Reaction to the BEA Report on the Accident to the Airbus A330 - flight AF 447 on 1st June 2009.

Some commonly used abbreviations are as follows:
PF = Pilot Flying
PNF = Pilot Non-Flying
AoA = Angle of Attack of the wing
ISIS = Integrated Standby Instrument System
FL = Flight Level
THS = Trimmable Horizontal Stabiliser

Scenario
The Captain was PNF; one of the co-pilots was PF. They were at FL350 at M0.82 with a pitch attitude of about 2.5 deg nose-up. Autopilot 2 and the autothrust were engaged. The aeroplane was heavy and its climb capability was limited.

Loss of Airspeed
Some mild turbulence was encountered, after which the autopilot and the autothrust disconnected and the aeroplane went into "Alternate Law". Air France have stated this was most likely due to the failure of the pitot probes. The indicated airspeed dropped from 275 KIAS (approx M0.80) to nearly 60 KIAS on the Primary Flight Display (PFD). Soon afterwards, the same occurred on the ISIS (the standby horizon/flight display). The stall warning sounded and the PF gave a pitch up input on the sidestick. He then stated that the (air) speed indications were lost.

Alternate Law
This is the first level of degraded flight control mode. As in Normal Law, the sidestick functions in pitch as a trajectory controller, with the neutral position commanding one "g" flight. Unlike Normal Law, it did not give AoA protection at low speeds and overspeed protection when exceeding the normal operating speed. The aeroplane has a stall warning system that is utilised in Alternate Law.

Pitch up and Climb from 35 000 ft
The aeroplane adopted a nose-up attitude of 10 deg, which is extreme at high altitude, as the pitch attitude is normally about 2.5 deg nose-up and the AoA is about the same at economical cruising speed in level flight. Simple maths shows that the extreme 10 deg NU pitch would produce an initial climb rate of about 7000 ft/min at 275 KIAS (corresponding to 500 KTAS), and this was recorded. It is not stated whether the PF was *entirely* responsible for this pitch up, but it is stated that a pitch up command was made on the sidestick.

The aircraft climbed from FL 350 o FL 375 and the IAS reduced to 215 KIAS (about 390 KTAS). The stall warning again sounded and the PF responded by selecting TOGA and with a further NU pitch input on the sidestick! At this point the horizontal stabiliser (THS) auto-trimmed itself to the full nose-up position as it would normally do to maintain a steady trajectory at low speed. It remained in this position for the rest of the flight. The AoA of the wing is commanded by the position of the THS and the thrust couple, and these together would have maintained a stalling AoA. It appears that the ISIS registered sensibly at 185 KIAS – very close to the speed expected at stalling AoA.

The Deep Stall

The maximum altitude reached was 38000ft, from where the aircraft began to descend. Shortly after this all speed indications were lost. (this happens at extreme AoA). The aircraft achieved a vertical speed of 10 000 ft/min by 35000 ft, with an AoA of 40 deg – the deep stall. For the remainder of the flight, the AoA remained above 35 deg and the rate of descent was up to 11 000 ft/min (almost the speed of a human free-fall). The pitch attitude was 15 deg nose-up and TOGA power was selected.

The pilots are not given an AoA display on the flight deck, or a warning of the THS position reaching its limit.

Despite this condition, the PF made long and sustained nose-up pitch inputs on the sidestick and lateral inputs that resulted in roll oscillations up to 40 deg of bank. There was clearly a problem in roll control, as one might expect in the region of negative aerodynamic damping, when the function of the ailerons is reversed.

Pitch Control in the Stall

At one point in this high AoA descent, a nose-down pitch command was made on the sidestick and this resulted in an immediate reduction in the AoA; also evidenced by the airspeed indications becoming valid again and the stall warning re-activating.

This is perhaps the most crucial part of the report and illustrates that the aeroplane, whilst in the deep stall, responded to nose-down pitch inputs such as to reduce the AoA. It was therefore recoverable.

The logical deduction is that had the recommended stall recovery procedure been followed with the stick held forward, that the AoA might have continued to reduce from the deeply stalled condition to the normal sub-stall operating range; from where the aeroplane could have been flown away with a smooth application of power.

Summary

After the autopilot disengagement:

- the airplane climbed to 38,000 ft,
- the stall warning was triggered and the aircraft stalled,
- the inputs made by the PF were mainly nose-up,
- the descent lasted 3 min 30, during which the airplane remained stalled. The angle of attack increased and remained above 35 degrees,
- the engines were operating and always responded to crew commands.

Common Questions on the Accident:

Was the aircraft stalled when it first received the stall warning at FL 350?

