

AIR ENGINEER



1990

AIR ENGINEER



The Journal of the Royal Air Force Air Engineer Branch

1990

Editorial

As this issue of *Air Engineer* goes to print, the inquiry into the M1 Boeing 737 disaster is exposing many of the shortcomings of the modern 'TV Screen' flight-deck. The accident was sad proof that advanced cockpit technology does not necessarily mean enhanced flight safety – indeed, in this case, it seems to have been a contributory factor to the accident. The weight of evidence against modern flightdeck data presentation is growing as less systems information is being presented to fewer crew members. When authorities as credible as a senior member of the AAIB suggest (albeit on a personal basis) that such an accident would probably not have occurred had a flight engineer been on the crew, surely it is time for aircraft operators and manufacturers alike to take a long, hard look at the way we manage our flightdecks. The suggestion that the presence of a flight engineer may have altered the outcome of the 737 incident, while gratifying in one way, brings to mind the line from the old Negro spiritual 'it ain't necessarily so'. On the one hand there is a clear advantage in having on the flightdeck a third person who, while the captain is fully involved in flying the aircraft and the copilot is busy renegotiating clearances with ATC, can concentrate on the analysis of the data presented to him.

On the other hand, the accuracy of the analysis depends on the amount of data available and the ease with which it can be assimilated and interpreted. Herein lies a problem.

The traditional three man flightdeck with its wall-to-wall dials and gauges not only has that invaluable extra pair of eyes, but also has far more diagnostic systems information clearly displayed so that, more often than not, an incipient problem is detected long before it becomes a drama. Take away the third person and immediately there is a problem in presenting systems data on a panel which, of necessity, must be dominated by flight information. The problem can be resolved only by making the indicators smaller and/or reducing the amount of systems data immediately available. Hence the opinion that 'it ain't necessarily so' that a flight engineer would have analysed the 737 engine data any better than the pilots did. Given his traditional gauge-laden panel he would have known exactly what was going on – but with the 'advanced' technology display – who knows?

The result of giving limited data to three men would probably be the same as giving comprehensive data to two men. But giving limited information to two men? Sounds like an accident waiting to happen!

Phil Coulson

On the cover...

The Flight Engineer's panel on a Belfast freighter of HeavyLift cargo.

Editorial Committee

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Please Note

Letters and articles for inclusion in the 1991 Journal should reach the editor before April 1, 1991. Please ensure that all articles are typed, double spaced and, ideally, illustrated with photographs when relevant. The total number of words in the article should be printed at the end. Any items which you wish to be returned should be clearly marked with your name and address. This is one publication where the editor does accept full responsibility for what is published, even though *Air Engineer* is not an official publication.

Please ensure your Station Co-ordinator is aware of any article which you intend to submit; he will also provide a 'whipping' service should the editor have an empty 'In' tray two weeks before the copy date!

Sergeant G A R Miller

November 4 1966 - April 30 1990

Sergeant Graham Miller, a single man, was born in Wallasey, Cheshire. A former head boy of his school, he also held the Chief Scouts award before joining the RAF in September 1985 as a direct-entrant SNCO Airman Aircrew. After recruit training at RAF Swindon, Graham joined No 130 Airman Aircrew Initial Training Course at RAF Finningley and felt much at home during leadership exercises in the Pennines where he had walked so often before.

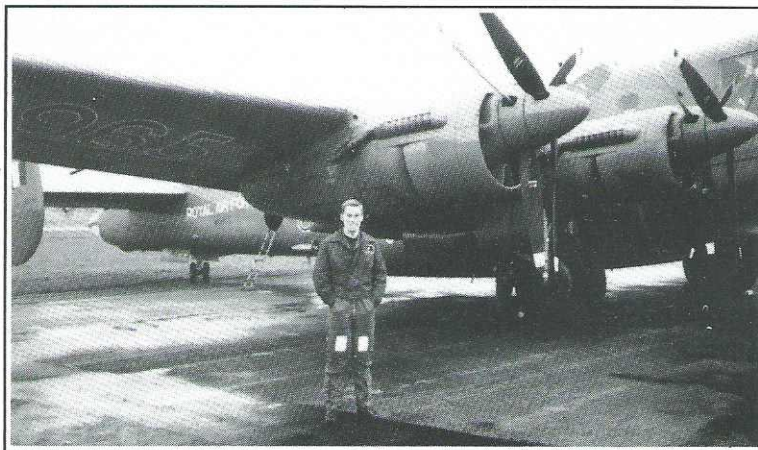
After Air Engineer training, Graham was posted to No 8 Squadron at RAF Lossiemouth in February 1987. Although

he had little experience of piston engines during basic training, and in spite of the fact that there is no Shackleton simulator to aid conversion training, Graham's keen and enthusiastic approach to flying the Shackleton meant he soon became a popular and well-respected member of 8 Squadron. In 1988 he was the Shackleton flying display Air Engineer, a job that he enjoyed tremendously.

Tragically, Graham was killed along with the nine other crew members of 'Gambia 08' on the island of Harris in the Outer Hebrides. He will be missed greatly by 8 Squadron, especially the Air



Engineers, and all those who knew him. Perhaps Graham's parents will find some solace in the knowledge that he loved his job so much.



Bruce and Edwina Miller and family wish to express their gratitude to all those friends and colleagues who mourned the loss of their son Graham and the crew of Gambia 08 with them. The cards, condolences and donations, many from people the family does not personally know, were a source of consolation and are most gratefully acknowledged.

Ex-MEng Clive Philips, AFM

1933 - 1990

Also affectionately known as 'Gropo', MEng Clive Philips died suddenly in Newlyn harbour (Penzance) on January 6, 1990 while on a delivery voyage.

During his time in the RAF he served as a flight engineer on 53 Squadron (Beverleys) at RAF Abingdon 1960-63 then on to 34 Squadron (also Beverleys) at RAF Seletar (Singapore) from December 1963 to May 1966.

During his time on 34 Squadron he was awarded the Air Force Medal for services above and beyond the call of duty and, in his spare time, caught the sailing bug. After 34 Squadron he returned to 53 Squadron - this time Belfasts at RAF Brize Norton. He stayed with 53 Squadron until it was disbanded and was

then posted to RAF St Mawgan and served in Task Control while waiting for a Nimrod course. He completed his OCU course in the mid 70s and was posted to 42 Squadron before retiring after 28 years' service.

He stayed in the county at Mylor Bridge then at Penryn and finally Millbrook (Nr Torpoint) to set up a sailing and navigation school, keen to encourage others to enjoy the pleasure of the sea in safety. He loved Cornwall, its people and the sea and it was on one of his many delivery voyages that he died.

His remains were cremated at Bodmin on January 12 and the ashes were scattered later by the Falmouth lifeboat crew off St Anthony's Head - on his

beloved sea where he had spent so much of his time in his later years. As a tribute to his popularity and kindness the chapel was full to overflowing and an RAF bugler sounded the Last Post and Reveille.

He leaves a wife Jean who intends to remain in Millbrook for the foreseeable future and a son Keith and family who live beside Loch Ness in Scotland.

Clive will be sorely missed by all those who knew him whether as relatives, former next-door neighbours, members of the sailing fraternity or past pupils. He had also made many friends in many ports on both sides of the Atlantic.

Donations to the Royal National Lifeboat Institute rather than flowers were requested by his family.

'...and here is the news'



by MEng Chris Anderson 101 Sqn

Picture, if you would, a September evening. The early autumnal sun sets slowly behind darkening hills. Hues of red and deepest blue spread across the Scottish countryside. City workers head for home, perhaps anticipating the weekend break. The flaming waters of the Tay flow relentlessly seaward with only an occasional fishing boat breaking the shimmering patterns.

On an airfield overlooking the river an air engineer crosses the dispersal towards the squadron's temporary accommodation. Behind him, the now silent VC10 tanker stoically endures her technicians' ministrations. The lone figure joins the other members of his crew as they emerge, disgruntled, from Sqn Ops. The reason for dismay is quietly communicated. An anguished cry rents the air ...

'What do you mean we're not going back with the rest of the Squadron? I was really looking forward to a post detachment cuddle tonight, I'm already walking with a limp!'

'I know how you feel, Eng, but someone has to transport the world's Press to take nice pictures of our boys seeing off the Bears who are taking nice pictures of the fleet.'

'That's all well and good, Capt, but has anyone phoned the Russians to make sure they're going to be there?'

'Well, if they don't turn up tomorrow we'll try again on Monday – anyway, look on the bright side, Anne Lucas is with one of the camera teams.'

'Yes, and I can guess whose Mess she'll be staying in. What time are we starting?'

'We're on stand-by from 0600Z.'

'My God! It doesn't get any better. Can't even take solace in a few pints tonight. Oh well, see you gentlemen in the morning.'

Sat. 0615Z, VC10 K3 flight deck. Engineer just finishing his sixth late change to the 'trim sheet'.

'Right then, are we now sure how many people are coming with us and how much gear they are bringing?'

Capt: 'Absolutely Eng. There will be 19 POB including us and the 'trolley tart'.'

'Nav – Eng the ZFW is 72.4 tonnes.'

'Thanks Eng.'

Capt: 'Well if everyone's ready to go we'll run the pre-start checks up to APU and then take turns monitoring the radios, you first Eng. The rest of us stack to the crewroom with the TV people. If you get the scramble call start the APU, that should bring us running. I'll relieve you in half an hour.'

'OK Capt, see you later.'

0630Z

V/UHF 1: 'This is the duty operations controller. Tansor scramble! I repeat. Tansor scramble!'

'Damn me. Someone did phone the Russians! OK here we go. No 1 battery stby, No 2 battery on. APU master on, and start button press. (Pause) APU running. No 1 battery on. APU bleed air on. Right, I'm ready for main engines. Ah! Here comes the roadshow. Wonder which one's Anne Lucas. Can't really see from here.'

The rest of the crew take their seats on the flight deck.

Capt on I/C: 'OK everyone, check in please.'

'Co,' 'Eng,' 'Nav'.

Capt: 'Good, checks please Nav. Eng, in your own time, start all four.'

The crew now follow a sequence of well-rehearsed checks and actions, a chronicle of which, dear reader, I won't bore you with, but which bring our heroes, some 30 minutes later, to FL310 heading north.

Eng: 'Where's our chick coming from?'

Capt: 'Southern Q'.

