



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.
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- 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  $V_a$  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.

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## **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 ( $UL = 1.5 \times LL$ ).

### 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  $V_{LS} - 10$ kts. 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 10<sup>th</sup> 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.*”

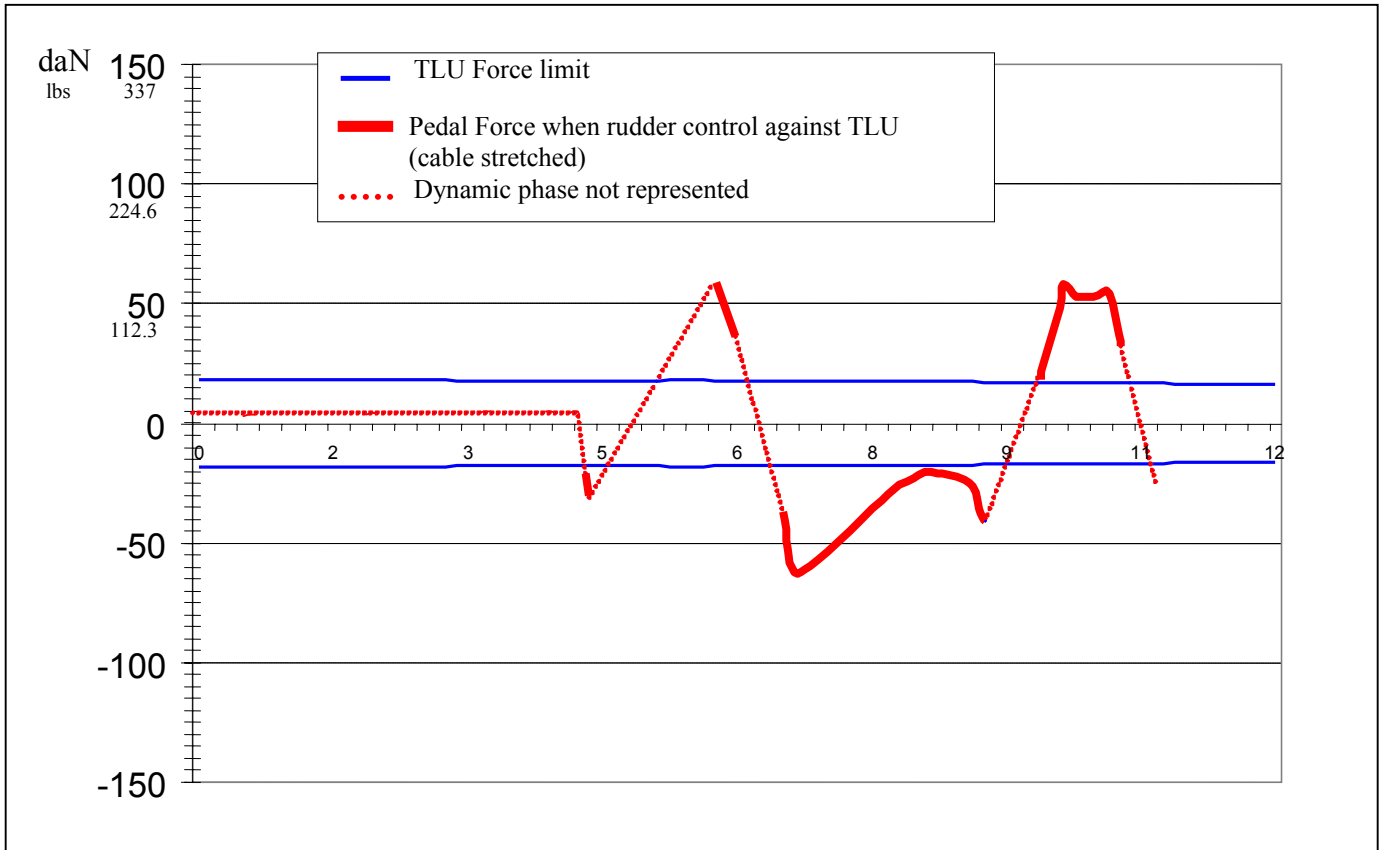
### **1.13.2.4 CVR spectrum analysis**

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

