have been documented, with high confidence, with data obtained during the ground tests that were made on the AIRBUS "Iron bird" and on a real aircraft.

The apparent discrepancies that occurred on three occasions can be accounted for by this mechanical elasticity effect that occurs under excessively high forces. This characteristic has been derived from ground tests.

2.4.2 Variable Lever Arm versus Travel Limit Unit

The following chart shows the amount of force applied by the co-pilot to the rudder pedals during the second wake encounter.



It is clear from this chart that the co-pilot applied forces (up to 139 lbs) on the rudder pedals far above the maximum value required to reach the rudder stops for any Commercial Air Transport category airplane. This demonstrates that his objective was to reach the pedal stop as quickly as possible, just as he was taught during AAMP training.

From these data, it can be concluded that, should the aircraft be equipped with a VLA design, the pilot would have similarly targeted and reached the pedal stops. It might have taken a bit more time to get there. But because of his AAMP training, it is believed that a VLA design would have made no difference in the outcome. As is seen from the DFDR analysis it was during the two-second period, when the co-pilot held the rudder pedal on its stop, that the sideslip had time to develop. Assuming that the aircraft had been equipped with a VLA, a larger sideslip might have developed earlier in the sequence, and the fin might have ruptured a bit earlier.

2.5 Pilot Induced Oscillation not supported by factual data

A major assumption used in the report "*A Pilot-induced Oscillation as a factor in the crash of American Airlines Flight 587,*" is known as "Pilot Regressive Behavior," and states that the pilot, under conditions of stress, may exhibit sub-par or incorrect control behavior and may try to control roll (or pitch) rates instead of roll (or pitch) attitudes.
The specific case examined in the report is the AA587 accident, in which the pilot controlled the aircraft using the control wheel and the rudder pedals. The Pilot Regressive Behavior model was adapted to take this situation into account and allowed comparison of the aircraft behavior with, and without, use of the pedal to control the aircraft roll-rate. The main parameter of the model (roll rate-to-control wheel gain) was derived from the accident recordings and was used in the Airbus analysis and study of the referenced report. Airbus used the "Pilot Regressive Behavior" model and parameters derived from the Dr HESS report. *Note: Their use in the Airbus report is not a formal approval by AIRBUS of the entirety of this theory but rather is simply a way to facilitate comparison between the Airbus study and the above-mentioned Reference Document.*

The main result of the Airbus study is that sustained or diverging lateral oscillations only appear when the pilot model is connected to both pedals and wheel. It also shows that the root cause of this phenomenon is the difficulty to control aircraft roll rate with the rudder on any aircraft with a standard dihedral effect. Moreover, the gain or "pedal sensitivity" must be reduced by a factor of 18 just to achieve stability, and by a factor of 36 to achieve a stability margin of 2, which would be equivalent to the margin present when using roll control alone. If this was done, pedal forces would be so high that normal aircraft control would no longer be possible.

When the model is connected to the wheel only, well-damped oscillations are observed with a gain margin higher than 2. This shows the good aircraft characteristics on the roll axis. Moreover, the rate limitation of the A300B4-605R servos has very limited effect on the above results.

2.6 Build up of loads on vertical stabilizer and associated structure

The development of fin loads during the last seconds of the recorded flight parameters was thoroughly assessed. Several methods were used to conduct this analysis. One relies on in-flight recorded parameters only (Kinetic "Ny Integration"), the others on flight mechanics simulation ("Simulations") using control movements as inputs. These processes generated load time histories.
Pylon/Wing attachments and Engine/Pylon mount loads developed during the last seconds of the recorded flight parameters were also assessed. Their levels remain within the respective design loads envelope until after fin separation from the aircraft.

The level of fin loads achieved at the estimated time of the fin rupture was identified using several different criteria. With reference to the fin root bending moment (the most significant loading condition), the possible range at fin separation was 1.95 to 2.14 times the Limit Loads. They were significantly higher than the fin Ultimate Loads (Ultimate Loads = 1.5 times the Limit Loads).

2.7 Reasons for vertical stabilizer separation

2.7.1 Composite material performed as designed and certified

Tests performed on various samples from the vertical stabilizer and the rudder have demonstrated that the composite materials used in the vertical fin and rudder performed as intended, without any significant deterioration in-service, even after more that 37,000 flight hours.
It is important to note that, though an appreciable portion of this aircraft's operating life had been spent in the hot and humid environment of the Caribbean, the composite materials performed as intended in this demanding environment.

All of the available data show that the aircraft was properly designed, manufactured, and tested to successfully demonstrate compliance with the applicable Airworthiness requirements. This includes the aircraft structure, vertical fin and rudder, as well as the redundancy and reliability of components.

2.7.2 Vertical stabilizer separated due to pilot-induced structural overload

The fin structure broke because it had been exposed to external aerodynamic loads generated by the aircraft movements and rudder deflections. These loads achieved the level of the structural strength capability.

The accident aircraft fin fractured almost 30 percent above the Ultimate Load design requirement. Furthermore, the failure mode of the vertical fin, including the attachment lugs, was consistent with the design predictions and the results of certification testing.

In addition to the previous certification rupture test, four additional fin lug tests were performed during this investigation. One of these used a new lug from production to validate the test bench. Another used a lug manufactured at the same time as the accident aircraft, and the last two tests used the rear lugs from the vertical fin of the aircraft that was involved in the AA903 accident. None of the Airbus fin attachment lugs in these tests failed below the expected value.

2.8 Deficiencies in AAMP

2.8.1 Emphasis on rudder for roll control

Certain aspects of the AAMP, as it was conducted at the time the pilots of flight 587 attended the training, might have led some pilots to believe that extraordinary control inputs, especially to the rudder pedals, were necessary to control the aircraft during recovery from a wake vortex encounter.

The AAMP video that was sent to all AAL pilots contained incorrect guidance concerning the use of rudder. Captain Rockliff and former NTSB Board Member Hammerschmidt directly observed the AAMP instructor emphasizing the use of rudder for roll control during upset recovery.

The initial AAMP video was amended by adding an advisory note at the end. However, there is no evidence that this advisory note was highlighted to the recipients of the tape or that the AA 587 crew ever saw the updated AAMP videotape.

The AAMP video shows that American Airlines also redefined the term "coordinated rudder", which may have contributed to the negative training generated by this program. The common definition of "coordinated rudder" means sufficient rudder to keep sideslip at zero. Again, this is an instance of closed-loop control behavior, in which the pilot simply applies sufficient rudder to achieve zero sideslip. However, the AAMP definition of the term was "rudder in the direction of roll." This is advocating "open loop" use of rudder—the pilot applies rudder in the direction of the roll, without reference to a performance target (ball-centered). This can lead to aggressive input of full rudder and very "uncoordinated" flight, exactly as observed in the case of AA 587

Additionally, some other aspects of the AAMP training could also have inadvertently produced a negative transfer of learning from the simulator to the actual aircraft. These were highlighted in the joint 1997 letter to American Airlines from representatives of three major aircraft manufacturers and the FAA.

For example, the severe roll upset generated by a simulated wake vortex encounter as used in the AAMP was highly misleading, in that there has never been an instance where a heavy aircraft such as an A300B4-605R has rolled to the extreme angles generated by the AAMP simulator (as modified by American Airlines). Use of this training scenario greatly exaggerated the potential of a severe roll upset that would require extraordinary flight control inputs to effect recovery from a wake encounter. This represents another example of negative transfer of learning from the AAMP

2.8.2 Simulator modification

Inhibiting the normal roll controls during initiation of the upset could produce very high sideslip angles that could be outside the range of valid aerodynamic data where the simulator response could be different from that of the actual aircraft. If this occurs, the relationship between flight control input and aircraft response would be incorrect, and negative transfer of learning from the simulator to the aircraft would take place.
Second, and most important, inhibiting normal roll controls during upset initiation would lead many A300B4-605R pilots to incorrectly conclude that a vortex can be so powerful that normal roll control alone is inadequate and substantial amounts of rudder must be used in the recovery. If this occurs, it would be negative transfer of learning from the simulator to the aircraft. This would be wrong and not consistent with the upset recovery techniques recommended by the manufacturers and many other aviation organizations, which is to use rudder only if use of all available roll control fails to counteract the rolling motion. This would also reinforce the false belief that recovery from wake vortex encounters in an A300B4-605R requires substantial rudder inputs.
The first exercise performed by the NTSB Human Performance group in the simulator clearly demonstrated this.

It is important to note that the operator recently changed the method of inducing upsets in the simulator. The current practice no longer uses a simulated wake vortex encounter and no longer inhibits normal roll control. Therefore, the potential for negative learning in the revised AAMP is now significantly reduced. However, the AAMP videotape still contains guidance that could lead some pilots to use inappropriate techniques during upset recovery.

2.8.3 Simulator motion platform limitations

As shown during the Human Performance group exercise, the average lateral acceleration at the aircraft center of gravity (resulting from the pilots inputs) would have been around 0.45 g's, producing a slightly higher value in the cockpit. Measurements performed by Airbus show that the lateral accelerations perceived in the simulator are 6 to 10 times lower than what they are in a real aircraft during these highly dynamic situations.

2.8.4 Law of primacy

The "law of primacy" says that people tend to remember best what they learned first. Because the pilots were first exposed to the AAMP scenario for wake vortex recovery on a modified simulator, they would tend to develop and remember inappropriate and dangerous techniques. A related important factor is the limitation of simulators to adequately represent the lateral accelerations that would have been generated by such control inputs in the airplane.

Because the First Officer of AA 587 flight learned upset recovery in the simulator, he was startled by the large accelerations of the aircraft that were not consistent with what he was expecting based on his experience in the simulator.

3 CONCLUSIONS

3.1 Findings

1. The investigation has established that the A300B4-605R was designed and manufactured in full compliance with all applicable regulatory requirements.

2. Static tests performed at the time of certification up to rupture demonstrates a structural capability of the fin that is above requirements (1.947x Limit Load compared to the requirement level of 1.5x Limit Load.)

3. The loads generated during the accident, as computed, are in the same range as the loads demonstrated during the static tests performed at the time of certification.

4. The composite materials used in the construction of the A300-600 vertical stabilizer performed as specified; this accident raises no questions regarding the application of composite materials in aircraft primary structure.

5. Maintenance and inspection processes defined by Airbus and applied by American Airlines Maintenance were appropriate for the composite materials as used in the A300B4-605R design; these were not a factor in this accident.

6. The A300B4-605R lateral flight control system is a conventional design that meets all certification requirements. After 16 million flight hours in service, there have been no adverse reports about rudder force and displacement characteristics. Furthermore, there is no evidence to suggest that the rudder control system of this aircraft fails to meet certification requirements and/or accepted practices for large transport aircraft. The A300B4-605R lateral flight control system was not a factor in this accident.

7. Weather was not a factor in this accident

8. Air Traffic Control was in accordance with defined procedures and regulations and was not a factor in this accident.

9. Filtering of rudder pedal and rudder position as used in the A300B4-605R DFDR did not preclude precise reconstruction of the time history of flight control position and aircraft response.

10. The Captain and First Officer held appropriate ratings for the conduct of AAL Flight 587.

11. The First Officer was flying the aircraft manually at the time of the accident; the autopilot was never engaged during the flight of AAL 587.

12. The First Officer believed that an encounter with the wake of the preceding B747 was possible, and was mentally primed to respond according to the training he received at American Airlines.

13. The First Officer responded to the initial encounter with the wake vortex; he made corrections with aileron only, and did not use rudder during this momentary encounter. At the time this initial encounter appeared, the aircraft was wings level.

14. The encounter with the first wake, and the Captain's subsequent comment about that encounter, caused the First Officer to mentally prepare for a second wake penetration by recalling the training he received in the AAMP program; he was primed to use rudder to aid in recovery from a potential upset.

15. The First Officer's control strategy during the second encounter was consistent with the training he received during AAMP. However, based on analysis of aircraft performance during this period of the flight, this was not consistent with the actual conditions encountered by AA 587. One important point is that at the time of this second encounter the aircraft was already in a commanded 20 degree bank angle, which is similar to the start of AAMP scenario for upset recovery.

16. Had the First Officer made no control inputs during the second wake encounter, the airplane would have reached a maximum of 30 degrees of roll. There was never a risk of loss of control due to the wake encounter. The intensity of the wake vortex was not a factor in this accident.

17. The time history of the First Officer's rudder inputs and the consequent aircraft response caused a rapid build up in aircraft sideslip angle, which in turn generated increasing side loads on the vertical stabilizer and attach fittings. These loads eventually exceeded 1.947 Limit Load, at which point the right rear attach lug failed in overload.

18. The accident would not have happened had the First Officer simply taken his feet off the rudder pedals at any time prior to the time of structural overload.

19. American Airlines modified the simulator to perform wake vortex upset recovery training. These modifications were done without Airbus agreement or involvement and led to negative training. This was a factor in the accident

20. Simulators cannot replicate aircraft accelerations and therefore led to negative training for upset recovery exercises. Airbus warned operators about simulator limitations for this kind of training during a conference in 1998. Four American Airlines representatives attended this conference. This misrepresentation of lateral acceleration in the simulator was a factor in the accident.

21. In its submission concerning the AA 903 accident, Airbus had warned American Airlines about the potential dangerous consequences of inappropriate rudder use. This submission was sent to all parties involved in this investigation.

22. In its report, the NTSB clearly identified the cause of the AA 903 accident, "*the flight crew's failure to maintain adequate airspeed during level off which led to an inadvertent stall, and their subsequent failure to use proper stall recovery techniques*" (emphasis added)."

23. Airbus, and others, made numerous attempts to communicate concerns regarding the elements of AAMP that advocated use of rudder for primary roll control. American Airlines however did not adequately respond to those concerns. This was a factor in the accident.

3.2 Probable cause

The Probable Cause of the accident involving AAL 587 was the structural overload of the vertical stabilizer induced by the inappropriate and unnecessary application of cyclic, stop-to-stop inputs to the rudder pedals by the First Officer in anticipation of what he mistakenly believed would be the aircraft reaction to an encounter with a wake vortex. This mistaken belief and the consequent inappropriate and unnecessary pilot actions were conditioned by elements of American Airline's AAMP that advocated the aggressive use of rudder for roll control. This was reinforced by negative training generated by the inherent limitations of simulators for this type of training, and also by American Airline's modification of the A300-600 training simulator that resulted in the temporary inhibition of normal roll control functions such that pilots were forced to use rudder as a primary means of roll control to recover from simulated wake vortex encounters. Contributing to the accident was the failure of American Airlines to make timely corrections to the AAMP in response to information provided to them by the manufacturers and FAA shortly after this specialized training program was introduced.

4 RECOMMENDATIONS

4.1 Previously issued recommendations resulting from this investigation

4.1.1 Pilot training

Airbus fully concurs with the NTSB recommendations A-02-01 and -02 from the 8th February 2002 concerning pilots training. It is clear that this training issue is at the heart of the AA 587 accident.

In response to these recommendations, Airbus published a Flight Crew Operating Manual bulletin on March 29, 2002.

4.1.2 Structural inspections following high lateral accelerations events

Airbus fully concurs with the NTSB recommendations A-03-41 through -44 from the 4th September 2003 concerning aircraft inspection, return to service, and data reporting in the event of high lateral loads. Although not foreseen by the commercial aviation community, this accident demonstrates the need for inspection criteria in the lateral axis similar to those which already exist for the vertical axis.
A300B4-605R Aircraft Maintenance Manual has been revised in June 2002 to include lateral accelerations criteria for aircraft inspection, and return to service.

4.1.3 DFDR characteristics, filtering and sampling rates

Airbus understands the NTSB rationale for the recommendations A-03-48 through -50 from November 6th 2003. In addition to these recommendations, the FAA is seeking rule changes for Part 121 operators on CVR and DFDR requirements.
Given the absence of an "unsafe condition," Airbus has proposed to the FAA to hold a Government/Industry meeting to discuss DFDR requirements in order to avoid the necessity for airlines to perform hardware changes at several different times for different reasons.

4.2 New recommendations

Airbus proposes five additional recommendations for consideration by the NTSB to address other issues raised by this accident.

4.2.1 VA definition in AFM

As detailed in paragraph 1.21.1.2, available information shows that there could be some major misconceptions concerning Design Maneuvering Speed (VA) between the FAA mandated wording in the AFM, the AC 61-23 wording, and the Operational Maneuvering Speeds. It is necessary for the Authorities to clarify and harmonize all those definitions. Airbus has already reviewed and revised the AFM in a first step with the DGAC and JAA on the 7th August 2002. Additionally, harmonized industry wording was selected and approved by the FAA on September 26th 2003. This was published by Airbus in the frame of the revision 09 of FAA approved AFM A300B4-605R.

4.2.2 Certification requirements for new designs

This investigation has brought to light the potential consequences of rudder control "reversals" or "doublets."
Consequently Airbus is ready to cooperate actively with other manufacturers and the Certification Authorities in an Industry group to determine how this could be considered in future certification.

4.2.3 Training Program Content

The accidents AA587 & AA903 have clearly demonstrated the potential consequences of teaching inappropriate use of rudder.

- It is therefore essential that training programs be approved by the Authorities with involvement of aircraft manufacturer.

4.2.4 Limitations of training means

The accidents AA587 & AA903 have clearly evidenced the effect of negative training. They have indeed demonstrated the need to once again warn aircraft operators of simulator limitations in a part of the flight domain where they are not representative of the actual aircraft, for example at high sideslip angle.
The upset recovery training as done by Airbus is purposely limited to "academic" briefing. This is the only way to avoid negative training.

- It is therefore essential to recall to all training centers the limits inherent to training devices.

- It is also essential to ensure that the definition of the training programs take into account those inherent training device limits.

4.2.5 Regulatory review and oversight of pilot training programs

A major factor contributing to the AA587 accident was the modification introduced by AAL on the training simulator that temporarily inhibited the roll control efficiency. Therefore:

- It is essential that simulator changes affecting flight characteristics be done with the airframe manufacturer involvement and with the Authorities approval.

APPENDIX 5.1

Manufacturer's Letter to American Airlines

(11 pages)

Docket No. SA-522

Exhibit No. 2-C

NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C.

Attachment H
Correspondence from Airplane Manufacturers To American Airlines and Response

(11 Pages)

August 20, 1997

Captain Cecil D. Ewell
Chief Pilot and Vice President of Flight
American Airlines
American Airlines Flight Academy
P.O. Box 619617
Dallas-Fort Worth Airport, Texas 75261-9617

Dear Captain Ewell:

After your AAMP conference Tom Melody, Larry Rockliff, Tom Imrich and Ken Higgins committed to provide you a coordinated package of recommendations for improving your already excellent program. This is our coordinated response. Our intent is to give you additional and corrected technical information as well as the benefit of our experience in unusual areas of the flight envelope for training pilots in various airplane models. We hope you accept this as part of growing industry-wide effort of working together on common training and flight safety issues.

Our inputs are organized into the following subjects:

- Aerodynamic Explanations
- The Use of Rudder
- Airplane Recovery from Upsets
- Use of Simulators
- Angle of Attack Indicators
- Technology Aversion
- Factual Errors

Aerodynamic Explanations

It is important that commonly accepted aeronautical terminology and notations be used. The AAMP does an excellent job in presenting many ideas in a short time span while keeping the technical information at a line pilot's level of understanding. The risk in doing this is that some terms may not always be used in the technically correct context. This could become misleading or in some cases, have a negative effect on training. The use of the term "phugoid" when describing speed stability is an example. Additionally, we believe that consistent and correct short-hand aeronautical notations should be used. We recommend that you refer to a commonly accepted reference such as Perkins and Hage, "Airplane Performance, Stability, and Control" or "Aerodynamics For Naval Aviators" that is issued by the Chief of Naval Operations Aviation Training Division.

The notion and application of corner speed should be revisited. The corner speed concept is not questioned and is entirely appropriate for combat aircraft when

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optimum combat maneuvering is necessary for achieving a competitive advantage. However, the issue is complex beyond practical use in procedural application for recovering a large transport airplane from an upset. The first limitation in applying corner speed to recovery is the fact that the speed is a function of several variables including airplane weight, and therefore is not a constant. For practicality, this is solved by identifying an average corner speed for the airplane model and accepting the resulting less than optimum turn radius. Additionally, there is the potential that pilots could fixate on obtaining and maintaining corner speed, while delaying or overlooking implementation of other recovery techniques, and result in unnecessary loss of altitude during a nose low recovery. Exposing pilots to the concept of corner speed and radius of turn as a basis for understanding why it may be necessary to increase speed in order to recover from a nose low, low altitude upset is beneficial. However, incorporating a corner speed into recovery procedure, we feel is inappropriate.

Use of Rudder

The excessive emphasis on the superior effectiveness of the rudder for roll control vis-à-vis aileron and spoilers, in high angle of attack, is a concern. Many of the AAMP slides associate high angle of attack with use of rudder. Although rudder usage for turn coordination and yaw control is emphasized and appropriate with improving "hands on" flying skills, modern aircraft have yaw dampers and turn coordinators designed to provide adequate yaw coordination and the manual application of rudder can defeat its purpose. The pilots are left with the impression that it must be used first in all high angle of attack situations. The factors associated with high angle of attack when considering aerodynamic and environmental variables presents the pilot with a technical challenge. When should it be used? How much should be used? How long should it be used? While some of this is touched upon, additional rudder use information should be provided with emphasis on the consequences of inappropriate use of rudder. Although a simple rule about rudder usage cannot be stated, a more appropriate standard is to first use full aileron control, if the airplane is not responding, use rudder as necessary to obtain the desired airplane response. Momentary actuation of spoilers during roll input does not significantly increase drag.

Sideslip angle is a crucial parameter that should be discussed in your program. It is probably not well understood by many line pilots, but has a significant impact on an airplane's stability and control. Large or abrupt rudder usage at high angle of attack can rapidly create large side slip angles and can lead to rapid loss of controlled flight. Rudder reversals such as those that might be involved in dynamic maneuvers created by using too much rudder in a recovery attempt can lead to structural loads that exceed the design strength of the fin and other associated airframe components. The hazard of inappropriate rudder use during windshear encounters, wake turbulence recovery and low airspeed at high angle of attack, for example, stick shaker, should also be included in the discussion. The use of "top rudder" without an explanation of

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the exact situation may cause pilots to inappropriately use excessive rudder when attempting to use coordinated rudder. In a high angle of attack condition, this could result in a delayed recovery, excessive bank angles or even a rapid roll in the opposite direction.

Airplane Recovery from Upsets

The AAMP recovery procedure for a high angle of attack, nose high upset instructs the pilot to unload and roll (limiting bank angle to approximately 70 degrees) toward the nearest horizon in order to lower the airplane nose. It is important to initially stress unloading the wing through (up to) full down elevator, and down stabilizer trim. Roll should be introduced only after exhausting the use of pitch axis controls and after considering the reduction of thrust (on airplanes with wing mounted engines). Introducing roll angles at extremely high angles of attack creates sideslip and hence has the same concerns as rudder usage. Accident and incident data indicate that many nose high, high angle of attack events are because of inappropriate stabilizer trim. The initial use of elevator and down stabilizer trim will normally be adequate in establishing a nose-down pitch rate. In combination with thrust reduction few failures can be conceived for which these measures would not be sufficient. As with all proposed scenarios, the use of roll to assist in pitch attitude reduction cannot be ruled out, but if the airplane is at high angles of attack, the sideslip introduced by rapid roll may result in departure from controlled flight.

As mentioned above, reducing thrust on underwing mounted engines is another way to assist the pilot in lowering the nose. While the effects of thrust on pitch are emphasized earlier in the presentation, the possibility of reducing thrust during a nose high recovery is not part of the discussion. In fact, the recovery procedure infers an increase in thrust in most nose high recoveries.

We identified our concerns with the use of rudder to generate a roll as a separate subject earlier. Inappropriate use of rudder during a high angle of attack, nose high upset should again be stressed while discussing the nose high recovery.

Use of Simulators

Associated with upset recovery is the ability to train pilots. Simulators have become practical and accurate training tools throughout the evolution of our industry. To that end, they have become accepted by the user community, with a high degree of confidence in the fidelity of their performance. Artificially manipulating a simulator into an environment that is way beyond valid engineering data creates a potential for negative learning. Current simulator limitations also do not permit the replication of linear or lateral load factors. Using a vortex flow in the simulator to induce an upset is a reasonable approach, however, inhibiting aileron inputs as apparently implemented in your training simulators, until the airplane has rolled through 90 degrees of bank will invariably result in large sideslip angles--probably outside the range of valid aero data. Additionally, without any aileron effectiveness during the

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first 90 degrees of roll, the pilot will probably use rudder in an attempt to roll the airplane erect. This will lead to an increase in sideslip that could invalidate the response of the simulator to any further inputs. Pilots need to be aware that the simulator will not necessarily respond as the airplane will when simulator capabilities are exceeded.

Angle of Attack Indicators
There is a strong recommendation for an analog Angle of Attack indicator. It is implied that this device can be used for a variety of functions, including detection of overweight conditions and as an indicator of critical performance parameters. Although an angle of attack indicator can be used to determine wing angle of attack and therefore be used for recovery from unusual attitudes, its use as a performance tool is limited without the inclusion of corrections such as accurate center of gravity, a parameter not currently available on commercial airplanes. Also, the accuracy of current angle of attack vanes (absent inertial correction) is not sufficient to indicate accurate medium to high-speed performance parameters. Additionally, the human factors such as aircrew performance while using angle of attack indications during recovery of large transport category airplanes have not been studied.