Eng: 'In that case will he be able to catch us?'

Capt: 'Good thinking Eng, better ease back to 280kt till we make contact. Co, get on to air traffic and see if they know where he is.'

A brief R/T call establishes that the fighter is some 100 miles astern at FL270.

Capt: 'OK Co, advise air traffic that we are descending to FL270 and will be holding in our present position. Eng, on levelling fly buffet plus 20. Nav have you got him on air to air yet?'

Nav: 'Not yet Capt. When he comes up on the radio ask him to set channel 57.'

Time passes. Contact is made with the fighter.

Capt on R/T: 'M3J this is C7G 37, my flight level 270, when cleared make your level 260, clear to join on the port, and set air to air 57.'

Fighter: 'Roger 37.'

Nav: 'He should be in our five o'clock, two miles closing.'

Eng: 'Looking for him on the TV. Visual, seven o'clock, half a mile. Coming onto the port wing, steady port echelon, you should be able to see him now, Capt.'

Capt: 'Yeah! Got him thanks Eng.'

Meanwhile the pax who have been squeezing onto the flight deck to watch

the fighter's approach on the CCTV, now rush to any available port window. The whirr and click of cameras is deafening.

Tanker and chick head north in search of Bears.

Sometime later the Scottish station's CO, who had jumped aboard the sortie at the last minute (well, no-one wants to miss a free Press opportunity) engages the engineer in conversation.

CO: 'I have a message here from Miss Anne Lucas.'

Eng: 'This is it. She's inviting me for a romantic dinner for two tonight.'

CO: 'Not quite, engineer, she wonders if you can pass the message through to her news desk at ITN.'

Eng: 'OK sir, we'll try to do that for the lady. Capt - Eng, Anne Lucas wants us to get a message out for her.'

Capt: 'Fine, take HF2 and go via Portishead Radio. Here's the list of frequencies.'

The engineer calls Portishead Radio and is quickly connected to the requested phone number.

Eng on R/T: 'sHello news desk, message from Anne Lucas as follows: Anne and team safely airborne. Will call on return to land. Message ends. This is Chris Anderson, News at Six, somewhere over the north Atlantic.'

Lady at newsdesk: 'Very funny, but thanks for the message, bye.'

The engineer terminates the radio link.

As the two aircraft are now an estimated 100 miles south of the intercept point, the captain decides that now would be a good time to refuel the fighter and calls for pre-tanking checks. These go without a hitch until the port hose is trailed.

'Capt - Eng, we have a problem with the port hose. No amber at full trail. Investigating.'

Capt: 'Roger Eng, didn't we have this the other day?'

Eng: 'Yes. Still I'll go through the drill again though I don't hold out much hope.'

Two minutes later...

'Capt - Eng, no joy with that hose I'm afraid. It will wind and trail but not refuel.'

Capt: 'OK, in that case we'll put the fighter on the starboard hose, someone advise the camera men and after this refuel we'll use the centre line.'

To gasps of amazement from the pax who can't decide whether to watch it on the CCTV or out of the cabin windows, the refuel is completed. Hoses are stowed and the pair continue to watch the anticipated intercept point.

'Contact! 11 o'clock low. Definite Bear. There goes the fighter. My throttles Eng.' 'Roger.' 'I'll come up on his starboard, tell the news people to get ready.'

The tanker formates on the fighter which in turn has formatted on the Russian's starboard wing. The phalanx

of aircraft commences a steady descent towards the uninviting waters below.

'Nav - Eng. What's the lowest forecast QNH for this area?'

'I'm afraid we don't have it Eng.'

'In that case Capt, how about we get the fighter to give us an update using his RadAlt. We're already through 1500' and still on 1013!'

'Well spotted Eng. Co, sort that out with the fighter.'

The formation levels at 500'. The Bear occasionally alters course as the fighter alternates between port and starboard echelon. The tanker, meantime, manoeuvres to give the Press the best shots while trying to maintain a safe height. The engineer resists the temptation to shut down the outboard engines, a throwback from a previous life on Nimrods, and continues to monitor height, speed and essential aircraft systems while trying to ignore the sound man's mike boom sticking in his ear.

The Bear climbs, much to the relief of our heroes, and as the formation levels at 5,000' it is now joined by a USAF F15 (seems everybody wants their pictures in the news). The tanker continues to manoeuvre around the formation as the insatiable newshounds request different aspects of the two allied fighters seeing off the hun.

Eventually the Bear's crew decide they've had enough harassment for one day and promptly turn their aircraft towards the nearest bank of clouds. Now anyone who has flown formation will tell you that it is stressful, to say the least. But being part of a multinational four-ship that is about to go IMC is no fun at all. So, discretion being the better part of valour, our heroes turn away from the melée and head for safer climes, much to the chagrin of the Press.

Still, every cloud bank has a silver lining. At least the crew could now relax a little and maybe even take lunch. After the thrill of the chase it was time to get back to the more mundane things in life. Working out fuel offload, engine health monitoring ('doing a trend' to the initiated), and completing a systems log.

Thus it was, as the engineer glanced at the CCTV...

'Capt - Eng, we have a panel hanging down several feet astern of the camera.'

'Roger Eng. Which panel is it?'

'It's very difficult to say, could be either hydraulics or a pressure relief panel, either way it's not too good. It now means we can't use the centre line hose!'

Capt: 'Right. We'll fill the fighter up using the starboard hose, and then head for home. I don't think we're of much further use here. Someone tell the Press what we're doing.'

While waiting for the fighter to return it

is decided to film Anne Lucas doing the news report sitting on the jump seat. This causes more disruption to the normal clockwork operation on the flight deck. Cameramen, sound men and lighting technician (not to mention the director) all struggle for optimum positions impervious to the discomfort their antics cause.

However, the compensation is the close proximity of the comely Anne Lucas. Chanel No 5 pervades the flight deck and everyone decides the place has never smelled so good. Following several abortive takes, the young lovely manages to get her lines right and the first part of her report is completed. However, an attempt to interview the captain is abandoned due to lighting difficulties and the imminent return of the fighter.

After an uneventful refuel, the tanker heads for base, leaving the fighter to guard against an unexpected return of the Bear. All on board were delighted with the day's efforts and poured praise on the crew for their professional handling of the sortie. All that remains, on return to base, is for the captain to be interviewed, with the rest of the crew in attendance, and their rise to stardom will be assured...

Now, dear reader, to say that the media are a fickle bunch is, on the whole, a gross understating of the facts, as anyone who has had dealings with them will testify. So it was, following an uneventful return to Scotland, the crew prepared to disemplane. Hair neatly combed and smiles fixed in place, they emerged to the anticipated glare of publicity...not a single click of a shutter, not one pop of a flash bulb. Nothing!

Capt: 'Chief, what happened to all the Press people?'

Chief: 'While they were waiting for you to finish shutting down the jet they heard the QRA start up and they all went running over there,' pointing to QRA sheds, 'to watch it scramble.'

Capt, to anyone in earshot: 'Bloody typical! Drag them round the skies for six hours, answering their inane questions and putting up with their antics and this is the thanks we get. First sound of a fast jet starting up and they're off like Pavlov's dogs. You watch, I'll bet tonight's news report doesn't carry a single mention of us.'

This last remark was subsequently proved to be entirely accurate.

Eng: 'Ok Chief, waive the turn round. We'll leave for home as soon as you're ready.'

Capt: 'One thing though at least you'll get your cuddle tonight Eng!'

Eng: 'Yeah! Who needs Anne Lucas anyway!'

*'trolley tart' — squadron member who takes a two-hour course and knows all there is to know about being a loadmaster.

Watching the Weather with Snoopy



by **MEng Alan Kidson**

Almost from the first time that I knew I was to join the Meteorological Research Flight (MRF) at RAE Farnborough, I was aware that many air engineers have a somewhat sketchy idea of the work of the 'Flight'.

We do not, as some people suspect, go flying off into the nearest cu-nim just to prove that it's there! As many of you will know, I have been around for too many years to allow myself to be put into a situation that is even remotely dangerous.

So what on earth, you ask, do you do? As most of the equipment used in the back of Snoopy (as our W Mk2 Hercules is affectionately known) is far too technical for this humble engineer to explain in detail, I will try to keep to basics and work on the KISS principle.

The MRF is currently a lodger unit at the Royal Aerospace Establishment, Farnborough and is a direct descendant of the RAF's high altitude flight. The RAF aircrew element of two pilots, two navigators and two air engineers operate the Hercules as an airborne research laboratory for numerous meteorological project scientists, supported by technical and scientific staff. Scientists at Bracknell (Met Office HQ) and several universities very often make use of our facility for a variety of atmospheric studies. Unlike most posts filled by RAF aircrew, we work completely within a civilian environment. This obviously means that the Service aircrew, civilian scientists and technical staff must work in close co-operation and with a mutual understanding of each

others' problems, if each sortie is to be a success.

Snoopy is an old friend of mine, being an ex-FEAF CMk1 (XV 208). Marshalls of Cambridge were given the task of modifying the airframe to a shape which is almost as we see it today. The major differences from the 'fleet' Hercules are the 22ft long 'barber's pole' on the nose, the transfer of the CCWR to a zero drag fairing above the flight deck, (shades of basic aerodynamics?) and three extra wing pods — the two larger ones using the fittings of the 'A' model Hercules external fuel tanks. There are also the many and various scoops, probes and vanes. The overall effect of the hangers-on is a reduction of target speed by about five knots and an increase of four knots in the minimum control speeds compared with the Mk1 and 3.

Inside, the flight deck is visually similar except for the addition of extra circuit breaker panels — providing power for the scientific equipment (MRF Power), an angle of attack and stall warning indicator and an inertial nav system. Behind the captain's position an extra seat is fitted to facilitate the aircraft scientist who directs operations from there in conjunction with the aircraft captain. Using a remote TV screen fitted to the rear of the captain's seat he relays any information from the scientists stationed in the depths of the freight bay. In the freight bay a team of scientists and observers work in two specially constructed caravans and at

pieces of equipment secured around the aircraft's insides.

From a scientific point of view the aircraft is used to study a variety of atmospheric phenomena ranging from the basics, such as the structure and dynamics of clouds and the evolution of weather fronts, to the effect of topographical features on wind structure and the more modern problems of transportation of pollutants and the amounts of trace gases in the atmosphere, a problem highlighted by the 'green revolution'.

