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No consideration of windshear can be complete without reference to and, admiration of the work of Professor T.T. Fujita of the University of Chicago and his associates, whose observations of damage originally attributed to tornadoes led to the identification of the downburst. Since 1974, Professor Fujita's work has made a major contribution to flight safety, as well as to meteorological science.
Also since 1974 the A300, Airbus Industrie's first product, has been in service. By judiciously combining the logic of its flight control systems, its design teams had anticipated formal scientific revelation of a phenomenon and built in the maximum protection against it. For over 11 years, every Airbus Industrie product has incorporated systems which provide wind-shear identification and guidance, and in many cases automatically initiate corrective action. The A310 and A300-600 embody further advances. With the A320 another step forward is taken.
CLASSIC WINDSHEAR

Shear, in engineering terms, is a type of deformation in which parallel planes in a body remain parallel but are relatively displaced in a direction parallel to themselves (Chambers Technical Dictionary). Windshear is an abrupt change in the speed and/or direction of the wind, whether at constant height above ground or as height above ground varies. Between about 2000ft above ground level (AGL) and the surface, in the boundary layer between earth and air, wind-speed reduces more or less progressively, and pilots learn to take this factor into account during their training. Nevertheless, running out of speed, height and ideas and into the undershoot or the long, hot float into the overshoot are not infrequently the result of a dose of classic windshear or wind gradient effect.

AIRMANSHIP

Real awareness of weather is not necessarily impressed upon every pilot during his training; it can depend on how much his early training program was affected by weather conditions. The piston and propeller generations of pilots rarely operated above 20,000ft and were therefore always in those layers of the atmosphere where weather happens. The jet pilot however can spend over 80% of his flying time above the weather, and, unless he mainly works very short sectors, may pass less than 10% in the weather band, and for only a fraction of that 10% is he below 2000ft, where wind gradients and windshear are most serious. Simulator training and professional alertness are part of the answer to this problem. Over 60% of the accidents and incidents to aircraft occur along the path between some 15 miles on approach and a similar distance along the climb-out path. While within this zone the pilot has many preoccupations, and unless he is well conditioned to notice signs of potential shear, he may miss any warnings that may be available, and could be read in the sky. However, the downburst can come almost literally out of the blue.

CONVECTION CLOUDS

While wind gradient is a factor to be taken into account during every approach and landing, more in the mind at present is a
shear with both vertical and horizontal components known as the downburst. The circulation system inside convection clouds, whether triggered by surface heating, orographic or frontal effects, with its rising and falling currents of warmer and cooler air, has long been recognized. A convection cloud is the visible part of a system which also includes invisible up-and-down draughts beneath and outside the cloud column. We talk of currents and draughts - using words with a connotation of steady motion - but a convection cloud is not a steady-state phenomenon; it is in constant, unsteady motion. A landscape being heated by the sun is like the base of a saucepan of water that is approaching the boil, with bubbles forming and breaking away at irregular intervals from the heated surface. This sporadic upwards motion has as its counterpart equally sporadic downwards motion of cooler air. Every convective system in effect breathes in and out, but, unlike the human body (the heat engine with which we are most familiar), the convection cloud does not breathe in and out through a defined orifice: it does it at any point beneath or near its base, at highly irregular, even spasmodic, intervals, producing pulses of high-velocity air and/or water-vapour projected at the ground.

THE DOWNBURST

Professor Fujita describes the downburst as a strong downdraught which induces an outburst of damaging winds on or near the ground. Damaging winds, either straight or curved, are highly divergent. Downburst size can vary from less than a kilometre to several tens of kilometres. The terms macroburst and microburst are applied to downbursts according to the horizontal windspeed generated, and horizontal dimension. While useful for scientific precision, the pilot caught in a downburst knows only too well that there is nothing micro about the forces involved, which may indeed be beyond the recovery capacity of any aircraft (Fig. 1.2.3). A macroburst is defined as a large downburst whose outburst winds extend over more than 4 km (2.2 nm) horizontally. Damaging winds, lasting from 5 to 30 minutes, can be as fast as 117 kts (60 m/sec). A microburst is a small downburst whose outburst of damaging winds extends over less than 4 km. However, despite its small size, an intense microburst can induce damaging winds as fast as 145 kts (75 m/sec). A well-documented occurrence is that at Andrews Air Force Base on 1 August 1983 (Figure 4): At 1404, Air Force One with the President of the USA on board landed on a dry runway, with a windspeed of slightly less than 20 kts. At 1409:20, wind-speed began to increase, reaching a peak of over 120 kts, one minute and twenty-five seconds later. At 1412:20, in the eye of the microburst, windspeed was only 2kts. One minute and ten seconds later, a second peak was reached, of 84 kts, diametrically opposed in direction to that of the first gust. At 1418 windspeed was again below 20 kts: the event had lasted about 10 minutes and substantially damaged buildings and trees on the eastern side of the base.

A case such as this is exceptional, only four microbursts with wind-speeds above 150 kts, being expected within the continental United States each year. Nevertheless, even milder occurrences can cause very close near misses to aircraft on approach or climb-out from many airports worldwide. These phenomena are neither new nor rare: line squalls and severe
thunderstorms are classic downburst generators and have been flattening crops and woods, and knocking down ships for millennia. They are as old as weather. They happen all over the world (Figure 5). What is new is that there are many more airfields than there were, and traffic intensity at these airports is increasing. Results of a trial at Denver suggest that on average an aircraft will encounter a downburst below 500 ft AGL once every four and a half days in the Denver area.

In the Andrews downburst, horizontal windshear reached 5.3 kts/sec. This is a rate of change of speed of 8.95 ft/sec/sec which, if produced by an aircraft, would be 0.12 g in the horizontal plane. As a comparison of the effect of such an event with aircraft performance, the deceleration experienced during A300-600 certification braketesting averaged 1.33 g (touchdown at 166 tonnes, 176 kts., time to stop 28 sec.).

The effects on aircraft performance are made dramatically clear by Professor Fujita in table 1 correlating the effects of tailwind and downflow on lift at various angles of attack and 150 kts indicated air speed (IAS):

Thus, an aircraft taking off at 150 kts with an angle of attack of 15° and experiencing a 20 kt tailwind where zero wind-speed had been forecast would experience a 26% reduction in lift. If it also experienced a 20kt downflow (2,000 ft/min - a not uncommon rate from a moderate downburst), it would experience a further 26% decrease in lift. Rates of descent of 7000 ft/min have been measured, which would cause a lift reduction of almost 90% at the same IAS and angle of attack. An aircraft on approach at 150 kts and 5° angle of attack, meeting a purely vertical downflow of 2000 ft/min would also experience a 90% reduction in lift.

Since 1962 windshear has been held responsible for at least 30 accidents involving over 680 deaths and 260 injuries. An equal number of incidents has been reported that narrowly - some literally by inches - escaped becoming accidents.