Little information is provided on the vulnerabilities or limitations associated with presenting angle of attack guidance. Factors such as its reliability with wing icing, or airplane configuration anomalies, such as loss or partial loss of a radome, or the additional training required to assure its proper use are overlooked. As you know, manufacturers are working with your company and others to respond to the angle of attack issue. We are defining the technical requirements, ways of displaying the information and associated costs. In the interim, the discussion of this subject should be more balanced.

Technology Aversion
The subject of the proper use of automation is right on target and timely. Airplane accident and incident data validate your concern in this area. Equally, engineering advances incorporated into all modern jetliners in recent years can share in the safety statistics the industry enjoys. The human factors issue associated with the proper use of automation is also excellent information for pilots. Indeed there are likely as many situations where a crew would be well served to use the technology available to them, rather than be primed to eliminate it. The key point is for the user to be situationally aware so they can make rational decisions instead of rote responses. To better balance the discussion, it should include some positive information about why technology was introduced and what it does to assist the pilot.

Factual Errors
Some of the information presented while using actual accident scenarios is incorrect or has been misinterpreted. For example, it was stated that the 737 rudder pedals did not indicate the rudder position if the rudder PCU had certain failures. This is

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incorrect, the rudder pedals indicate the direction and motion of the rudder except for yaw damper inputs. Information about the A300 Nagoya accident also has some fundamental errors. We recommend you review this information and work with the manufacturers or safety organizations in order to maintain correct information in your program.

The AAMP is an excellent program and we applaud American Airlines for expending the time and money in developing and implementing it. The concerns we identified can easily be mitigated with some modifications. As you know, the industry is working to develop an Airplane Upset Recovery Training Aid that should include many of the AAMP ideas and information. We hope that your staff will continue to provide that industry team with the benefit of American Airlines information and experience. We appreciate the opportunity to make this input.

Sincerely,

J. Kenneth Higgins
Boeing Commercial
Airplane Group
Vice President
Flight Operations and Validation

Tom Imrich
FAA
National Resource Specialist,
Air Carrier,
Operations

Tom Melody
Boeing Douglas Products Division
Sr. Manager/Chief Test Pilot
Experimental Flight Test
and Customer Service

Larry Rockliff
Airbus Service Company,
Training Center
Flight Training
Director and Chief Pilot

(6)

AmericanAirlines

October 6, 1997

Mr. J. Kenneth Higgins, Vice President
Boeing Commercial Airplane Group
Flight Operations and Validation

Mr. Tom Imrich, FAA
National Resource Specialist
Air Carrier, Operations

Mr. Tom Melody, Senior Manager/Chief Test Pilot
Boeing Douglas Products Division
Experimental Flight Test and Customer Service

Mr. Larry Rockliff, Director and Chief Pilot
Airbus Service Company Training Center
Flight Training

Reference: Letter dated August 20, 1997 from the Addressees

Subject: Recommendations for AAMP

Gentlemen:

In response to your August 20, 1997 coordinated package of recommendations regarding our AAMP program, I would submit the following.

Aerodynamic Explanations:

The Aerodynamics section of the program was and is founded on several recognized sources. Perkins and Hage, "Airplane Performance, Stability, and Control" was a primary reference. Additionally, we have been telling pilots for many years that "Aerodynamics for Naval Aviators" by Hugh Hurt is the best single source document available on this subject.

The use of Greek letters and formulas does not play well with pilots. In converting to English letters and modifying words, some technically correct terminology was lost. Tom Imrich and Warren VanderBurgh have worked together over the past three months on this issue. It is my understanding that Tom is satisfied with the modifications we made (although the labeling will continue to differ somewhat from that in Perkins and Hage). These improvements are included in Revision 16 to the AAMP booklet.

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Recent accident history highlights the importance of understanding corner speed. We are presenting the corner speed issue correctly and feel that we are applying it appropriately. Our experience with the AAMP simulator sessions over the past two years have very clearly indicated a need for exposure in this arena.

Use of Rudder

Let me say this one more time, we do not advocate the introduction of large sideslip angles when flying at high angle of attack. You seem to be predisposed to the belief that we are using rudder first or rudder only. The workbook is not a stand-alone document and nothing should be inferred without listening carefully to the presentation. In four different sections of the AAMP, emphasis is focused on the fact that when the airplane is not responding to aileron and spoiler control, you should use smooth application of coordinated rudder to obtain the desired roll response. Additionally, let me re-emphasize that AAMP stresses keeping the airplane inside the flight envelope at all times regardless of attitude. Our pilots are taught to always "respect" the stick shaker.

The hazard associated with large or abrupt application of rudder at high angle of attack is clearly exemplified by the NTSB video re-creations of the 737 accidents at Colorado Springs and Pittsburgh. (If you accept the NTSB's conclusion of a hard-over rudder as the most probable cause). Additionally, the Boeing Company developed videos dealing with 'Crossover angle of attack' which are very helpful in emphasizing the rudders' powerful affect on roll control at higher angles of attack.

The proper use of "top rudder" and the low alpha conditions under which it is applied are very clearly explained in the presentation.

Airplane Recovery from Upsets

Ken, this is an arena in which we clearly disagree totally with your position. After disconnecting the autopilot and autothrottles, the first two steps of our current nose high recovery procedure are as follows:

Unload with Forward yoke pressure toward zero "G" force
Roll the aircraft toward the nearest horizon -- limit bank angle to approximately 60°

At American Airlines, we teach our pilots to fly the airplane first using primary flight controls. If unloading with elevator does not generate an adequate nose down pitch rate, then we will not hesitate to roll the lift vector off the vertical to generate the required nose down pitch rate. This procedure will work on all of our aircraft. Any delay in initiating the roll (if required) could lead to a very tenuous situation.

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We <u>will not</u> teach nose down stabilizer trim as the next step after unloading. There are significant risks associated with running stabilizer trim during an upset recovery. This is not to say that a pilot cannot attempt to trim off excessive stick forces during the recovery process.

Preservation of energy is a primary concern on a nose high recovery. We <u>will</u> not teach the reduction of thrust prior to rolling the lift vector off the vertical. This would be totally counter-productive on more than half of our aircraft. It may also be counter-productive on airplanes with underwing engines, depending upon altitude and kinetic energy levels. Only after we unload and roll will we consider thrust and in most nose high recoveries we will increase thrust. Depending on energy levels (altitude and airspeed), we will consider reducing thrust on airplanes with underwing engines.

We do not understand your concern about high angle of attack maneuvering during nose high recoveries. Regardless of attitude, the action of unloading will lower angle of attack and the airplane should respond normally to its roll controls.

<u>Use of Simulators</u>

The AAMP simulator training models have been in continuous development over the past two years and we continue to refine them. We have come a long way toward representing realistic scenarios. One of our covenants has always been to abide by the control laws in each of our eight fleet type aircraft. Initially, inhibiting aileron input response on the vortex model simulation was a necessary compromise to achieve both realism and the desired learning objective. However, this <u>does not</u> result in large sideslip angles as you suggest. On your next visit to our Flight Academy, we will be pleased to show you the Beta readouts during this event.

The AAMP modeling and training in our simulators focuses on maintaining the airplane inside its flight envelope regardless of attitude. It is our belief that the fidelity of our simulators is reasonably good as long as we remain inside the envelope. We do not accept your statement that we are "manipulating a simulator into an environment that is way beyond valid engineering data".

The simulator training portion of AAMP is proving to be invaluable, with a steep learning curve for a significant percentage of our pilots. They are reporting that the simulator experience is both challenging and rewarding. Obviously, our emphasis is on recognition and basic recovery maneuvers, not fidelity of aircraft performance.

<u>Angle of Attack Indicators</u>

In the process of reviewing catastrophic events resulting from upsets or unusual attitudes we wonder if, in certain circumstances, IAS and attitude are providing sufficient information to the pilot to affect a recovery or extract optimal aerodynamic performance. This situation is, of course, compounded in the case of Pitot and/or static blockage. The

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consequences of a corrupted CADC on a highly automated "electric" airplane has gone well beyond mere loss of airspeed and caused numerous unexpected alerts and system failures. These often ambiguous indications can result in the crew becoming task saturated. We are pursuing the installation of some sort of display that will provide *situational awareness relative to the flight envelope at all times.*

I am pleased to hear that progress is being made in the study of an intuitive display on the 737-800 aircraft. Working together with the superb flight deck engineering group at Boeing, I am confident we can find a solution providing this enhanced situational awareness.

Technology Aversion

Let me say first that American Airlines does not have an aversion to technology. It is obvious that we have embraced many of the new technologies and incorporated them into our cockpits.

Automation dependency is the issue we have highlighted in AAMP. The discussion revolves around levels of automation and technology judgment; i.e., what is the appropriate level of automation for a particular task? Over the years, our industry has unwittingly developed a culture that drives us to attempt to operate at the highest levels of automation at all times. It is our opinion automation lacks the ability to create flexible responses to unanticipated changes in flight path requirements.

AAMP Training embodies a cultural change in the way we use the various levels of automation available in each of our aircraft. It takes us back to the precept that the pilot should always "fly the airplane first". It's not that aircraft automation is bad or unreliable, it is just that over the years, we have come to over depend on automation, which has obvious consequences.

In both the AAMP, and in Human Factors and Safety Training, we are attempting to re-establish a proper balance between automation and the maintenance of our pilots flying skills. The guidance is that if immediate direct control is required, then manual control should be applied. If the airplane is departing its intended vertical or lateral path in a threat environment, then the pilot should disconnect the autopilot and autothrottles to regain and maintain the intended flight path. AAMP seeks to reassign the appropriate role of aircraft automation within the cockpit, recognizing that ultimately, it will be the human being who is held responsible for the safety of our passengers and our aircraft.

Factual Errors

We have complete accident reports available through our corporate safety department. The AAMP tries to represent each example correctly. However, the intent of the AAMP is not to analyze accidents in detail, but to capture the essence of the event.

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There is not time nor is it appropriate to conduct detailed accident briefings during the AAMP presentation.

The purpose of AAMP is to provide the pilots with the knowledge and skills to recover from any of these upset events and to extract maximum performance from the airplane when required. We also think it important to emphasize the role of the pilot as final arbiter, operator and decison maker.

In closing, your suggestions and recommendations have been carefully analyzed. Ultimately, as you are aware, we are charged with the responsibility of the lives of our passengers and crew in a real life, everyday environment, not one which is technically and optimally controlled, as in a simulator or academia.

We thank you for your input and time, it is greatly appreciated.

Sincerely,

Captain C. D. Ewell
Chief Pilot
and Vice President-Flight

cc:
Mr. R. W. Baker
Capt. L. R. Schumacher
Capt. P. W. Railsback
Capt. R. D. Miner
Capt. W. VanderBurgh

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APPENDIX 5.2

FAST Article on Upset Recovery

(8 pages)

Docket No. SA-522

Exhibit No. 2-T

NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C.

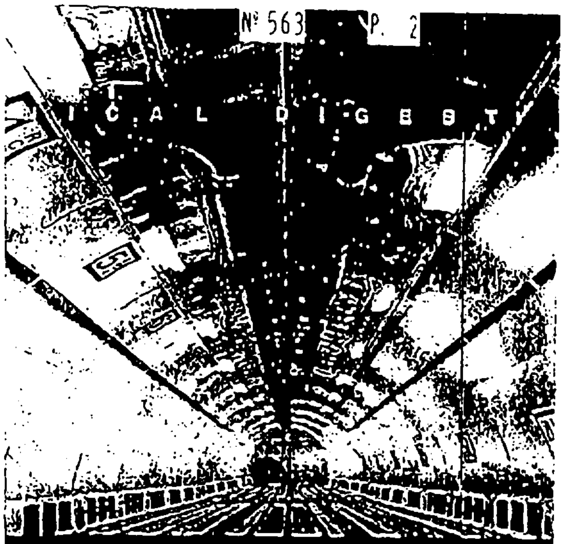
Airbus Technical Digest *FAST, Number 24*
Airplane Upset Recovery

(8 Pages)

1

AIRBUS TECHNICAL DIGEST

FAST 24



MAY 1999

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FAST may be read on Internet http://www.airbus.com

This issue of FAST has been printed on paper produced without using chlorine, to reduce waste and help conserve natural resources. 'Every little helps'.

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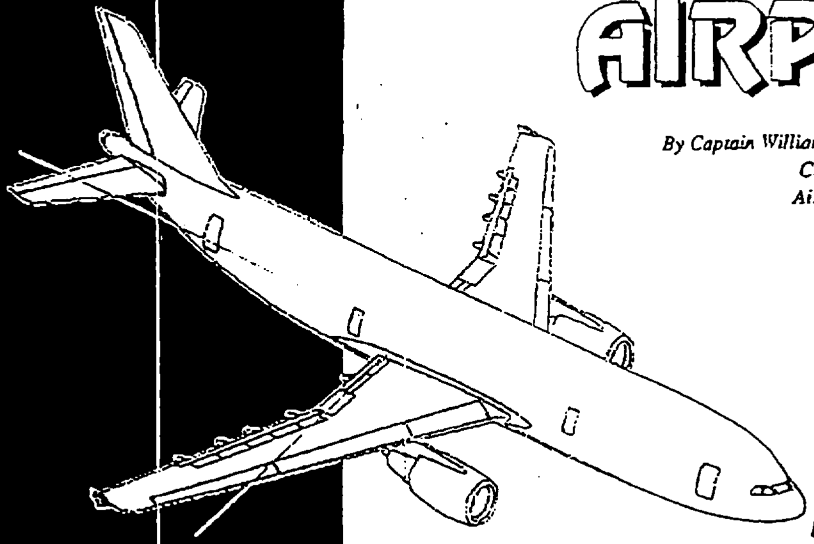

AIRPLANE

By Captain William Wainwright
Chief Test Pilot
Airbus Industrie

The idea for a joint industry working group to produce an Airplane Upset Recovery Training Aid was first proposed by ATA in June 1996. It was in response to increasing interest by the NTSB in aircraft loss of control accidents which, together with Controlled Flight Into Terrain, cause a large proportion of all accidents. They were putting a lot of pressure on the FAA to produce new regulations covering this subject.*

The working group was a voluntary industry initiative to see what could be done within the existing regulations to improve the situation.

The joint industry team consisted of representatives of all sides of industry: aircraft manufacturers, airlines, governmental authorities, and pilots' unions. It was a good example of how the entire industry, designers, users, and regulators can co-operate on safety issues that are common to everyone. It also marked a "first" in showing that the "Big 3" aircraft manufacturers could and will work together on technical, non-commercial issues. More than 80 persons coming from all around the world, but principally from the USA, participated from time to time.

The end result of two years work is a training package including a video and a CD-ROM, giving an airplane upset recovery training aid. This package is on free issue to all our customers, to use as they wish. However, all

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** The Training Aid itself was the basis of the article entitled "AERODYNAMIC PRINCIPLES OF LARGE AIRCRAFT UPSETS" that appeared as a Special Edition of FAST in June 1998.*

③

UPSET RECOVERY

A test pilot's point of view

members of the joint industry group agreed that the package is aimed at preventing loss of control accidents on conventional aircraft. It is not aimed at protected Fly-by-Wire aircraft.

There is no need for this type of continuation training on protected aircraft, although a general knowledge of the principles involved is useful for every pilot.

The content of the package is not the subject of this article, but there are a few issues of general interest which I gained from my experience as a member of the working group which I would like to mention.

THE BEGINNING

The issue of upset training was not new; major airlines around the world, and in particular in the USA, had already produced Upset Recovery Training Programmes, or were using one produced by another company. Amongst the members of the group were training pilots from American Airlines, Delta, and United who were already running such training programmes in their simulators. Since this was essentially seen as a training issue, initially the Flight Test Departments of the three main manufacturers were not involved. Airbus was represented by Larry Rockliff, Chief Pilot at Airbus Training Centre in Miami. Right from the beginning there was a conflict between the technical advice given by the manufacturers' training pilots and that expressed by those of the principal airlines already practising upset training. They naturally considered themselves to be the experts on this subject, based on the many hours of training that they had already conducted on a large number of pilots in their simulators.

At the beginning of 1997, the Flight Test Departments were asked to come in to support their training pilots. From then on, the chief test pilots of the three major manufacturers became members of the working group. But the conflict over the different opinions on aircraft handling and recovery techniques continued for a long time until we finally achieved agreement at the last meeting in January 1998. The reasons for these differences of opinion are the subject of this article.

There is no need for this type of continuation training on protected fly-by-wire aircraft

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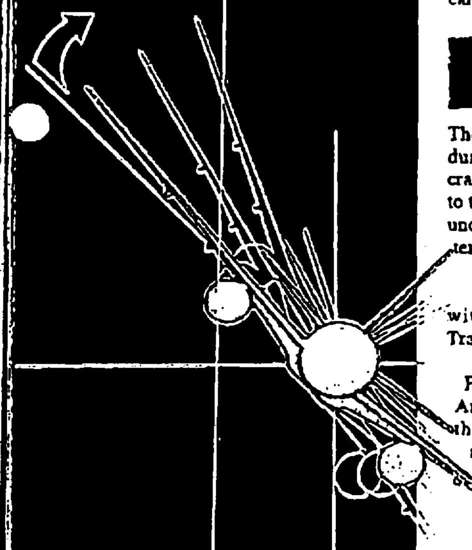
If altitude permits, flight tests have shown that an effective method to get a nose-down pitch rate is to reduce the power on underwing mounted engines.



Do not confuse an approach to the stall and a full stall. An approach to stall is controlled flight. An airplane that is stalled is out of control and must be recovered.

THE DIFFERENCES OF OPINION

The differences of opinion were mainly concentrated in the following areas:

- Procedures versus general advice
- Ease of training versus failure cases
- Stalling
- Use of rudder
- Use of simulators.

It is worth saying that there was never any difference of opinion between the three test pilots on the group. Although we come from different backgrounds and have worked in different organisations with different work cultures, we always agreed on our technical advice.

PROCEDURES VERSUS GENERAL ADVICE

The airlines wanted simplified procedures which were common to all aircraft in their fleets and which were easy to teach and easily reproducible. This is understandable because everyone is interested in having a standard product at the end of his training programme. And this is what they already had with the Airplane Upset Recovery Training that they were already doing.

For the training managers from American Airlines, Delta, and United, the only thing necessary was to give an overall industry approval to their existing programmes; they already worked, because the many pilots that had undergone training all came out of it with the same standardised reactions to the standard upsets. For them, this was the necessary proof that their training programme worked.

Where we differed was in our conviction that there is no such thing as a standard upset and our reluctance to endorse simplified procedures for recovery from an upset.

We wanted a general knowledge based approach, as opposed to a rule based one. For this, after proposing some initial actions, we talk about "additional techniques which may be tried". This obviously is more difficult to teach.

Where we reached a compromise was in the order of presenting the various actions that might be considered to recover the situation. For us, the order of presentation is for guidance only; it represents a series of options that should be considered and used as appropriate to the situation. It is not meant to represent rigid procedures that must be followed in an exact sequence. However, the order can be used in training scenarios if a procedural approach is needed for training.

The airline instructors also wanted procedures which would apply to all the aircraft in their fleets. This meant that they were against certain actions, because they were inappropriate on others. For example, the thrust effects of underwing-mounted engines were being ignored, whereas it has a significant influence on recovery. Again, we reached a compromise by using the following words: " if altitude permits, flight tests have shown that an effective method to get a nose-down pitch rate is to reduce the power on underwing-mounted engines".

EASE OF TRAINING VERSUS FAILURE CASES

The training that was already being done, considered upsets as being due to momentary inattention, with a fully serviceable aircraft, that was in trim when it was upset. We wanted to consider other cases that involve aircraft with temporarily insufficient control authority for easy recovery. This of course complicates the situation, because recovering an aircraft which is in trim, possessing full control authority and normal control forces, is not the same as recovering an aircraft with limited control available or with unusual control forces.

Thus, for us, an aircraft that is out-of-trim, for whatever reason, should be re-trimmed. Whereas the airline instructors were against the use of trim because of concerns over the possibility of a pilot overtrimming and of trim runaways which are particularly likely on some older aircraft types which are still in their fleets.

We spent a lot of time discussing the use of elevator trim and we never reached agreement. All the major US airlines were adamant on their policy to recover first using "primary controls" which excluded any reference to trimming.

Again, a compromise was necessary. What we have done is to talk about using trim if a sustained column force is required to obtain the desired response whilst mentioning that care must be used to avoid using too much trim. And, the use of trim is not mentioned in the simplified lists of actions to be taken.

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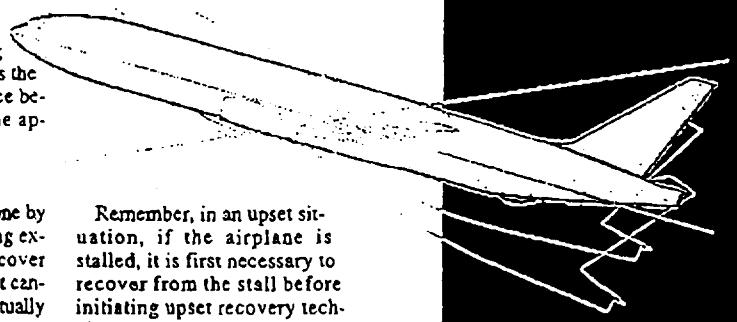
STALLING



Another aspect that was being ignored in the existing training was the stall. By this I mean the difference between being fully stalled and the approach to the stall. In training, you do an approach to the stall with a recovery from stick shaker, which is often done by applying full thrust and maintaining existing pitch attitude in order to recover with minimum loss of height. Height cannot be maintained if an aircraft is actually stalled and should be of secondary importance.

Even those pilots who do stalls on airtests, as might be done after a heavy maintenance check, only do them with gentle decelerations, and they recover immediately without penetrating very far beyond the stalling angle of attack. There is a world of difference between being just before, or even just at, the stall, and going dynamically well into it.

When we started our discussions, the training being given in the airlines to recover from excessive nose-up pitch attitudes emphasised rolling rapidly towards 90° of bank. This is fun to do, and it was not surprising to find that most of the instructors doing the training were ex-fighter pilots who had spent a lot of time performing such manoeuvres in another life. The training was being done in the same way, with an aircraft starting in trim with a lot of energy and recovering while it still had some. However, the technique being taught only works if the aircraft is not stalled.

We start our briefing on recovery techniques with the following caution:

Recovery techniques assume that the airplane is not stalled. If the airplane is stalled, it is imperative to first recover from the stalled condition before initiating the upset recovery technique.

Do not confuse an approach to the stall and a full stall. An approach to stall is controlled flight. An airplane that is stalled is out of control and must be recovered.

A stall is characterised by any, or a combination of the following:

- Buffeting, which could be heavy at times
- Lack of pitch authority
- Lack of roll control
- Inability to arrest descent rate.

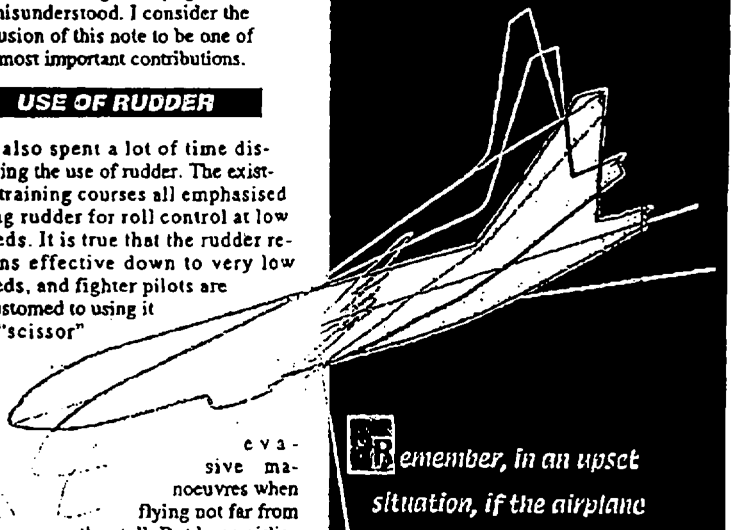
To recover from a stall, the angle of attack must be reduced below the stalling angle. Apply nose down pitch control and maintain it until stall recovery. Under certain conditions with under-wing mounted engines, it may be necessary to reduce thrust to prevent the angle of attack from continuing to increase.

Remember, in an upset situation, if the airplane is stalled, it is first necessary to recover from the stall before initiating upset recovery techniques.

This is something that we are well aware of in testing, but it was either being totally ignored or misunderstood. I consider the inclusion of this note to be one of our most important contributions.

USE OF RUDDER

We also spent a lot of time discussing the use of rudder. The existing training courses all emphasised using rudder for roll control at low speeds. It is true that the rudder remains effective down to very low speeds, and fighter pilots are accustomed to using it for "scissor" evasive manoeuvres when flying not far from the stall. But large airliners, with all the inertias that they possess, are not like fighter aircraft. Based on our experience as test pilots we are very wary of using rudder close to the stall. It is the best way to provoke a loss of control if not used very carefully, particularly with flaps out.



We finally got the training managers to agree to play down the use of rudder in their existing courses. But we do not say never use the rudder at low speed. We say that, if necessary, the aileron inputs can be assisted by coordinated rudder in the direction of the desired roll. However, we also caution that "excessive rudder can cause excessive sideslip, which could lead to departure from controlled flight".