Although other nations have meteorological research aircraft, with which we work closely at times, none are so comprehensively equipped. This allows us so much more flexibility in completing the many tasks allocated to the Flight.

A typical day on the Flight starts with an up-to-the-minute met briefing at 0830. Much use is made of Meteossat pictures that are regularly updated. Following the general met brief, the scientist concerned with the day's experiment will give a specific brief on what he or she requires from the aircraft, crew and met observers. The general area of operations is decided at this point, although precise locations and altitudes will be left until we approach the area. Flexibility is the name of the game and the plan could and often does change as the experiment is progressing. From the aircrew side, the pilots and navigators will make final arrangements

with the various air traffic agencies and special tasks controllers. With the take-off due at 1030 the two air engineers confirm any special requirements with the scientist. On occasion the cabin altitude must be kept at a set height or it may be that a certain piece of equipment needs to be kept cooler than is usual. They then move out to Snoopy, the operating Eng to check the paperwork and the number two to check the all important rations. Then the aircraft checks are completed with very little change from the standard Hercules checks.

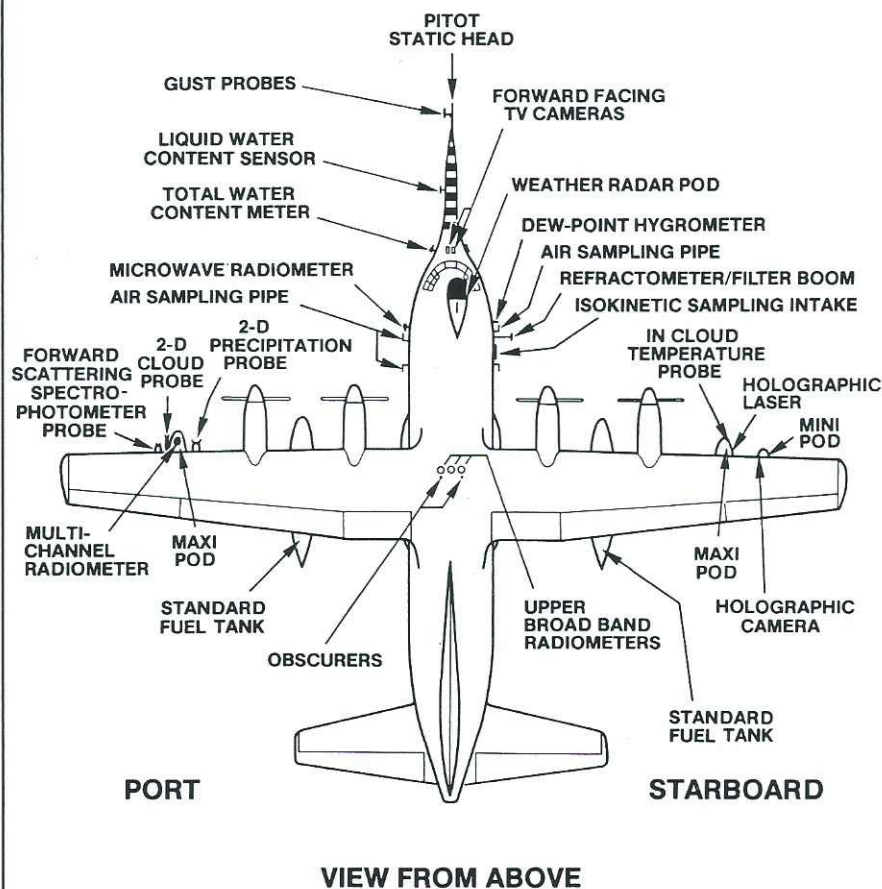
Our typical experiment could take us out over the South-Western Approaches looking for cumulus clouds to study the effect they may have on solar and terrestrial radiation. Having reached the area and the aircraft scientist is happy with the cloud formation, a profile descent is then made. This would probably commence at FL250 at a constant 180kt and 1,000ft/min down to 50ft above the sea. During the descent, the aircraft has been acting as a controllable sonde measuring temperature, pressure and humidity. Accurate flying is essential especially towards the bottom of the profile. To this end the air engineer will call out radar altimeter heights, also checking visually and on radar for possible obstructions – ships, rigs etc. Once down at low level we could be required to fly at anything between 75 and 200ft over a leg length of up to 150km to take measurements of sea surface temperature. Similar runs would be made within and above selected clouds over the same geographical point or within the same air mass, requiring considerable navigational accuracy. Once the scientists are satisfied with the data collected (or airfield closing time approaches!) a final profile ascent will be made and the aircraft flown back to base. The scientific data is recorded on magnetic tapes for later evaluation and can also be taken from the in-flight computers on paper copy for up-to-the-minute assessment.

Met Research Flight has a requirement for worldwide operation to research into weather phenomena. Recently we have taken Snoopy on detachment to Norway to evaluate satellite remote probing systems. Also we spent 10 days in Finland, based at Oulu, studying the properties of snow and ice surfaces and the effect that they may have on met satellites. Coming up soon we are to co-operate with several

other nations on an experiment that is to be based in Crete for ten days.

Such are the happenings of Snoopy and crew. A small unit remote from the mainstream of the Service, helping with experiments so that weather may be forecast more accurately, thus helping aircrew to fly more safely. (Oh, I forgot to tell you – we have our own specially built and fitted loos as well!).

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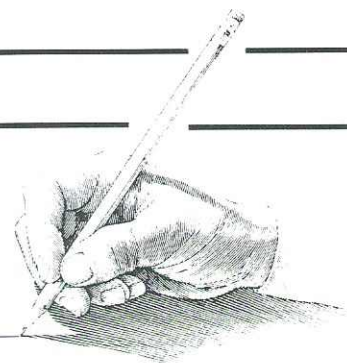
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letter to the editor...

Dear Editor

In the wake of the enormously popular and worthwhile change from using QFE to using QNH for all arrivals and departures, I would like to float another wizard idea.

As you are aware, all our aircraft performance figures are based on the use of nautical miles per hour – knots – and evidence suggests that crews slavishly relate these figures to their air speed indicators, also calibrated in knots.

My suggestion is that we replace our trusty, proven ASIs with speedometers calibrated in mph. The major advantage of the change would be in preventing under-arousal in crews during the most critical stages of flight. Performance speeds, holding speeds, approach speeds etc can all be converted easily to mph by mental calculation using the formulae:

$$\text{Mph} = \text{Knots} \times 1.15078 \text{ or } \text{Knots} = \text{mph} \times 0.86898$$

A further advantage is that outside the UK FIR, multiplying mph by 1.60934 will give Km/hr which, when multiplied by 0.53996 brings you back to knots!

Yours keenly
Dicky Conrod

The Editor replies...

Dear Dicky

Thank you for your well-reasoned letter which is very much in line with current thinking. Sadly, I doubt that your idea will be adopted because the case is not strong enough to convince the financiers who control the Jolly Good Wheeze budget.

For your guidance, an example of the sort of idea that the financiers go for in a big way is the proposed change to all TAPs, SIDs and STARs whereby all headings will be printed in degrees True. The cost of reprinting all the various FLIP Docs will be recouped by removing the Variation Units from all aircraft.

Yours etc,
Editor

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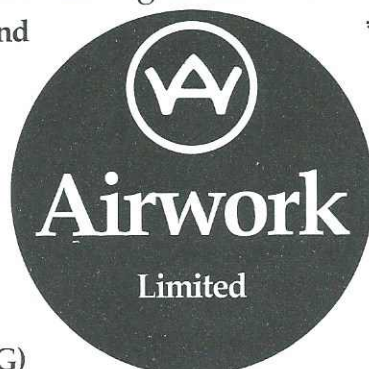
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Wide-Chord Fan Proved in More Than Five Years of Service

The first large airline engine with a fuel efficient wide-chord fan went into airline service in October 1984 on the Rolls-Royce RB211-535E4 engine powering the Boeing 757 airliner. This design of fan was pioneered by Rolls-Royce. It has proved its value by cutting fuel consumption and establishing a reliability record better than previous types of fan, as well as reducing the noise level of airliners.

The wide-chord fan has already been applied to four other types of advanced civil engine following its introduction on the RB211-535E4 engine. These are the Tay turbofan, the five nation V2500, current high thrust developments of the RB211-524 engine, and the new RB211-524L scheduled for certification in 1992. This will provide 67,500lb of take-off thrust with future development potential to 80,000lb.

These engines have been specified for a range of new commercial aircraft. The Tay powers the Gulfstream IV business jet and the Fokker 100 airliner; versions of the engine are planned to re-engine earlier aircraft types such as the BAe One-Eleven and McDonnell Douglas DC-9. The V2500 is in production for the Airbus A320 airliner and the RB211-524G/H is being produced for long range 747-400s and twinjet Boeing 767s. The RB211-524L is being developed for such aircraft as the McDonnell Douglas MD-11, the Airbus A330 and advanced developments of the Boeing 747 and 767.

Requirements

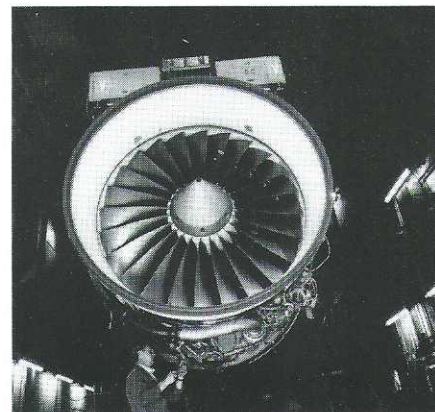
The fan is a key component of high-bypass turbofan engines for jet airliners. More than 80 per cent of the air entering the fan bypasses the gas generator of the engine and the fan acts like a very efficient propeller to provide nearly three quarters of the total engine thrust.

The low-pressure turbine on the RB211 extracts 50,000hp or more from the hot gas flow through the turbines to drive the fan. The residual hot jet stream provides about a quarter of the total engine thrust.

The fan is highly loaded and has an impressive performance. On the RB211-524G, for example, the fan has a diameter of more than seven feet and the maximum airflow through it is 1,670lb a second.



For comparison: the snubbed fan of a RB211-524D4 engine and the more efficient wide-chord fan of a RB211-524G (right)



Pumping an airflow of this size is equivalent to removing the air over a football pitch to a height of nearly 22ft in a minute.