**DETECTION AND WARNING**

By nature transitory, windshear is hard to detect and harder to forecast. Intense downburst activity has been encountered that hardly showed up on radar. Low Level Windshear Alerting Systems (LLWAS), developed by the FAA, have been installed at some 60 airports in the USA and are to be installed at 50 more. The system consists of an airport-centered array of anemometers separated by about 5000 feet.
1.5 nm from each other and recording wind velocity at 10-second intervals. Whenever a velocity difference of 15 kt is noted between two recorders, traffic controllers are warned of possible windshear conditions. However, a downdraft that has not yet landed, (Figure 3 - mid air microburst) and is thus a hazard to aircraft on climb-out or on approach, cannot be detected by LLWAS: in addition, as a report from the National Transportation Safety Board (NTSB) stated in August 1985, Sensors only detect what is practically on top of them: there could be a violent event some distance away, and it would not affect the system. Outside the USA, no alerting systems are in use.

A surveillance system needs to watch the whole area round an airport, in 3 dimensions, concentrating on providing advanced warning of downbursts moving towards, or occurring along, the extended centre-line of the runway. Project CLAWS (Classify, Locate and Avoid Wind Shear) conducted at Denver in July and August 1984 confirmed that Doppler radar can provide 2-4 minutes warning. However, skilled meteorologists were needed to interpret the data: algorithms have yet to be developed to enable a computer to take over the task. It was not possible for the meteorologists to provide the quantitative assessment that pilots need of the severity of the detected shear. When a production version of this type of system could be available, and at what cost, is not known. Nor is it clear under just what local micro-meteorological conditions downbursts are likely to develop: they may be incipient tornadoes (or mini-typhoons), with similarities to waterspouts or dust devils - Professor Fujita describes them as inverted tornadoes (Figures 1 and 6). A great deal of work remains to be done, both on the scientific meteorological side and on the hardware, before the downburst can be satisfactorily tamed.

Ground-based detection and warning systems have the disadvantage of an unavoidable lag, compounded by the fact that no ground-to-air system, however reliable, can issue a direct command to the aircraft or its systems. By the time a ground-based system has issued its warning and the ground controller has passed it - along with all the other information he has to note, collate and pass - the alert pilot may well already have taken the appropriate action. Or it may already be too late.

THE SITUATION TODAY

No ground-based or airborne system exists that will provide crews with reliable warning of windshear and thus enable them to adopt the safest solution - keep well away from it. (Weather radar detects precipitation, but not vertical motion inside a cloud).

The responsibility for coping with windshear, if it is encountered, therefore remains - and will remain for several years, especially in areas where sophisticated equipment is already a budgetary problem - firmly within the aircraft itself.

Figure 6

Downburst flow patterns

Combined downburst and cyclonic flow

Aviators in the Far East may find food for thought in this diagram: similar flows have also been noted by Airbus Industrie staff over the Aegean and in the Eastern Mediterranean.

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ON THE FLIGHT DECK

The problem
Take-off, initial climb-out, final approach and landing are high task-load periods on the flight deck: possible windshear is only one of the factors to be taken into account, while most of the other problems occur every day. If there is significant windshear along or near the climb-out or approach paths, neither the airport control staff nor the meteorological services may be aware of it: other pilots may or may not be mentioning it in radio transmissions: the reports, if made, may not be heard. A windshear warning may or may not be in force: even if it is, there is no guarantee that any particular aircraft will actually encounter windshear of any gravity. Windshear is often met out of the blue, in conditions where there is no heavy black linesquall or rain, nor any phenomenon that appears even remotely threatening.

If windshear is encountered, many of the necessary pilot reactions are not instinctive. Although the responsibility for coping with windshear remains on the flight deck, pilots are not necessarily well equipped to deal with it, especially to make the uncivil and brutal movements required that are certainly not within the normal range of airline experience and practice: simulator training increases windshear awareness, though it must be continuously refreshed to ensure that the necessary action can be triggered immediately when needed.

The Royal Aircraft Establishment (RAE) at Bedford in England has developed 3-dimensional mathematical models of downbursts from data recorded during normal commercial flights, test flights with instrumented aircraft and during its participation in JAWS (Joint Airport Weather

<table>
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<tr>
<th>Aircraft (in-service date)</th>
<th>Total thrust (K-lbs)</th>
<th>MTOW (tonnes)</th>
<th>Max Ldg Wt (tonnes)</th>
<th>Take-off Index</th>
<th>Landing Index</th>
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<td>484</td>
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<tr>
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<td>51.7</td>
<td>653</td>
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<td>63.5</td>
<td>58</td>
<td>606</td>
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<tr>
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<td>67.8</td>
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<td>72.5</td>
<td>63.3</td>
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<td>61</td>
<td>757</td>
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<td>843</td>
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<tr>
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<td>110</td>
<td>150</td>
<td>123</td>
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<td>894</td>
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The Thrust/Weight Index indicates the capability of an aircraft to accelerate: the higher the figure, the greater the capability and thus the greater its ability to cope with windshear. Comparison of the indices gives an indication of relative (but not absolute) capability. Modern engine technology provides increased thrust: modern structures technology decreases weight, thus improving the thrust/weight index. The A320's thrust/weight index is well into the region hitherto reserved for the big twins.

Modern engine technology provides increased thrust: modern structures technology decreases weight, thus improving the thrust/weight index. The A320's thrust/weight index is well into the region hitherto reserved for the big twins.

In addition, advances in aerodynamics have increased CL max., thus improving the CD/CL ratio, which indicates the aircraft's ability to climb. The Take-Off and Landing indices are given purely to indicate the relative capabilities of the various types during windshear encounters both on take-off and during final approach.
Study at Denver. A software package derived from the RAE data will shortly be available, to enable operators of certain types of simulator to provide fully realistic simulation of downbursts. Downburst angle can be varied and its intensity controlled, up to the (probably unsurvivable) 8,500 ft/min. downburst. Normal downward velocities are from 4000-6000 ft/min. (see Table 1 - loss of lift).

Answer
Since 1974, every Airbus aircraft that has entered service has been equipped to counter windshear: to react quickly to the rapidly changing micro-environment, to generate automatically the high lift and high thrust necessary, and thus provide the best chances of coping with a sudden, severe, windshear encounter.

Coping with windshear needs:
- Identification
- Maximum lift
- Maximum power

For airworthiness reasons, a big twin has an inherently high power/weight ratio. It therefore accelerates faster, which minimises its time during and after take-off in the sensitive zone below 500 ft AGL, and it has a greater power reserve (Table 2).

THE A300
Thrust control
The thrust computer takes into account the N1 or EPR proportionate to the particular combination of variables affecting thrust (height, temperature, bleed offtake, etc.) and the mode selected (take-off, go-around, climb, cruise, flexible take-off, max. climb). The appropriate rating for the mode and the limit rating for the conditions are displayed to the crew.

In Automatic, the normal day-to-day case with the A300, the autothrottle acquires and maintains the required thrust, or, in Speed Select Mode, varies the thrust in order to maintain the desired speed.

Go-around mode is commanded by pressing the go-levers on the throttle control. It has absolute priority over all other modes, and automatically selects maximum thrust. Under windshear conditions, this obviates the need for pilots to slam forward the throttle levers; the reaction necessary in an unexpected windshear encounter. A300 thrust control provides maximum thrust quickly but without brutality.