But why did we have so much difficulty in convincing the training pilots that it is not a good idea to go kicking the rudder around at low speed?

Their reply was always the same; but it works in the simulator! This leads me on to my last point.

Remember, in an upset situation, if the airplane is stalled, it is first necessary to recover from the stall before initiating upset recovery techniques.

Excessive rudder can cause excessive sideslip, which could lead to departure from controlled flight.

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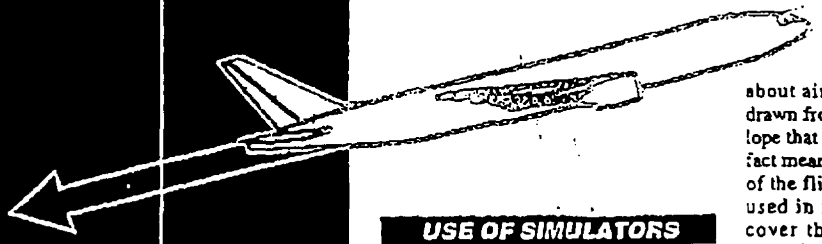

Simulators should not be used to develop techniques at the edges of the flight envelope.

USE OF SIMULATORS

We manufacturers were very concerned over the types of manoeuvres being flown in simulators and the conclusions that were being drawn from them. Simulators, like any computer system, are only as good as the data that goes into them. That means the data package that is given to the simulator manufacturer. And we test pilots do not deliberately lose control of our aircraft just to get data for the simulator. And even when that happens, one isolated incident does not provide much information because of the very complicated equations that govern dynamic manoeuvres involving non-linear aerodynamics and inertia effects.

The complete data package includes a part that is drawn from actual flight tests, a part that uses wind tunnel data, and the rest - which is pure extrapolation. It should be obvious that firm conclusions about aircraft behaviour can only be drawn from the parts of the flight envelope that are based on hard data. This in fact means being not far from the centre of the flight envelope; the part that is used in normal service. It does not cover the edges of the envelope. I should also add that most of the data actually collected in flight is from quasi-static manoeuvres. Thus, dynamic manoeuvring is not very well represented. In fact, a typical data package has *flight test data for the areas described* in Table 1.

In other words, you have reasonable cover up to quite high sideslips and quite high angles of attack (AOA), but not at the same time. Furthermore, the matching between aircraft stalling tests and the simulator concentrates mainly on the longitudinal axis. This means that the simulator model is able to correctly reproduce the stalling speeds and the pitching behaviour, but fidelity is not ensured for rolling efficiency

Table 1

	Sideslip	*Angle of attack*
SLATS OUT		
• All Engines Operating	Around neutral	Between 0° and 22°
	Between + 15° and -15°	Between 0° and 12°
• One Engine Inoperative	Between +8° and -8	Between 5° and 12°
SLATS IN, LOW MACH		
• All Engines Operating	Around neutral	Between 0° and 12°
	Between +10° and -10°	Between 2° and 9°
• One Engine Inoperative	Between +8° and -8°	Between 2° and 8°
SLATS IN, HIGH MACH		
• All Engines Operating	Around neutral	Between 0° and 5°
	Between +5° and -5°	Between 1° and 3°
• One Engine inoperative	Between +2° and -2°	Between 1° and 3°

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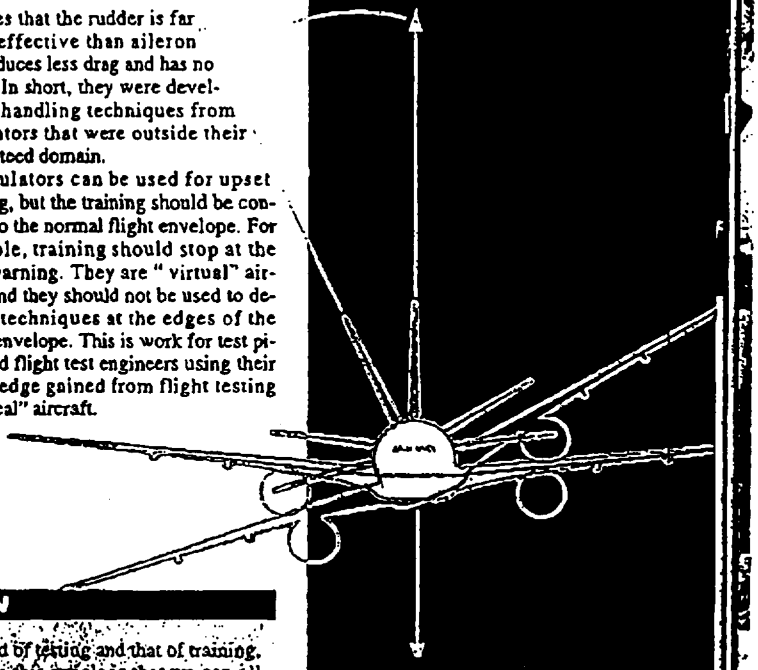
Table 2

	Sideslip	*Angle of attack*
SLATS OUT	From +18° to -18°	From -5° to 25°
SLATS IN, LOW MACH	From +18° to -18°	From -5° to 12°
SLATS IN, HIGH MACH	From + 8° to -8°	From -2° to 8°

(based on a simplified model of wind tunnel data) or for possible asymmetric stalling of the wings. Also, the range for one engine inoperative is much less than the range for all engines operating and linear interpolation is assumed between low and high Mach numbers. Wind tunnel data goes further. For example, a typical data package would cover the areas described in table 2.

In fact, this is a perfectly adequate coverage to conduct all normal training needs. But it is insufficient to evaluate recovery techniques from loss of control incidents. Whereas, the training managers were all in the habit of demonstrating the handling characteristics beyond the stall; often telling their trainees that the rudder is far more effective than aileron and induces less drag and has no vices! In short, they were developing handling techniques from simulators that were outside their guaranteed domain.

Simulators can be used for upset training, but the training should be confined to the normal flight envelope. For example, training should stop at the stall warning. They are " virtual" aircraft and they should not be used to develop techniques at the edges of the flight envelope. This is work for test pilots and flight test engineers using their knowledge gained from flight testing the " real" aircraft.



CONCLUSION

It may seem that there is a gulf between the world of testing and that of training, but the message that I would like to get over in this article is that we can all learn from each others' experiences and that we should not do things in isolation. It is all about working together, which is what we all did when we met to prepare and review this training aid, even though we sometimes had some very lively sessions. And there is one word that crops up frequently: compromise. Life is a compromise, and you always have to search for that ideal point between two extremes which Aristotle called "the golden mean". By finding suitable compromise solutions, our two worlds of testing and training were able to resolve their differences and develop something that satisfied everyone.

Of course there are also some points about piloting that were raised during our discussions which I feel should have a larger audience. They are important, but they should be kept in context. On the whole they are related to recovery of an aircraft which is already out of control, or is about to be. This is an area in which the test pilots have some experience which other pilots do not normally have, because the aim of training should be to prevent an aircraft getting into such a situation. The end result of all the discussions that took place was to concentrate everyone's attention on taking action early enough to prevent the occurrence of loss of control. We put the emphasis on training within the known flight envelope, and to avoid going into that part which cannot be guaranteed one hundred per cent and which may have a negative effect.

In conclusion, we must use each other's competences in the areas where they are expert. Of course the training programmes must be designed by training pilots, but these training programmes must stay in a reasonable flight envelope. And the test pilots are best qualified to define the flight envelope that should be used. That is what we now have with this joint industry training aid, which is a very good example of how we can all work together in everyone's interest. ■

Concentrate everyone's attention on taking action early enough to prevent the occurrence of loss of control.

APPENDIX 5.3

Excerpts from the Industry Upset Training Aid

(31 pages)

Docket No. SA-522

Exhibit No. 2-Q

NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C.

Attachment V
Excerpts from the Boeing/Airbus Training Aid

(31 Pages)

Pilot Guide to Airplane Upset Recovery

2.0 Introduction

The "Pilot Guide to Airplane Upset Recovery" is one part of the *Airplane Upset Recovery Training Aid*. The other parts include an "Overview for Management" (Sec. 1), "Example Airplane Upset Recovery Training Program" (Sec. 3), "References for Additional Information" (Sec. 4), and a two-part video.

The goal of this training aid is to increase the ability of pilots to *recognize and avoid* situations that can lead to airplane upsets and to improve their ability to recover control of an airplane that has exceeded the normal flight regime. This will be accomplished by increasing awareness of potential upset situations and knowledge of aerodynamics and by application of this knowledge during simulator training scenarios.

The education material and the recommendations provided in the *Airplane Upset Recovery Training Aid* were developed through an extensive review process to achieve a consensus of the air transport industry.

2.1 Objectives

The objectives of the "Pilot Guide to Airplane Upset Recovery" are to provide pilots with
- Knowledge to recognize situations that may lead to airplane upsets so that they may be prevented.
- Basic airplane aerodynamic information.
- Airplane flight maneuvering information and techniques for recovering airplanes that have been upset.

It is intended that this information be provided to pilots during academic training and that it be retained for future use.

2.2 Definition of Airplane Upset

Research and discussions within the commercial aviation industry indicated that it was necessary to establish a descriptive term and definition in order to develop this training aid. Terms such as "unusual attitude," "advanced maneuver," "selected event," "loss of control," "airplane upset," and others are terms used within the industry. The team decided that "airplane upset" was appropriate for this training aid. An airplane upset is defined as an airplane in flight unintentionally exceeding the parameters normally experienced in line operations or training.

While specific values may vary among airplane models, the following unintentional conditions generally describe an airplane upset:
- Pitch attitude greater than 25 deg, nose up.
- Pitch attitude greater than 10 deg, nose down.
- Bank angle greater than 45 deg.
- Within the above parameters, but flying at airspeeds inappropriate for the conditions.

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2.4.1.1.5 Microbursts

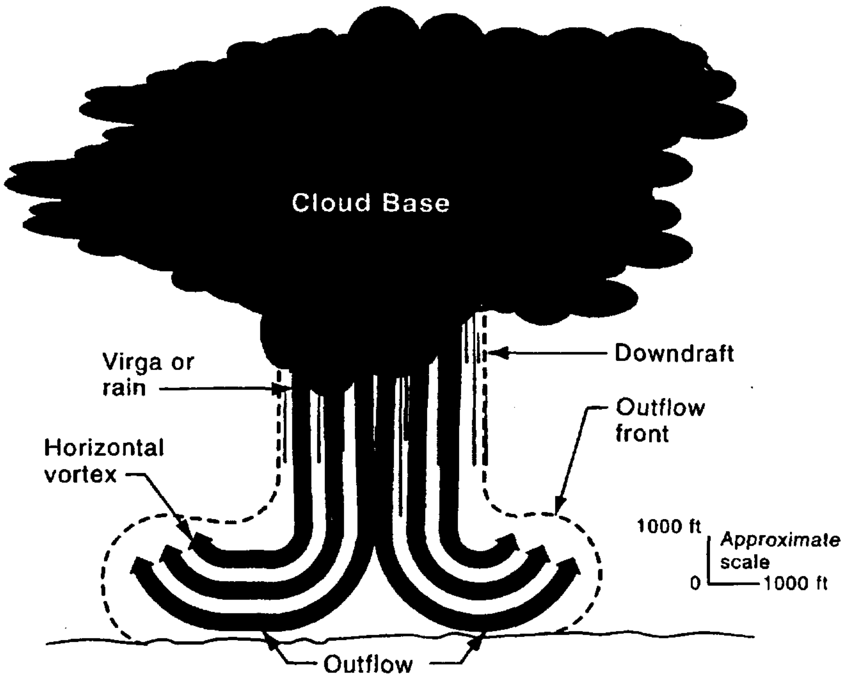
Identification of concentrated, more powerful downdrafts—known as microbursts—has resulted from the investigation of windshear accidents and from meteorological research. Microbursts can occur anywhere convective weather conditions occur. Observations suggest that approximately 5% of all thunderstorms produce a microburst. Downdrafts associated with microbursts are typically only a few hundred to 3000 ft across. When a downdraft reaches the ground, it spreads out horizontally and may form one or more horizontal vortex rings around the downdraft (Fig. 6). Microburst outflows are not always symmetric. Therefore, a significant airspeed increase may not occur upon entering outflows, or it may be much less than the subsequent airspeed loss experienced when exiting the microburst. Windspeeds intensify for about 5 min after a microburst initially contacts the ground and typically dissipate within 10 to 20 min after ground contact.

It is vital to recognize that some microbursts cannot be successfully escaped with any known techniques.

2.4.1.2 Wake Turbulence

Wake turbulence is the leading cause of airplane upsets that are induced by the environment. The phenomenon that creates wake turbulence results from the forces that lift the airplane. High-pressure air from the lower surface of the wings flows around the wingtips to the lower pressure region above the wings. A pair of counter-rotating vorti-

Figure 6
Symmetric Microburst—An airplane transiting the microburst would experience equal headwinds and tailwinds.



③

ces are thus shed from the wings: the right wing vortex rotates counterclockwise, and the left wing vortex rotates clockwise (Fig. 7). The region of rotating air behind the airplane is where wake turbulence occurs. The strength of the turbulence is determined predominantly by the weight, wingspan, and speed of the airplane. Generally, vortices descend at an initial rate of about 300 to 500 ft/min for about 30 sec. The descent rate decreases and eventually approaches zero at between 500 and 900 ft below the flight path. Flying at or above the flight path provides the best method for avoidance. Maintaining a vertical separation of at least 1000 ft when crossing below the preceding aircraft may be considered safe. This vertical motion is illustrated in Figure 8. Refer to the *Wake Turbulence Training Aid* for comprehensive information on how to avoid wake turbulence. This aid is available from the National Technical Information Service or The Boeing Company.

An encounter with wake turbulence usually results in induced rolling or pitch moments; however, in rare instances an encounter could cause structural damage to the airplane. In more than one instance, pilots have described an encounter to be like "hitting a wall." The dynamic forces of the vortex can exceed the roll or pitch capability of the airplane to overcome these forces. During test programs, the wake was approached from all directions to evaluate the effect of encounter direction on response. One item was common to all encounters: without a concerted effort by the pilot to reenter the wake, the airplane would be expelled from the wake and an airplane upset could occur.

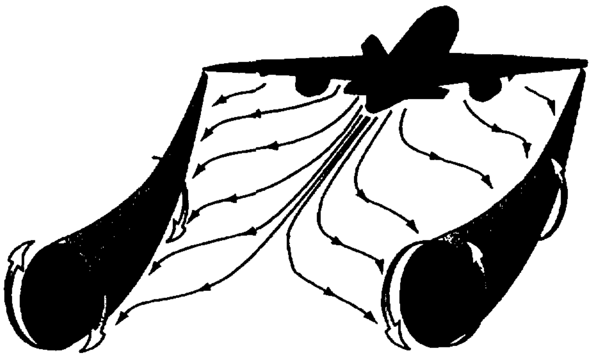


Figure 7
Wake Turbulence Formation

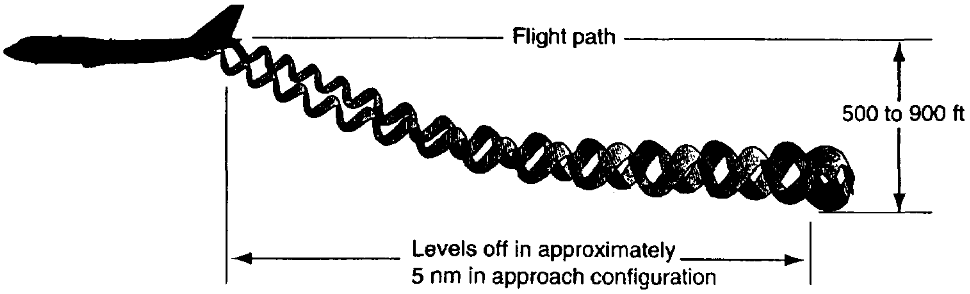


Figure 8
Vertical Motion Out of Ground Effect

④

Counter-control is usually effective and induced roll is minimal in cases where the wingspan and ailerons of the encountering airplane extend beyond the rotational flowfield of the vortex (Fig. 9). It is more difficult for airplanes with short wingspan (relative to the generating airplane) to counter the imposed roll induced by the vortex flow.

Avoiding wake turbulence is the key to avoiding many airplane upsets. Pilot and air traffic control procedures and standards are designed to accomplish this goal, but as the aviation industry expands, the probability of an encounter also increases.

2.4.1.3 Airplane Icing

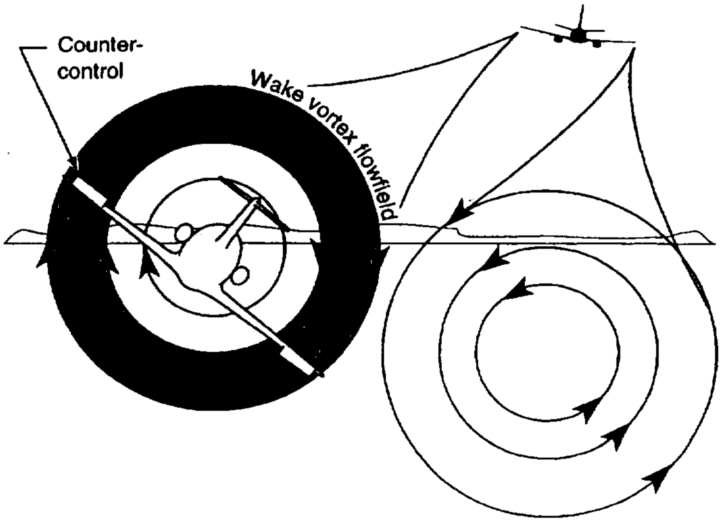
Technical literature is rich with data showing the adverse aerodynamic effects of airfoil contamination. Large degradation of airplane performance can result from the surface roughness of an extremely small amount of contamination. These detrimental effects vary with the location and roughness, and they produce unexpected airplane handling characteristics, including degradation of maximum lift capability, increased drag, and possibly unanticipated changes in stability and control. Therefore, the axiom of "Keep it clean" for critical airplane surfaces continues to be a universal requirement.

2.4.2 Systems-Anomalies-Induced Airplane Upsets

Airplane designs, equipment reliability, and flight crew training have all improved since the Wright brothers' first powered flight. Airplane certification processes and oversight are rigorous. Airlines and manufacturers closely monitor equipment failure rates for possible redesign of airplane parts or modification of maintenance procedures. Dissemination of information is rapid if problems are detected. Improvement in airplane designs and equipment components has always been a major focus in the aviation industry. In spite of this continuing effort, there are still failures. Some of these failures can lead to an airplane upset. That is why flight crews are trained to overcome or mitigate the impact of the failures. Most failures are survivable if correct responses are made by the flight crew.

An airplane was approaching an airfield and appeared to break off to the right for a left downwind to the opposite runway. On downwind at approximately 1500 ft, the airplane pitched up to nearly 60 deg and climbed to an altitude of nearly 4500 ft, with the airspeed deteriorating to almost 0 kn. The airplane then tail-slid, pitched down, and seemingly recovered. However, it continued into another steep pitchup of 70 deg. This time as it

Figure 9
Induced Roll



⑤

in such a way as to get the aerodynamics of the tab to hold the elevator in the desired position. The airplane is then in trim (because the required load on the tail has been achieved) and the column force trim condition is met as well (because the tab holds the elevator in the desired position). One side effect of this configuration is that when trimmed near one end of the deflection range, there is not much more control available for maneuvering in that direction (Fig. 24).

In the case of the all-flying tail, the entire stabilizer moves as one unit in response to column commands. This changing of the angle of attack of the stabilizer adjusts the tail lift as required to balance the moments. The tail is then held in the desired position by an irreversible flight control system (usually hydraulic). This configuration requires a very powerful and fast-acting control system to move the entire tail in response to pilot inputs, but it has been used quite successfully on commercial jet transport airplanes.

In the case of the trimmable stabilizer, the proper pitching moment is achieved by deflecting the elevator and generating the required lift on the tail. The stabilizer is then moved (changing its angle of attack) until the required tail lift is generated by the stabilizer with the elevator essentially at zero deflection. A side effect of this configuration is that from the trimmed condition, full elevator deflection is available in either direction, allowing a much larger range of maneuvering capability. This is the configuration found on most high-performance airplanes that must operate through a very wide speed range and that use very powerful high-lift devices (flaps) on the wing.

Knowing that in the trimmed condition the elevator is nearly faired or at zero deflection, the pilot instantly knows how much control power is available in either direction. This is a powerful tactile cue, and it gives the pilot freedom to maneuver without the danger of becoming too close to surface stops.

2.5.5.4 Lateral and Directional Aerodynamic Considerations

Aerodynamically, anti-symmetric flight, or flight in sideslip can be quite complex. The forces and moments generated by the sideslip can affect motion in all three axes of the airplane. As will be seen, sideslip can generate strong aerodynamic rolling moments as well as yawing moments. In particular the magnitude of the coupled roll-due-to-sideslip is determined by several factors.

2.5.5.4.1 Angle of Sideslip

Just as airplane angle of attack is the angle between the longitudinal axis of the airplane and the relative wind as seen in a profile view, the sideslip angle is the angle between the longitudinal axis of the airplane and the relative wind, seen this time in the plan view (Fig. 25). It is a measure of whether the airplane is flying straight into the relative wind.

With the exception of crosswind landing considerations requiring pilot-commanded sideslip, commercial transport airplanes are typically flown at or very near zero sideslip. This usually results in the lowest cruise drag and is most comfortable for passengers, as the sideways forces are minimized.

For those cases in which the pilot commands a sideslip, the aerodynamic picture becomes a bit more complex. Figure 25 depicts an airplane in a

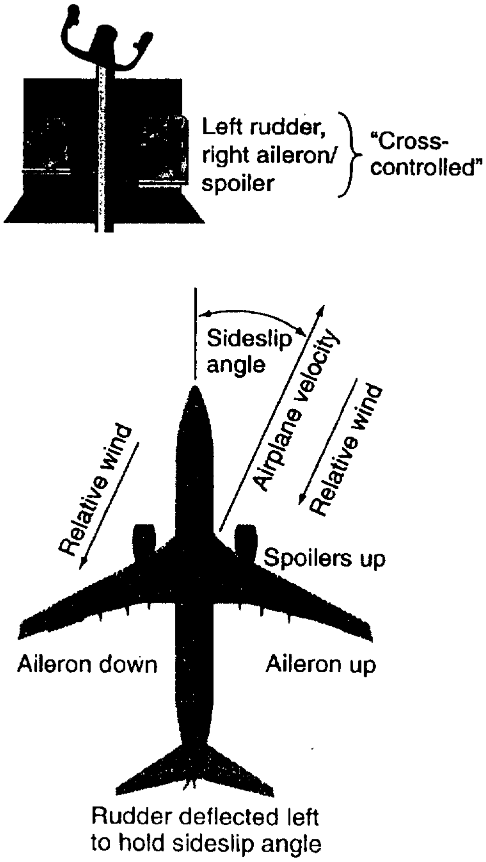


Figure 25
Angle of Sideslip

⑥

commanded nose-left sideslip. That is, the velocity vector is not aligned with the longitudinal axis of the airplane, and the relative wind is coming from the pilot's right.

One purpose of the vertical tail is to keep the nose of the airplane "pointed into the wind," or make the tail follow the nose. When a sideslip angle is developed, the vertical tail is at an angle of attack and generates "lift" that points sideways, tending to return the airplane to zero sideslip. Commercial jet transport airplanes are certificated to exhibit static directional stability that tends to return the airplane to zero sideslip when controls are released or returned to a neutral position. In order to hold a sideslip condition, the pilot must hold the rudder in a deflected position (assuming symmetrical thrust).

2.5.5.4.2 Wing Dihedral Effects

Dihedral is the positive angle formed between the lateral axis of an airplane and a line that passes through the center of the wing, as depicted in Figure 26. Dihedral contributes to the lateral stability of an airplane, and commercial jet transport airplanes are certificated to exhibit static lateral stability. A wing with dihedral will develop stable rolling moments with sideslip. If the relative wind comes from the side, the wing into the wind is subject to an increase in lift. The wing away from the wind is subject to a decrease in angle of attack and develops a decrease in lift. The changes in lift effect a rolling moment, tending to raise the windward wing; hence, dihedral contributes a stable roll due to sideslip. Since wing dihedral is so powerful in producing lateral stability, it is used as a "common denominator term" of the lateral stability contribution of other airplane components, such as rudder and wing sweep. In other words, the term "dihedral effect" is used when describing the effects of wing sweep and rudder on lateral stability and control.

A swept-wing design used on jet transport airplanes is beneficial for high-speed flight, since higher flight speeds may be obtained before components of speed perpendicular to the leading edge produce critical conditions on the wing. In other words, wing sweep will delay the onset of compressibility effects. This wing sweep also contributes to the dihedral effect. When the swept-wing airplane is placed in a sideslip, the wing into the wind experiences an increase in lift, since the effective sweep is less, and the wing away from the wind produces less lift, since the effective sweep is greater (Fig. 25). The amount of contribution, or dihedral effect, depends on the amount of sweepback and lift coefficient of the wing. The effect becomes greater with increasing lift coefficient and wing sweep. The lift coefficient will increase with increasing angle of attack up to the critical angle. This means that any sideslip results in more rolling moment on a swept-wing airplane than on a straight-wing airplane. Lateral controls on swept-wing airplanes are powerful enough to control large sideslip angles at operational speeds.