The fan blades provide thrust in the same way as the wings of an aircraft produce lift, but the speed at which the fan blade meets the intake air increases along its span. Near its root the twisted aerofoil sections of a fan blade act like the wing of a subsonic aircraft, progressively changing to that of a fighter flying at supersonic speed near the tip.

The 524G's fan rotates at up to 4,000rpm and its blade tip speed is about 1,500 ft/sec. Intake air approaches the blade tips at a relative speed of 1,600ft/sec, or Mach 1.5.

Conventional fan blades of solid metal construction are restricted in width (chord) by a limit on blade weight. A blade weighing about 15lb imposes a centrifugal load of up to 60 tons in its root fixing and on the disc which supports it. A wider-chord blade, if solid, gives rise to an increasingly heavy disc until a point is reached where the disc can no longer be designed. Additionally, official airworthiness certification requires that if a blade is severed at the root it must not penetrate the engine casing and hazard the aircraft. This is not easy to accomplish because a 15lb blade has kinetic energy similar to that of a compact family car travelling at 30mph.

A containment ring is therefore needed around the fan casing. The heavier the fan blades, the more substantial and heavy this ring must be. These factors limit the weight – and thus the chord – of fan blades made from solid titanium alloy.

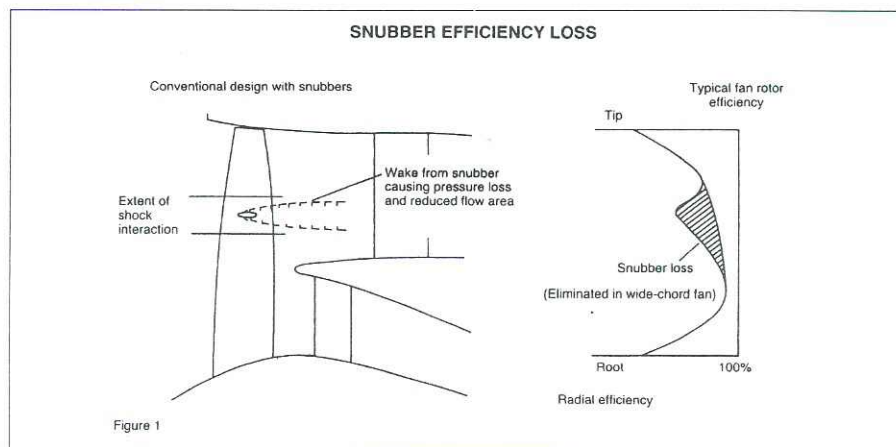
Eliminating Snubbers

Previous high bypass fans have, therefore, been universally designed with relatively narrow blades. These are aerodynamically unstable and would flutter and fail rapidly in fatigue if they were not stabilised part-way along their length by projections on the side of each blade known as snubbers (clappers). These are in close proximity when the fan is static and act as a stiffening ring when the fan rotates.

This ring is in the high-velocity airflow through the fan and reduces the blade's efficiency by causing pressure losses and a reduction in effective fan area, as Figure 1 shows. A larger fan is needed for a given thrust than would be the case for a fan without snubbers, causing a significant increase in engine size.

Because the fan produces so much of an engine's thrust, any advance which improves its efficiency has a powerful effect in reducing fuel consumption. There are many advantages if the stiffening snubbers can be eliminated by the use of blades which are sufficiently stiff, strong and light. This approach has been studied at Rolls-Royce for more than 20 years.

If blade width is increased, blades become stiffer and aerodynamic stability can be achieved without the use of snubbers. The number of blades required depends on their chordal width. As a result, fewer of the wider blades are needed – typically a reduction from 33 to 22 blades for the Rolls-Royce wide-chord fan of the 535E4 engine and to 24 for the fan of the 524G engine.



Weight and containment considerations make it impracticable to use wider blades for larger engines unless they are considerably lighter than the same blade produced from any known solid metal alloy. The Rolls-Royce solution is a hollow blade with a metal honeycomb core. It has involved a massive investment in man years and money to develop the wide-chord fan.

Many exacting requirements had to be met in addition to those already mentioned – ensuring that stress levels are maintained to provide an adequate fatigue life after allowing for likely surface marks and scratches; minimising vibration stresses; providing adequate resistance to impact by birds and other foreign objects; and evolving production techniques to ensure economic manufacture to the highest quality standards.

Four causes of performance loss are avoided when fans are designed without snubbers. They are the reduction in overall blade efficiency caused by the snubber; the extra blockage and profile drag caused by the snubber's frontal and surface area; the shockwave interaction with the basic flow over the fan aerofoil around the snubber; and the local thickening of the aerofoil necessary to absorb snubber loads.

Elimination of snubbers makes it much

easier for aerodynamicists to develop the most efficient aerofoil shapes for fan blades and optimise the transonic gas flow over them by using three-dimensional (3D) fluid-flow simulation techniques on supercomputers.

The performance improvement using a wide-chord fan is shown in Figure 2, which compares its cruise efficiency with that of an equivalent snubbed fan designed for the same duty. There is also an enhancement of the core engine performance by using a wide-chord fan.

The elimination of snubbers allows a smaller-diameter fan to be used for the same duty; this reduces total powerplant weight and also reduces drag. Alternatively, if a wide-chord fan is used for a higher thrust development of an engine which previously had a conventional fan, the extra flow provides higher thrust within the same nacelle diameter. This approach has been used in the development of the RB211-524 from 53,000 to 60,600lb of thrust.

The fan with wider blades also has a better surge margin. This allows a further improvement in performance to be achieved by operating the fan at a higher pressure ratio for a given rotational speed.

Rolls-Royce engines with wide-chord fans also have common exhaust nozzles; the fan and turbine exhaust flows are combined and leave the engine via a

single nozzle. A common exhaust nozzle provides an efficiency benefit in its own right which is maximised when combined with a wide-chord fan. A high-bypass engine operates over a better area of the fan-efficiency envelope during climb and cruise, using this combination.

The overall benefits in terms of sfc saving are shown in Figure 3, which compares the improvement in specific fuel consumption (sfc) for the 535E4 engine's wide-chord fan with the performance using a snubbed fan and separate hot and cold nozzles. The sfc improvement is more than four per cent at maximum cruise and climb thrusts.

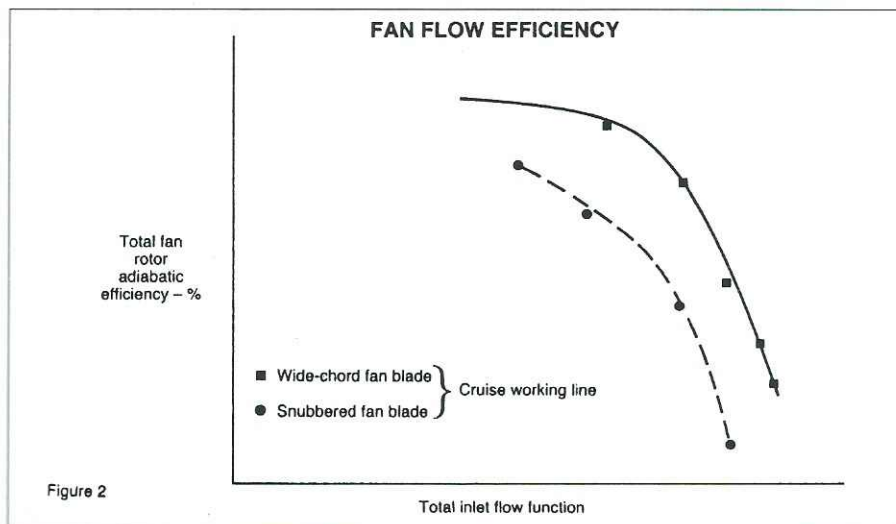
Noise

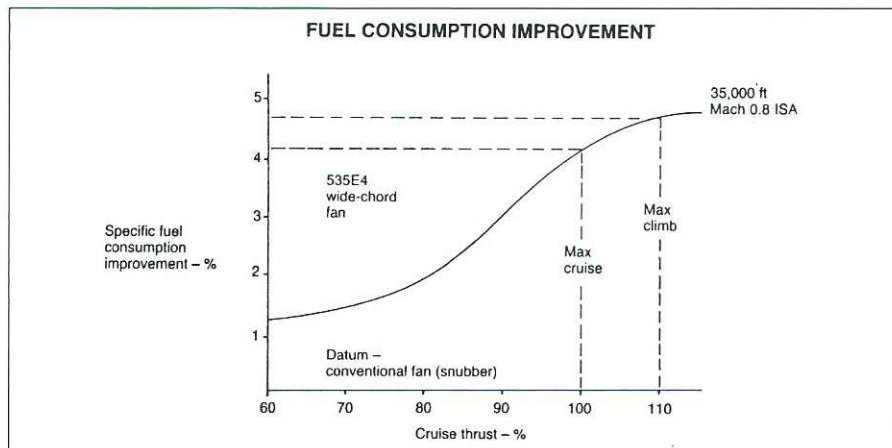
The wide-chord fan and common exhaust nozzle have both helped to reduce engine noise levels. The most significant demonstration of this noise reduction is the approval for night-time take-offs and landings by 535E4-powered Boeing 757s at Washington National Airport. This airfield imposes very tight noise limits for night-time operations and the Boeing 757 with 535E4 engines is the largest jet airliner cleared for such arrivals and departures. Boeing 757s with US engines do not qualify.

The wide-chord fan and common nozzle reduce noise during both landing and take-off. Much of the noise of a jet engine during the landing approach is fan noise escaping forward through the engine intake. A significant amount of this noise is produced by the 'siren' effect resulting from the airflow leaving the fan interacting with the fixed vanes behind it. The smaller number of blades on the wide-chord fan helps the designer to avoid the generation of significant tones, and the 'blockage' effect produced by the wider fan blades also makes it more difficult for noise to escape forwards through the fan.

At high powers, during take-off and climb, the more rigid wide-chord fan blades produce less of the irritating 'buzz saw' sound that results from the supersonic flow over the tips of more flexible blades. Also at these powers, jet noise is reduced because the fan and hot-jet exhaust flows are mixed before leaving the engine. This reduces the speed of the hot core jet exhaust through the common nozzle, which results in lower noise because jet noise increases as the eighth power of the speed of the jet.

At v8, doubling the speed of an exhaust jet increases its noise level by 24dB, making it perceived as more than four times noisier. More important, a small reduction in jet speed provides a major reduction in noise level.