Speed Reference System (SRS)
The SRS computes the aircraft's potential flight path by combining airspeed vector direction and angle of attack (i.e. the dynamic attitude of the aircraft in the relative airflow) with pitch and roll accelerations (Figure 7). Any mismatch between the actual and potential flight path of the aircraft is signalled to the horizontal command bars of the Flight Director to enable the pilot to adjust his pitch angle appropriately. The SRS provides pitch guidance to the pilot to enable him to fly the proper airspeed (V_{REF}+10 kts, or V_{REF} in the engine failure case) during the second segment climb after take-off, and, in the go-around phase, to rotate and capture the proper speed (V_{REF}+10 kts, or V_{REF} in the engine failure case). If windshear is encountered during climb-out after take-off, the SRS commands stick movement to maintain a positive gradient (+0.5'). To ensure this, the SRS may trade airspeed against pitch demand (lift increase) until stick shaker speed is reached. This is exactly the procedure recommended by all authorities: in the A300, built-in systems provide the information and guidance that must be hunted for and flown seat-of-the-pants in other aircraft.

Alpha-floor protection
A simple protective circuit (Figure 8), making use of the airspeed, actual and potential flight path and angle of attack information provided to the SRS, commands the autothrottle to maximum thrust if the aircraft should reach an excessive angle of attack (for example, incorrect speed setting). In the case of a windshear encounter, where the relative airflow can change extremely rapidly, the need for maximum thrust at the earliest possible moment is thus automatically satisfied - earlier than the resultant changes could possibly be recognised by an alert pilot. In addition, the nose-up change of attitude which accompanies the increase in power automatically provides an additional safety factor: even before the pilot can receive and act on nose-up SRS commands, the angle of attack is already tending to increase.

A characteristic of flight through windshear by large aircraft is that airspeed and groundspeed frequently vary in opposite senses: the inertia of wide-body aircraft is such that rapid wind fluctuations cause large, near-instantaneous airspeed variations, but slower changes in groundspeed. In the A300's Alpha floor protection system, comparison of the accelerations to which the aircraft is being subjected in effect enables airspeed and groundspeed derivatives to be compared, even when the INS option is not selected. As soon as a
particular variation threshold is reached - it is continuously computed and varies with configuration, potential and actual flight paths, and airspeed - maximum thrust is automatically commanded from the autothrottle. The Alpha floor protection system thus also incorporates windshear protection.

**Beam deviation warning**
Authorities strongly recommend that windshear recovery action be initiated if an uncommanded 1-dot variation is experienced on the glide slope (among other criteria). However, on approach windshear is frequently met after the pilot has switched to flying by visual cues. In some airlines it is required practice that the non-flying pilot remains on instruments at this stage. The non-flying pilot is thus in a position to pass information about a deviation that may (or may not) be due to a sudden windshear encounter late on the final approach. On the A300 a beam deviation warning light is fitted top centre on each pilot’s instrument panel. The pilot is thus positively warned of potential danger even when flying visual, in addition to the automatic sense-and-react systems provided. Beam deviation also triggers the Autoland warning, which mandatorily means go-around on approaches with the autopilot engaged: a further built-in trend towards safety.

Airbus pilots are trained to execute a go-around if the automatic windshear protection triggers, which is the safest way of coping with the situation.

The A300 systems thus identify a micro-environment characteristic of windshear and provide the thrust required to power one’s way out of a potentially dangerous situation. Maximum lift can then be obtained by obeying the recommendations of all authorities and flying the aircraft to CL max., i.e. just on stick-shaker. The SRS mode provides the necessary guidance during take-off and climb-out, and the go-around mode during approach and landing. In numerous simulator exercises the windshear protection features of the A300 flight system have successfully coped with situations that have caused fatal accidents on other aircraft.

**THE A310 AND A300-600**
In addition to the systems described above (incorporated in the A300 for over 11 years) the A310 and A300-600 are equipped with CRT Flight Displays which present additional information that helps the pilot in the recognition and action phases of a windshear encounter.

**Primary Flight Display (PFD)**
On the PFD (Figure 9), the speed trend arrow shows the pilot what his speed will be in 10 seconds time if current engine and aircraft parameters are maintained. Any variation in these parameters will therefore cause an immediate change in the length and/or sense of the trend arrow. Especially during the take-off run, a sudden and unusual change in the length and/or sense of the speed trend arrow can provide early and unmistakable warning of windshear onset. Stick shaker speed is also displayed in the low-speed, low altitude conditions where windshear is a major potential hazard. The clear display enables the pilot to fly stick shaker speed (without falling below it into a higher drag, lower performance, and hence more hazardous, situation), while VCu or 1.3 Vfs is also permanently displayed.

**Navigation Display (ND)**
In its map and arc modes, ND shows true air speed (TAS), groundspeed, and the wind speed and direction currently affecting the aircraft: all potential indicators of entry into windshear (Figure 10). The non-flying pilot is able to monitor wind velocity and the relationship between TAS and ground speed, while the pilot in charge, being properly in the information loop, is able to extract the maximum performance from his aircraft in a situation which urgently demands it.

**Flight Path Vector (FPV)**
The FPV symbol on the PFD, computed from inertial information supplied by the inertial reference system (IRS), displays the inertial trajectory of the aircraft relative to the ground. It provides a precise and immediate reference for monitoring the flight path, especially during approaches without precise glide-slope guidance, and also when visual cues are degraded by heavy rain or low sun, when sloping terrain, unusual runway width/length ratio or runway slope provide misleading visual cues or when landing at night with no approach or foreground lights - the black hole approach. While the glide slope index indicates position relative to the glide path, the FPV indicates rate of change of position. It is predictive, and therefore provides immediate and direct indication of flight path deviation, a characteristic of immense value in a windshear encounter, enabling the pilot to take immediate corrective action.

**THE A320**
The A320 builds in every respect on the accumulated experience of Airbus Industrie in designing and building modern medium range aircraft for worldwide operation. Flight deck layout, progressing from that of the A310 and A300-600, is based upon a fundamental research program that has already generated the most advanced flight decks in current service. The A320’s fly-by-wire control system has already been fully described in a previous issue of FAST. One of its many advanced features is that excursions outside the flight envelope are not possible. Hence, windshear and stall protection are inherent.

During approach a speed increment is automatically computed, the target is displayed and, in autoflight, maintained. The computation is based on accelerometer outputs, "real-time" wind variations obtained from the IRS, the wind speed from the control...
tower entered into the control display unit (CDU) of the flight management system (FMS) just before the approach, as is $V_{REF}$, the zero wind approach speed. Windshear approach procedures in which the crew monitors ground-speed can result in high indicated airspeed, perhaps even exceeding $V_{APP}$. The A320 system is designed to respond appropriately to the aircraft's immediate environment, and also to modulate the thrust / speed demands so that the touchdown point is reached at the desired speed. The necessary degree of anticipation is thus provided: in current aircraft it can only be estimated, and is often over-riding by the immediate demands of the windshear encounter. The carefree handling concept ensures that when the side-mounted pilot's control is pulled right back, the flight control computers immediately configure the A320 for maximum lift. The autothrottle system (ATS) provides maximum thrust, and angle of attack is increased to that for CL max and no more, generating maximum lift without endangering the aircraft at a time when the pilot literally needs all the lift he can get. The A320 thus makes a considerable further advance on the current state-of-the-art as represented by the A310 and A300-600, themselves ahead of the competition in this respect as in many others.