Rudder input produces sideslip and contributes to the dihedral effect. The effect is proportional to the angle of sideslip. (That is, roll increases with sideslip angle; therefore, roll increases with increasing rudder input.) When an airplane is at a high angle of attack, aileron and spoiler roll controls become less effective. At the stall angle of attack, the rudder is still effective; therefore, it can produce large sideslip angles, which in turn produces roll because of the dihedral effect.

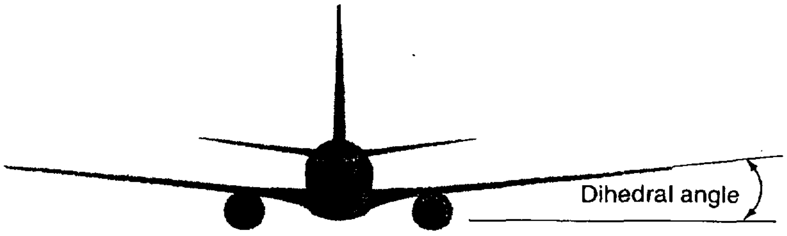


Figure 26
Wing Dihedral Angle

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2.5.5.4.3 Pilot-Commanded Sideslip

It is important to keep in mind that the rudders on modern jet transport airplanes are usually sized to counter the yawing moment associated with an engine failure at very low takeoff speeds. This very powerful rudder is also capable of generating large sideslips (when an engine is not failed). The large sideslip angles generate large rolling moments that require significant lateral control input to stop the airplane from rolling. In maneuvering the airplane, if a crosswind takeoff or landing is not involved and an engine is not failed, keeping the sideslip as close to zero as possible ensures that the maximum amount of lateral control is available for maneuvering. This requires coordinated use of both aileron/spoilers and rudder in all maneuvering.

One way to determine the sideslip state of the airplane is to "feel" the lateral acceleration; it feels as if the pilot is being pushed out of the seat sideways. Another way is to examine the slip-skid indicator and keep the ball in the center. Pilots should develop a feel for the particular airplanes they fly and understand how to minimize sideslip angle through coordinated use of flight controls.

Crossover speed is a recently coined term that describes the lateral controllability of an airplane with the rudder at a fixed (up to maximum) deflection. It is the minimum speed (weight and configuration dependent) in a 1-g flight, where maximum aileron/spoiler input (against the stops) is reached and the wings are still level or at an angle to maintain directional control. Any additional rudder input or decrease in speed will result in an unstoppable roll into the direction of the deflected rudder or in an inability to maintain desired heading. Crossover speed is very similar in concept to Vmca, except that instead of being Vmc due to a thrust asymmetry, it is Vmc due to full rudder input. This crossover speed is weight and configuration dependent. However, it is also sensitive to angle of attack. With weight and configuration held constant, the crossover speed will increase with increased angle of attack and will decrease with decreased angle of attack. Thus, in an airplane upset due to rudder deflection with large and increasing bank angle and the nose rapidly falling below the horizon, the input of additional nose-up elevator with already maximum input of aileron/spoilers will only aggravate the situation. The correct action in this case is to unload the airplane to reduce the angle of attack, which will regain aileron/spoiler effectiveness and allow recovery. This action may not be intuitive and will result in a loss of altitude.

Note: The previous discussion refers to the aerodynamic effects associated with rudder input; however, similar aerodynamic effects are associated with other surfaces.

2.5.5.5 High-Speed, High-Altitude Characteristics

Modern commercial jet transport airplanes are designed to fly at altitudes from sea level to more than 40,000 ft. There are considerable changes in atmospheric characteristics that take place over that altitude range, and the airplane must accommodate those changes.

One item of interest to pilots is the air temperature as altitude changes. Up to the tropopause (36,089 ft in a standard atmosphere), the standard temperature decreases with altitude. Above the tropopause, the standard temperature remains relatively constant. This is important to pilots because the speed of sound in air is a function only of air temperature. Aerodynamic characteristics of lifting surfaces and entire airplanes are significantly affected by the ratio of the airspeed to the speed of sound. That ratio is Mach number. At high altitudes, large Mach numbers exist at relatively low calibrated airspeeds.

As Mach number increases, airflow over parts of the airplane begins to exceed the speed of sound. Shock waves associated with this local supersonic flow can interfere with the normally smooth flow over the lifting surfaces, causing local flow separation. Depending on the airplane, as this separation grows in magnitude with increasing Mach number, characteristics such as pitchup, pitchdown, or aerodynamic buffeting may occur. Transport category airplanes are certificated to be free from characteristics that would interfere with normal piloting in the normal flight envelope and to be safely controllable during inadvertent exceedances of the normal envelope, as discussed in Section 2.5.4, "Aerodynamic Flight Envelope."

The point at which buffeting would be expected to occur is documented in the Approved Flight Manual. The Buffet Boundary or Cruise Maneuver

⑧

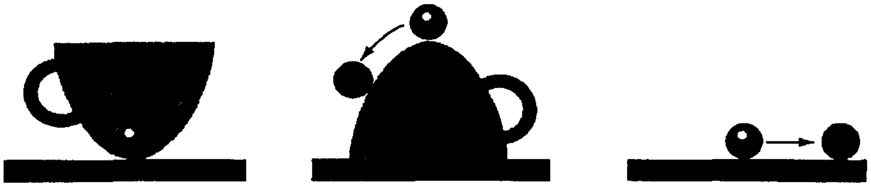
All transport airplanes demonstrate positive stability in at least some sense. The importance here is that the concept of stability can apply to a number of different parameters, all at the same time. Speed stability, the condition of an airplane returning to its initial trim airspeed after a disturbance, is familiar to most pilots. The same concept applies to Mach number. This stability can be independent of airspeed if, for example, the airplane crosses a cold front. When the outside air temperature changes, the Mach number changes, even though the indicated airspeed may not change. Airplanes that are "Mach stable" will tend to return to the original Mach number. Many jet transport airplanes incorporate Mach trim to provide this function. Similarly, commercial airplanes are stable with respect to load factor. When a gust or other disturbance generates a load factor, the airplane is certificated to be stable: it will return to its initial trimmed load factor (usually 1.0). This "maneuvering stability" requires a sustained pull force to remain at elevated load factors—as in a steep turn.

One important side effect of stability is that it allows for some unattended operation. If the pilot releases the controls for a short period of time, stability will help keep the airplane at the condition at which it was left.

Another important side effect of stability is that of tactile feedback to the pilot. On airplanes with static longitudinal stability, for example, if the pilot is holding a sustained pull force, the speed is probably slower than the last trim speed.

2.5.5.7 Maneuvering in Pitch

Movement about the lateral axis is called "pitch," as depicted in Figure 30.



Stable
When ball is displaced, it returns to its original position.

Unstable
When ball is displaced, it accelerates from its original position.

Neutral
When ball is displaced, it neither returns, nor accelerates away—it just takes up a new position.

Figure 29
Static Stability

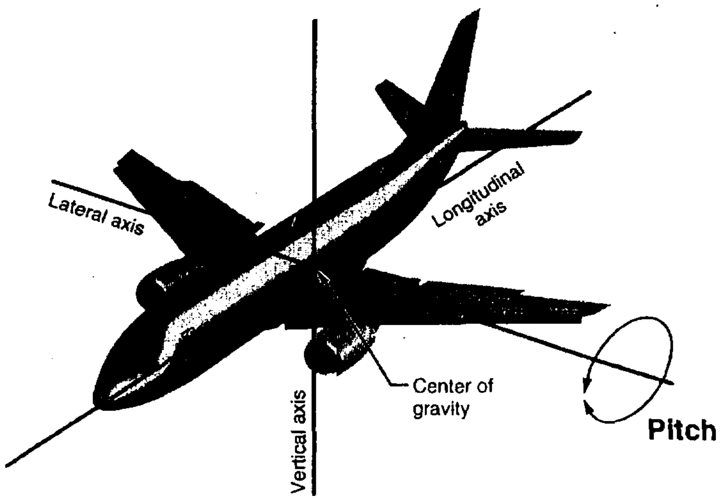


Figure 30
Reference Axis Definitions

⑨

the speed and sinkrate, the pilot pulls on the column and applies up-elevator. However, at a large bank angle, the only effect of the up-elevator is to further tighten the turn. It is imperative to get the wings close to level before beginning any aggressive pitching maneuver. This orients the lift vector away from the gravity vector so that the forces acting on the airplane can be managed in a controlled way.

Knowledge of these relationships is useful in other situations as well. In the event that the load factor is increasing, excess lift is being generated, and the pilot does not want speed to decrease, bank angle can help to keep the flight path vector below the horizon, getting gravity to help prevent loss of airspeed. In this situation, the excess lift can be oriented toward the horizon and, in fact, modulated up and down to maintain airspeed.

2.5.5.9 Lateral Maneuvering

Motion about the longitudinal axis (Fig. 35) is called "roll." Modern jet transport airplanes use combinations of aileron and spoiler deflections as primary surfaces to generate rolling motion. These deflections are controlled by the stick or wheel, and they are designed to provide precise maneuvering capability. On modern jet airplanes, the specific deflection combinations of ailerons and spoilers are usually designed to make adverse yaw virtually undetectable to the pilot. Even so, coordinated use of rudder in any lateral maneuvering should keep sideslip to a minimum.

As described in Section 2.5.5, "Aerodynamics," trailing edge control surfaces lose effectiveness in the downgoing direction at high angles of attack. Similarly, spoilers begin to lose effectiveness as the stall angle of attack is exceeded.

Transport airplanes are certificated to have positive unreversed lateral control up to a full aerodynamic stall. That is, during certification testing, the airplane has been shown to have the capability of producing and correcting roll up to the time the airplane is stalled. However, beyond the stall angle of attack, no generalizations can be made. ***For this reason it is critical to reduce the angle of attack at the first indication of stall so that control surface effectiveness is preserved.***

The apparent effectiveness of lateral control, that is, the time between the pilot input and when the airplane responds, is in part a function of the airplane's inertia about its longitudinal axis. Airplanes with very long wings, and, in particular, airplanes with engines distributed outboard along the wings, tend to have very much larger inertias than airplanes with engines located on the fuselage. This also applies to airplanes in which fuel is distributed along the wing span. Early in a flight with full wing (or tip) tanks, the moment of inertia about the longitudinal axis will be much larger than when those tanks are nearly empty. This greater inertia must be overcome by the rolling moment to produce a roll acceleration and resulting roll angle, and the effect is a "sluggish" initial response. As discussed before, airplanes of large mass and large inertia require that pilots be prepared for this longer response time and plan appropriately in maneuvering.

From a flight dynamics point of view, the greatest power of lateral control in maneuvering the airplane—in using available energy to maneuver the flight path—is to orient the lift vector. In particular, pilots need to be aware of their ability to orient the lift vector with respect to the gravity vector. Upright with wings level, the lift vector is opposed to the gravity vector, and vertical flight path is controlled by longitudinal control and thrust. Upright with wings not level, the lift vector is not aligned with gravity, and the flight path will be curved. In addition, if load factor is not increased beyond 1.0, that is, if lift on the wings is not greater than weight, the vertical flight path will become curved in the downward direction, and the airplane will begin to descend. Hypothetically, with the airplane inverted, lift and gravity point in the same direction: down. The vertical flight path will be-

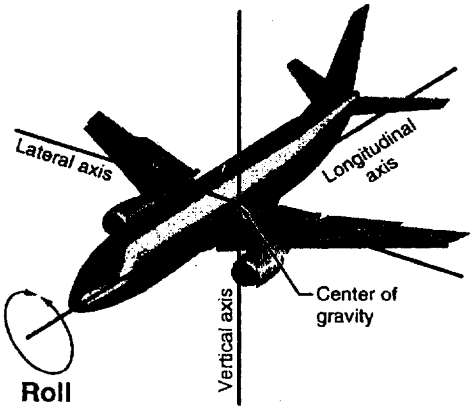


Figure 35
Roll Axis

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come curved and the airplane will accelerate toward the earth quite rapidly. In this case, the pilot must find a way to orient the lift vector away from gravity. In all cases, the pilot should ensure that the angle of attack is below the stall angle and roll to upright as rapidly as possible.

2.5.5.10 Directional Maneuvering

Motion about the vertical axis is called "yaw" (Fig. 36). The character of the motion about the vertical axis is determined by the balance of moments about the axis (around the center of gravity). The principal controller of aerodynamic moments about the vertical axis is the rudder, but it is not the only one. Moments about the vertical axis can be generated or affected by asymmetric thrust, or by asymmetric drag (generated by ailerons, spoilers, asymmetric flaps, and the like). These asymmetric moments may be desired (designed in) or undesired (perhaps the result of some failure).

Generally, the rudder is used to control yaw in a way that minimizes the angle of sideslip, that is, the angle between the airplane's longitudinal axis and the relative wind. For example, when an engine fails on takeoff, the object is to keep the airplane aligned with the runway by using rudder.

On modern jet transports with powerful engines located away from the centerline, an engine failure can result in very large yawing moments, and rudders are generally sized to be able to control those moments down to very low speeds. This means that the rudder is very powerful and has the capability to generate very large yawing moments. ***When the rest of the airplane is symmetric, for example, in a condition of no engine failure, very large yawing moments would result in very large sideslip angles and large structural loads, should the pilot input full rudder when it is not needed.*** Pilots need to be aware of just how powerful the rudder is and the effect it can have when the rest of the airplane is symmetric. Many modern airplanes limit the rudder authority in parts of the flight envelope in which large deflections are not required, for example, at high speeds. In this way, the supporting structure can be made lighter. Pilots also need to be aware of such "rudder limiting" systems and how they operate on airplanes.

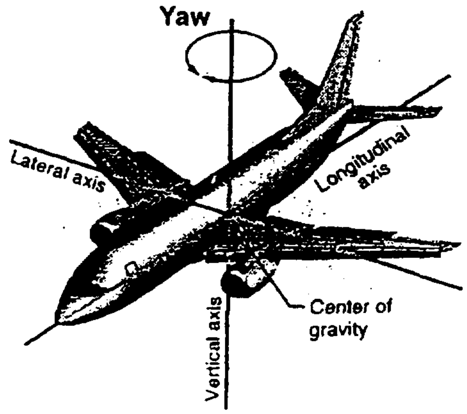

Figure 36
Yaw Axis

There are a few cases, however, when it is necessary to generate sideslip. One of the most common is the crosswind landing. In the slip-to-a-landing technique, simultaneous use of rudder and aileron/spoiler aligns the airplane with the runway centerline and at the same time keeps the airplane from drifting downwind. The airplane is flying "sideways" and the pilot feels the lateral acceleration.

Static stability in the directional axis tends to drive the sideslip angle toward zero. The vertical fin and rudder help to do this. The number of times the airplane oscillates as it returns to zero sideslip depends on its dynamic stability. Most of the dynamic stability on a modern transport comes, not from the natural aerodynamics, but from an active stability augmentation system: the yaw damper. If disturbed with the yaw damper off, the inertial and aerodynamic characteristics of a modern jet transport will result in a rolling and yawing motion referred to as "dutch roll." The yaw damper moves the rudder to oppose this motion and damp it out very effectively. Transport airplanes are certificated to demonstrate positively damped dutch-roll oscillations.

The installed systems that can drive the rudder surface are typically designed in a hierarchical manner. For example, the yaw damper typically has authority to move the rudder in only a limited deflection range. Rudder trim, selectable by the pilot, has authority to command much larger rudder deflections that may be needed for engine failure. In most cases, the pilot, with manual control over rudder deflection, is the most powerful element in the system. The pilot can command deflection to the limits of the system, which may be surface stops, actuator force limits, or any others that may be installed (e.g., rudder ratio changers).

second largest force acting on the airplane is the weight vector. Getting the airplane maneuvered so that the lift vector points in the desired direction should be the first priority, and it is the first step toward managing the energy available in the airplane.

2.6 Recovery From Airplane Upsets

Previous sections of this training aid review the causes of airplane upsets to emphasize the principle of avoiding airplane upsets. Basic aerodynamic information indicates how and why large, swept-wing airplanes fly. That information provides the foundation of knowledge necessary for recovering an airplane that has been upset. This section highlights several issues associated with airplane upset recovery and presents basic recommended airplane-recovery techniques for pilots. There are infinite potential situations that pilots can experience while flying an airplane. The techniques that are presented in this section are applicable for most situations.

2.6.1 Situation Awareness of an Airplane Upset

It is important that the first actions for recovering from an airplane upset be correct and timely. Guard against letting the recovery from one upset lead to a different upset situation. ***Troubleshooting the cause of the upset is secondary to initiating the recovery. Regaining and then maintaining control of the airplane is paramount.***

It is necessary to use the primary flight instruments and airplane performance instruments when analyzing the upset situation. While visual meteorological conditions may allow the use of references outside the airplane, it normally is difficult or impossible to see the horizon. This is because in most large commercial airplanes the field of view is restricted. For example, the field of view from an airplane that exceeds 25-deg, nose-up attitude probably is limited to a view of the sky. Conversely, the field of view is restricted to the ground for a nose-down pitch attitude that exceeds 10 deg. In addition, pilots must be prepared to analyze the situation during darkness and when instrument meteorological conditions (IMC) exist. Therefore, the Attitude Direction Indicator (ADI) is used as a primary reference for recovery. Compare the ADI information with performance instrument indications before initiating recovery. For a nose-low upset, normally the airspeed is increasing, altitude is decreasing, and the VSI indicates a descent. For a nose-high upset, the airspeed normally is decreasing, altitude is increasing, and the VSI indicates a climb. Cross-check other attitude sources, for example, the Standby Attitude Indicator and the Pilot Not Flying (PNF) instruments.

Pitch attitude is determined from the ADI Pitch Reference Scales (sometimes referred to as Pitch Ladder Bars). Most modern airplanes also use colors (blue for sky, brown for ground) or ground perspective lines to assist in determining whether the airplane pitch is above or below the horizon. Even in extreme attitudes, some portion of the sky or ground indications is usually present to assist the pilot in analyzing the situation.

The Bank Indicator on the ADI should be used to determine the airplane bank.

Situation analysis process:
- Locate the Bank Indicator.
- Determine pitch attitude.
- Confirm attitude by reference to other indicators.
- Assess the energy.

Recovery techniques presented later in this section include the phrase, ***"Recognize and confirm the situation."*** This situation analysis process is used to accomplish that technique.

2.6.2 Miscellaneous Issues Associated With Upset Recovery

Several issues associated with recovering from an upset have been identified by pilots who have experienced an airplane upset. In addition, observation of pilots in a simulator training environment has also revealed useful information associated with recovery.

2.6.2.1 Startle Factor

It has already been stated that airplane upsets do not occur very often and that there are multiple causes for these unpredictable events. Therefore, pilots are usually surprised or startled when an upset occurs. There can be a tendency for pilots to react before analyzing what is happening or to fixate on one indication and fail to properly diagnose the situation. Proper and sufficient training is the best solution for overcoming the startle factor.

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The pilot must overcome the surprise and quickly shift into analysis of what the airplane is doing and then implement the proper recovery. ***Gain control of the airplane and then determine and eliminate the cause of the upset.***

2.6.2.2 Negative G Force

Airline pilots are normally uncomfortable with aggressively unloading the g forces on a large passenger airplane. They habitually work hard at being very smooth with the controls and keeping a positive 1-g force to ensure flight attendant and passenger comfort and safety. Therefore, they must overcome this inhibition when faced with having to quickly and sometimes aggressively unload the airplane to less than 1 g by pushing down elevator.

Note: It should not normally be necessary to obtain less than 0 g.

While flight simulators can replicate normal flight profiles, most simulators cannot replicate sustained negative-g forces. Pilots must anticipate a significantly different cockpit environment during less-than-1-g situations. They may be floating up against the seat belts and shoulder harnesses. It may be difficult to reach or use rudder pedals if they are not properly adjusted. Unsecured items such as flight kits, approach plates, or lunch trays may be flying around the cockpit. These are things that the pilot must be prepared for when recovering from an upset that involves forces less than 1-g flight.

2.6.2.3 Use of Full Control Inputs

Flight control forces become less effective when the airplane is at or near its critical angle of attack or stall. Therefore, pilots must be prepared to use full control authority, when necessary. The tendency is for pilots not to use full control authority because they rarely are required to do this. This habit must be overcome when recovering from severe upsets.

2.6.2.4 Counter-Intuitive Factors

Pilots are routinely trained to recover from *approach* to stalls. The recovery usually requires an increase in thrust and a relatively small reduction in pitch attitude. Therefore, it may be counter-intuitive to use greater unloading control forces or to reduce thrust when recovering from a high angle of attack, especially at lower altitudes. If the airplane is stalled while already in a nose-down attitude, the pilot must still push the nose down in order to reduce the angle of attack. Altitude cannot be maintained and should be of secondary importance.

2.6.2.5 Previous Training in Nonsimilar Airplanes

Aerodynamic principles do not change, but airplane design creates different flight characteristics. Therefore, training and experience gained in one model or type of airplane may or may not be transferable to another. For example, the handling characteristics of a fighter-type airplane cannot be assumed to be similar to those of a large, commercial, swept-wing airplane.

2.6.2.6 Potential Effects on Engines

Some extreme airplane upset situation may affect engine performance. Large angles of attack can reduce the flow of air into the engine and result in engine surges or compressor stalls. Additionally, large and rapid changes in sideslip angles can create excessive internal engine side loads, which may damage an engine.

2.6.3 Airplane Upset Recovery Techniques

An Airplane Upset Recovery Team comprising representatives from airlines, pilot associations, airplane manufacturers, and government aviation and regulatory agencies developed the techniques presented in this training aid. These techniques are not necessarily procedural. Use of both primary and secondary flight controls to effect the recovery from an upset are discussed. Individual operators must address procedural application within their own airplane fleet structure. The Airplane Upset Recovery Team strongly recommends that procedures for initial recovery emphasize the use of primary flight controls (aileron, elevator, and rudder). However, the application of secondary flight controls (stabilizer trim, thrust vector effects, and speedbrakes) may be considered incrementally to supplement primary flight control inputs after the recovery has been initiated.

For instructional purposes, several different airplane upset situations are discussed. These include the following:

- Nose high, wings level.
- Nose low, wings level.
  - Low airspeed.
  - High airspeed.
- High bank angles.
  - Nose high.
  - Nose low.

This provides the basis for relating the aerodynamic information and techniques to specific situations. ***At the conclusion of this recovery techniques section, recommended recovery techniques are summarized into two basic airplane upset situations: nose-high and nose-low.*** Consolidation of recovery techniques into these two situations is done for simplification and ease of retention.

◆ Following several situations, where appropriate, abbreviated techniques used for recovery are indicated by the solid diamond shown here.

Airplanes that are designed with electronic flight control systems, commonly referred to as "fly-by-wire" airplanes, have features that should minimize the possibility that the airplane would enter into an upset and assist the pilot in recovery, if it becomes necessary. But, when fly-by-wire airplanes are in the degraded flight control mode, the recovery techniques and aerodynamic principles discussed in this training aid are appropriate. Some environmental conditions can upset any airplane. But the basic principles of recognition and recovery techniques still apply, independent of flight control architecture.

Airplane autopilots and autothrottles are intended to be used when the airplane is within its normal flight regime. ***When an airplane has been upset, the autopilot and autothrottle must be disconnected as a prelude to initiating recovery techniques.*** Assessment of the energy is also required.

2.6.3.1 Stall

The recovery techniques assume the airplane is not stalled. An airplane is stalled when the angle of attack is beyond the stalling angle. A stall is characterized by any of, or a combination of, the following:

a. Buffeting, which could be heavy at times.
b. A lack of pitch authority.
c. A lack of roll control.
d. Inability to arrest descent rate.

These characteristics are usually accompanied by a continuous stall warning.

A stall must not be confused with stall warning that occurs before the stall and warns of an approaching stall. Recovery from an approach to stall warning is not the same as recovering from a stall. An approach to stall is a controlled flight maneuver. A stall is an out-of-control condition, but it is recoverable. ***To recover from the stall, angle of attack must be reduced below the stalling angle—apply nose-down pitch control and maintain it until stall recovery.*** Under certain conditions, on airplanes with underwing-mounted engines it may be necessary to reduce thrust to prevent the angle of attack from continuing to increase. ***If the airplane is stalled, it is necessary to first recover from the stalled condition before initiating upset recovery techniques.***

2.6.3.2 Nose-High, Wings-Level Recovery Techniques

Situation: Pitch attitude unintentionally more than 25 deg, nose high, and increasing.

Airspeed decreasing rapidly.

Ability to maneuver decreasing.

Start by disengaging the autopilot and autothrottle and recognize and confirm the situation. Next, apply nose-down elevator to achieve a nose-down pitch rate. This may require as much as full nose-down input. If a sustained column force is required to obtain the desired response, consider trimming off some of the control force. However, it may be difficult to know how much trim should be used; therefore, care must be taken to avoid using too much trim. Do not fly the airplane using pitch trim, and stop trimming nose-down as the required elevator force lessens. If at this point the pitch rate is not immediately under control, there are several additional techniques that may be tried. The use of these techniques depends on the circumstances of the situation and the airplane control characteristics.