Blade Design and Manufacture

Rolls-Royce wide-chord fan blades are designed to provide high performance at low weight and acceptable cost, with a long service life. Typical construction is shown in Figure 4. The blade is of sandwich construction, with titanium-alloy skins and a thin-walled honeycomb core, also of titanium alloy.

Skin panels are manufactured from flat plate by forging, hot isothermal forming and chemical machining to form the internal cavity. The core is produced by machining honeycomb made of titanium foil which is crimp rolled and resistance welded.

The panels and honeycomb core are joined by activated diffusion bonding, a liquid-phase process of diffusion bonding developed by Rolls-Royce. Blades have been subjected to intensive testing for integrity and durability, both on engines and in rigs, and have met all test requirements. Later tests of these blades to destruction have confirmed the effectiveness of the bonding technique, with no bond failures.

The stress and vibration analysis of wide-chord fan blades using computer modelling is now a routine procedure. It is also used to assess deformation of the blade leading edge when it is hit by 1.5 and 4lb birds.

Experience

Overall, Rolls-Royce fans have had an excellent record in service, both for the types with snubbed and wide-chord fans. Since these fans entered service, they have operated for more than 30 million engine hours without a single blade failure, with very occasional blade damage caused by ingestion of foreign objects. The integrity record of the company's fans for large engines puts it ahead of other manufacturers in this field.

Since the 535E4 engine entered service in 1984, the wide-chord fan has also had an excellent record and has

been trouble free. Consumption of spare blades on Rolls-Royce engines has been half that of the snubbed fans, which themselves have low spares usage. This reflects the improvement in resistance to damage caused by bird strikes and ingestion of foreign objects.

In service, the wide-chord fan blade is showing not only how resistant it is to foreign object damage (FOD) but also how well it is protecting the gas generator from FOD. The wider chord of the fan enables any debris entering the engine intake to be centrifuged more readily outwards, passing harmlessly down the bypass duct rather than through the core. This characteristic is being reflected in service on the 535E4 where there has been only one engine removal for FOD in more than one million engine hours – an unprecedentedly low rate.

Other Rolls-Royce engines with wide-chord fans are following the 535E4 into service. The Tay turbofan entered service in 1987 and is being followed this year by the V2500 and RB211-524G. Because of its smaller size, the wide-chord fan of the Tay has solid rather than hollow blades, but the wide-chord fans of the five nation V2500 and the RB211-524G/H and 524L engines have fabricated hollow blades.

The wide-chord fan has proved its advantages in reducing fuel consumption, cutting engine noise and improving resistance to ingestion damage in service. Rolls-Royce has a considerable start in this area of advanced technology, but

other manufacturers are also investigating the use of wide-chord fans on their future engines.

Meanwhile, Rolls-Royce is continuing its work on both aerodynamic and fabrication improvements which are expected to maintain its lead in this field. One example is the application of superplastic forming and diffusion bonding for the next generation wide-chord fan for the RB211-524L engine, giving improved strength and reduced weight.

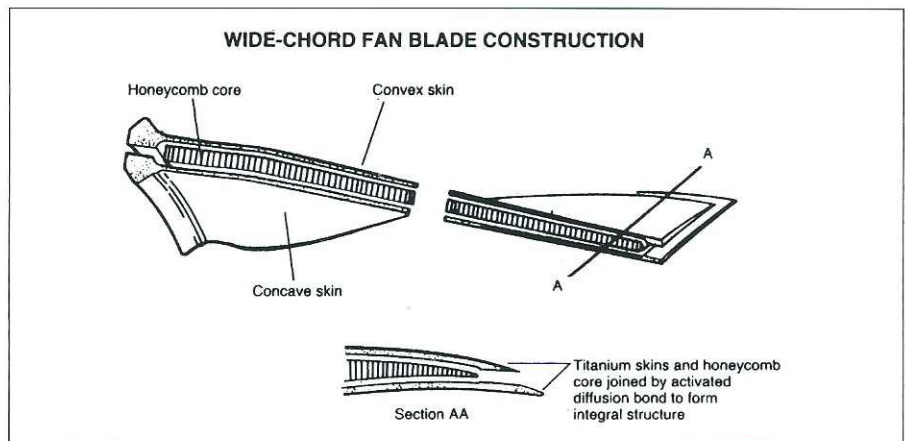
The 524L will be the world's most powerful engine. It will be certificated in 1992 at 67,500lb thrust and will have development potential to more than 80,000lb thrust.

Wide-chord fan blades for this new engine will be made in a new manufacturing cell by a controlled process ensuring continued quality, lower cost and shorter lead times. Fan blade containment for the 524L will be provided by the use of high-strength lightweight Kevlar material wrapped around an aluminium isogrid containment ring which has already been demonstrated by component testing.

Philip Ruffles is technical director of Rolls-Royce. After obtaining a BSc degree in engineering he joined the company in 1961 and worked in the preliminary design group.

He was later involved in the development of the RB211 and became chief engineer of the RB211-22B in 1977 and of the RB211-524D4 in 1979. In 1981, he was appointed head of engineering of the company's small engine group. From 1984 he was successively head of technology, director of technology and director of design engineering. He took up his present appointment in March 1989.

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AVAD A Welcome Voice in the Cockpit

by Dr PD Wheeler, PhD, CEng, MIEE
Racal Acoustics Limited

Racal Acoustics' AVAD—Automatic Voice Alerting Device—has found acceptance in military and civil aircraft fleets, both fixed wing and rotary wing, in the UK and abroad, since its introduction in 1984. AVAD provides clear, natural voice messages—in any language—and psychologically engineered attention getting tones (attensons), with fully programmable prioritisation and 'intelligent' control. Modern avionic systems can provide a wealth of system status and threat information, but the uncontrolled proliferation of visual and audio warnings can distract or confuse the aircrew. Rapid advances in measurement, sensing and control technology have resulted in avionic systems of such complexity that vital status and warning information may be misinterpreted, not acted on soon enough or missed altogether, and there are well documented reports, in both military and civil areas, of such incidents.

The Human Factors Element

The Human Factors Element is central to this problem of optimising information flow to the aircrew. In Information Technology (IT) research, this area, known as Man-Machine Interface (MMI), has become recognised as crucial to the successful introduction of new technology and it is, of course, essential that these ergonomic aspects are taken into account in avionic systems design.

In MMI terms, while the aircrew's visual senses are perhaps fully loaded in an emergency situation in the cockpit, the auditory channel may have capacity for the presentation of useful information, if it is not unnecessarily 'blocked' by the indiscriminate generation of excessively

loud 'klaxon' warnings, for example.

Problem areas with existing audio warnings in the cockpit include the possibility of confusion or delay due to the increasing numbers of different tones, disruption and startle due to sudden onset and excessive loudness, clash of warning priorities from competing signals and masking of voice communications from ongoing warning sounds. A frequently encountered response from aircrew is to cancel the warning signal before dealing with the fault condition, in order to allow proper control and communication to be resumed!

Signal Masking in Noise

The perception of audio warning signals (and speech) in a high noise environment is an area in which Racal Acoustics has an international reputation, working closely with the leading academic researchers in the UK to implement the latest technology into avionics practice. In a high noise environment, when trying to listen to a sound such as an audio warning tone, the ear's threshold of detection is determined by the ratio of the signal energy to the noise energy—the signal to noise ratio (SNR). The ear operates as a series of band-pass filters,

noise can penetrate the filter and degrade SNR even for signals in the 1kHz to 3kHz range. The problem is compounded when the attenuation characteristics of the typical ear defender headset are taken into account, in that all conventional circumaural headsets provide little or no attenuation at low frequencies, but provide 20 to 30dB attenuation at higher frequencies. The noise spectrum at the ear, under the headset, in an aircraft noise environment, is therefore dominated by low frequency noise which can penetrate the ear's natural selectivity

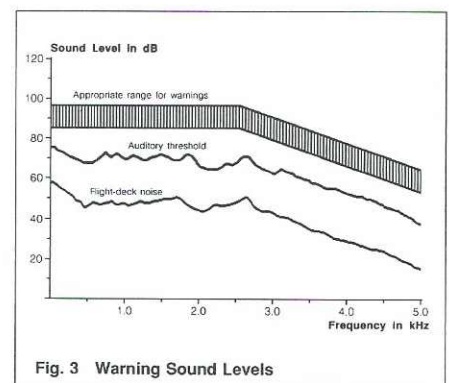


Fig. 3 Warning Sound Levels

when listening to speech or audio tones, to 'mask' and disrupt reception, as illustrated in fig. 2. The auditory filter bandwidth varies from person to person, and tends to increase with age and exposure to noise, resulting in increasing difficulty in separating speech from noise in situations such as the 'cocktail party'—a phenomenon with which most of us are only too familiar! This filter broadening, which can only be measured using sophisticated audiological equipment and which does not show up in normal hearing tests, also increases in the high noise levels found in performance aircraft, adding further to the difficulties of audio communication in the cockpit. For the future, Racal Acoustics is tackling this low frequency masking problem for communications in high noise with the introduction of its Active Noise Reduction (ANR) option for military headsets. The patented ANR system literally cancels out more than 95 per cent of the noise reaching the crew member's ear under his headset, by the superimposition of an 'antiphase' noise signal. ▶

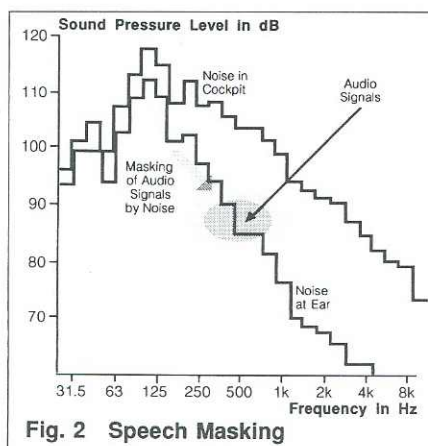


Fig. 2 Speech Masking

with for example the typical 3dB bandwidth at 1kHz being of the order of 200Hz to 250Hz, and so what determines the SNR is the integrated noise energy within the filter bandwidth. However, the mid-range 'auditory filter' has a very shallow, low frequency slope, as shown in fig. 1, and as a result high levels of low frequency