**SUMMARY**

Windshear in its extreme forms can unleash forces greater than the recovery capacity of any aircraft, however high its power / weight ratio and / or lift-generating capability. Unfortunately, neither ground-based nor airborne devices exist to detect windshear and provide truly reliable warning and they may never, exist. The best answer to the question *What do I do if I get into windshear?* is still the old man's answer to the young man contemplating marriage: *Don't*. Airbus Industrie's product line incorporates the maximum windshear protection available on current production aircraft or on aircraft coming into production. Nevertheless crews must be aware of the indications of possible windshear, especially during seasons of high convective cloud activity, and of the need for alertness and firmly positive, even aggressive action, when dealing with an encounter. Awareness is the only sure way of weighing the risk, and dealing with it appropriately.

**RECOMMENDATIONS**

**On take-off:**
- Delay until danger is past.
- Use maximum thrust.
- Follow SRS commands and speed trend arrow (A300-600, A310).
- Be prepared to trade speed for lift.

**If shear is encountered:**
- Ensure maximum thrust commanded and being delivered.
- Follow SRS commands.
- Monitor speed trend arrow, fly to stick-shaker speed (PFD display on A310 an A300-600).
- Pilot non-flying (A300-600 and A310) to monitor flight path vector.

**Approach and landing:**
- Delay until danger is past.
- Make automatic approach and landing - the autopilot's reaction is quicker and always in the proper sense.
- Monitor flight path vector, especially if landing aids are limited.
- Monitor ground-speed (GS) against indicated airspeed (if GS reaches $V_{APP}$ minus 10 kts disengage autothrottle, increase power to increase speed, try to maintain accurate flight path).
- Be prepared for immediate go-around at any stage.
- Fly instruments: do not attempt to transition to visual cues.

**If caught in shear:**
- Apply full thrust.
- Pull up for go-around.
- Follow SRS commands and speed trend arrow.
- Pilot non-flying to monitor Flight Path Vector (A300-600, A310).
- Fly as for encounter during take-off and initial climb-out.

The immediate needs in windshear downdrafts are maximum power, maximum lift, and maximum distance from the ground. These give the maximum chance of normal service being resumed as soon as possible.

As a former airline captain, now an airline consultant, has stated providing a timely warning is important, but we must go one step further in the windshear escape manoeuvre and provide continuous pitch guidance that will produce the best possible climb profile for the escape manoeuvre.

Airbus Industrie has already gone that one step further - over eleven years ago, since when it has continuously improved the system with every addition to its product line, maintaining the lead established.
Every airline engineer knows that dispatch reliability is one of the main parameters used to assess the technical performance of an airline fleet. Therefore close monitoring of fleet behaviour and trend has to be exercised to keep the performance level as high as possible and also to decide timely improvements.

To help operators to make improvement decisions, Airbus Industrie runs a Reliability Improvement Program and published in March 1985 a brochure giving its recommendations for the A300B2 / B4. In subsequent editions of FAST subjects of importance to dispatch reliability improvement for all Airbus models will be dealt with in detail.

In this issue the subject is Service Bulletins designed to improve A300 B2/B4 servo control units (SCU P/N 30505-411) operating the outer speed brakes and roll spoilers. Also a corrective measure on the roll spoiler indication system is discussed herein.

GENERAL

Before going into details, some general words on the position indication system for the roll spoilers and speed brakes (see figures 1 and 2).

Each outer roll spoiler drives a position transmitter and each center roll spoiler drives a differential position transmitter. A common output signal, representing the sum of both, is sent by the differential position transmitter to the LH or RH spoiler position scale on the Flight Control Position Indicator (FCPI) where the average of both is displayed. The inner roll spoiler is not provided with any position indication system.

Each outer and inner speed brake is provided with a micro switch, fitted to sense the retracted position. As soon as one of the speed brakes deflects, the speed brake light on the Flap and Slat Position Indicator (FSPI) illuminates.

In order to provide a better understanding of this system and to demonstrate the positive impact of SB incorporation on daily operation, the following two cases, experienced in service, are described.

CASE ONE

The initial condition was reported by the flight crew in the following observation: during previous flight a slow initial, and too low, LH roll spoiler deflection has been indicated on FCPI. At landing and after ground spoiler application, LH roll spoiler did not retract completely, FCPI indication still 10°.

Visual inspection confirmed that the LH center roll spoiler was immobilized in an intermediate position, i.e. FCPI indication was correct. However, the immobilization of an outer roll spoiler would lead to an identical indication.

The above and similar occurrences had been reported to Airbus. Investigations by operators revealed corrosion on the needle bearings of the SCU input lever of roll spoilers and outer speed brakes (Figure 2) which created high friction during articulation of the lever. This in turn results in break-out of the associated
Figure 1
Roll spoiler and speed brake position indication system (left hand)
- Position transmitter
- Differential position transmitter
- Microswitch

Roll spoilers
- Outer
- Center
- Inner

Speed brakes
- Outer
- Inner

Flight Control Position Indicator
Flap and Slat Position Indicator
detent unit when input movements are transmitted either in flight or on the ground and thus slows down or cancels further operation of the affected SCU. Should such a case occur on the inner roll spoiler, no abnormal indication would be detected but the flight crew probably would have reported that a slight aerodynamic asymmetry has been noticed which had to be compensated by the aileron. If it occurs with one of the outer speed brakes, asymmetry would be similar and, in addition, if one of the speed brakes remains deflected, the speed brake light on the FSPI would remain “ON”. In order to avoid such an occurrence, Airbus published the technical follow-up sheet (TFSU) 27 60 00 02, dated June 1985. It recommends the incorporation of the following Air Equipment service bulletins:

- SB 27-61-OG introduces a change of grease applied to the input lever needle bearings (Figure 3). The new grease, Aeroshell 15 A, has a better compatibility to hydraulic fluid and alleviates the risk of corrosion development;
- SB 27-61-OL recommends as a complementary measure to SB 27-61-OG the replacement of the input lever bearing cage by a stainless steel one to improve the resistance to corrosion (for aileron, rudder and pitch SCUs refer to SB 27-111-05/211-0/221-03/31-03).

Since the above SB can be incorporated only at repair/overhaul, timely planning for its incorporation should be envisaged.

However, if an immediate action is required to dispatch the aircraft on-time and if no spare SCU is available, the following can be tried: experience revealed that the application of lubricating oil, WD 40 or equivalent, and several movements of the input lever from stop to stop will clean and free the bearings for further flights.