Pitch may be controlled by rolling the airplane to a bank angle that starts the nose down. The angle of bank should not normally exceed approximately 60 deg. Continuous nose-down elevator pressure

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will keep the wing angle of attack as low as possible, which will make the normal roll controls effective. With airspeed as low as the onset of the stick shaker, or lower, up to full deflection of the ailerons and spoilers can be used. The rolling maneuver changes the pitch rate into a turning maneuver, allowing the pitch to decrease. (Refer to Fig. 33.) In most situations, these techniques should be enough to recover the airplane from the nose-high, wings-level upset. However, other techniques may also be used to achieve a nose-down pitch rate.

If altitude permits, flight tests have shown that an effective method for getting a nose-down pitch rate is to reduce the power on underwing-mounted engines. (Refer to Sec. 2.5.5.11, "Flight at Extremely Low Airspeeds.") This reduces the upward pitch moment. In fact, in some situations for some airplane models, it may be necessary to reduce thrust to prevent the angle of attack from continuing to increase. This usually results in the nose lowering at higher speeds, and a milder pitchdown. This makes it easier to recover to level flight.

If control provided by the ailerons and spoilers is ineffective, rudder input may be required to induce a rolling maneuver for recovery. ***Only a small amount of rudder input is needed. Too much rudder applied too quickly or held too long may result in loss of lateral and directional control.*** Caution must be used when applying rudder because of the low-energy situation. (Refer to Sec. 2.5.5.10, "Directional Maneuvering.")

To complete the recovery, roll to wings level, if necessary, as the nose approaches the horizon. Recover to slightly nose-low attitude to reduce the potential for entering another upset. Check airspeed, and adjust thrust and pitch as necessary.

Nose-high, wings-level recovery:
- Recognize and confirm the situation.
- Disengage autopilot and autothrottle.
- Apply as much as full nose-down elevator.
- Use appropriate techniques:
  - Roll to obtain a nose-down pitch rate.
  - Reduce thrust (underwing-mounted engines).
- Complete the recovery:
  - Approaching horizon, roll to wings level.
  - Check airspeed, adjust thrust.
  - Establish pitch attitude.

2.6.3.3 Nose-Low, Wings-Level Recovery Techniques

Situation: Pitch attitude unintentionally more than 10 deg, nose low.

Airspeed low.

Recognize and confirm the situation. Disengage the autopilot and autothrottle. Even in a nose-low, low-speed situation, the airplane may be stalled at a relatively low pitch. It is necessary to recover from the stall first. This may require nose-down elevator, which may not be intuitive. Once recovered from the stall, apply thrust. The nose must be returned to the desired pitch by applying nose-up elevator. Avoid a secondary stall, as indicated by stall warning or airplane buffet. Airplane limitations of g forces and airspeed must be respected. (Refer to Sec. 2.5.2, "Energy States.")

Situation: Pitch attitude unintentionally more than 10 deg, nose low.

Airspeed high.

Recognize and confirm the situation. Disengage the autopilot and autothrottle. Apply nose-up elevator. Then it may be necessary to cautiously apply stabilizer trim to assist in obtaining the desired nose-up pitch rate. Stabilizer trim may be necessary for extreme out-of-trim conditions. Reduce thrust, and, if required, extend speedbrakes. The recovery is completed by establishing a pitch, thrust, and airplane configuration that corresponds to the desired airspeed. (Refer to Sec. 2.5.2, "Energy States.") Remember that a very clean airplane can quickly exceed its limits. When applying nose-up elevator, there are several factors that the pilot should consider. Obviously, it is necessary to avoid impact with the terrain. Do not enter into an accelerated stall by exceeding the stall angle of attack. Airplane limitations of g forces and airspeed should also be respected.

Nose-low, wings-level recovery:
- Recognize and confirm the situation.
- Disengage autopilot and autothrottle.
- Recover from stall, if necessary.
- Recover to level flight:
  - Apply nose-up elevator.
  - Apply stabilizer trim, if necessary.
  - Adjust thrust and drag, as necessary.

2.6.3.4 High-Bank-Angle Recovery Techniques

Bank angles can exceed 90 deg. In high-bank situations, the primary objective is to roll the airplane in the shortest direction to near wings level. However, if the airplane is stalled, it is first necessary to recover from the stall.

Situation: Bank angle greater than 45 deg.

Pitch attitude greater than 25 deg, nose high.

Airspeed decreasing.

A nose-high, high-angle-of-bank attitude requires deliberate flight control inputs. A large bank angle is helpful in reducing excessively high pitch attitudes. (Refer to Sec. 2.5.5.8, "Mechanics of Turning Flight.") Recognize and confirm the situation. Disengage the autopilot and autothrottle. Unload (reduce the angle of attack) and adjust the bank angle, not to exceed 60 deg, to achieve a nose-down pitch rate. Maintain awareness of energy management and airplane roll rate. To complete the recovery, roll to wings level as the nose approaches the horizon. Recover to a slightly nose-low attitude. Check airspeed and adjust thrust and pitch as necessary.

Situation: Bank angle greater than 45 deg.

Pitch attitude lower than 10 deg, nose low.

Airspeed increasing.

A nose-low, high-angle-of-bank attitude requires prompt action, because altitude is rapidly being exchanged for airspeed. Even if the airplane is at an altitude where ground impact is not an immediate concern, airspeed can rapidly increase beyond airplane design limits. Recognize and confirm the situation. Disengage the autopilot and autothrottle. Simultaneous application of roll and adjustment of thrust may be necessary. ***It may be necessary to unload the airplane by decreasing backpressure to improve roll effectiveness. If the airplane has exceeded 90 deg of bank, it may feel like "pushing" in order to unload. It is necessary to unload to improve roll control and to prevent pointing the lift vector towards the ground.*** Full aileron and spoiler input may be necessary to smoothly establish a recovery roll rate toward the nearest horizon. It is important that positive g force not be increased or that nose-up elevator or stabilizer trim be used until the airplane approaches wings level. If the application of full lateral control (ailerons and spoilers) is not satisfactory, it may be necessary to apply rudder in the direction of the desired roll. As the wings approach level, extend speedbrakes, if required. Complete the recovery by establishing a pitch, thrust, and airplane drag device configuration that corresponds to the desired airspeed. In large transport-category airplanes, do not attempt to roll through (add pro-roll controls) during an upset in order to achieve wings level more quickly. Roll in the shortest direction to wings level.

2.6.3.5 Consolidated Summary of Airplane Recovery Techniques

These summaries incorporate high-bank-angle techniques.

NOSE-HIGH RECOVERY:

- Recognize and confirm the situation.
- Disengage autopilot and autothrottle.
- Apply as much as full nose-down elevator.
- Use appropriate techniques:
  - Roll (adjust bank angle) to obtain a nose-down pitch rate.
  - Reduce thrust (underwing-mounted engines).
- Complete the recovery:
  - Approaching the horizon, roll to wings level.
  - Check airspeed, adjust thrust.
  - Establish pitch attitude.

NOSE-LOW RECOVERY:

- Recognize and confirm the situation.
- Disengage autopilot and autothrottle.
- Recover from stall, if necessary.
- Roll in the shortest direction to wings level—bank angle more than 90 deg: unload and roll.
- Recover to level flight:
  - Apply nose-up elevator.
  - Apply stabilizer trim, if necessary.
  - Adjust thrust and drag as necessary.

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Example Airplane Upset Recovery Training Program

3.0 Introduction

The overall goal of the *Airplane Upset Recovery Training Aid* is to increase the ability of pilots to *recognize and avoid* situations that may lead to airplane upsets and improve the pilots' ability to recover control of an airplane that has exceeded the normal flight regime. This may be accomplished by increasing awareness of potential upset situations and knowledge of aerodynamics and by application of this knowledge during simulator training scenarios. Therefore, an academic and training program is provided to support this goal.

This "Example Airplane Upset Recovery Training Program" is structured to stand alone, but it may be integrated into existing initial, transition, and recurrent training and check programs, if desired. The Academic Training Program is designed to improve awareness by increasing the pilot's ability to recognize and avoid those situations that cause airplanes to become upset. The academic program also provides aerodynamic information associated with large, jet, swept-wing airplanes. This information provides the basis for understanding aircraft behavior in order to avoid upsets and for understanding why various upset recovery techniques are recommended. Finally, airplane upset recovery techniques are provided for pilots to use to return an airplane to the normal flight regime once it has been upset.

The Simulator Training Program includes a simulator briefing outline and simulator exercises. These exercises are designed for pilots to analyze upset situations and properly apply recovery techniques. A methodical building block approach is used so that pilots can learn the effect of each recovery technique and develop the required piloting skills in applying them. The recommended exercises are the minimum that pilots should accomplish. Operators are encouraged to develop additional exercises and scenarios. Recurrent training should, to the maximum extent possible, use real-time situation-integrated presentations with various levels of automation. Over several recurrent cycles, flight crews should be presented with upsets involving various levels of pilot and automation interface. Good communication, crew coordination, and other skills associated with crew resource management should be an integral part of recurrent training in upset recovery. Use of airplane systems, flight control, or engine malfunctions to accomplish these objectives is encouraged. However, training scenarios should not exceed the limitations of simulator engineering data or mechanical operation. Use of simulators beyond their mechanical or engineering data capabilities can lead to counterproductive learning and should be avoided. Operators are encouraged to assess the capabilities of their simulators and improve them, if necessary, to conduct this training. Simulator engineering information is provided in Appendix 3-D. The purpose of this information is to aid operators in assessing simulators.

3.1 Academic Training Program

The Academic Training Program focuses on the elements that are important to preventing an airplane from being upset and recovery techniques available for returning an airplane to the normal flight regime.

3.1.1 Training Objectives

The objectives of the training program are to provide the pilot with the following:

- Aerodynamic principles of large, swept-wing airplanes.
- The ability to recognize situations that may lead to airplane upsets so that they may be prevented.
- Airplane flight maneuvering information and techniques for recovering from an airplane upset.
- Skill in using upset recovery techniques.

A suggested syllabus is provided, with the knowledge that no single training format or curriculum is best for all operators or training situations. All training materials have been designed to "stand alone." As a result, some redundancy of the subject material occurs. However, using these materials together in the suggested sequence will enhance overall training effectiveness.

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3.1.2 Academic Training Program Modules

The following academic training modules are available for preparing an academic training curriculum.

Pilot Guide. The "Pilot Guide to Airplane Upset Recovery" (*Airplane Upset Recovery Training Aid,* Sec. 2) is a comprehensive treatment of prevention and lessons learned from past upset accidents and incidents. The pilot guide is designed as a document that should be reviewed by an individual pilot at any time before formal upset recovery academic or simulator training.

Pilot Guide Questions. A set of questions based on the material contained in the Pilot Guide is contained in Appendix 3-A. These questions are designed to test the pilot's knowledge of each section of the Pilot Guide. In an airplane upset recovery curriculum, these questions may be used in one of two ways:

1. As part of a pilot's review of the Pilot Guide.
2. As an evaluation to determine the effectiveness of the pilot's self-study prior to subsequent academic or simulator training for upset recovery.

Airplane Upset Recovery Briefing. A paper copy of viewfoils with descriptive words for each one that can be used for a classroom presentation is contained in Appendix 3-B. The briefing supports a classroom discussion of the Pilot Guide.

Video (optional). *Airplane Upset Recovery*—This video is in two parts. Part One is a review of causes of the majority of airplane upsets. It emphasizes awareness as a means of avoiding these events. Part One also presents basic aerodynamic information about large, swept-wing airplanes. This part of the video provides the background necessary for understanding the principles associated with recovery techniques. Part Two presents airplane upset recovery techniques for several different upset situations. Part Two is excellent as an academic portion of recurrent training.

3.1.3 Academic Training Syllabus

Combining all of the previous academic training modules into a comprehensive training syllabus results in the following suggested Academic Training Program:

Training Module	Method of Presentation
Pilot Guide	Self-study/classroom
Pilot Guide Questions	Self-study/classroom
Video (optional)	Classroom
Airplane Upset Briefing	Classroom

3.1.4 Additional Academic Training Resources

The *Airplane Upset Recovery Training Aid* is provided in CD-ROM DOS format. The complete document and the two-part video are included in this format. This allows for more flexible training options and makes the information readily available to pilots. For example, the Pilot Guide (Sec. 2 of the document) may be printed from the CD-ROM format and distributed to all pilots.

3.2 Simulator Training Program

The Simulator Training Program addresses techniques that pilots should use to recover an airplane that has been upset. Training and practice are provided to allow the pilot to, as a minimum, recover from nose-high and nose-low airplane upsets. The exercises have been designed to meet the following criteria:

- Extensive simulator engineering modification will not be necessary.
- All exercises will keep the simulator within the mathematical models and data provided by the airplane manufacturer.
- Exercises will not result in negative or counterproductive training.

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To be most effective, simulator training requires the pilot-in-training to be familiar with the material in the Academic Training Program.

Simulator training exercises are developed so that an operator needs only minimum training capability to encourage the implementation of an effective airplane upset recovery training program. The training exercises may be initiated by several means:

- Manual maneuvering to the demonstration parameters.
- Automated simulator presets.
- Stabilizer trim to induce the demonstration as best suits the pilot-in-training requirements.
- Other appropriate airplane-system, flight-control, or engine malfunctions.

Instructors may be called on to maneuver the simulator to assist the pilot-in-training in order to obtain the desired parameters and learning objectives. The instructors need to be properly trained to avoid nonstandardized or ineffective training.

3.2.1 Simulator Limitations

Simulator fidelity relies on mathematical models and data provided by the airplane manufacturer. The simulator is updated and validated by the manufacturer using flight data acquired during the flight test program. Before a simulator is approved for crew training, it must be evaluated and qualified by a regulatory authority. This process includes a quantitative comparison to actual flight data for certain test conditions, such as those specified in the International Civil Aviation Organization (ICAO) *Manual of Criteria for the Qualification of Flight Simulators.* These flight conditions represent airplane operation within the normal operating envelope.

When properly accomplished, the training recommended in this training aid should be within the normal operating envelope for most simulators. However, operators must assess their simulators to ensure their ability to support the exercises. This assessment should include, at a minimum, aerodynamic math models, their associated data tables, and the performance capabilities of visual, flight instrument and motion systems to support maneuvers performed in the simulator.

Appendix 3-D, "Flight Simulator Information," was developed to aid operators and training organizations in assessing their simulators. The information is provided by airplane manufacturers and based on the availability of information. Simulator manufacturers are another source for information.

The simulation may be extended to represent regions outside the typical operating envelope by using reliable predictive methods. However, flight data are not typically available for conditions where flight testing would be very hazardous. From an aerodynamic standpoint, the regimes of flight that are not generally validated fully with flight test data are the stall region and the region of high angle of attack with high-sideslip angle. While numerous approaches to stall or stalls are flown on each model (available test data are normally matched on the simulator) the flight controls are not fully exercised during an approach to stall, or during a full stall, because of safety concerns. Training maneuvers in this regime of flight must be carefully tailored to ensure that the combination of angle of attack and sideslip angle reached in the maneuver do not exceed the range of validated data or analytical/extrapolated data supported by the airplane manufacturer. The values of pitch, roll, and heading angles, however, do not affect the aerodynamics of the simulator or the validity of the training as long as angle of attack and sideslip angles do not exceed values supported by the airplane manufacturer. For example, a full 360-deg roll maneuver conducted without exceeding the valid range of the angle of attack and sideslip angle will be correctly replicated from an aerodynamic standpoint. However, the forces imposed on the pilot and the ratio of control forces to inertial and gravity forces will not be representative of the airplane.

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Simulator technology continues to improve, which allows more training opportunities. However, trainers and pilots must understand that simulators still cannot replicate all things. For example, sustained g forces, both negative and positive, are not replicated. This means that a pilot cannot rely on complete sensory feedback that would be available in an actual airplane. Additionally, such things as loose items that would likely be floating in the cockpit during a negative-g situation are clearly not replicated in the simulator. However, a properly programmed simulator should provide accurate control force feedback (absent any sustained g loading), and the motion system should provide airframe buffet consistent with the aerodynamic characteristics of the airplane which could result from control input during certain recovery situations.

The importance of providing feedback to a pilot when control inputs would have exceeded airframe, physiological, or simulator model limits must be recognized and addressed. Some simulator operators have effectively used a simulator's "crash" mode to indicate limits have been exceeded. Others have chosen to turn the visual system red when given parameters have been exceeded. Simulator operators should work closely with training departments in selecting the most productive feedback method when selected parameters are exceeded.

3.2.2 Training Objectives

The objective of the Simulator Training Program is to provide pilots with the necessary experience and skills to

- Recognize and confirm airplane upset.
- Gain confidence and understanding in maneuvering the airplane during upsets.
- Successfully apply proper airplane upset recovery techniques.

3.2.3 Simulator Training Syllabus

The training given during initial, transition, and recurrent phases of training should follow a building block approach. The first time an upset is introduced, it should be well briefed and the pilot should have general knowledge of how the airplane will react. Since full limits of control forces may be necessary during a recovery from an upset, it may be appropriate to allow the pilot opportunity for maneuvering using all flight control inputs.

Exercises are initiated by the instructor pilot. Once the desired upset situation is achieved, the pilot-in-training then applies appropriate techniques to return the airplane to its normal flight regime or to maneuver the airplane during certain demonstrations, depending on the exercise. It may take several iterations before the pilot-in-training has the required skills for recovering the airplane.

3.2.4 Pilot Simulator Briefing

Pilots should be familiar with the material in the Ground Training Program before beginning Airplane Upset Recovery Training. However, a briefing should be given to review the following:

- Situation analysis process:
  - Callout of the situation.
  - Location of the Bank Indicator.
  - Determination of the pitch attitude.
  - Confirmation of attitude by reference to other indicators.
  - Assessment of the energy.
- Controlling the airplane before determining the cause of the upset.
- Use of full control inputs.
- Counter-intuitive factors.
- G-force factors.
- Use of automation.
- Recovery techniques for nose-high and nose-low upsets.

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Exercise 1. Nose-High Characteristics (Initial Training)

Objective

Develop skills for recovery from a nose-high airplane upset.

General Description

This exercise should be used for initial training. The pilot is exposed to airplane nose-high aerodynamic characteristics. The exercise is designed to allow the pilot-in-training to develop proficiency in techniques for recovering from a nose-high airplane upset. Specifically, the pilot-in-training is required to recover from a minimum of a 40-deg, nose-high upset by recognizing and confirming the situation, verifying that the autopilot and autothrottle are disengaged, and applying appropriate recovery techniques. The first iteration requires the pilot-in-training to use up to full nose-down elevator. The second iteration requires the pilot-in-training to roll the airplane as a technique for reducing the pitch. The third iteration requires the pilot-in-training to use thrust reduction as a pitch-reduction recovery technique, if the airplane model has underwing-mounted engines. All iterations require the pilot to complete the recovery by rolling to wings level, if necessary, and, at the appropriate time, checking airspeed and establishing a final recovery pitch attitude.

Initial Conditions

Altitude:	1000 to 5000 ft above ground level.
Center of gravity:	Midrange.
Airspeed:	Maneuvering plus 50 kn.
Autopilot:	Disengaged.
Autothrottle:	Disengaged.
Attitude:	40-deg, nose-up pitch, wings level.

Exercise 1. Iteration One—Use of Nose-Down Elevator

Instructions for the Instructor Pilot

1. Establish initial conditions. Briefly point out or discuss the pitch-angle scale for various pitch attitudes. Have the pilot-in-training note the pitch attitude for the initial conditions.

2. Initiate the exercise by the following means:
   - Manual maneuvering to the demonstration parameters.
   - Automated simulator presets.
   - Stabilizer trim to induce the demonstration as best suits the pilot-in-training requirements.
   - Other appropriate airplane-system, flight-control, or engine malfunctions.

3. Transfer airplane control to the pilot-in-training.

4. Instruct the pilot-in-training to slowly release the control column and simultaneously increase thrust to maximum. As the airplane pitch attitude passes approximately 40 deg, instruct the pilot-in-training to initiate recovery by simulating disengaging the autopilot and autothrottle and countering pitch; by use of nose-down elevator; and, if required, by using stabilizer trim to relieve elevator control pressure.

5. The pilot-in-training completes the recovery when approaching the horizon by checking airspeed, adjusting thrust, and establishing the appropriate pitch attitude and stabilizer trim setting for level flight.

Common Instructor Pilot Errors

- Achieves inadequate airspeed at entry.
- Attains stall angle of attack because of too-aggressive pull-up.
- Does not achieve full parameters before transfer of airplane control to the pilot-in-training.

Common Pilot-in-Training Errors

- Fails to simulate disengaging the autopilot and autothrottle.
- Hesitates to use up to full control input.
- Overtrims nose-down stabilizer.

Exercise 1. Iteration Two—Use of Bank Angle

Instructions for the Instructor Pilot

1. Establish initial conditions.

2. Initiates the exercise by the following means:
    - Manual maneuvering to the demonstration parameters.
    - Automated simulator presets.
    - Stabilizer trim to induce the demonstration as best suits the pilot-in-training requirements.
    - Other appropriate airplane-system, flight-control, or engine malfunctions.

3. Slowly release the control column and simultaneously increase thrust to maximum.

4. Transfer airplane control to the pilot-in-training.

5. Allow the simulator to pitch up until approximately 40 deg.

6. Have the pilot-in-training roll the airplane until a nose-down pitch rate is detected.

7. The pilot-in-training completes the recovery when approaching the horizon by rolling to wings level and slightly nose low, checking airspeed, adjusting thrust, and establishing the appropriate pitch attitude and stabilizer trim setting for level flight.

Common Pilot-in-Training Errors

- Achieves the required roll too slowly, which allows the nose to drop too slowly and airspeed to become excessively low.
- Continues the roll past what is required to achieve a nose-down pitch rate; therefore, the difficulty of recovery is unnecessarily increased.
- Rolls out at a pitch attitude that is too high for conditions and encounters an approach to stall.

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Exercise 1. Iteration Three—Thrust Reduction (Underwing-Mounted Engines)

Instructions for the Instructor Pilot

1. Establish initial conditions.

2. Initiate the exercise by the following means:
   - Manual maneuvering to the demonstration parameters.
   - Automated simulator presets.
   - Stabilizer trim to induce the demonstration as best suits the pilot-in-training requirements.
   - Other appropriate airplane-system, flight-control, or engine malfunctions.

3. Slowly release the control column and simultaneously increase thrust to maximum.

4. Allow the airplane to pitch up until 40 deg.

5. Transfer airplane control to the pilot-in-training.

6. Instruct the pilot-in-training to initiate recovery by reducing thrust to approximately midrange until a detectable nose-down pitch rate is achieved.

7. The pilot-in-training completes the recovery when approaching the horizon by checking airspeed, adjusting thrust, and establishing the appropriate pitch attitude and stabilizer trim setting for level flight.

Common Pilot-in-Training Errors

- Fails to simulate disengaging the autopilot and autothrottle.
- Fails to reduce thrust sufficiently to obtain nose-down pitch.
- Reduces thrust excessively.

Exercise 2. Nose-Low Characteristics (Initial Training)

Objectives

- Demonstrate low-speed and high-speed accelerated stalls.
- Develop skills for recovery from a nose-low airplane upset.

General Description

This exercise should be used for initial training. Selected iterations should also be used for recurrent training as determined by the operator. The pilot is exposed to airplane nose-low aerodynamic characteristics. The exercise is designed to demonstrate what an approach to accelerated stall is and how to recover from it. The pilot-in-training is required to recover from a minimum of a 20-deg, nose-low upset. High-bank-angle (up to inverted flight), nose-low upset iterations are used. To recover, the pilot-in-training recognizes and confirms the situation and verifies that the autopilot and autothrottle are disengaged. Thrust is adjusted for the appropriate energy condition. For a satisfactory nose-low recovery, the pilot-in-training must avoid ground impact and accelerated stall and respect g-force and airspeed limitations. The pilot-in-training is required to recover to stabilized flight with a pitch, thrust, and airplane configuration that corresponds to the desired airspeed.

Initial Conditions

Altitude:	1000 to 10,000 ft above ground level.
Center of gravity:	Midrange.
Airspeed:	L/D maximum or minimum maneuvering.
Autopilot:	Disengaged.
Autothrottle:	Disengaged.
Attitude:	Level flight, then establish up to 20 deg, nose low, and about 60 deg, of bank.

Exercise 2. Iteration One—High Entry Airspeed

Instructions for the Instructor Pilot

1. Begin the exercise while in level flight.
2. Have the pilot-in-training roll the airplane to 60 deg with no attempt to maintain altitude.
3. Have the pilot-in-training observe the nose drop and airspeed increase and the outside view of the ground.
4. Instruct the pilot-in-training to recover by recognizing and confirming the situation; verifying that the autopilot and autothrottle are disengaged; rolling to approaching wings level, then applying nose-up elevator; applying stabilizer trim, if necessary; and adjusting thrust and drag as necessary.

Common Pilot-in-Training Errors

- Forgets to disengage the autopilot and or autothrottle.
- Fails to use full control inputs.
- Initiates pull-up before approaching wings level.
- Attempts to precisely obtain wings level and delays pull-up.
- Enters secondary stall.
- Exceeds positive g force during pull-up.
- Fails to reduce thrust to idle for high speed.
- Fails to use speedbrakes, if required.
- Achieves inadequate pull-up to avoid ground impact.