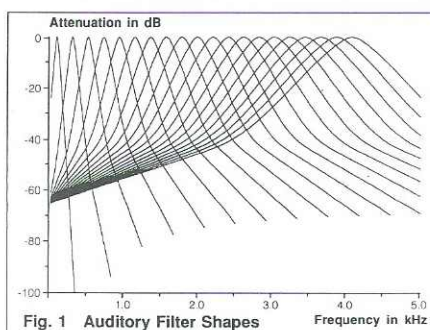
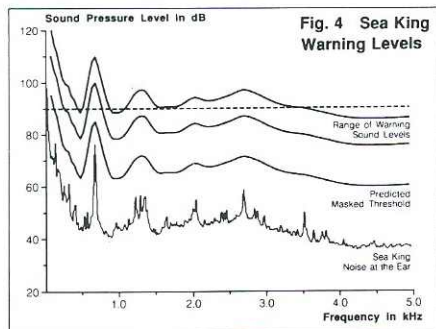


Fig. 1 Auditory Filter Shapes



Audio Warning Design

To ensure reliable detection and recognition, but to avoid startle and auditory overload, the warning sound level should be set between 15 to 25dB above the masking noise threshold, which can be calculated from a measurement of the cockpit noise spectrum, as shown in fig. 3. Once the required warning spectrum has been defined, the AVAD signal output, as a function of frequency, can be set to allow for the response characteristics of either the aircrew headset earphones or the cockpit loudspeaker, ensuring that the correct warning sound actually reaches the crew's ears. As an example, fig. 4 shows the sound level requirements for a Sea King helicopter audio warning, and fig. 5 shows the resultant spectrum shaping that should be applied to the AVAD tone output to allow for the frequency response characteristics of an RAF flying helmet. Tone and voice messages can be assembled to form auditory warning sequences, comprising, for example, as illustrated in fig. 6 an initial (I) attenson, followed by a voice

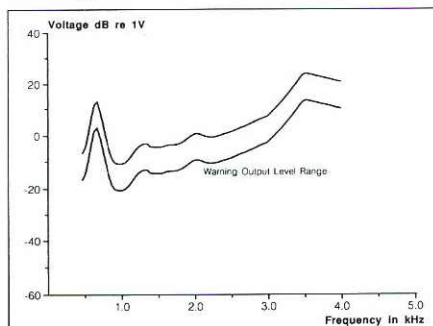


Fig. 5 Sea King Warning - AVAD Output

message (VM), which if not responded to can be repeated in more urgent (U) form, with raised pitch and amplitude, reducing to background (B) level, if appropriate, for continued awareness.

AVAD Features

AVAD units are fully programmable to control all audio warning signals to the aircrew. In a typical installation, AVAD can provide voice and/or attensons in response to up to 15 dc and four analogue sensor input channels, although three of the dc channels are normally allocated to specific functions such as crew inhibit, manual test facility and a message regrade facility, which allows for change of message priorities in certain flight conditions. The four analogue channels allow varying voltage levels to be sensed for activating a warning, and a stabilised voltage output is available for use as a reference for an external potentiometer. A typical variable input might be an aircraft height signal from a radio altimeter – in the AVAD software, an excessive rate of change can be recognised as an invalid input so that temporary wild fluctuation in the altimeter signal will not trigger a false warning. A 'debounce' facility is also provided on both dc and analogue inputs, which ensures that unwanted electrical spikes do not trigger the unit. A customer-definable crew manual-inhibit facility is

provided, which can inhibit any message in progress without affecting other messages. The message thus inhibited remains so until its sensor input is removed and reapplied – alternatively the inhibit can be removed after a specified time and the message will be generated if the sensor input is still present. A further inhibit facility prevents message outputs on power-up.

A Suspend facility is provided, which will inhibit the output of chosen warnings for a given period of time. The Suspend period is initiated by activation of the Suspend input and lasts for any predefined time. All messages are prioritised such that an important message can, if required, interrupt one of a lower defined priority, and the two messages can be interleaved with each other at customer defined spacing. The message and attenson structure, priorities, inhibit and regrade functions are all flexible and can be configured to suit specific needs. Racal Acoustics engineering staff have considerable expertise in customising AVAD to meet a wide variety of military and civil requirements. The successful introduction of AVAD to the aerospace industry, transferring the science of audio warnings to avionics equipment design, is part of Racal Acoustics' mission to provide total technology solutions in voice systems.

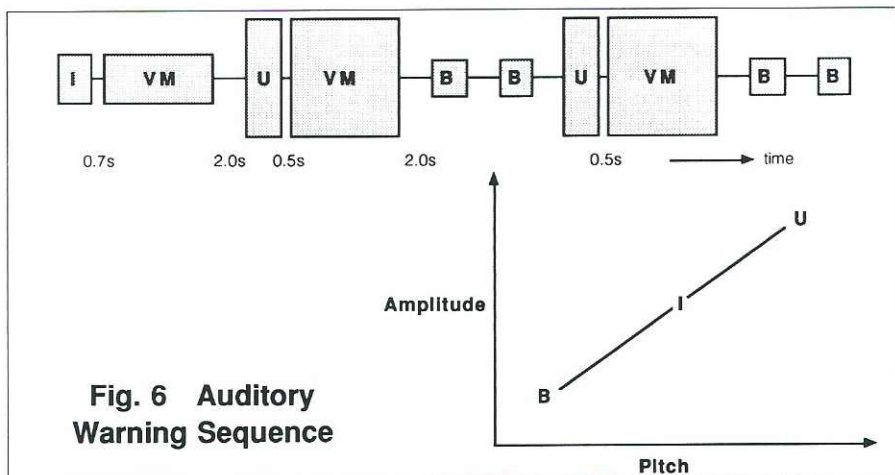


Fig. 6 Auditory Warning Sequence

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FOCUS ON HEAVY LIFT

In the early spring of 1980 there began a most unlikely aviation venture which has nevertheless turned out to be an undoubted success. Initially with access to three of the ex-Royal Air Force fleet of Belfast freighters, HeavyLift Cargo Airlines began operating from Stansted Airport in Essex, with the belief that the unique carrying capabilities of this Shorts designed transport would provide the basis for a specialist, outsized cargo airline. It was, however, an aircraft which had never been operated commercially and for which the manufacturer had not needed to obtain civil certification, a task which uniquely fell to the airline itself, in close co-operation with Marshall of Cambridge who became its design authority and under whose direction the test flying programme was successfully completed.

Even among the original thirty or so staff who embarked upon this strange endeavour, there was a degree of scepticism as to the chances of there being a successful outcome to it all. You would certainly have got amazing odds against the airline out-surviving the likes of Laker or British Island Airways and even BCal, but the Belfasts continue to provide the specialist air transport service for which HeavyLift was set up.

They have since been joined in this work by the uniquely-modified Conroy CL-44-0 Guppy, and a second swing-tail – and stretched – Canadair CL-44 J-type, and in more recent times by Boeing 707 and Lockheed Hercules freighters, ensuring that the airline – part of the Trafalgar House Group and now employing almost 150 people – can offer comprehensive air transport services on a worldwide charter basis.

In the beginning aircrew made up more than half of the staff complement. Of the first six flight engineers it was perhaps not too surprising that half were ex-53 Squadron members, the sole squadron to have operated the RAF's ten-strong fleet of giant Belfasts. Two more came off Hercules, giving the early engineer intake a distinctly ex-Service background. Now, some ten years on, one of those originals has retired, one has moved on to another job, but four remain with the airline, and their collective experience of the aircraft has been invaluable, for example, during the line training of less experienced aviators in the right-hand seat. In fact, out of approximately 2,000 UK-licensed flight engineers in the early 80s, only 12 have ever held CAA type-rating on the mighty Belfast aircraft, which have flown almost 33,000 hours in that period. Among those now current on type are an ex-Laker A300 flight engineer, a former VC10 ground engineer and, at 26 years of age, the most recently recruited of the three ex-Hercules men is almost younger than the Belfasts themselves!

Of course, the appeal of HeavyLift's operations has always been the unusual flying, not only in

terms of cargoes carried, but also the wide ranging and unusual destinations to which they are to be delivered.

Many of the airline's customers are major players in the world aerospace community and the Belfasts currently play a vital part by providing the transport link for international collaboration on the Fokker 100, BAe 146 and Ariane space projects. The airline's fleet has also played a part in the aftermath of man-made and natural disasters, delivering much needed specialist equipment and more general relief supplies to deal with the major oil spillage off the Alaskan coast, the earthquake in Armenia or the hurricanes which later devastated the Caribbean region.

A World War Two Liberator bomber retrieved from India, fresh produce – including grapes and even a full load of Iceberg lettuce ahead of the Christmas shopping spree – and regular assignments (Ascension Island 1982-85) for their former owner, the UK MOD, have kept the Belfasts busy over recent years. From Spitzbergen to Seattle, Liverpool to Lima and Hanover to Havana – only New Zealand has so far failed to feature on the airline's route structure. A spokesman said: 'We're working on it!'

There are flight engineers on all types operated by HeavyLift Cargo Airlines and this results in a steady stream of enquiries about job prospects with the airline. Peter Rooley, personnel and publicity manager, has provided the following as guidance for would-be new entrants.

'We do not crew the L100-30 series Hercules which are currently flying for us and we have no early plans to do so. However, Hercules engineers have successfully converted on to the Tyne-powered Belfasts and CL-44 aircraft and we are always pleased to hear from them, although both fleets are presently fully crewed (as at May 1989).

As far as our recently introduced Boeing 707-324C is concerned, six of our long-serving flight engineers have converted on to the new type, their replacements on the turbo-prop having been recruited and trained in advance. In the future, I would expect us to give preference to suitable 707 type-rated applicants but it is possible that we might take TriStar and Nimrod engineers for conversion.

Other main requirements are the UK CAA flight engineer's licence with a valid medical and we prefer crews to live, or be prepared to move to within 90 minutes of Stansted Airport.