The second possibility is the mechanical deactivation of the affected surface per MEL (depending on the operator’s version). To do so, the input connecting rod between the SCU and associated detent unit has to be removed and the SCU input lever secured in the retracted mode to keep the SCU pressurized in the retracted position during the flight.

Of course, in both cases the defective SCU should be replaced at the earliest opportunity.

CASE TWO

The initial condition was reported by the flight crew as follows: During previous flight a slow initial, and too low, LH roll spoiler deflection was indicated on the FCPI (see also case one). Subsequent visual verification disclosed that the deflection of all three roll spoilers corresponded to the bank-input, but its position indication did not correspond to LH actual spoiler deflection.

Those occurrences have been experienced in the past by several operators and led to the issue of Airbus SIL A300-27-037. This SIL discusses the potential for erroneous spoiler position indication caused by excessive friction of a teflon-lined bearing on the control rod, connecting the outer and center roll spoilers to their associated position transmitters (Figure 4). During spoiler deflection, the friction of the bearing prevents the spring from keeping the moving pick-off pin in contact with the outer slot end which results in a slow and/or too low spoiler position indication on the FCPI.

As a corrective action, the SIL recommends the installation of a control rod provided with an improved low friction bearing. If the above case is reported between two scheduled flights and no spare rod is available, there is only one possibility to avoid a delay: dispatch of the aircraft under the MEL (depending on operator’s version) and placard the affected roll spoiler position as inoperative.

CONCLUSION

As a conclusion and to facilitate troubleshooting, it should be noted if there is a slow and too low roll spoiler position indication, it can be created by either: high friction in the needle bearing of the input lever to the SCU’s of the center and outer roll spoilers, i.e. true position indication, or high friction of the teflon bearing in the control rod to the position transmitter of the center and outer roll spoilers, i.e. false position indication.

If there is an aerodynamic asymmetry reported in flight and the FCPI and the FSPI display retracted surface positions, the SCU of the inner roll spoiler (no indicating system) is affected.

If the same symptoms occur as above, but the ‘speed brake’ light of the FSPI is illuminated, one SCU of the outer speed brakes is affected.
Sustained in hot weather

John R. Kearney, Manager Engineering & Repair

Every year to the summer months, Saudi Airlines use a water-cooled engine to cool the summer heat. The purpose of this is to reduce the engine temperature effect on our fleet. Hence, the summer months, which we consider as the worst time in Saudi Arabia, brings out the region's heat waves which seldom go below 90+% humidity levels, especially during the hot summer at around 45°C. A large proportion of our aircraft...
Operations
weather

Manager Field Support
Manager Field Support
Reliability, SAUDIA

...prior
summer
season,
episodes the but-
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part of this program, is
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appropriate. Summer
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ings daily temperatures
low 32°C, and frequently
s, often accompanied by
especial in Jeddah, where
aircraft movements occur.
Saudia has learned from long experience in this part of the world that the operation of aircraft in sustained high ambient heat conditions, incurs not only performance penalties (although manufacturers, and particularly engine manufacturers, might choose to disagree) but another class of penalty which translates into a reduction of system and component reliability, with consequent effects on dispatch performance and greatly increased component repair costs.

The same could be said to be true for operations in any weather extreme, whether hot or cold. However there is an important difference between the hot and cold situations that makes hot weather operation potentially, or actually worse: in terms of end effect in cold weather it seldom gets as cold, and it should normally not get colder, inside the aircraft than it does outside. The aircraft thus provides its internal components with some measure of protection against the low outside temperature.

However in hot weather the reverse is true. The temperature inside the fuselage, can be much higher than that on the outside, especially if the aircraft has been allowed to heat soak during peak temperature periods for several hours without air conditioning or ventilation. In fact, a temperature survey conducted by Saudia in the summer of 1982 revealed that the outside / inside temperature differential can be as much as +15°C in the cockpit, and progressively less in areas or zones that are better ventilated and which do not suffer the greenhouse effect which results from the sun shining through windshield transparencies. In addition, cockpit temperatures can be further elevated due to the heat given off by instruments, and cockpit and panel lighting.

So, how or why does all of this affect reliability? Unfortunately, the mechanism of heat-induced failure is too complex a subject for discussion in a short article like this, but one thing that we all know for sure is that too little or too much heat very definitely does play a part in component reliability as well as equipment performance. We should thus try at every stage, from design to operation, to ensure that component core or metal temperatures are as far from design limits (low and high) as possible. In a perfect world, all equipment, would operate in a benign ambient environment, which optimally would be at or near room temperature, with no thermal cycling and entirely free of dust and vibration. The majority of aircraft components will, today, only ever see conditions approaching these, in the repair shop.

Nonetheless, great advances have been made in recent years in the evolution of on-board environmental control systems and these advances have brought significant improvements in component / system reliability. However in reality, no aircraft can, with the current state of the art in systems technology, offer an optimal component operating environment throughout the entire envelope of operation, e.g. on ground, hot day - taxi - take off - climb / cruise / descent - landing - taxi. During these phases of operation, one or more on-board ambient parameters will be varying, with consequential impact on expected component MTBF, which means that for the time being anyway, we are stuck with what we have got, i.e. systems / components that are vulnerable to the ravages of their environment.

Can an operator do anything to improve the situation? Saudia believes the answer is a firm Yes! and can demonstrate considerable success in reducing the effects of a harsh operating environment on equipment reliability, over the past three years. We realise that there is little an operator can do to eliminate vibration or dust, and nothing it can do to control the weather. But we believe that there is much that can be done at the operator level to reduce the effects of hot weather on our equipment and we set out in 1982 to translate that belief into reality.

An analysis of our equipment monthly operating performance over a two year period showed that certain ATA chapters demonstrated much higher malfunction event rates during the hottest months. The worst performing chapters were: ATA 21, ATA 26, ATA 34 and ATA 36. The problems concerned were experienced on our Boeing and Lockheed fleets at that time.

However, much of what we experience can hold true for any aircraft type, with variations in degree only. Each of the affected systems was subjected to further analysis.

### Aircraft out of service time in summer months of 1982, 1983 and 1984, due to problems related to:

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Time in aircraft-hours</th>
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<tr>
<td>ATA 21</td>
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<td>ATA 26</td>
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<td>ATA 36</td>
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ATA 21
AIR CONDITIONING
System performance deteriorates because of the very heavy demands made upon it during hot weather, before and after passenger boarding. Air conditioning packs are constantly running full cold for passenger comfort, resulting in accelerated wear-out of air cycle machines (with conventional bearings); heat exchangers have to work harder and are therefore more susceptible to the effects of blockage and cracking; APU performance (which tends to fall off in hot weather, on some models) greatly affects the number of pilot reports we receive concerning poor performance of the air conditioning system. The efficiency of air conditioning systems is crucial to the success or failure of a special summer maintenance program.

ATA 26
FIRE PROTECTION
In general, fire / overheat detection systems operate with much reduced margins, between normal operating temperature and their alarm settings in hot weather conditions, especially when these conditions are combined with gas or bleed air leakage in certain very hot engine zones. This results in spurious warnings, the cause of which are often quite difficult to detect. Obviously, gas / air leakage and fire / overheat detector integrity can greatly affect the event rate for this system.