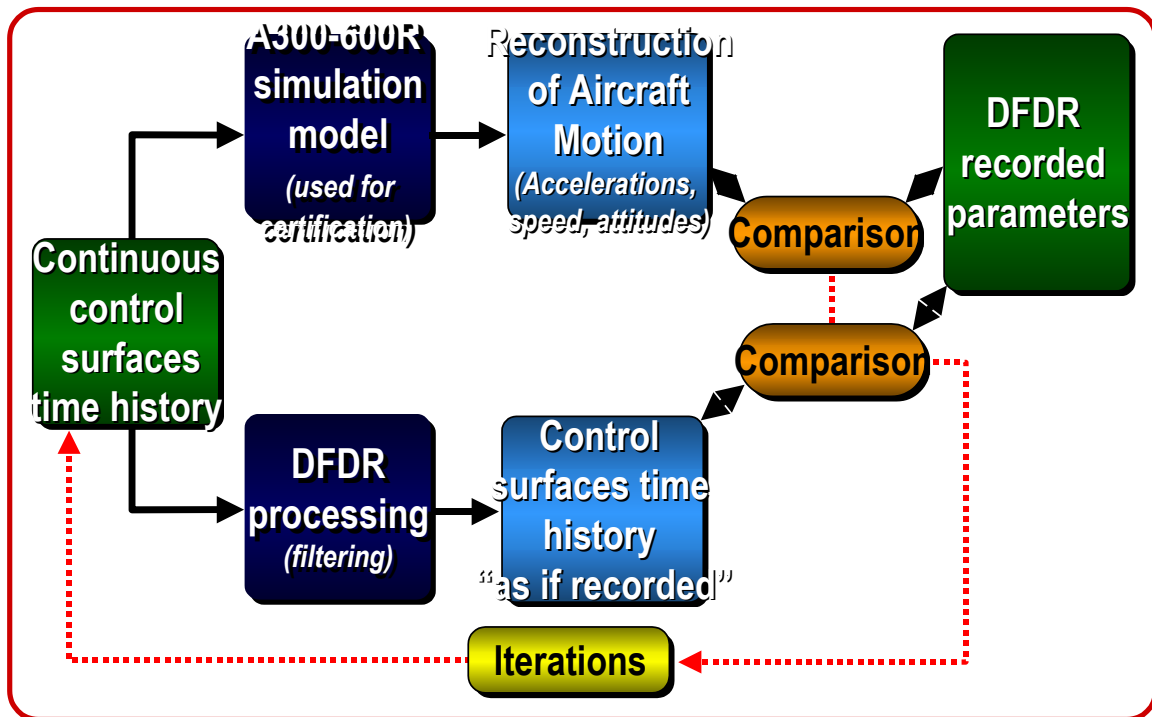
### 2.1 Reconstruction of aircraft performance from DFDR data

#### 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 than 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.

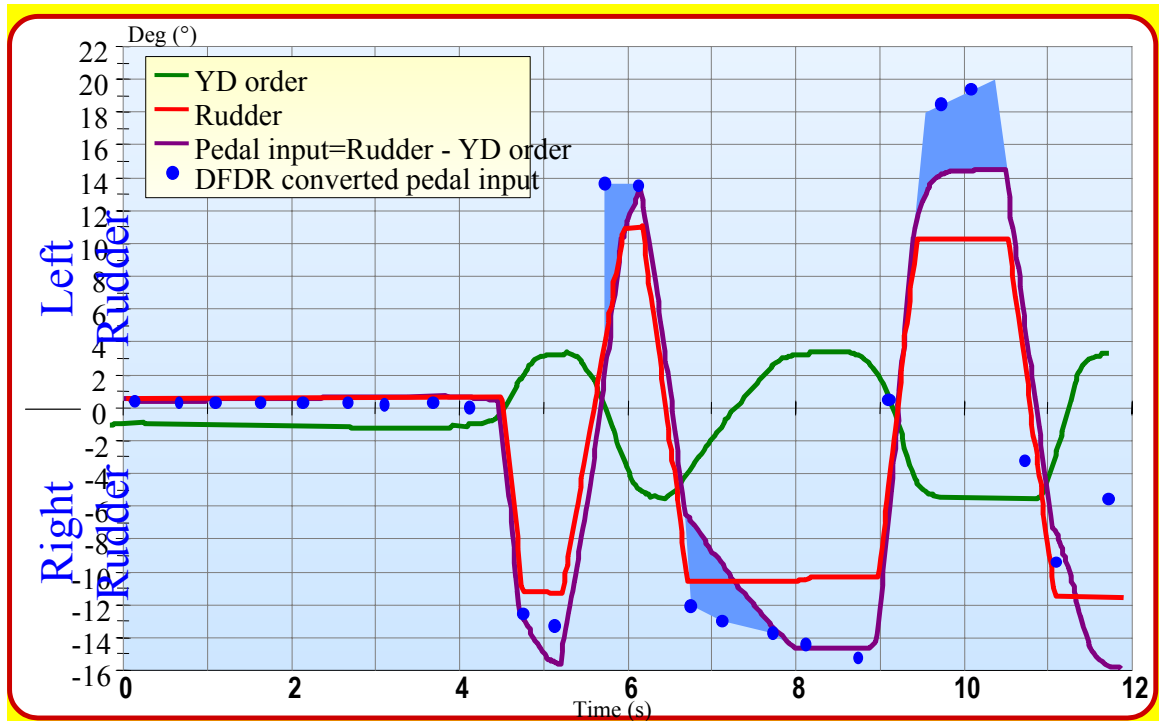
In order to minimize the probability of inadvertent crew actions on the rudder pedals, by design, a minimum force of 22 pounds must be applied on the pedals before any displacement occurs. This breakout force also ensures positive centering of the rudder pedals when foot pressure is released. Despite 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.