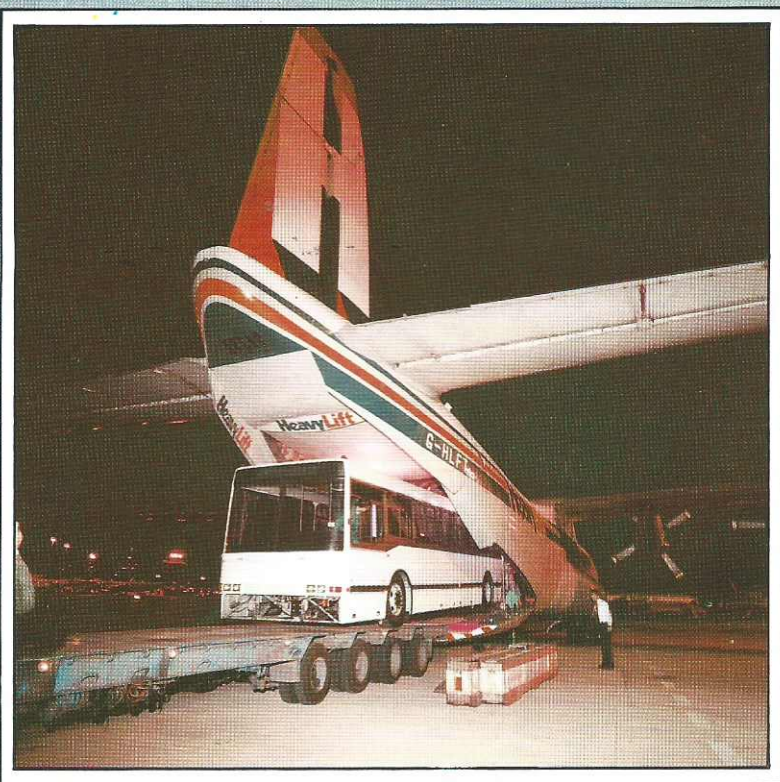
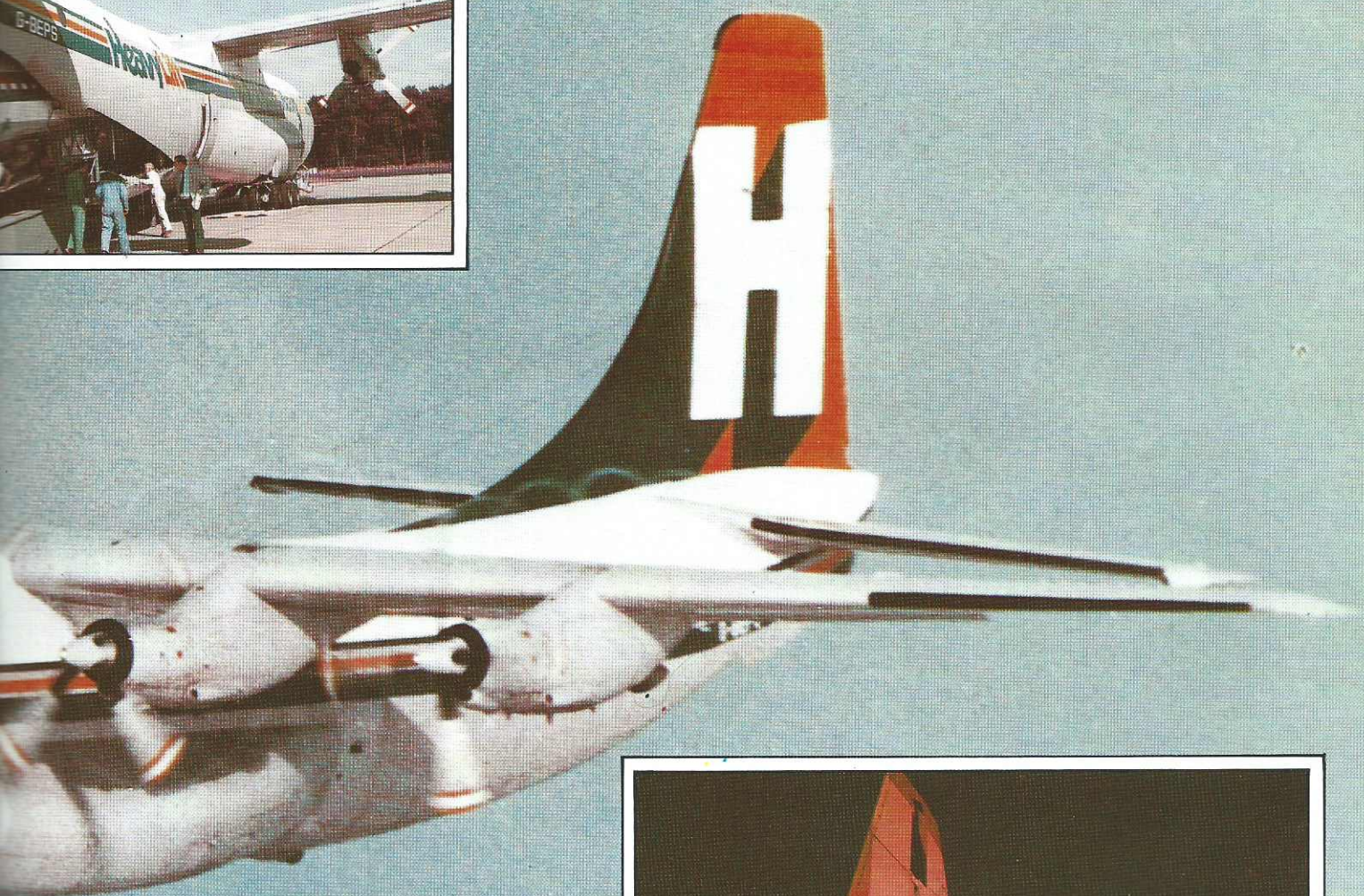
We look for candidates who have also had ground engineering experience and have a definite interest in our kind of flying – ad-hoc charters play havoc with your domestic and social life and some people just can't get used to the very unpredictable nature of our business; others say it's just like being back on the Squadron!

FOCUS ON HEAVY LIFT

SC5 Belfast



Belfast G-BEPS brings back the fuselage of a Fokker F28 for refurbishment at Woensdrecht, Holland.



Manchester - Nashville September 1987

Single deck Ikarus bus
airlifted to USA aboard Belfast G-HLFT.
It weighed 12,000kg (26,450lb) and measured
12.3m x 3.1m (39ft long by 8ft wide by 10ft high).



Belfast G-BEPS brings back the fuselage of a Fokker F28 for refurbishment at Woensdrecht, Holland.



fast

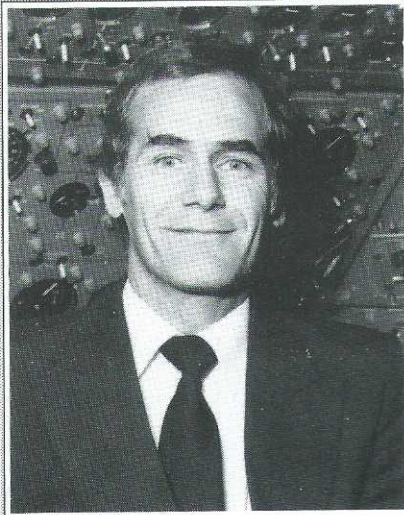
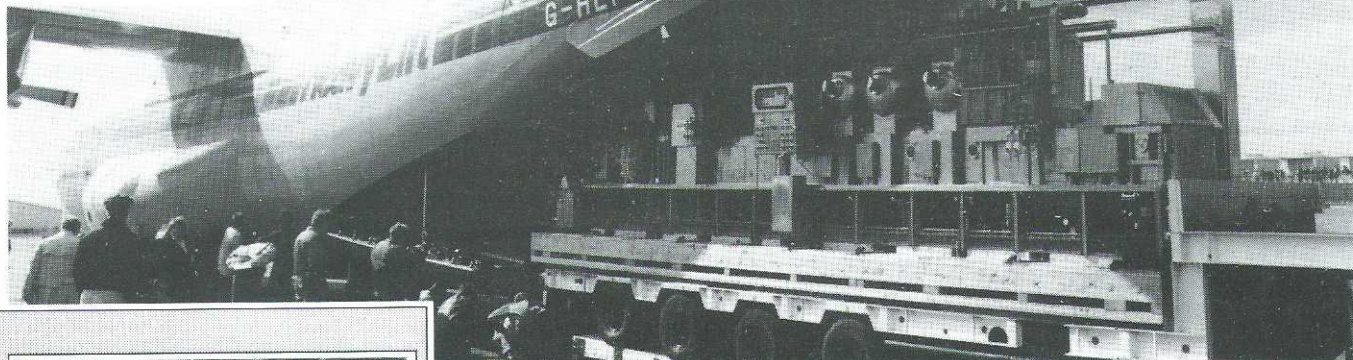
Manchester – Nashville September 1987

Single deck Ikarus bus
airlifted to USA aboard Belfast G-HLFT.
It weighed 12,000kg (26,450lb) and measured
12.2m x 2.1m (20ft long by 8ft wide by 10ft high)



Another Ripping Yarn

(by B M Fane)



**Barry M Fane
(aged 48)**

1957 - 60 Aircraft Apprentice, RAF Halton

1960 - 65 Airframe Fitter, 1st and 2nd Line Servicing

1965 - 76 Flight Engineer - Argosy, Britannia, Belfast

1976 - 78 Flight Engineer - Britannia (civil)

1978 - date Training Engineer, Heavy Lift Cargo Airlines, Belfast

In addition to his base and line training duties, Barry held the post of Fleet Engineer from 1978-85 and currently instructs on the Belfast type-technical groundschools for pilots and flight engineers.

Good (Yawn) Morning

It is 0600 on a crisp April morning, I have left my nice warm bed for a cold car and the 80-mile drive to work. As I have often asked myself before: 'What am I doing here? Why can't I have a proper job?' Of course if I did have a 'proper job', - nine to five, five days a week - I would be bored out of my skull and moaning twice as much!

What I am 'doing here' is travelling from my home near Norwich to Stansted Airport to perform my duties as a flight engineer on a Belfast aircraft. The flight will deliver a 'Jello' pudding making machine from Saarbrücken in Germany to Toledo, Ohio, USA. The machine, weighing 25 tons and measuring 50ft by 10ft 6in by 11ft, is one of several similar machines built in Germany for installation in US factories.

Meet the Team

Once at the company operations desk, one hour and 15 minutes prior to scheduled departure, I meet the rest of the flight deck crew (captain and first officer) and after a chat get down to the pre-flight routine. After checking the fuel and water-methanol requirements for the first sector (water-meth injection for engine power restoration can only be used in ambient temperatures above ISA, therefore there will be no requirement on this flight) I am driven to the aircraft to carry out the pre-flight checks. The pilots will check weather, notams, etc, and make any adjustments to the fuel plan. The captain will check the flight brief for details

of the handling, hotel accommodation, etc.