ATA 31
INSTRUMENTS
ATA 34
NAVIGATION

We have experienced very large increases in malfunction event rate / component removal rates for these two systems. This is due to a number of factors such as reduced air conditioning system efficiency, high compartment or zone temperature due to heat soak on the ground; high component metal or core temperature due to either inadequate instrument cooling system performance, or excessive heat soak with no ventilation, coupled with heat generated by components when energised. The worst possible operating scenario for these two ATA systems is when an aircraft is left to bake in the mid-day heat with no air-conditioning or inadequate ventilation and with its electrical busses energised, such as is often the case when undergoing maintenance. The outcome in terms of reduced component reliability, is inevitable.

ATA 36
PNEUMATICS
Our principal problem with this system has been a big increase in the number of area or duct overheat / leak events. Again, as in ATA 26, this system suffers from reduced margins between its operating temperature and the alarm level of its overheat or duct leak sensors, due to the higher ambient heat levels, and again, as in ATA 26, the problem is exacerbated by hot bleed air leaking from duct flanges or joints, which in cooler weather would be relatively insignificant.

Our Heatguard program is designed to reduce, if not actually eliminate these particular hot weather problems. It is comprised of:
- a number of preventive maintenance items which are performed in addition to the normal maintenance program,
- certain preventive maintenance items carried out at increased frequency levels,
- an active in-house publicity campaign highlighting summer problems and advising all maintenance and flight operations staff to observe certain recommendations on how to reduce heat or avoid systems abuse.
In launching Heatguard as mentioned earlier, we recognize that there is nothing we can do to control the weather, but there is much we can do to control aircraft internal heat levels. The following is a selection of some of the items in our program, that have proven to be very successful in this regard:
- close cabin window shades on the sunny side of the aircraft after every flight,
- switch off or dim all unnecessary lights, particularly passenger reading lights and cockpit instrument panel lights after each flight,
- make extensive use of ground air conditioning units especially if the aircraft is required for flight within say, three hours from last arrival,
- fabricate cockpit window blanks, or sun screens, and install these when the aircraft is on the ground between flights, to eliminate heat due to greenhouse effect,
- colour code all cockpit circuit breakers which affect heat...
generating instruments, avionic components or systems that are not required on ground, and make it mandatory for maintenance or flight crew personnel to pull these after every flight.

- switch off galley power whenever possible,
- if it is not practical to supply air conditioning for long periods of time, switch off all electrical busses that are not required, using only the ground service bus when practicable,
- open as many doors or access hatches as possible to help dissipate heat by ventilation, especially during extended maintenance periods in the open,
- drain and refill the oil in the air cycle machine (ACM) every 15 days (as opposed to every 300 flight hours normally),
- remove air conditioning coal- escer bags every 15 days and replace with clean bags,
- perform in-situ cleaning and leak check of heat-exchangers fleetwide, prior to the official first day of summer,
- check the integrity of the inter- tray seals in the equipment cooling rack,
- all flight station and zone trim temperature sensors to be cleaned once only before summer,
- all filters and inlet screens in the instrument cooling system to be cleaned monthly during summer,
- prior to commencement of summer, perform a fleet-wide campaign to detect and elimi- nate all leaks in the pneumatic ducts even if they appear to be only slight,
- prior to summer, whenever engines are being run-up for maintenance checks, personnel should inspect all exposed bleed ducts and valves for leaks and rectify any found.

There are many other items in the program which are tailored to specific aircraft types. The above items are general and can be applied to just about any transport aircraft. None of these items will be suc-

Heatguard has practically eliminated the most recurrent summer related technical flight interruptions experienced previously by Saudia. It has improved our on-time performance. The results, as shown, clearly speak for themselves.
WEIGHT & BALANCE SYSTEM

The purpose of a Weight and Balance System (WBS) is to determine on the ground the gross weight and the center of gravity of an aircraft and to provide the information to the flight crew, eventually replacing the Load and Trim Sheets.

THE BACKGROUND

There have been many attempts to build a system capable of providing directly the aircraft weight and center of gravity without being obliged either to use scales or to calculate by using Load and Trim Sheets. The best location for such systems are the landing gears because their well known geometry allows the necessary calculations to be made easily.

Generally, the systems used strain gauges to measure bending forces or shear forces. The results given by this method were sometimes altered by external factors such as side forces. However the use of strain gauges was forsaken mainly for maintenance reasons which were expected to be costly and difficult.

Other systems tried to use pressure transducers to measure oil or gas pressure inside the landing gear shock absorbers. This method was forsaken since too many factors tended to alter the results: friction coefficient, uneven surfaces, side loads, etc...

In fact all these systems were trying to measure directly the forces resulting from the aircraft weight. For some years now, new methods have been under development to measure the effects of weight on the aircraft parts which means measurement of deflections. In such a way the sensing devices themselves are no longer under stress forces.

CURRENT PRINCIPLES

Nowadays the two main principles being developed are the measurement by transducers of the bending moments or shear forces induced by aircraft weight.

Measurement of deformations due to bending

When a beam is loaded with a force P, it bends and the angle C is proportional to the bending moment which means proportional to P. Therefore if the angle C can be measured accurately, the force P will also be determined accurately (Figure 1).

Measurement of deformations due to shear forces

When a beam is loaded with a force P, the displacement T of
section A with respect to section B is directly proportional to the shear force and therefore to P. Therefore, as above, if the displacement T can be measured with accuracy, the force P will be known with precision (Figure 2). Thus both systems are based on the measurement of very small deformations, a system which is delicate and needs accurate transducers.

**Transducers**
The choice of transducers depends on the principle chosen to set up the Weight and Balance system.

**Measurement of angles**
To measure the angle of deflection resulting from bending moments, Sundstrand Data Control is proposing accelerometers used as inclinometers. These accelerometers are servo-mechanisms in which the variation of acceleration and function of the angle C on a pendulous seismic element is accurately measured.

**Measurement of displacement**
To measure the displacements resulting from shear forces, the transducers are mainly composed of two parts, each one attached to one point of the aircraft structure. The relative movement of one part to the other is sensed either by a variation of reluctance, the VDO/Weico system, or by a variation of capacitance, the SFENA system.

As part of the principles themselves, all of the transducers must be fixed rigidly to the structure to avoid parasitic deformation.

**Computers**
As already mentioned, the transducers are generally fitted on the landing gear. The output signal of each transducer is sent to a computer which is able to determine the weight bearing on each gear and then, to calculate the total weight and the center of gravity of the aircraft.
The computer needs other parameters, such as:
- aircraft attitude, from a specific sensor, in order to make the correction to the pitch angle during determination of the center of gravity;
- aircraft status (landing gear position, ground or flight) which permits the initiation of some self-tests such as auto-zero load check and adjustment in case of transducer drift;
- the status of transducers (temperature, etc.) in order to compensate the environmental influences or to initiate some corrections due to configuration changes for instance, loading, unloading.