Exercise 2. Iteration Two—Accelerated Stall Demonstration

Instructions for the Instructor Pilot

1. Establish initial conditions.

2. Initiate the exercise by the following means:
   - Manual maneuvering to the demonstration parameters.
   - Automated simulator presets.
   - Stabilizer trim to induce the demonstration as best suits the pilot-in-training requirements.
   - Other appropriate airplane-system, flight-control, or engine malfunctions.

Note: For manual maneuvering to the demonstration parameters, the instructor pilot applies nose-up elevator assisted with a small amount of nose-up stabilizer trim to slowly achieve up to 20-deg, nose-high pitch. Do not change the entry thrust. Allow the airspeed to decrease. Upon reaching approximately 20 deg of nose-up pitch, the instructor pilot rolls the airplane until a nose-down pitch rate is achieved. The instructor pilot holds that bank angle until the nose is well below the horizon.

3. Have the pilot-in-training note the reduced ability to visually detect the horizon once below 10 deg, nose low.

4. Transfer airplane control to the pilot-in-training.

5. When approximately 20 deg below the horizon, instruct the pilot-in-training to slowly apply backpressure while maintaining the bank angle. Sufficient backpressure is applied until achieving stick shaker. Note the airspeed, and unload to eliminate stick shaker. Again, after allowing bank to increase and pitch to go lower, have the pilot-in-training slowly apply backpressure until achieving stick shaker. Note the airspeed, and unload and initiate recovery.

6. Recovery is accomplished by recognizing and confirming the situation and verifying that the autopilot and autothrottle are disengaged. The pilot-in-training rolls to approaching wings level and then recovers to level flight by applying nose-up elevator and nose-up stabilizer trim, if necessary, and adjusting thrust and drag as necessary.

Common Instructor Pilot Errors

- Allows airspeed to become excessive for final recovery.
- Allows the pilot-in-training to pull to stick shaker too quickly, and angle of attack exceeds simulator fidelity.
- Allows the pilot-in-training to reduce bank angle and pitch before final recovery.

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Exercise 2. Iteration Three—High Bank Angle/Inverted Flight

Instructions for the Instructor Pilot

1. Establish initial conditions.

2. Initiate the exercise by the following means:
   - Manual maneuvering to the demonstration parameters.
   - Automated simulator presets.
   - Stabilizer trim to induce the demonstration as best suits the pilot-in-training requirements.
   - Other appropriate airplane-system, flight-control, or engine malfunctions.

Note: For manual maneuvering to the demonstration parameters, the instructor pilot applies nose-up elevator assisted with small amounts of nose-up stabilizer trim to slowly achieve up to 20 deg of pitch. Do not change the entry thrust.

3. Transfer airplane control to the pilot-in-training.

4. At approximately 20 deg of nose-up pitch, the pilot-in-training rolls the airplane until a nose-down pitch rate is achieved. Use a roll rate that will achieve 120 deg of bank at about 20 deg, nose low.

5. Have the pilot-in-training note the reduced ability to visually detect the horizon.

6. When approximately 20 deg below the horizon, the pilot-in-training recovers by recognizing and confirming the situation and verifying that the autopilot and autothrottle are disengaged. The pilot-in-training must unload and roll. The pilot-in-training, when approaching wings level, recovers to level flight by applying nose-up elevator and nose-up stabilizer trim, if necessary, and adjusting thrust and drag as necessary.

Common Instructor Pilot Errors

- Allows airspeed to become excessive for final recovery.
- Allows the pilot-in-training to pull to stick shaker too quickly and exceed stall angle of attack or g-force limit.
- Fails to notice improper control inputs.

Common Pilot-in-Training Errors

- Forgets to disengage the autopilot or autothrottle.
- Fails to unload.
- Fails to use sufficient control inputs.
- Initiates pull-up before approaching wings level.
- Attempts to precisely obtain wings level and delays pull-up.
- Exceeds positive g-force limits during pull-up.
- Fails to reduce thrust to idle for high speed.
- Fails to use speedbrakes, if required.
- Achieves inadequate pull-up to avoid ground impact.

Exercise 3. Optional Practice Exercise

Objectives

- Develop skills for recovery from a nose-high, low-energy airplane upset.
- Expose the pilot to a realistic airplane upset that requires disengaging the autopilot and autothrottle.

General Description

This exercise may be used for initial training modified for the airplane model. It is a good example for a recurrent training scenario. The instructor pilot is not required to occupy a pilot position. No additional training time is required, since a normal takeoff and departure is continued. The pilots are exposed to a nose-high, low-energy situation. It allows the pilot-in-training to experience a challenging airplane upset recovery. The focus of this exercise is on the entry and recovery from an airplane upset, not on the engine thrust reduction. Malfunction analysis or nonnormal procedure accomplishment should not be done. A normal takeoff is made. During the second segment climb with the autopilot and autothrottle engaged at 1000 ft above ground level, thrust is reduced to idle on one engine (the outboard engine for airplanes with more than two engines). The intent is to create a nose-high, significant yaw and roll condition with decreasing airspeed. When the bank angle is approximately 45 deg, the instructor pilot informs the pilot-in-training to recover by using appropriate recovery techniques. After recovery, normal thrust is restored.

Initial Conditions

Altitude:	1000 ft above ground level and climbing.
Center of gravity:	Midrange.
Airspeed:	Second segment climb airspeed.
Autopilot:	Engaged.
Autothrottle:	Engaged.
Thrust:	As required.
Target parameters:	45-deg bank angle. Autopilot and autothrottle engaged. Minimum of 1000 ft above ground level.

Exercise 3. Instructions for the Simulator Instructor

1. Establish initial conditions.
2. Reduce thrust to idle on one engine (the outboard engine for airplanes with more than two engines). Maintain thrust on other engine(s).
3. Have the pilot-in-training observe the developing yaw and roll condition and decreasing airspeed.
4. Upon passing 45 deg of bank, instruct the pilot-in-training to recover by assessing the energy, disengaging the autopilot and autothrottle, and applying appropriate recovery techniques. Roll control may require as much as full aileron and spoiler input and use of coordinated rudder.
5. After recovery, normal thrust is used and training continues.

Common Instructor Pilot Errors

- Autopilot and autothrottle are not engaged at 1000 ft above ground level.
- Has the pilot-in-training initiate recovery before allowing the autopilot to fly to 45 deg of bank angle.

Common Pilot-in-Training Errors

- Forgets to disengage the autopilot or autothrottle.
- Fails to unload.
- Fails to use full control inputs.
- Fails to complete the recovery before ground impact.

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Recurrent Training Exercises

The pilot-in-training should be given the opportunity to review the airplane handling characteristics. Those events identified as pre-exercise practice are appropriate for this review. The length of review should depend on pilot-in-training experience and skill level.

Recurrent training should incorporate a nose-high situation. This situation can be induced by the pilot-in-training, or by the Pilot Not Flying (PNF) (with perhaps the pilot-in-training closing his or her eyes to force an assessment of the situation and energy), or by conditions available to the instructor by the use of simulator engineering. The pilot-in-training should recover by using appropriate techniques discussed in initial training.

Recurrent training should incorporate a nose-low, high-bank-angle situation. This situation can be induced by the pilot-in-training, or by the PNF (with perhaps the pilot-in-training closing his or her eyes to force an assessment of the situation and energy), or by conditions available to the instructor by the use of simulator engineering. The pilot-in-training should recover by using appropriate techniques discussed in initial training.

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APPENDIX 3-D

Flight Simulator Information

General Information

The ability of the simulators in existence today to adequately replicate the maneuvers being proposed for airplane upset recovery training is an important consideration. Concerns raised about simulators during the creation of the *Airplane Upset Recovery Training Aid* include the adequacy of the hardware, the equations of motion, and the aerodynamic modeling to provide realistic cues to the flight crew during training at unusual attitudes.

It is possible that some simulators in existence today may have flight instruments, visual systems or other hardware that will not replicate the full six-degree-of-freedom movement of the airplane that may be required during unusual attitude training. It is important that the capabilities of each simulator be evaluated before attempting airplane upset training and that simulator hardware and software be confirmed as compatible with the training proposed.

Properly implemented equations of motion in modern simulators are generally valid through the full six-degree-of-freedom range of pitch, roll, and yaw angles. However, it is possible that some existing simulators may have equations of motion that have unacceptable singularities at 90, 180, 270, or 360 deg of roll or pitch angle. Each simulator to be used for airplane upset training must be confirmed to use equations of motion and math models (and associated data tables) that are valid for the full range of maneuvers required. This confirmation may require coordination with the airplane and simulator manufacturer.

Operators must also understand that simulators cannot fully replicate all flight characteristics. For example, motion systems cannot replicate sustained linear and rotational accelerations. This is true of pitch, roll, and yaw accelerations, and longitudinal and side accelerations, as well as normal load factor, "g's." This means that a pilot cannot rely on all sensory feedback that would be available in an actual airplane. However, a properly programmed simulator should provide accurate control force feedback and the motion system should provide airframe buffet consistent with the aerodynamic characteristics of the airplane which could result from control input during certain recovery situations.

The importance of providing feedback to a pilot when control inputs would have exceeded airframe, physiological, or simulator model limits must be recognized and addressed. Some simulator operators have effectively used a simulator's "crash" mode to indicate limits have been exceeded. Others have chosen to turn the visual system red when given parameters have been exceeded. Simulator operators should work closely with training departments in selecting the most productive feedback method when selected parameters are exceeded.

The simulation typically is updated and validated by the airplane manufacturer using flight data acquired during the flight test program. Before a simulator is approved for any crew training, it must be evaluated and qualified by a national regulatory authority. This process includes a quantitative comparison of simulation results to actual flight data for certain test conditions such as those specified in the ICAO *Manual of Criteria for the Qualification of Flight Simulators*. These flight conditions represent airplane operation within the normal operating envelope.

The simulation may be extended to represent regions outside the typical operating envelope using wind tunnel data or other predictive methods. However, flight data are not typically available for conditions where flight testing would be very hazardous. From an aerodynamic standpoint, the regimes of flight that are usually not fully validated with flight data are the stall region and the region of high angle of attack with high sideslip angle where there may be separated airflow over the wing or empennage surfaces. While numerous approaches to stall or stalls are flown on each model (available test data are normally matched on the simulator), the flight controls are not fully exercised during an approach to stall or during a full stall, because of safety concerns. Also, roll and yaw rates and sideslip angle are carefully controlled during stall maneuvers to be near zero; therefore, validation of derivatives involving these terms in the stall region is not possible. Training maneuvers in this regime of flight must be carefully tailored to ensure that the combination of angle of attack and sideslip angle reached during the maneuver does not exceed the range of validated data or analytical/extrapolated data supported by the airplane manufacturer.

Values of pitch, roll, and heading angles, however, do not directly affect the aerodynamic characteristics of the airplane or the validity of simulator training as long as angle of attack and sideslip angles do not exceed values supported by the airplane manufacturer. For example, the aerodynamic characteristics of the upset experienced during a 360-deg roll maneuver will be correctly replicated if the maneuver is conducted without exceeding the valid range of angle of attack and sideslip.

Simulator Alpha-Beta Data Plots

The aerodynamic model for each simulation may be divided into regions of various "confidence levels," depending on the degree of flight validation or source of predictive methods if supported by the airplane manufacturer, correctly implemented by the simulator manufacturer and accurately supported and maintained on an individual simulator. These confidence levels may be classified into three general areas:

1. High: Validated by flight test data for a variety of tests and flight conditions.
2. Medium: Based on reliable predictive methods.
3. Low: Extrapolated.

The flaps up data represent the maximums achieved at low speeds flaps up and do not imply that these values have been achieved at or near cruise speeds. For flaps down, the maximums were generally achieved at landing flaps, but are considered valid for the flaps down speed envelope.

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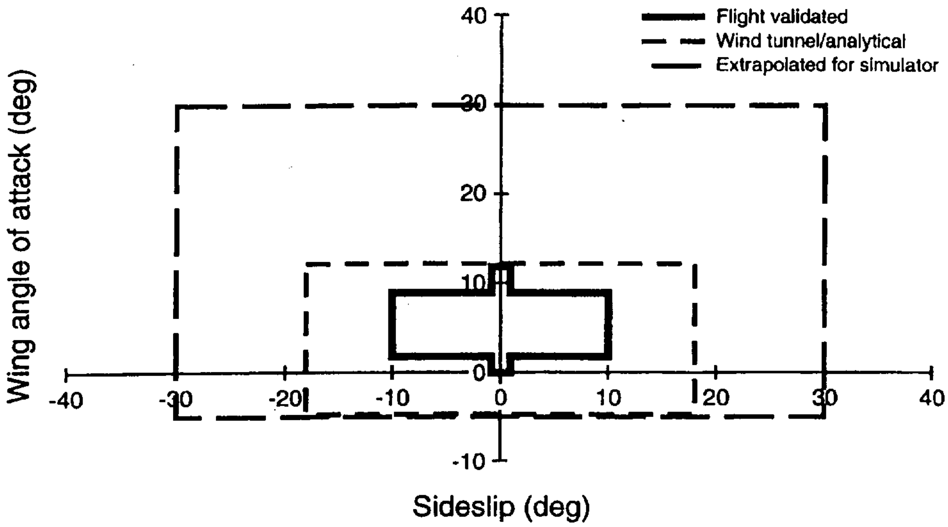
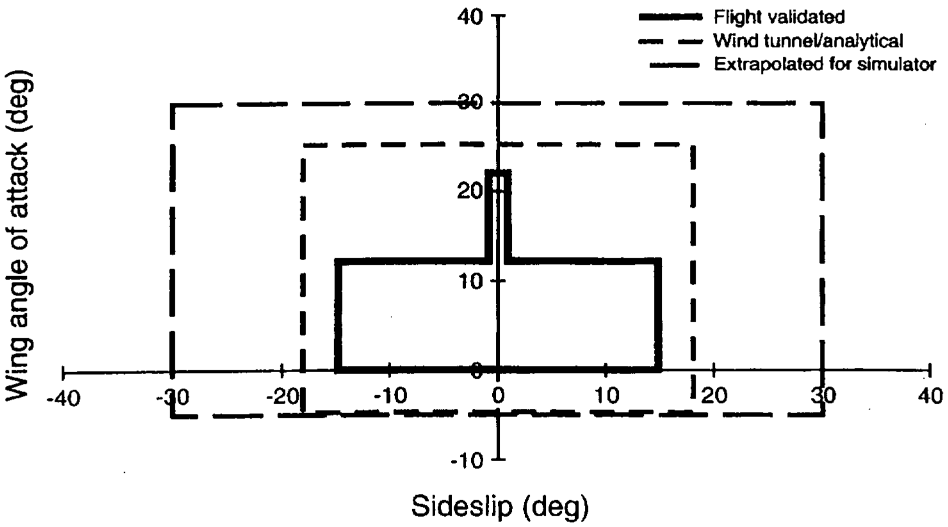
A300/A310 Flaps Up Alpha/Beta Envelope



A300/A310 Alpha/Beta Envelope



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APPENDIX 5.5

NTSB Final Report on AA 903

(1 pages)

NTSB Identification: **DCA97MA049** . The docket is stored in the (offline) NTSB Imaging System.
Scheduled 14 CFR Part 121: Air Carrier operation of AMERICAN AIRLINES
Accident occurred Monday, May 12, 1997 in WEST PALM BEACH, FL
Probable Cause Approval Date: 2/11/00
Aircraft: Airbus Industrie A300B4-605R, registration: N90070
Injuries: 1 Serious, 1 Minor, 163 Uninjured.

The flight was assigned an airspeed of 230 knots and cleared to descend from FL240 to 16,000 feet in preparation for landing at Miami. The FDR indicated that while the autopilot was engaged in the descent, the power levers moved from the mechanical autothrottle limit of 44 degrees to the manual limit of 37 degrees. As the aircraft leveled at 16,000 feet the airspeed decreased. The F/O began a right turn to enter a holding pattern and added some power, which stabilized the airspeed at 178 knots. However, the right bank and the resultant angle of attack (AOA) continued to increase, despite left aileron input by the autopilot. As the autopilot reached the maximum input of 20 degrees, bank angle increased past 50 degrees, and the AOA increased rapidly from 7 degrees to 12 degrees. At this point the stick shaker activated, the autopilot independently disconnected, the power was increased, and full left rudder was used to arrest the roll. The bank angle reached 56 degrees, and the AOA reached 13.7 degrees at 177 knots. The aircraft then pitched down, and entered a series of pitch, yaw, and roll maneuvers as the flight controls went through a period of oscillations for about 34 seconds. The maneuvers finally dampened and the crew recovered at approximately 13,000 feet. One passenger was seriously injured and one flight attendant received minor injuries during the upset. According to wind tunnel and flight test data the A300 engineering simulator should adequately represent the aircraft up to 9 degrees AOA. Unlike the accident aircraft; however, the simulator recovered to wings level promptly when the lateral control inputs recorded by the FDR were used. The roll disagreement between the simulator and accident aircraft began at 7 degrees AOA, and it appears that some effect not modeled in the simulator produced the roll discrepancy. Just prior to the upset the accident aircraft entered a cloud deck. The winds were approximately 240 degrees, 35 knots, and the ambient air temperature was approximately minus 4 degrees C. An atmospheric disturbance or asymmetric ice contamination were two possible explanations considered, but unproven.

The National Transportation Safety Board determines the probable cause(s) of this accident as follows:

The flightcrew's failure to maintain adequate airspeed during leveloff which led to an inadvertent stall, and their subsequent failure to use proper stall recovery techniques. A factor contributing to the accident was the flightcrew's failure to properly use the autothrottle.

APPENDIX 5.4

Airbus Submission on AA 903

(11 pages)

Docket No. SA-522

Exhibit No. 2-V

NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C.

Airbus Industrie Submission to the National Transportation Safety Board Regarding American Airlines Flight 903

(11 Pages)

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OUR REFERENCE	AI/E-fs 420.0213/98
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Mr. Jim HALL
Chairman
National Transportation Safety Board
490 L'Enfant Plaza East SW
Washington D.C. 20594-2000
U.S.A.

Dear Mr. Hall,

In May 1997, an A300-600 operated by American Airlines experienced an in-flight upset above Palm Beach. The aircraft subsequently landed safely. Only a few injuries were reported.

Airbus Industrie was given the opportunity to investigate this event with your technical experts and I take this opportunity to thank all of them for the very fruitful co-operation encountered during the work.

Please find attached the Airbus Industrie submission to support the National Transportation Safety Board in this investigation.

Obviously, I remain with all my team at your disposal should you require any further information from us.

With my best regards,

Yves BENOIST
Director Flight Safety

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Airbus Industrie Submission

Related To The American Airlines Flight 903 Investigation

Airbus Industrie welcomes the opportunity to make this submission in its continuing efforts to support the National Transportation Safety Board (NTSB) in its investigation of the events that occurred on American Airlines Flight 903 on May 12, 1997.

Airbus Industrie commends the NTSB for the professional manner in which this investigation was conducted. The investigation was very thorough and all significant operational and technical factors were examined in detail. The factual reports of the various Groups show that the pertinent events were thoroughly examined and the significant factors associated with these events were fully understood, considering the limitations of the information available. To further assist the NTSB in its deliberations in the next phase of its investigation, Airbus Industrie offers the following comments for consideration.

Comments Concerning Aircraft Motion During The Event.

Airbus Industrie believes that the following portions of the conclusions in the Aircraft Performance Group Report very succinctly summarize the most significant aspects of the event. Airbus Industrie is in full agreement with these conclusions.

"The evidence presented and analyzed by this Performance Study indicates that after descending to 16,000 ft., AA903 slowly decelerated until the angle of attack exceeded the angle of attack for maximum lift and the aircraft stalled. Following the nose down pitching motion associated with the stall, the aircraft pitched nose up in response to elevator commands, increasing the angle of attack into a secondary stall. This cycle was repeated three more times for a total of five excursions above the stall angle of attack."

"During these pitch oscillations, the aircraft underwent large oscillations in the lateral and directional axes in response to full coordinated lateral/directional control inputs. The oscillations about all three aircraft axes resulted in large longitudinal, lateral, and vertical load factors at the aircraft CG. Control of the aircraft was regained when the airspeed increased to the point that the pitch excursions no longer increased the angle of attack beyond stall."

"Prior to the first stall, the aircraft was in a right turn. In spite of left roll control commands by the autopilot, the bank angle departed to the right and reached 56° before it was arrested with left rudder inputs just as the aircraft reached stall[1]. The effect of the bank angle disturbance is to increase the lift required for level flight and accelerate the rate at which the angle of attach increases, thereby shortening the time required to exceed the stall angle of attack."

"Conclusive knowledge of the reasons for the roll departure is not required to evaluate the significance of the departure in the mechanics of the overall upset, or to determine its effects on the aircraft motion if encountered at a different initial condition. On the accident flight, the roll departure resulted in a stall because the aircraft was flying at an airspeed that did not allow sufficient angle of attack margin to increase the lift as necessary to compensate for the increased bank angle. Simulator tests indicate that had the roll upset been encountered at an airspeed of 210 kts. The event could have been controlled easily by the autopilot."

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[1] In the text of the final factual report, this statement is slightly amended, to take into account the fact that the rudder inputs were not the only means for arresting the roll.

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"Simulator tests also indicate that the control techniques used to recover from the stall have a strong effect on the post stall motion. Techniques that attempt to maintain a nose-high attitude while controlling bank angle with large rudder and wheel inputs result in the secondary stalls and large lateral/directional oscillations experienced by AA903. Techniques that attempt to first lower the nose and angle of attack and use small, coordinated rudder and wheel inputs result in a quicker and smoother return to controlled, level flight."

Comments Concerning Procedure Application.

The Aircraft Performance Group, Operations Group, Air Traffic Control Group, and Meteorological Group all determined that significant weather existed in the area. The American Airlines Operating Manual has very detailed guidance for crews operating in these conditions.

Airbus Industrie supports the guidance American Airlines provides to its flight crews in its Flight Manual, Part I, Human Factors Policy. The Human Factors Policy states, in part, "maintain situation awareness by preparing for what can be reasonably expected and by setting and acting on priorities in any abnormal situation." The Turbulent Air Section of the Operating Manual provides detailed guidance on how to comply with the Human Factors Policy when operating in an area of known turbulence. Specific guidance is provided, in the Turbulent Air Section, for target airspeed, autopilot/autothrottle use, and proper aircraft attitude.

The American Airlines Windshear/Microburst Escape Procedure is also detailed in the Operating Manual. It provides specific procedures for crews to use in a windshear encounter. Additionally, it emphasizes the phases of flight in which the use of this procedure is appropriate. All of these phases involve flight in close proximity to the ground. The procedure is not associated with operations at medium to high altitude.

Unusual Attitude Recoveries are referenced in the Techniques Section of the American Airlines Operating Manual. This section specifies recovery methods for both nose-high and nose-low situations. The nose-high recovery procedure instructs pilots to unload the aircraft and roll to regain the horizon. This procedure is opposite, for valid reasons, to the Windshear/ Microburst Escape Procedure, which instructs the pilot to increase pitch to the target attitude to minimize altitude loss and thereby avoid ground contact.

Comments On The Reason For The Very Low Speed.

As noted in the Aircraft Performance Group Report, the aircraft slowly decelerated to 178 knots (32 knots below the 210-knot target speed) because the Autopilot was maintaining 16,000 feet and the engines were at idle, until just before the stall occurred.

The engagement status of the Autothrottle system was not recorded by the DFDR. This is due to the mismatch of the a/c wiring introduced when American Airline installed an improved FDAU. However, other information on the DFDR shows that the autothrottles were disconnected during the descent to 16,000 feet.

During the early stages of this descent, supporting data indicates that the autothrottles were most likely still engaged because the Throttle Lever Angle (TLA) is never lower than 5°. This is the minimum position that the autothrottles can command (when flaps are retracted) and this is the normal throttles position during a typical descent

However, supporting data shows that the autothrottles were most likely disconnected at DFDR time 19:25:46, prior to reaching 16,000 feet and about 3 minutes and 20 seconds prior to the first stall. At this

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time, the TLA is reduced to 0° (TRA=38°), which is below the operating range of the autothrottles. This means that the throttles were disconnected and manually moved to the flight idle position.

The supporting data also shows that the autothrottles remained functional and there were no failures. If the autothrottle system had failed prior to the stall, the Alpha Floor "thrust protection" function would not have remained armed. Since the Alpha Floor function remained armed and was activated during the event, it is very unlikely that there was a failure in the autothrottles. Furthermore, the autothrottle system is a "dual" design, which makes it very unlikely that the system experienced a latent undetected failure.

Note : The autothrottle may be a "dual dual" design should a standard option being selected (installation of a second Thrust Control Computer).

The throttles stayed in the flight idle position until just 8 seconds prior to the first stall, which caused the speed to slowly decrease to 178 knots, after the autopilot captured and maintained 16,000 feet. The deceleration from 210 knots to stall occurred over a forty-second period.

Comments On Autothrottle Disconnection and Pilot Attention Getters.

The NTSB is correct in noting that the design of the A300-600 autothrottle system is different from some of the other manufacturers. However, Airbus Industrie believes that the A300-600 system design is more robust and more tolerant to human error than the other designs.

First, as previously mentioned, the system is a "dual" system, which makes the occurrence of undetected failures very remote.