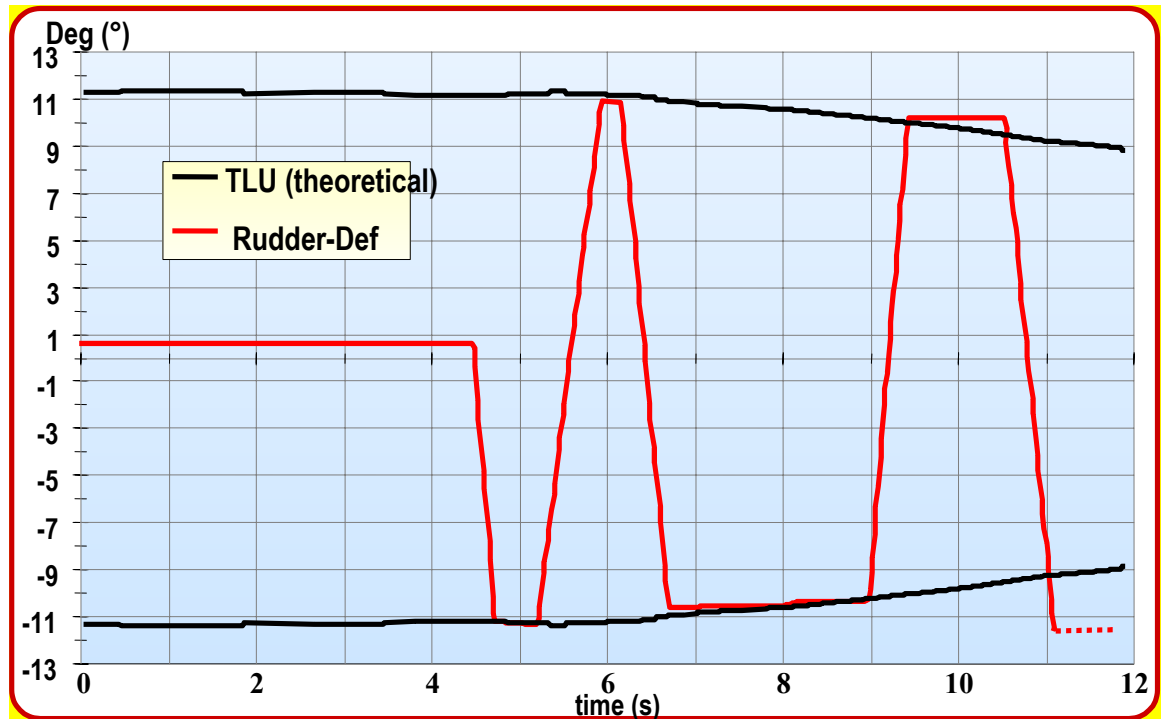
Also, during initial and recurrent simulator training for engine failures during takeoff, the pilot routinely experiences the aircraft response (at least in terms of visual cues) to required rudder pedal inputs, frequently up to speeds on the order of 220 to 250 knots.

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  $V_c$ . 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.