To perform the calculations, the computer uses the characteristics of each individual aircraft which is stored in a separate calibration module. This module is in fact an auxiliary memory for the computer.

The weight and center of gravity can then be displayed to the flight crew on a specific indicator and control panel or through an aircraft system like the ECAM on A310 and A300-600.

If the system is used only as a back-up for the load and trim sheet, one computer only is necessary, but if a primary use is expected two computers with cross-talk are necessary, as well as other parameters such as fuel quantity, and to ensure the requested redundancies most of the transducers also have to be duplicated. Figure 3 shows the general design of a primary weight and balance system.

As a free of charge function, most of the vendors develop a tyre low pressure warning system by using the same transducers and computers. Nevertheless the main objectives remain the weight and the center of gravity.

MAINTENANCE

The objectives of all vendors are:
- to build computers with self-test functions able to detect a failed LRU (transducers, computer or calibration module) that the replacement of a failed LRU should be easy and fast; and that the replacement of an LRU should not need a re-calibration, including the calibration module which must be easily reprogrammed.

EVALUATION / EXPERIENCE

Some years ago, vendors, such as Sundstrand, VDO / WEICO and SFENA, after having developed their principles and performed some laboratory tests, went to the airlines to experiment their systems on landing gears of service aircraft (DC10, 747, A300).

Under normal environmental conditions and realistic constraints the results were encouraging but revealed that some improvements were needed.

Then the vendors came to Airbus Industrie in order to perform more specific tests on developing aircraft (A310 and A300-600), on which it was also more convenient to do comparisons between the WBS readings and the actual weight and center of gravity determined by weighing on scales.

The transducers of the three systems were fitted on the bogie beams of the main landing gear and inside the nose wheel axles. In general, the figures given by the different systems related to accuracy were acceptable, but unfortunately were altered by some weak points or adverse effects. The main problem that occurred was some discrepancy in the readings apparently due to poor integrity of the transducer attachments, mainly inside the nose wheel axles. In addition it was found that:
- the geometry of the landing gear and its structure can give some errors due to variable external forces inside the assemblies (i.e. pitch dampers);
- the side loads, uneven surfaces or slopes can also lead to some discrepancies that in some cases appear to be difficult to correct by software;
- the loading and unloading of the aircraft can lead to some hysteresis in the WBS but this can be reduced and may be corrected in the computer;
- the adverse environment of the transducers positioned on the landing gear is detrimental to good reliability.

These are the main problems identified, none of them appear to be insurmountable or prohibitive for the systems, nevertheless they must be cured in order to have systems able to give the weight and the center of gravity with more reliability and with an accuracy which remains in the target limits of 1%. On the maintenance aspect, all the objectives will certainly be achieved by the vendors. However, for the time being, the initial calibration is too long and will need to be simplified.

CONCLUSION

Of the various principles of Weight and Balance systems in development, mainly based on the measurement of bending or shear deformations, three of them, made by Sundstrand, VDO / WEICO, SFENA, have been assessed on Airbus Industrie A310 and A300-600. All gave encouraging results. A320 will be equipped with provisions for a Weight and Balance System.
With the introduction of the A300 into the Brazilian domestic network, VASP took a decision that they have never regretted.

Innovative VASP

Roberto Cossi
Technical Director
VASP

The underfloor cargo compartments of the A300 meant that the airline could now provide greatly increased freight capacity compared with the two 737-200Cs that represented until then the airline's only capability in the freight market. So quick was the response to the new capability and the technical reliability of the VASP A300s that VASP soon became the leader in Brazilian domestic freight.

However, the recession soon found its way into Brazil and one effect was the fall in passenger loads on the main trunk routes during the year. Naturally, during Carnaval not a seat could be found, but the problem of low passenger loads became critical during the low season. But freight did not vary with the seasons: it was there all the year around. Customers needed air transport for their products. VASP carried out economic studies which showed that even with a depressed passenger market the A300 could perform well in terms of economics, if only they could increase the cargo loads. How to do this?

After discussions with Airbus Industrie specialists, VASP found the solution. They would convert their aircraft into Airbus Combis. The Engineering Department of VASP was given the task of designing and producing a kit for the conversion. The first kit was to be tried on one of the aircraft during a period of heavy maintenance and low traffic, and from it, modified and refined if necessary, two further kits would be produced. Skilled engineers and manpower soon came up with the drawings and conversion items. Seats, hatracks, ceiling and lateral panels were removed aft of the emergency exits, a new class divider equipped with blow-out panels in the upper area was fitted, and a communicating door to give passengers and cabin crew access to the aft toilet block and galleys. Behind the dividing partition, new protective sidewalls, lateral and ceiling panels were installed together with floor tracks, fixation nets and the mandatory smoke detectors. To further isolate the freight area, a longitudinal partition wall was provided, leading to the rear of the aircraft and fitted with a safety rail.

The manufacture and assembly of the first prototype conversion kit took about seven and a half
weeks. Following this, all necessary decompression, smoke, fire and flight tests took place leading to certification by the Brazilian authorities. Conversion of the second two aircraft lasted three weeks for each aircraft, but this time is now reduced to 18 hours for the passenger to freight mode conversion and 24 hours for the freight to passenger mode, the slightly longer time being due to extra checks needed on the entertainment system and passenger emergency related items. Target times quoted for these conversions is 12 and 18 hours respectively; the total workforce is only ten persons.

In service, the aircraft, now with 164 seats (26 first and 138 economy), has an extra upper deck cargo area enabling nearly five tonnes of cargo to be loaded through the no. 4 left passenger door, in addition to its normal underfloor load of pallets and LD3 containers.

High volume, low density freight is ideal for this A300 operation and this exists in Brazil. Manaus in Amazonia is a free port area and tremendous potential exists for freight both in and out. From Sao Paulo, for example, VASP carries partially built-up television chassis accompanied by television tubes. In Manaus, the electronics and wiring are installed and the completed sets are flown back to Sao Paulo for retail distribution. Quick, economical, profit-making.

No technical or operational delays have been reported attributable to the new cargo system in the first months of service. In fact up to four tonnes of freight are unloaded and reloaded within the 50 minutes scheduled turn-around time at Manaus.

VASP's spirit of initiative and the A300's versatility are making an important contribution to Brazil's economic recovery.
Cabin steps for
Malaysian airline system
Airbus A300

Bright Spark, a Quality Control Circle from Malaysian Airline System, came out with an ingenious idea to minimize passenger seats damage during maintenance. Through problem identification, problem analysis, data analysis and brainstorming, they designed a cabin step which is adaptable to MAS fleet, is extendable in height, has better stability, better safety, good manoeuvring and control. The Bright Spark circle comprises Licenced Aircraft Engineers and Artisans from the electrical, instrument and radio trade. All of them are based at Base Maintenance Section of Kuala Lumpur Airport. They have worked on the project for five months and when they presented their solution to the damaged seats problem to the Maintenance Management, it was accepted and implemented.

The cabin steps can be placed in between seats, and access to the A300 ceiling, especially with the extendable feature, is rather easy and comfortable. With the availability of the Bright Spark designed cabin steps, damage to seats is minimised and workers safety enhanced.