Second, when the autothrottle are disconnected, an amber "MAN THR" warning appears in the "thrust window" of the Flight Mode Annunciator (FMA) which is located across the top of the Primary Flight Display (PFD). This amber warning remains in the FMA as long as the autothrottle remains disconnected. Therefore, the "thrust window" in the FMA continuously provides both pilots with information, within their primary field of view, concerning the engagement status of the autothrottle. Since the FMA is part of a pilots normal instrument scan, information concerning the autothrottle engagement status is continuously available to both pilots.

Third, if a failure occurs in the autothrottle system, the system is automatically disconnected. An immediate aural and visual warning is generated to alert the pilots.

The only time that an aural warning is not provided is when a pilot pushes the "instinctive disconnect" button. In this case, the visual amber "MAN THR" annunciation is provided on the PFD FMA to confirm that the system has properly responded to the pilot's instruction. In the AA903 event, it is the Airbus Industrie opinion that the only possible explanation is that the autothrottle was disconnected by one of the pilots pressing the autothrottle instinctive disconnect button.

Airbus Industrie is aware that some aircraft from other manufacturers use a "two click" process for disconnection of the autothrottles. However, operational experience has shown that many pilots routinely "double click" the autothrottle instinctive disconnect button in these aircraft, thereby negating any perceived benefits from a "two click" disconnection design.

Airbus Industrie believes that continuously displaying the current autothrottle engagement status in the FMA "thrust window" is more tolerant to human error than a design that permits information concerning the engagement status to be cancelled or erased. Furthermore, Airbus Industrie believes that this design is more error tolerant than designs that rely on a "two click" disconnection process.

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Nevertheless, Airbus Industrie is evaluating the NTSB recommendation to determine if further design enhancements are necessary.

Comments Concerning Unusual Attitude Recovery Techniques.

The conclusions in the Aircraft Performance Group Report concerning recovery techniques are consistent with Airbus Industrie recommended training practices, which are supported by flight test results on all Airbus Industrie aircraft. Furthermore, all major aircraft manufacturers and the FAA support the use of these techniques. Boeing (including Douglas) and Airbus Industrie have joined their efforts to produce a common document "Aerodynamic Principles of Large Airplane Upsets). A copy of this brochure is given in annex.

In Unusual Attitude Recovery training, it is important to initially stress unloading the wing through (up to) full down elevator, and down stabilizer trim as necessary. Roll inputs will only be efficient when angle of attack has been reduced. Roll should be introduced only after exhausting the use of the pitch axis controls and after considering the reduction of engine thrust (on airplanes with wing mounted engine). Accident and incident data indicate that many nose high, high angle of attack events are because of inappropriate stabilizer trim. The initial use of elevator and down stabilizer trim will normally be adequate in establishing a nose-down pitch rate. In combination with thrust reduction few failures can be conceived for which these measures would not be sufficient.

As with all proposed scenarios, the use of roll to assist pitch attitude reduction cannot be ruled out, but if the airplane is at high angles of attack, the sideslip introduced by rapid roll may result in departure from controlled flight.

Although a simple rule about rudder usage cannot be stated, an appropriate standard is to first use full aileron control. Then, if the aircraft is not responding, use rudder as necessary to obtain the desired airplane response. Momentary actuation of spoilers during roll input does not significantly increase drag.

Sideslip angle is a crucial parameter during a recovery maneuver. This is probably not well understood by many line pilots, but it has a significant impact on an airplane's stability and control. Large or abrupt rudder usage at high angles of attack can rapidly create large sideslip angles and can lead to rapid loss of controlled flight. Rudder reversals such as those that might be involved in dynamic maneuvers created by using too much rudder in a recovery attempt can lead to structural loads that exceed the design strength of the fin and other associated airframe components. The hazards of inappropriate rudder use during a windshear encounter, wake turbulence recovery, or recovery from low airspeed at high angle of attack (e.g., stick shaker) should also be included in any Unusual Attitude Recovery discussion.

Comments On The Momentary Loss Of The Primary Flight Displays.

The pilots involved in the incident noted that the Primary Flight Displays (PFDs) blanked for a few seconds during one of the post-stall recovery maneuvers. The investigation into this possibility shows that this event occurred and that it was triggered by the extreme roll rates induced by the piloting techniques used during the recovery.

During one of the recovery maneuvers, the roll rate exceeded 45 degrees per second. This extremely high roll rate caused the Symbol Generator Unit (SGU) monitoring function to blank the PFDs for about 3 seconds. The DFDR shows that the data that passes through the SGU (pitch, roll, etc.) were actually frozen for 3 seconds. This is a consequence of a reset of the SGU caused by the extreme roll rates experienced at this time.

(6)

One of the monitoring functions in the SGU is to assure that the roll attitude information displayed on the PFD is equivalent to the information sent by the Inertial Reference System (IRS). In other words, the purpose of this monitoring function is to prevent displaying false attitude information to the pilots.

With respect to roll angle, the monitoring function compares the roll angle coming from the IRS to the roll angle derived from the roll information received by the PFD. The process for computing and comparing the IRS information and the "reverse computation" (the roll angle derived from the information received by the PFD) requires a finite amount of time. Therefore, computational delays can cause the monitoring function to trigger when extreme roll rates are encountered.

The monitoring function triggering level used in the A300-600 takes into account the normal operating and upset recovery techniques recommended by all major manufacturers and all major regulatory agencies. This triggering level was also determined to be acceptable by all of the aircraft certification authorities.

The SGU monitoring function prevents the display of erroneous roll attitude information by triggering a reset of the SGU when the difference between the roll angle coming from the IRS and the one resulting from the "reverse computation" exceeds the monitoring function triggering level.

Airbus Industrie believes that the current triggering threshold for the SGU monitoring function is an appropriate selection, considering the potentially hazardous consequences of displaying erroneous roll information to pilots as well as the recovery techniques and recommended safe operating practices commonly accepted within the industry. Furthermore, pilots cannot properly decipher and use information that is changing at extreme rates.

Nevertheless, Airbus Industrie is re-examining these design choices, in light of the NTSB's recommendations, to determine if it is practical to implement other techniques to accomplish the SGU monitoring function's safety objectives.

Airbus Industrie Corrective Actions.

In March 1998, Airbus Industrie issued Temporary Revisions to the A300-600 Flight Crew Operating Manual (FCOM) and the Quick Reference Handbook (QRH) to alert flight crews to the possibility of momentary blanking of the Primary Flight Displays in situations such as the AA903 event. These changes have also been incorporated into the Airbus Industrie flight crew training programs for the A300-600. This properly responds to the NTSB's recommendation n° 2

As already mentioned above, Airbus Industrie is re-examining the design choices, in light of the two other NTSB's recommendations:
. First to determine if it is practical to implement other techniques to accomplish the SGU monitoring function's safety objectives
. and second to determine if further design enhancements to the autothrottle system are necessary.

(7)

Attachment 1

Copies of the Temporary Revisions to the FCOM and QRH.

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Attachment 2

FAST Special Dated June 1998

Aerodynamic Principles of Large-Airplane Upsets

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Dominique Buisson → Y. Benoist

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Dear Colleagues and Party Co-ordinators,

Please find attached the Airbus Industrie submission given to the National Transportation Safety Board in the frame of the AAL903 upset investigation.

I remain obviously at your disposal to answer any query you may have.

With my best regards,

YB

Yves BENOIST
Director Flight Safety

AI/EE Circul.	A	C	D	L	M	P	Q	S	T	W

13 AOUT 1998

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APPENDIX 5.6

AA 903 Chronology of Events

(2 pages)

APPENDIX 5.6 AA 903 CHRONOLOGY OF EVENTS

- On 21 May 1997, eight days after the event, Airbus received the first copies of the DFDR data, as decoded by the operator. This data did not seem to give any indications that very high lateral forces had been encountered.
- On 5 June 1997, thirty-four days after the event, Airbus finally received the raw DFDR data and immediately began decoding it.
- On 9 June 1997, four days after receiving the "raw" DFDR data, the General Loads Department informed the Lateral loads experts of the event and requested that they undertake an analysis to determine if the aircraft could have exceeded certificated loads and, if so, specify the inspections that should be performed.
- On 12 June 1997, three days later, Lateral Loads experts transmitted their initial assessments that indicated that the certification limit loads could have been exceeded and recommended that inspections be conducted.
- On 16 June 1997, seven days after receiving the request, Lateral Loads notified General Loads that it was likely that based on engineering judgment, ultimate loads could have been exceeded and strongly recommended that the aircraft be inspected.
- On 18 June 1997, nine days after the request was received, Vertical Loads experts recommended that additional checks be performed on the wings and fuselage. On this same day, Lateral Loads experts recommended that the aircraft should be grounded to do the required inspections. Also, Airbus learned on this day that the operator had performed certain inspections, but had refused to provide the list of findings to Airbus
- On 20 June 1997, one day later, the operator was notified that the aircraft had sustained very high loads, which required that the aircraft be further inspected.
- Thus, on 20 June 1997, fifteen days after the "raw" DFDR data was decoded by Airbus, the operator notified Airbus of the details of the inspections that had been performed, which did not include the upper portion of the fin, and that no discrepancies had been found. At this point, the Airbus structure team was asked to evaluate the inspection results and determine if any further inspections were needed. One day later, Airbus recommended to the operator that, based on the inspection results, it was not immediately necessary to ground the aircraft, but to perform some

additional tests no later than the next A Check. The operator agreed to perform the tests as requested.

- On 24 June 1997, nineteen days after receiving the "raw" data, Airbus was notified that the required inspections could not be accomplished because the operator did not own any of the tools referenced in the inspection procedures and requested to delay the inspections for another 450 flight hours
- On 27 June 1997, three days later, the operator informed Airbus that the additional inspections had been completed and that there was some damage to the wing areas and engine nacelles. However, the inspection did not discover any discrepancies in the vertical fin or its fittings.
- After a careful review of all of the inspection reports, Airbus determined that there was no need for any further inspections of the vertical fin or its attachments.
- Following the AA 587, the fin of the aircraft involved in AA 903 was checked again with the following conclusion :
    - On February 22, 2002, American Airlines informed Airbus that it had performed a series of inspections since the event, including the tail inspection required by AD 2001-23-51. They had completed the follow on inspection on January 8, 2002. American Airlines also noted that it had added a NDT inspection of the rudder attach fittings.
    - On the 11th March 2002, the original vertical fin was removed because it was subjected to very high loads (above ultimate loads) and structural damage was found (some delamination on one fin attachment lug revealed by ultrasonic NDT inspection). Under NTSB supervision, the subject lugs have now been tested up to rupture, and those tests have demonstrated that not only were these lugs still able to sustain the Certification requirement (UL), but their residual strength remained so high that they broke at the level of a pristine lug, even with the noted delamination.

APPENDIX 5.7

Excerpts from 10th Performance Conference

(7 pages)

Docket No. SA-522

Exhibit No. 2-F

NATIONAL TRANSPORTATION SAFETY BOARD

Washington, D.C.

Attachment K
Excerpt from Airbus Industrie Presentation at 10th Performance and Operations Conference

(7 Pages)

①

AIRPLANE UPSET RECOVERY TRAINING AID

By Captain William Wainwright

1. INTRODUCTION

The idea for a joint industry working group to produce an Airplane Upset Recovery Training Aid was first proposed by ATA in June 1996. It was in response to increasing interest by the NTSB in aircraft loss of control accidents which, together with CFIT, cause a large proportion of accident. They were putting a lot of pressure on the FAA to produce new regulations covering this subject. The working group was a voluntary industry initiative to see what could be done within the existing regulations and to pre-empt new regulations being produced which might only increase the training workload without really improving the situation.

The joint industry team consisted of representatives of all sides of industry; aircraft manufacturers, airlines, governmental authorities, and pilots' unions. It was a good example of how the entire industry, designers, users, and regulators can cooperate on safety issues that are common to everyone. It also marked a "first" in showing that the "Big 3" aircraft manufacturers could and will work together on technical, non-commercial issues. More than 80 persons coming from all around the world, but principally from the USA, participated from time to time

The end result of 2 years work is a training package including a video and a CD-ROM, giving an airplane upset recovery training aid. This package is on free issue to all of you, to use or not to use as you wish. All members of the joint industry group agreed that the package is aimed at preventing loss of control accidents on conventional aircraft. It is not aimed at protected Fly-by-Wire aircraft. There is no need for this type of continuation training on protected aircraft, although a general knowledge of the principles involved is useful for every pilot.

The content of the package is not my subject today, but there are a few issues of general interest which I gained from my experience as a member of the working group which I would like to talk about.

2. THE BEGINNING

The issue of upset training was not new; major airlines around the world, and in particular in the USA, had already produced Upset Recovery Training Programs, or were using one produced by another company. Amongst the members of the group were training pilots from American Airlines, Delta, and United who were already running such training programmes in their simulators.

Since this was essentially seen as a training issue, initially the Flight Test Departments of Boeing and Airbus were not involved. We were represented By Larry Rockliff, Chief Pilot at ATC Miami, and Boeing by Dave Carbaugh and Doug Forsythe from their Flight Ops Safety group. Right from the beginning there was a conflict between the technical advice given by the manufacturers' training pilots and that expressed by those of the principal airlines already practicing upset training. They naturally considered themselves to be the experts on this subject, based on the many hours of training that they had already conducted on a large number of pilots in their simulators.

At the beginning of 1997, the Flight Test Departments were asked to come in to support their training pilots. From then on, the chief test pilots of the 3 major manufacturers became members of the working group; John Cashman of Boeing, Tom Melody of McDonnell-Douglas (now Boeing – Douglas Products), and myself. But the conflict over the different opinions on aircraft handling and recovery techniques continued for a long time until we finally achieved agreement at the last meeting in January 1998. The reasons for these differences of opinion are the subject of my talk today.

3. THE DIFFERENCES

The differences of opinion were mainly concentrated in the following areas:

- Procedures versus general advice.
- Ease of training versus failure cases.
- Stalling.
- Use of rudder.
- Use of simulators.

It is worth saying that there was never any difference of opinion between the 3 test pilots on the group. Although we come from different backgrounds and have worked in different organisations with different work cultures, we always agreed on our technical advice.

4. PROCEDURES VERSUS GENERAL ADVICE

The airlines wanted simplified procedures which were common to all aircraft in their fleets and which were easy to teach and easily reproducible. This is understandable because you are all interested in having a standard product at the end of your training programmes. And this is what they already had with the Airplane Upset Recovery Training that they were already doing. For the training managers from American Airlines, Delta, and United, the only thing necessary was to give an overall industry approval to their existing programmes; they already worked, because the many pilots that had undergone training all came out of it with the same standardised reactions to the standard upsets. For them, this was the necessary proof that their training programme worked.

3

Where we differed was in our conviction that there was no such thing as a standard upset and our reluctance to endorse simplified procedures for recovery from an upset. We wanted a general knowledge based approach, as opposed to a rule based one. For this, after proposing some initial actions, we talk about "additional techniques which may be tried". This obviously is more difficult to teach.

Where we reached a compromise was in the order of presenting the various actions that might be considered to recover the situation. For us, the order of presentation is for guidance only; it represents a series of options that should be considered and used as appropriate to the situation. It is not meant to represent rigid procedures that must be followed in an exact sequence. However, the order can be used in training scenarios if you need a procedural approach for your training.

The Airline Instructors also wanted procedures which would apply to all the aircraft in their fleets. This meant that they were against certain actions, because they were inappropriate on others. For example, the thrust effects of underwing-mounted engines were being ignored, whereas it has a significant influence on recovery. Again, we reached a compromise by using the following words: "if altitude permits, flight tests have shown that an effective method to get a nose-down pitch rate is to reduce the power on underwing-mounted engines".

5. EASE OF TRAINING VERSUS FAILURE CASES

The training that was already being done considered upsets as being due to momentary inattention with a fully serviceable aircraft that was in trim when it was upset. We would like to consider other cases that involve failures of control systems or human errors leaving the aircraft with insufficient control authority for easy recovery. This of course complicates the situation, because recovering an aircraft which is in trim, possessing full control authority and normal control forces, is not the same as recovering an aircraft with limited control available or with unusual control forces.

Thus, for us, an aircraft that is out-of-trim, for whatever reason, human or mechanical failure, should be re-trimmed. Whereas the airline instructors were against the use of trim because of concerns over the possibility of a pilot overtrimming and of trim runaways which are particularly likely on some older aircraft types which are still in their fleets. We spent a lot of time discussing the use of elevator trim, and we never reached agreement. All the major US airlines were adamant on their policy to recover first using "primary controls" which excluded any reference to trimming.

Again, a compromise was necessary. What we have done is to talk about using trim if a sustained column force is required to obtain the desired response whilst mentioning that care must be used to avoid using too much trim. And, the use of trim is not mentioned in the simplified lists of actions to be taken.

6. STALLING

Another aspect that was being ignored in the existing training was the stall. By this I mean the difference between being fully stalled and the approach to the stall. In training, you do an approach to the stall with a recovery from stick shaker, which is often done by applying full thrust and maintaining existing pitch attitude in order to recover with minimum loss of height. Height cannot be maintained if an aircraft is actually stalled and should be of secondary importance.

Even those of you who do stalls on airtests, as might be done after a heavy maintenance check, only do so with gentle decelerations and recover immediately without penetrating very far beyond the stalling angle of attack. There is a world of difference between being just before, or even just at, the stall, and going dynamically well into it.

The training being given in the airlines at the time to recover from excessive nose-up pitch attitudes emphasised rolling rapidly towards 90° of bank. This is fun to do, and it was not surprising to find that most of the instructors doing the training were ex-fighter pilots who had spent a lot of time performing such manoeuvres in another life. The training was being done in the same way, with an aircraft starting in trim with a lot of energy and recovering while it still had some. However, the technique being taught only works if the aircraft is not stalled.

We start our briefing on recovery techniques with the following caution:

Recovery techniques assume that the airplane is not stalled. If the airplane is stalled, it is imperative to first recover from the stalled condition before initiating the upset recovery technique. Do not confuse an approach to stall and a full stall. An approach to stall is controlled flight. An airplane that is stalled is out of control and must be recovered. A stall is characterised by any, or a combination of the following:

- Buffeting, which could be heavy at times.
- A lack of pitch authority.
- A lack of roll control.
- Inability to arrest descent rate.

To recover from a stall, the angle of attack must be reduced below the stalling angle. Apply nose down pitch control and maintain it until stall recovery. Under certain conditions with under-wing mounted engines, it may be necessary to reduce thrust to prevent the angle of attack from continuing to increase. **Remember, in an upset situation, if the airplane is stalled, it is first necessary to recover from the stall before initiating upset recovery techniques.**

This is something that we are well aware of in testing, but it was either being totally ignored, or misunderstood. I consider the inclusion of this note to be one of our most important contributions.

7. USE OF RUDDER

We also spent a lot of time discussing the use of rudder. The existing training courses all emphasised using rudder for roll control at low speeds. It is true that the rudder remains effective down to very low speeds, and fighter pilots are accustomed to using it for "scissor" evasive manoeuvres when flying not far from the stall. But large airliners, with all the inertias that they possess, are not like fighter aircraft. Based on our experience as test pilots we are very wary of using rudder close to the stall. It is the best way to provoke a loss of control if not used very carefully, particularly with flaps out.

We finally got the training managers to agree to play down the use of rudder in their existing courses. But we do not say never use the rudder at low speed. We say that, if necessary, the aileron inputs can be assisted by coordinated rudder in the direction of the desired roll. We also caution that "excessive rudder can cause excessive sideslip, which could lead to departure from controlled flight".

But why did we have so much difficulty in convincing the training pilots that it is not a good idea to go kicking the rudder around at low speed? Their reply was always the same; but it works in the simulator! This leads me on to my last point.

8. USE OF SIMULATORS

We manufacturers were very concerned over the types of manoeuvres being flown in simulators and the conclusions that were being drawn from them. Simulators, like any computer system, are only as good as the data that goes into them. That means the data package that is given to the simulator manufacturer. And we test pilots do not deliberately lose control of our aircraft just to get data for the simulator. And even when that happens, one isolated incident does not provide much information because of the very complicated equations that govern dynamic manoeuvres involving non-linear aerodynamic and inertia effects.

The complete data package includes a part that is drawn from actual flight tests, a part that uses wind tunnel data, and the rest which is pure extrapolation. It should be obvious that conclusions about aircraft behaviour can only be drawn from the parts of the flight envelope that are based on hard data. This in fact means being not far from the centre of the flight envelope; the part that is used in normal service. It does not cover the edges of the envelope. I should also add that most of the data actually collected in flight is from quasi-static manoeuvres. Thus, dynamic manoeuvring is not very well represented.

In fact, a typical data package has flight test data for the following areas:

Slats Out

All Engines Operating	- sideslip around neutral - AOA between 0° and 22° - sideslip between +15° and -15° - AOA between 0° and 12°
One Engine Inoperative	- sideslip between +8° and -8° - AOA between 5° and 12°

Slats In, Low Mach

All Engines Operating	- sideslip around neutral – AOA between 0° and 12° - sideslip between +10° and -10° - AOA between 2° and 9°
One Engine Inoperative	- sideslip between +8° and -8° - AOA between 2° and 8°

Slats In, High Mach

All Engines Operating	- sideslip around neutral – AOA between 0° and 5° - sideslip between +5° and -5° - AOA between 1° and 3°
One Engine Inoperative	- sideslip between +2° and -2° - AOA between 1° and 3°

In other words, you have reasonable cover up to quite high sideslips and quite high AOAs, but not at the same time. Furthermore, the matching between aircraft stalling tests and the simulator concentrates mainly on the longitudinal axis. This means that the simulator model is able to correctly reproduce the stalling speeds and the pitching behaviour, but fidelity is not ensured for rolling efficiency (based on a simplified model of wind tunnel data) or for possible asymmetric stalling of the wings. Also, the engine out range is much less than the all engines operating one, and linear interpolation is assumed between low and high Mach numbers. Wind tunnel data goes further.

For example, a typical data package would cover the following areas:

Slats Out	- sideslip from +18° to –18° and AOA from –5° to 25°
Slats In, Low Mach	- sideslip from +18° to –18° and AOA from –5° to 12°
Slats In, High Mach	- sideslip from +8° to –8° and AOA from –2° to 8°

In fact, this is a perfectly adequate coverage to conduct all normal training needs. But it is insufficient to evaluate recovery techniques from loss of control incidents. [redacted]ers were all in the habit of demonstrating the handling characteristics beyond the stall, often telling their trainees that the rudder is far more e[redacted]hort, they were [redacted] techniques from simulators that were outside their guaranteed [redacted].

Simulators can be used for upset training, but the training should be confined to the normal flight envelope; For example, training should stop at the stall warning. They are "virtual" aircraft and they should not be used to develop techniques at the edges of the flight envelope. This is work for test pilots and flight test engineers using their knowledge gained from flight testing the "real" aircraft.

7

APPENDIX 5.8

Ny and Handling Qualities modeling

(5 pages)

APPENDIX 5.8 Ny and Handling qualities modeling

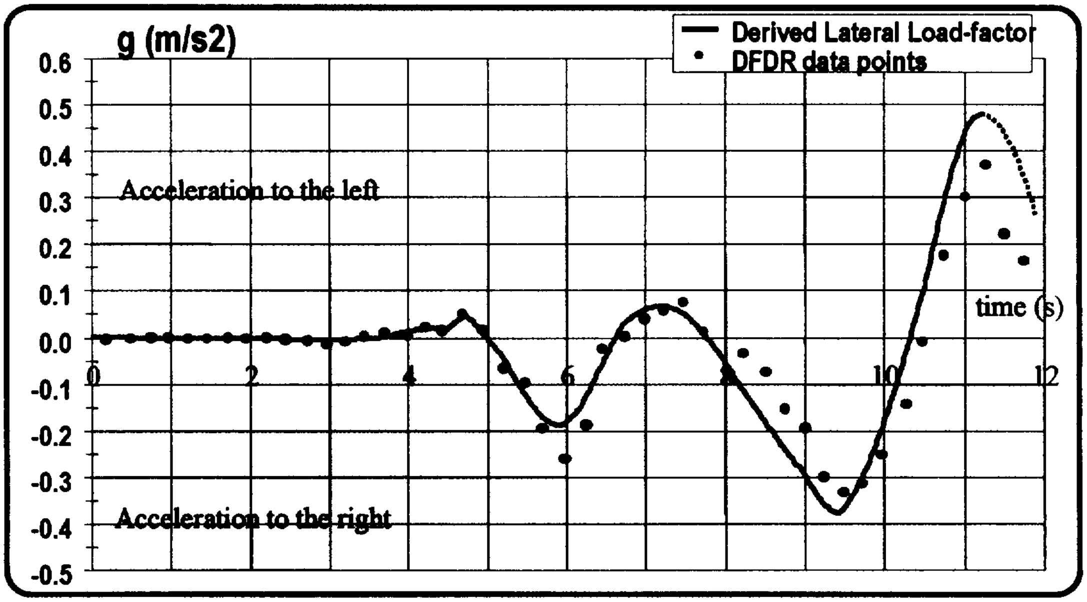
The simulation analysis starts with the time history for the control surface positions, using a data rate of 64 points per second, which is essentially continuous. This continuous control surfaces time history is fed into a model of the A300B4-605R, the same model used for certification of the aircraft. The result of the simulation gives the aircraft motion parameters, for example accelerations, speed, and attitudes can be computed.