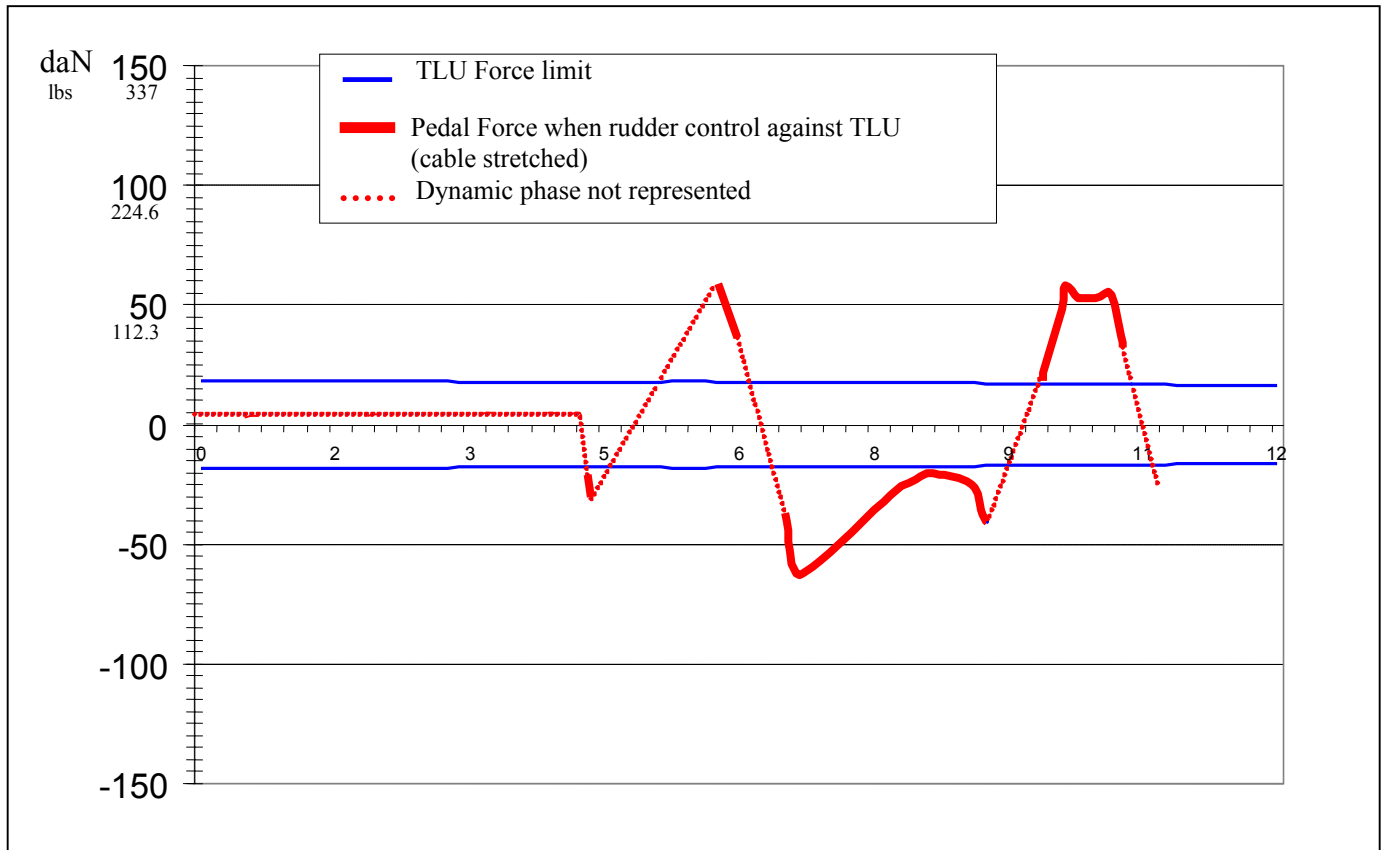
For a full understanding of the observed rudder positions, it is necessary to realize two things. The first is that the order coming from the rudder pedals will be added to the order coming from the yaw damper and the sum of these orders is limited by the TLU. When the rudder is on the stop, the rudder 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 than 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 8<sup>th</sup> 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 4<sup>th</sup> 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 6<sup>th</sup> 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 7<sup>th</sup> August 2002. Additionally, harmonized industry wording was selected and approved by the FAA on September 26<sup>th</sup> 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.