Drawings or details are available with Mr Sitham Nadarajah Maintenance Manager Malaysian Airline System 4 Jalan Sulaiman Box 513 Kuala Lumpur Malaysia
LATERAL TRIMMING

Marie-Claude Pomery
Flight Handling Manager
Airbus Industrie

The most efficient means of trimming an aircraft varies with its aerodynamic characteristics. Taking as an example the Airbus A310...
There are several ways to trim an aircraft to ensure steady cruise flight on a straight flight path with constant heading. However, special procedures are needed to trim an aircraft in cruise and keep performance at or below the norm given in the Performance Engineer Manual (PEM).

It is therefore of great interest, in today's fuel-saving world, to know if flying, operational and maintenance practices are compatible with fuel saving policies.

**THE SYMMETRICAL AIRCRAFT**

Let us consider the case of an aircraft, which is laterally symmetrical from an aerodynamic, thrust and weight standpoint, being flown steadily on a straight flight path with constant heading. For such an aircraft the lateral forces, rolling and yawing moments are naturally equal to zero so no trimming is required. Therefore all lateral aircraft attitude angles and control surfaces would be at zero, i.e. side slip ($\phi$)=0, bank angle ($\phi$)=0, rudder setting ($\delta_r$)=0, wheel deflection ($\delta_{pw}$)=0, and therefore all ailerons ($\delta_{ASA}$) and spoilers ($\delta_{sp}$) would be in neutral position.

However experience shows that even symmetrical aircraft are not always properly trimmed in cruise. Flying a symmetrical aircraft with sideslip and control surface deflections, when it would have been possible to leave them at zero, keeping the same track constraints, obviously introduces a drag increase and therefore a specific range penalty which is not negligible.

Taking an example from figure 1 it can be seen that the selection of rudder trim at 1 degree left results in 0.5° sideslip, 0.9° bank angle and aileron trim 2.5° right wing down resulting in a loss in specific range of about 1.5%.

**THE ASYMMETRICAL AIRCRAFT**

An aircraft can be asymmetrical for one of several reasons (or a combination of them) as listed below:

- production tolerances on the indication of the trimmed positions of the rudder and ailerons;
- production tolerances on wing, fin and rudder twist, flap and slat misalignment;
- engine thrust asymmetry;
- fuel/cargo loading asymmetry.

During acceptance test cruise flights, prior to delivery, Airbus Industrie verifies that its aircraft are within the tolerances for asymmetry. In-service operations, however, can introduce asymmetry which, depending on its origin produces additional rolling ($\Delta Cl$) or yawing ($\Delta Cn$) moments which have to be cancelled by trimming.

Whereas on a symmetrical aircraft, if one parameter is at zero, the others would also be at zero, to fly straight and level (Figure 1), on an aircraft with a given level of asymmetry, setting one parameter to zero would lead to a given set of positions for the others and therefore an associated drag penalty. Figure 2 shows that an aircraft suffering from a roll asymmetry ($\Delta Cl$ 0.01) which has the aileron control wheel at zero will have about 0.6° of bank angle, 0.5° rudder deflection and about 0.3° side slip.

**OPTIMUM TRIM**

Airbus Industrie has devoted a number of hours to wind tunnel
and flight tests to define which is the optimum trim technique with regard to fuel saving for the A310 and the easiest to apply are the three following techniques:
- the wing level technique ($\beta = 0$),
- the zero control wheel procedure ($\delta_{pw} = 0$),
- the zero side-slip technique ($\beta = 0$).
(Note that no side-slip indicators are fitted to the A310 due to the poor accuracy of the systems currently available).

To each technique corresponds a given set of aircraft attitude angles, control surface deflections and therefore a given drag penalty. Figure 3 shows conclusively that an aircraft suffering from either roll or yaw asymmetry flies most economically when the zero control wheel procedure is used. The gain in specific range of the zero control wheel procedure over the wing level technique can be up to 0.7% and even more in the case of a combined roll and yaw asymmetry.

Airbus Industrie has verified that using the zero control wheel technique does not impair passenger comfort since the bank angle, for a high operational level of roll and yaw asymmetry, will be less than 1.5°.

**RECOMMENDED TRIM PROCEDURES**

The minimum drag for cruise flight is obtained when the control wheel is neutral. This condition is obtained by the following procedure:
- ensure symmetric fuel loading,
- ensure accurate symmetric thrust, autothrottle disengaged,
- engage the autopilot, if not already engaged, in HDG SEL mode and in ALT mode in CMD,
- adjust the rudder trim in order to get a zero control wheel position (aileron deflection scale on the wheel),
- verify that the bank angle is not too large for passenger comfort (1.5° appears to be a reasonable value),
- check against the lateral and rudder trim conditions and retrim if necessary when there is a noticeable change in flight conditions.

If after a given number of flights consistent and accurate trim procedures show a homogenous set of non-zero values, it can be concluded that a persistent asymmetry has arisen on this aircraft.

Identifying the type of asymmetry is necessary to guide corrective maintenance actions. To do that two trims should be carried out in flight, first by the wings level technique, for engineering analysis, then by the zero control wheel procedure to continue the flight in the most economical manner.

Figure 4 shows examples of three aircraft where the rudder trim and aileron control wheels have been noted consistently off zero when the wing level technique is applied.

If the aircraft under consideration behaves like aircraft A which has 1.2° rudder and 4° control wheel deflection (right wing down) it can be concluded that it is suffering from a pure yaw asymmetry, probably linked to a thrust unbalance problem. Maintenance checks should be directed to N1 or EPR indicating systems. Aircraft B has probably got a fuel/cargo loading problem inducing a pure roll asymmetry.

In the case of Aircraft C, suffering from combined roll and yaw asymmetry, a check mainly oriented towards the wing moving surfaces should be performed.

**CONCLUSION**

Owing to necessary production build tolerances, it is unlikely that an aircraft will be perfectly symmetrical although all aircraft will leave the factory within the specified limits.

Situations will arise in service which will introduce asymmetric tendencies. Careful monitoring of trim setting will enable the maintenance team to correct such tendencies. Use of the zero control wheel method of lateral trimming will eliminate unnecessary fuel burn.
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Eighty years ago lateral trimming of flying machines was not one of the primary concerns of the magnificent men who dared to take to the air in them. Ailerons and spoilers were complications which hadn’t been invented. Lateral control was achieved by simply warping (or twisting) the wings, a system patented by the Wright brothers in 1906.

The warping of the wings was effected by two cable systems: one active, which was attached to the top ends of the two outer rear struts on either wing and linked to the right control lever (in red), the passive system was linked to the lower ends of the same struts (in blue). The active system pulled down the two struts (and the wing tips) on one side while the passive system automatically pulled up the two struts (and the wing tips) on the other wing. The right lever also controlled the rudder; the elevators were controlled by the left lever.

The Wright Flyer
AIRBUS INDUSTRIE
ALL THE EXPERIENCE
OF EUROPEAN AVIATION
IN ONE

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