Almost certainly it was not stalled as it would not have had the energy to climb a further 3000 ft. It was probably a false warning as might have occurred with the failing of the pitot-static system in icing conditions. It appears that at least two systems failed similarly and in close succession, as the report indicates from the FDR with the left hand PFD and the ISIS, each fed independently.

Was the aeroplane stalled at 38 000 ft, or was it a false warning?

The FDR showed the aeroplane transitioning into the deeply stalled AoA region. The position of the THS seems to confirm this.

Shouldn't the application of TOGA thrust have "powered" the aeroplane out of the stall?

This is a serious but unfortunately widespread misconception. Evidence for this misunderstanding was also present with the A320 accident off the French coast of Canet-Plage. TOGA power with underslung engines can provide such a powerful pitch up couple that it can render the aeroplane difficult to control; the lower the airspeed, the more difficult this becomes. With the THS in the fully nose-up position and at stalling AoA, it may well become uncontrollable. Many aircraft of this configuration have similar handling qualities. Nevertheless, there are many pilots on line who will respond to the stall by a sudden application of TOGA thrust. Airbus have become so concerned by this that they have revised the stall recovery / approach to stall procedures (now just one procedure) to separate the application of power from the breaking of the stall itself.

Did the pilots have displays of pitch attitude available to them?

There would have been 3 displays of pitch attitude: each PFD and the standby, or ISIS flight display. Each of these are powered by a separate Inertial Reference Unit, unaffected by icing. Additionally, the engine instruments should have been functioning normally with accurate displays of N1 for setting thrust (albeit manually).

If a pilot can lose control of an aeroplane so easily, should this not be an airworthiness and certification consideration?

Not at all! There are many aeroplanes where a pilot is not able to use power indiscriminately. Many aerobatic types, including our Pitts, are noteworthy – a sudden application of full power at the beginning of the take-off roll will cause an uncontrollable swing and rapid exit to the left of the runway. The P51 Mustang was similar, and flown by pilots with far less experience than the average airline first officer today! It is all about making an input and assessing the response in order to judge a further input - all part of the art of piloting!

What guarantees do we have regarding the behaviour of such a large aeroplane in the stall?

All such aircraft certified by the EASA must comply with "CS 25; Certification Specification for Large Aeroplanes". It states that the stalling characteristics have been tested as follows.

> It must be possible to produce and to correct roll and yaw by unreversed use of aileron and rudder controls, up to the time the aeroplane is stalled. No abnormal nose-up pitching may occur. The longitudinal control force must be positive up to *and throughout* the stall. In addition, it must be possible to promptly prevent stalling and to recover from a stall by normal use of the controls.

If the Angle of Attack exceeded 30 deg nose-up, why did the aircraft not enter Abnormal Attitude Law.

This is a very good question and undoubtedly will be followed up by guidance from Airbus. Either the Flight Control Computers did not accept the data that it was receiving from the sensors (AoA vanes) or that degradation to Alternate Law precludes a further transition to Abnormal Attitude Law. There is very little stated in the Flight Crew Operating Manuals to date. Undoubtedly more information on this will come from Airbus.

The Standard Stall Recovery has always invoked the use of full power – so why change it?

Firstly consider the high altitude case. There may be little margin between cruise power and maximum power, and the expectation to "power out" of an approach to stalling scenario when there is little thrust margin but much drag may not be effective, particularly if the engines take time to spool up. A safer way to avoid the stall is to reduce the demand on the wings by pitching nose-down to reduce the AoA and allowing the increase in speed (swapping potential for kinetic energy) to enable the wings to produce the required lift to maintain level flight.

Secondly, it can be difficult to distinguish between an approach-to-stall situation and the actual stall. Both may involve aerodynamic buffet. If the wings have actually stalled, a reduced angle of attack must be commanded by moving the sidestick to a nose-down position. This will move the elevator nose-down and the THS will automatically trim to an in-line position with the elevator through an integrating unit. This will directly determine the AoA of the wings and is the only action that will recover the stall.

Also consider an aeroplane that has pitch-up inertia, as may be the case if it was disturbed by a wake vortex or trim malfunction. The only way to reduce the power-pitch nose-up couple and thereby minimise the upset may be to *reduce* the power.

Why did the pilots make continual and prolonged nose-up pitch inputs whilst in the stalled condition, against the guidance of Airbus and Air France?

This will be the subject of a great deal of investigation and subsequent discussion. They were certainly confused as indicated by the PF handing control to PNF in the late stages of the descent; on overwhelming number of chimes and ECAM messages may have contributed to this. This event will almost certainly have widespread implications regarding the ab initio and continuation training of airline pilots in *all ICAO countries.*

Where can such training be found?

You're in the right place!

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