Another part of this process starts with the assumed control surface time histories. Then data filtering algorithms are introduced to produce the information that would have been recorded by the DFDR as a result of the changes in aircraft motion caused by these assumed control surface movements. This is done so that the filtering process is taken into account before any comparisons with data actually recorded on the DFDR. This is done primarily for rudder, aileron, and elevator deflections.

Using this process, control surface time histories are produced exactly as they would have been recorded on the DFDR. These results are compared with the actual DFDR recording. In other words, the simulated aircraft motion is compared with the DFDR motion parameters, and the simulated DFDR parameters are compared to the actual DFDR data.

If the comparison reveals discrepancies, the continuous control surface position time histories are iterated until a satisfactory correlation is achieved, including the comparison with the aircraft motions and the comparison between the recorded rudder, aileron, and elevator positions.

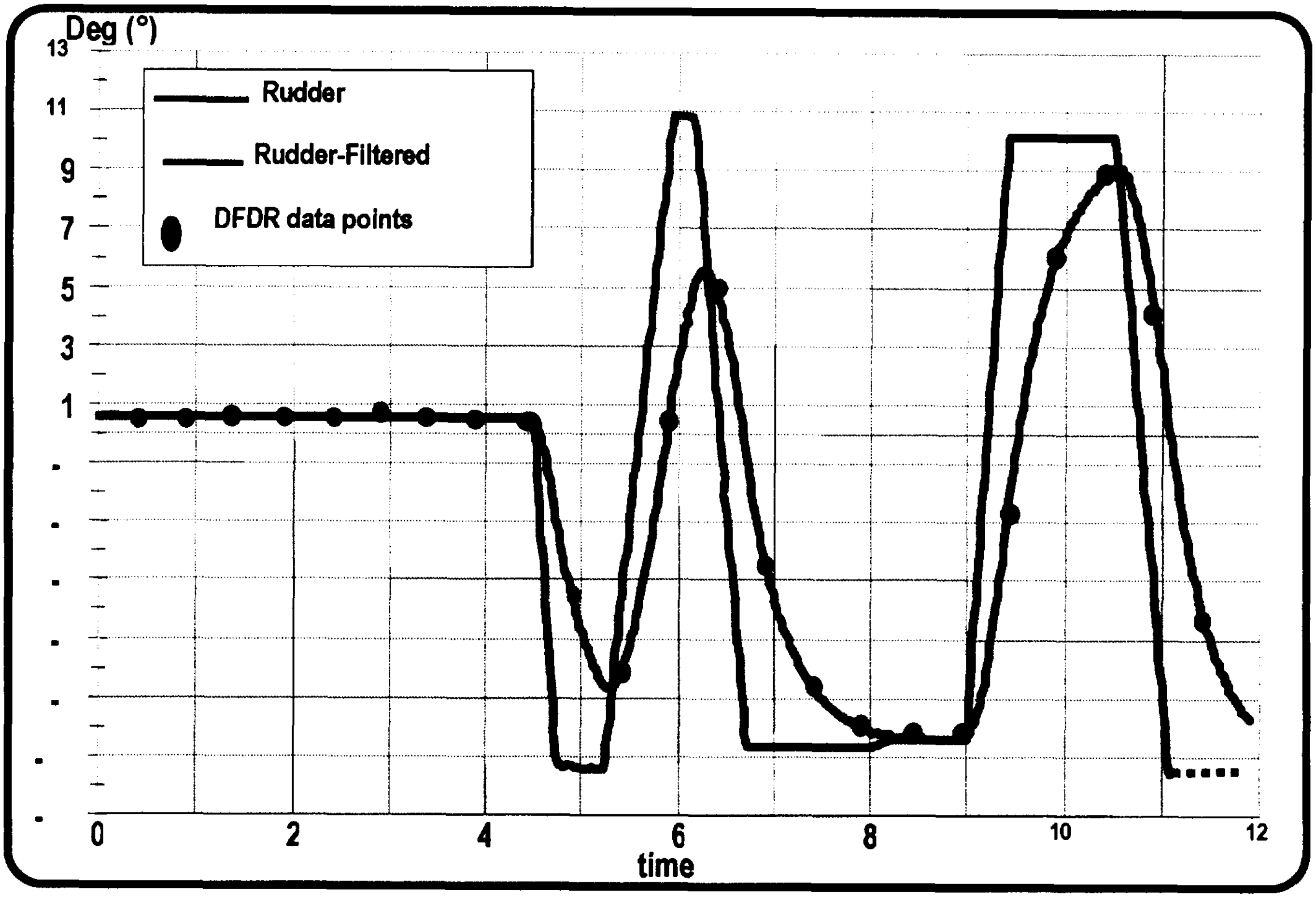
The following diagram illustrates some of the results from these analyses. The lateral load factor computed by the model is shown in red and the recorded points from the DFDR with their sampling rate is shown in blue. The diagram shows that there is a relatively good match of the lateral accelerations. This is basically a good representation of the last 12 seconds of the flight before fin separation. The dotted line is the results of the model, which does not and cannot account for fin separation.



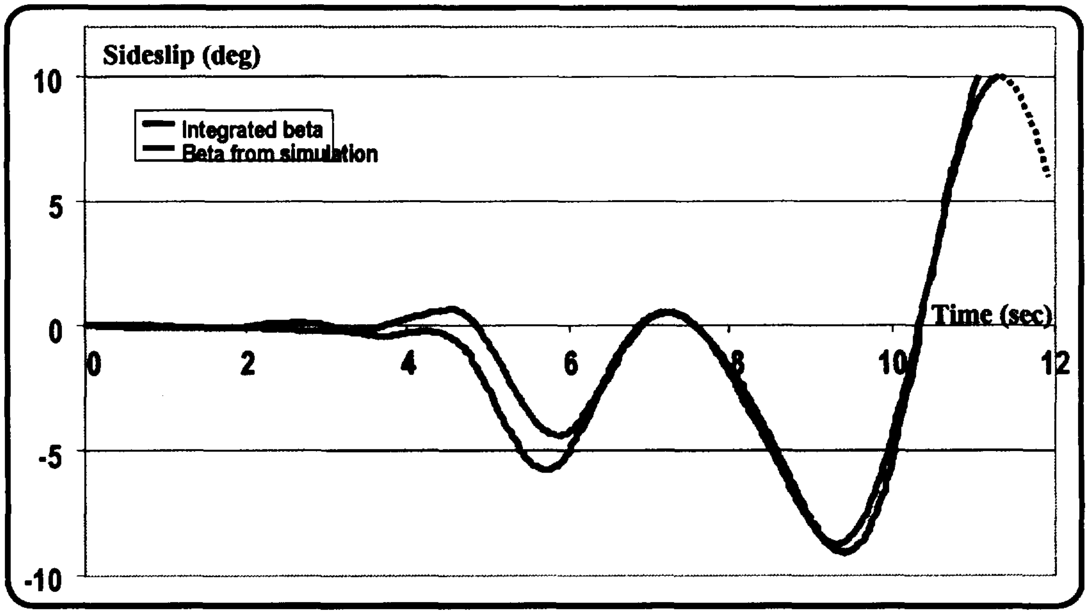
NOTE: Assuming no lateral gust/vortex at this stage.

It is important to note that this simulation has been run assuming no lateral gust or vortex. So, the results and a reasonable match can be obtained without any assumptions about wind.

The diagram that follows shows the results of the second comparison. The red curve shows the rudder position used to drive our simulation. The blue curve shows the filtered rudder data, which means it is the parameter that would have been recorded on the DFDR. This filtered data can then be compared with the blue dots, which are the actual DFDR recorded points. The diagram shows that a fairly good match was achieved, without using any assumptions about wind.



The following diagram shows the basic process used in this analysis. The process starts using the accelerations as they are retrieved from the DFDR. Then, some angular corrections are made in order to provide the direct derivative of the main parameters. For the angular correction, the DFDR attitude is used to correct for bank, pitch angles, etc. Then, by a mathematical integration (which is basically a trapezoidal type of integration), we can get the sideslip as computed by a method called N_Y integration. These results are then compared with the sideslip computed by the aircraft simulation.



NOTE: Beta from simulation assumes no lateral gust/vortex

Sideslip coming from the simulation (in red) can be compared with the sideslip coming from the integration method (in blue). There is good agreement between the two methods at the end of this time period, which is around the time of fin separation.

In examining this diagram, it is important to note that blue is ground sideslip, red is air sideslip. It is likely that there was some wind, which may account for the small differences between the two curves (approximately only one degree of sideslip). This was not considered in the analysis because good results can be achieved without taking into account any lateral wind. One degree of sideslip at this speed (250 knots) means roughly speaking five knots of lateral wind.

These comparisons between the DFDR recorded parameters and the aircraft motion derived from the simulation are in good agreement, which means that the aircraft model and the aircraft involved in Flight 587 behaved in similar ways. Consequently almost all the lateral motions of Flight 587 can be accounted for by the roll and yaw surface deflection.

Finally, the latest simulations performed confirms that taking very moderate wind into account, there is an excellent matching between the aircraft motion derived from the simulation and the AA 587 flight parameters as recorded on the DFDR.

APPENDIX 5.9

American Airlines internal memo

(16 pages)

AmericanAirlines®

February 6, 2003

Mr. Robert Benzon
Investigator In Charge
National Transportation Safety Board
AS-10
490 L'Enfant Plaza, SW
Washington, D.C. 20594-003

Re: American Airlines Flight 587
Accident at Belle Harbor, New York
November 12, 2001

Dear Mr. Benzon:

Attached please find two versions of a draft internal (May 1997) American Airlines memorandum from Captain Paul Railsback, Managing Director of Flight Operations Technical, to Captain Cecil D. Ewell, Chief Pilot and Vice President of Flight for American Airlines.

The two versions of these memoranda were only recently located as part of the discovery process in the Flight 587 litigation. The version of the Railsback memorandum that is attached as Exhibit 1 is dated May 27, 1997 and it was provided to us on January 30, 2003 by Captain Railsback from his personal files at home. We had not previously seen this or any other version of this memorandum. The version of the Railsback memorandum that is attached as Exhibit 2 is, according to Captain Railsback, an earlier version of the same memorandum. We received this version of the memorandum from Airbus' attorneys on January 31, 2003, but we do not know who provided Airbus with this version of the memorandum. We have reason to believe that Airbus' attorneys have been in possession of this document for several months at least, but they refused to produce this document for unknown reasons.

We are continuing to search for the final version of this memorandum, but we wanted to provide you with these drafts in the meantime. Captain Delvin Young, American's representative to the Operations Group, simultaneously will be providing a copy of these memoranda to Dave Ivey, Operations Group Chairman.

Sincerely yours,

Original Signed

Curt Lewis, P.E., CSP
Manager Systems Safety
Party Coordinator

Attachments

NYOFFICE 576932v1

DRAFT

May 27, 1997

To: C. D. Ewell

One of the key concepts articulated in AAMP training is that "at higher angles of attack, the rudder becomes the primary roll control" (see the attachments to this report). The program further states that aileron application in these situations is less desirable since it will create drag caused by spoiler deflection. In no uncertain terms pilots are told to use rudders as the primary means of roll control in unusual attitude recoveries involving windshear events and recovery from high angle-of-attack situations.

Consider the following facts:

- The use of *excessive* rudder at high angles-of-attack will cause a spin or a snap roll.
- The rolling moment caused by rudder input is generated by sideslip, which is slow to take effect, then rapidly becomes uncontrollable resulting in spin, snap roll or successive pilot induced oscillations. This is exacerbated by the inertia generated by the weight of wing mounted engines.
- Yaw dampers remain active at high angles-of-attack, or stall, with unpredictable and perhaps adverse consequences.
- Excessive yawing events will create gyroscopic effects and twisting moments on wing mounted engines, which may result in engine damage or even separation from the airplane.
- Jet transport airplane wings are designed so that ailerons are effective even at slow airspeeds and high angles-of-attack.
- Drag caused by spoiler activity during aileron input when returning to wings level or maintaining wings level is so small as to be inconsequential. In fact, drag caused by the sideslip effect yaw is much greater.
- John Cashman, Boeing Chief Test Pilot has stated to me that he "vehemently disagrees" with the AAMP high angle-of-attack theory..."no data supports Warren's assertions ". Tom Melody, McDonnell Douglas Chief Test Pilot also has expressed "serious concern and disagreement" with the rudder theories presented in AAMP.

- Much of the rudder theory and technique described in AAMP was "proven" in our simulators. Our simulators are training devices only, and not engineering simulators. They do not accurately represent the complex dynamics of flight in regimes that are not required for normal training events. A simulator is not an airplane.

In the context of the above points, consider the AA 903 accident: While the investigation is not complete, early analysis of the available information suggests that the rudder input played a significant role. The flight data recorder information became partially unreliable just after the onset of the event due to the g forces, but the crew statements, the available FDR readout and the observations of a deadheading check airman clearly point to the probability that at least one pilot induced snap roll occurred.

AA 903

AA 903 had descended to 16,000 feet to enter a holding pattern in an area of convective activity. The flight was experiencing only light chop. The crew stated that the autothrottles and autopilot were on and 210 knots was set in the speed window. As the airplane began a right turn to enter the holding pattern, for reasons unknown, the autothrottles did not advance and the speed decreased to about 190 knots (stall speed at current weight, 1g, is about 150 knots).

The crew realized that the airspeed had slowed and believing that they were in a microburst, executed a takeoff and landing microburst escape procedure despite the fact that the altitude was 16,000 feet. The FO added full power, pulled the nose up to twenty degrees pitch and attempted to roll the airplane to wings level with full inputs of left aileron and left rudder. The crew stated that the airplane then violently rolled to the left about to eighty degrees bank. They responded with aileron and rudder in the opposite direction and they think the airplane then violently rolled to the right to about eighty degrees bank (this is not confirmed by FDR data). They continued to hold the pitch at twenty degrees nose up and eventually regained control after a large altitude loss.

Probable cause

The crew believes that they encountered a convective weather phenomena, either a microburst or descending vertical airmass, which upset the airplane and caused the altitude loss. However the airplane immediately following reported no turbulence or convective activity in the same area. Even though microbursts are transient in nature, the extreme airplane bank activity is not consistent with either a microburst or downdraft, unless in the middle of a thunderstorm.

The microburst escape procedure...which specifies twenty degrees nose up...is intended to be used in the takeoff and landing phase of flight (e. g. Delta 191). The correct procedure for their situation...approach to stall, which is taught in simulator training during every recurrent training cycle...is to add power, lower the nose, roll the wings level, recover airspeed and return to assigned altitude. The extreme bank angles occurred because of excessive rudder inputs which caused the airplane to snap roll at least once and possibly more. The behavior of the airplane, the altitude loss and the engine damage to the acoustic lining is exactly consistent with the previous points regarding rudder input at high angle of attack.

I submit that the violent nature and altitude loss of the AA 903 accident was not caused by turbulence, but was a pilot induced snap roll caused by excessive rudder inputs while the airplane was at high angle-of-attack.

Furthermore, we are presently conducting high angle of attack training and demonstrations in simulators which do not accurately replicate the behavior of the airplane and are very likely to provide a false sense of confidence and knowledge to our pilots.

I strongly recommend that we take immediate corrective action to change our training programs and advise our flight crews of the correct nature and danger of rudder input at high angle-of-attack.

P. W. Railsback

Aerodynamic Definitions

Dihedral Effect (3)

The effectiveness of the rudder as a roll control will increase with increasing angle of attack. At the higher angles of attack, THE RUDDER becomes the primary roll control.

Notes

Aerodynamic Definitions

Dihedral Effect (3)

The effectiveness of the rudder as a roll control will increase with increasing AOA. At the higher angles of attack, THE RUDDER becomes the most effective roll control.

Smooth application of coordinated rudder will improve roll response significantly at higher AOA.

Notes

Windshear / Microburst

- Avoidance
- Buy Insurance
- Recognition (Wind Arrow ↗)
- Initial Response (A/P - A/T - S/B)
  - 15° Deck Angle or FD Commands
- Pilot-Not-Flying Responsibilities
- High AOA Maneuvering = RUDDER
- Respect Stick Shaker (Phugoid)
- Autopilot Limitations

Notes

Pilot Response to Wake Turbulence

- Rolling moment on aircraft with shorter wing spans can be dramatic.
- Resulting attitude may be nose low with more than 90° of bank.
- Apply the appropriate unusual attitude recovery procedure.
  - Do not apply any back pressure on yoke at more than 90° of bank. ROLL FIRST - THEN PULL.
  - High AOA maneuvering = RUDDER.
  - Corner speed - high lift devices extended.

Notes

Stall Warning on Takeoff or After Takeoff

- Takeoff Considerations
  - Runway Length
  - Takeoff Roll Distance
  - Acceleration Rate
  - Elevator Feel at Rotation
  - Airspeed above V1
- After Takeoff
  - High AOA Maneuvering - RUDDER

Notes

Ground Proximity Warning System

- Mode 2 "Terrain - Terrain" Response

Autopilot / Autothrottles . . . . . Disconnect
Throttles . . . . Full Forward
Pitch . . . .Rotate to 20° or Greater (3°/sec)
Speed Brakes . . . . Retracted

  - **Wings level pull if IMC**
  - **Pilot-Not-Flying responsibilities**
  - **Respect stick shaker - Phugoid**
  - **High AOA Maneuvering - RUDDER**
  - **Continue climb to MEA if IMC?**

Notes

AAMP Simulator Training

- High AOA Maneuvering Demonstration
  - Apply climb power
  - Maintain 15° to 30° deck angle
  - Respect the stick shaker (Fly in the PLI)
  - Now roll alternately left and right to 40° of bank - MAINTAIN HIGH AOA
    - ▲ First, use only ailerons and spoilers
      - Note: Sluggish roll response - Developing <u>sink</u> rate
    - ▲ Second, use <u>only rudder</u> - (smoothly)
      - Note: Improved roll response - Developing <u>climb</u> rate
    - ▲ Third, practice combination (both aileron & rudder)
      - Note: Optimum <u>roll</u> response

Notes

AAMP Simulator Training

- Sim profiles designed to develop & reinforce specific flying skills.
  - High AOA maneuvering demo - NOT full stalls
  - Unusual attitudes - nose high & nose low
  - Microburst - demanding level
  - Engine failure - low altitude & low energy
  - GPWS - mode 2 'Terrain' profile
  - High altitude upset - fleet specific
- Integrated into each fleet Transition & Recurrent Training Syllabus.

Notes

FLIGHT DEPARTMENT DEBRIEF/REPLY RECORD: DE-IDENTIFIED

DATE: 12-May-97 DTN: 97006566
EMP#: 52075 BASE: MIA
PLT#: 903 / 12-May-97 / BOS-MIA A/C#: 070 TYPE: 300
REPLY REQUESTED: Y

PROCESSING DATA

DBF RECVD: 13-May-97 [1 Days] CODE: IRTUZZZZ-A (B) at: MIA
PROCESSED: 13-May-97 [0 Days] TO: 135/ V (A) by: 166501
REPLY RCV: [Days] FROM: / Res:
FORWARDED: [Days] via: Result: NA Mag:

SUMMARY

SEVERE TURBULANCE

DEBRIEF DETAIL

Z TIME- 1830Z FREQ/ALTITUDE- 124.85/16000
ATC FACILITY- MIA APPROACH
LOCATION- HEATT INTERSECTION
AT 16000 FT WE WERE CLEARED TO HOLD AT HEAT INTERSECTION AS DEPICTED. WE OBSERVED ON RADAR THAT A CELL EXISTED AT OR JUST SOUTH OF HEATT. WE REQUESTED PERMISSION TO HOLD 10 MILES NORTH OF HEATT WHICH APPEARED TO BE CLEAR OF WTHR ANOTHER AA AIRCRAFT REQUESTED THE SAME CLEARENCE. AS WE APPROACHED OUR NEW HOLDING POINT WE NOTICED THE AIRSPEED OF 210 KTS (AUTO PILOT AND AUTO THROTTLES WE NOTICED OUR AIRSPEED DROPPING FROM OUR SELECTED SPEED. WE IMMEDIATELY ADVANCED THE THROTTLES.2 TO 3 SECONDS LATER WE FELT
TURBULANCE BUILDING FOLLOWED BY SHARP CHANGES IN PITCH AND ROLL. AS THIS TRANSPIRED WE APPLIED MAX (FIRE WALL) POWER AND CONTROLLED ROLL WITH RUDDER AND FLEW APPROX 20 DEGREES NOSE UP STILL LOSING APPROX 4000 FEET BY THE EXIT POINT. THE EVENT LASTED APROX. 15-20 SECS

NO ELECTRONIC REPLY DETAIL

END

Required Report

To: C. D. Ewell

I have grave concerns about some flawed aerodynamic theory and flying techniques that have been presented in AAMP. Furthermore, I believe that these concerns are validated by the recent AA 903 accident. Let me explain:

One of the key concepts articulated in AAMP training is that "at higher angles of attack, the rudder becomes the primary roll control". The program further states that aileron application in these situations is undesirable since it will create drag caused by spoiler deflection. In no uncertain terms pilots are told to use rudders as the primary means of roll control in unusual attitude recoveries involving windshear events and recovery from high angle-of-attack situations.

This is not only wrong, it is exceptionally dangerous. Consider the following facts:

- The use of excessive rudder at high angles-of-attack will cause a spin or a snap roll.
- The rolling moment caused by rudder input is generated by sideslip, which is slow to take effect, then rapidly becomes uncontrollable resulting in spin, snap roll or pilot induced oscillation.
- Yaw dampers remain active at high angles of attack or stall with unpredictable and perhaps adverse consequences.
- Excessive yawing events will create twisting moments to wing mounted engines, which may result in engine damage or even separation from the airplane
- Jet transport airplane wings are designed so that ailerons are effective even at slow airspeeds and high angles-of-attack.
- Drag caused by spoiler activity during aileron input when returning to wings level or maintaining wings level is so small as to be inconsequential. In fact, drag caused by yaw is probably much greater.
- John Cashman, Boeing Chief Test Pilot says that he "vehemently disagrees" with the aggressive use of rudder at high angle-of-attack..."it is extremely dangerous and unpredictable". Tom Melody, McDonnell Douglas Chief Test Pilot also has expressed "serious concern and disagreement" about the rudder theories presented in AAMP.

- Much of the rudder theory and technique described in AAMP was "proven" in our simulators. Our simulators are training devices only, and not engineering simulators. They do not accurately represent flight regimes that are not required for normal training events. A simulator is not an airplane.

In the context of the above points, consider the AA 903 accident: The flight data recorder information became partially unreliable just after the onset of the event due to the g forces, but the crew statements, the available FDR readout and a statement by a deadheading check airman paint a pretty clear picture.

The Setup

AA 903 was descending to 16,000 feet to enter a holding pattern in an area of convective activity, although they were experiencing only light chop. The crew stated that the autothrottles and autopilot were on and 210 knots was set in the speed window. As the airplane entered a right holding pattern turn, for reasons unknown, the autothrottles did not advance and the speed decreased to about 190 knots (stall speed at their weight, 1g, is about 150 k).

The Event

The crew realized that the airspeed had slowed and believing that they were in a microburst, executed an escape procedure in spite of the fact that the altitude was 16,000 feet. The FO added full power, pulled the nose up to twenty degrees pitch and attempted to roll the airplane to wings level with full inputs of left aileron and rudder. At this point the flight data recorder information becomes unreliable because the forces on the airplane caused the tape to separate from the head. The crew stated that the airplane violently rolled to the left about eighty degrees bank. They responded with aileron and rudder in the opposite direction and the airplane then violently rolled to the right to about eighty degrees bank. They continued to hold the pitch at twenty degrees nose up and eventually regained control after a large altitude loss.

Probable cause

The crew believes that they encountered a convective meterological phenomena, either a microburst or descending vertical airmass, which upset the airplane and caused the altitude loss. However the airplane immediately following reported no significant turbulence or convective activity in the that same area. Even though microbursts are transient in nature, the extreme airplane bank activity is not consistent with either a microburst or downdraft.

The microburst escape procedure specifying twenty degrees nose up is intended to be used in the takeoff and landing phase of flight (e. g. Delta 191). The correct procedure for their situation...approach to stall, which is taught in simulator training during every recurrent training cycle...is to add power, lower the nose, roll the wings level, recover airspeed and return to assign altitude. The radical bank angles occurred because of excessive rudder inputs which caused the airplane to snap roll in both directions. The behavior of the airplane, the altitude loss and the engine damage is exactly consistent with the previous points regarding rudder input at high angle of attack.

I submit that the violent nature of the event was not caused by turbulence, but by excessive rudder inputs by the crew, which is exactly what they were taught by AAMP. I further believe that American Airlines is at grave risk of a catastrophic upset because AAMP is teaching aerodynamic theory and technique regarding high angle of attack flying that is wrong, dangerous, and directly contrary to the stated opinion of both Boeing and McDonnell Douglas.

I also want to point out that since we are selling or giving this program to other airlines we will be held legally accountable if an accident occurs which can in any way be linked to AAMP, particularly since Boeing and McDonnell Douglas have both expressed disagreement with the high angle of attack theory being advocated.

Furthermore, we are presently conducting high angle of attack training in simulators which do not accurately replicate the behavior of the airplane and are very likely to provide a false sense of confidence to our pilots. This is negative training at its worst.

I suggest that American Airlines take immediate corrective action to change our training programs and advise our flight crews of the correct nature and danger of rudder inputs at high angle of attack.

P. W. Railsback