Hello Plane!

There is a bustle of activity around the aircraft as the maintenance crew complete their preparations and the loadmaster checks the roller tracking system and lashing equipment. Unless the payload weight is critical, the aircraft operates with all freight handling equipment on board for maximum flexibility of operation. Similarly, spare wheels and other essential spares are carried on the aircraft in an attempt to make the aircraft technically self-supporting while away from base.

After checking the technical log for outstanding or deferred defects and ensuring that no 'hours-related' maintenance will fall due during the planned flight (a little difficult to predict since, as in this case, the flight may be open-ended) the pre-flight checks commence. As on other aircraft, these consist of a general walk-around internally and externally and a systematic check of all aircraft systems on the flight deck. The safety equipment is also checked.

By this time the loadmaster has computed the zero fuel weight and I can work out the aircraft all up weight, which allows me to check the take off speeds, any fuel jettison requirement if an immediate return is required, and the performance ceiling which determines the initial cruise level. The aircraft is now switched on, warmed up and ready to go - but something is missing!

So Pleased You Could Come!

About 30 minutes before departure, the pilots arrive in the crew bus with their luggage, the duty free order, and most important, the rations! Many flights are self-catering, ie 'the makings' in tins, packets, etc, are cooked on board as required. A fan oven in the galley is used to provide what can only be described as culinary masterpieces.

Soon we are all sitting comfortably and the first officer completes his pre-flight check – instruments, radio and navigation aids, the take-off speeds and flap retract height are compared and initial cruise level confirmed. Prior to requesting start-up clearance the operating pilot gives the take-off and departure brief to ensure the flight deck crew are in no doubt as to who does what and when.

With start clearance approved I start the engines and wave away the ground power unit. When all engines are running the after start checks are completed and the Omega navigation system programmed. We are ready to roll.

As we taxi, the take-off checks are started and the departure clearance copied. Turning on to the runway the control locks are selected out. When all the control surfaces are free a mechanical interlock is removed to allow all four power levers to be advanced to the take-off position. With the controls locked only two power levers may be advanced thus preventing a take-off attempt with the controls locked – not recommended!

Into the Wide Blue Yonder

With take-off approved and the aircraft lined up, the operating pilot relinquishes control of the power levers and calls for full power. I advance the power levers to the full power position, check that full power is achieved and that the propeller safety devices are engaged and we accelerate (slowly) down the runway. 'V1 Rotate V2'; we are airborne and climbing. The non-operating pilot selects the gear up. When flap retraction height and speed are achieved I retract the flaps and reduce engine power to the climb setting when requested by the operating pilot.

The after take-off checks are completed and while the pilots concentrate on the departure and air traffic communications I contact the company and advise our departure time and ETA destination. Routine communications to base or handling agents are usually covered by the flight engineer to spread the workload.

As the ambient temperature decreases during the climb the deicing systems – propeller, engine, wing leading edge and

tailplane/fin leading edge are all functioned and I settle down to general monitoring.

When cruise altitude is achieved the aircraft speed is allowed to increase from the climb setting and then I reduce the engine fuel flow to a value extracted from the cruise control tables of the performance manual. This should result in a cruise true airspeed and fuel usage combination assumed at the planning stage.

Back on Terra Firma

Since it is a short first sector, thoughts soon turn to the descent and landing. The sector fuel burn is calculated and the landing fuel and all up weight is determined to allow me to check the landing speeds. When the destination weather is copied the landing weight can be checked against the performance tables for the destination to confirm that the landing distance is adequate and that water-methanol injection is not required for an overshoot.

During the descent and landing I will set the flaps and engine power and the non-operating pilot will operate the gear and handle the radio. When the aircraft has settled on the runway with the power levers at flight idle, the Beta Arming Lever is moved to the 'ground' position. This action removes a mechanical stop to allow the power levers and hence the propellers to enter the beta or ground range. A green light shows for each propeller when the propeller pitch decreases below the flight fine pitch stop position and reverse power for braking can be applied. When taxi speed is achieved the operating pilot takes control of the power levers and I retract the flaps and complete the after-landing checks. When the aircraft is parked the shutdown checks are completed and we all relax a little.

A Short Intermission

While the loadmaster supervises the loading team I carry out an external check of the aircraft and tidy up the flight deck. We brought enough fuel with us to proceed to Prestwick so the technical log can be completed ready for the captain's signature.

All Heavy Lift flight engineers have maintenance approval to carry out daily and weekly servicing, fuel and oil replenishment and minor rectification to enable the aircraft to operate independently of base engineering staff.

The first officer is meanwhile obtaining updated weather forecasts and the captain is paying the handling bill. When the loading is finished and the paperwork

completed we repeat all of the above on the way to Prestwick where we will take rest before launching out across the Atlantic.

Why is that Amber Light Flashing?

The sector from Saarbrücken to Prestwick proceeds according to plan until, while passing Newcastle, a flashing amber light on the throttle pedestal draws attention to a fault caption on the flight engineer's warning system. The caption warns of low oil pressure in number three engine-driven auxiliary gearbox. Each engine-driven gearbox drives two AC generators, a cabin pressurisation compressor and a hydraulic pump, and unlike more modern aircraft the drive cannot be disconnected using a switch on the flight deck.

Having confirmed the fault and in accordance with the checklist I shut down the engine and transfer the electrical loads to the remaining alternators. The air conditioning and hydraulic systems require no further action as they are supplied in parallel. The weather at Prestwick is good and the options for rectification are within the capabilities of the crew so we continue and carry out a three-engine landing.

Can You Fix It?

When the shut-down checks have been completed a visual check of the number three gearbox reveals an empty sight glass, the low pressure is due to lack of oil. The gearbox is refilled and the engine is turned using the starter motor. Oil is observed running from one of the cabin compressor trains, revealing the source of the leak. (The gearbox oil is transferred to the compressor where it is increased in pressure to control the compressor output).

The rectification is easy – remove the quill drive – but in practice is a little more involved since the compressor, weighing 80lb, must be removed along with associated pipework to allow the driveshaft to be withdrawn. Then all except the drive is replaced, oil level topped up and the job is done. With the assistance of the loadmaster, (who is also an experienced maintenance engineer) the job is done in two hours, and we can top up the engine and gearbox oils, refuel and go to the hotel.

After a shower and a change, we assemble for a snack and a small glass of lemonade (what do you mean, it looks like draught Guinness?) then it's off to bed and dream about what tomorrow may bring as we head West.

But that's another (yawn) story!

The Lockerbie Aircraft Disaster

By Michael M Charles

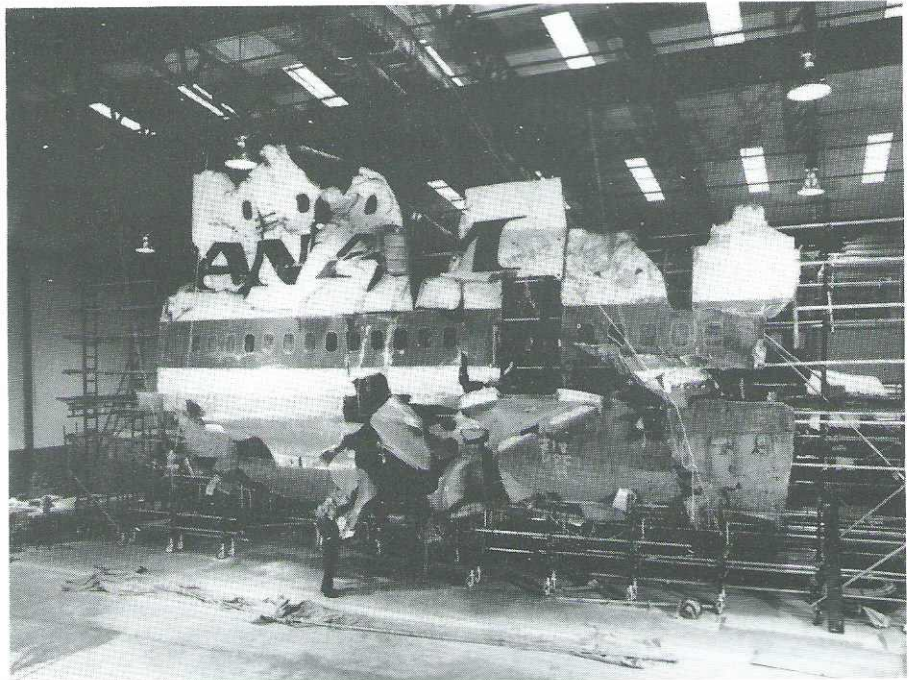
Mr Michael M Charles was appointed as 'Investigator-in-Charge' of the investigation by the Air Accidents Investigation Branch (AAIB) into the Boeing 747 disaster at Lockerbie. In accordance with Annex 13 of the Convention on International Civil Aviation, teams from the United States National Transportation Safety Board, Federal Aviation Administration and the aircraft and engine manufacturers participated in the AAIB investigation.

A Boeing 747-100 of Pan American World Airways, Flight PA103 from London Heathrow to New York, was destroyed by an explosive device on December 21, 1988 with the loss of all 259 people on the aircraft and an additional 11 people on the ground. The aircraft was flying level at FL310 and had been established in cruising flight for approximately seven minutes when the last secondary radar return was received just before 1903 hours. Thereafter the radars showed multiple primary returns eventually splitting into two distinct groups which were carried eastwards by the strong westerly winds.

Major portions of the wreckage landed on the town of Lockerbie, Scotland, causing a huge fireball and destroying several houses. Other large parts, including the flight deck, landed in the countryside to the east of the town with lighter debris being strewn along a trail stretching as far as the east coast of England, a distance of about 80 miles. The accident is the subject of a criminal investigation by the police and the following paper therefore deals with the management and organisational aspects from the aircraft accident investigation viewpoint.

Introduction

The Air Accidents Investigation Branch was notified 40 minutes after the event and the investigation team (initially of 10 inspectors) assembled at London Heathrow within two hours. There was then a small delay while other interested parties arrived at Heathrow but the team departed for Carlisle, the nearest airport to the scene, arriving at 0130hrs the following morning. While on the aircraft it was decided that the majority of the team would go straight to hotel accommodation with the aim of being relatively fresh for work first thing in the morning. The chief inspector, one senior engineering



Lower forward port fuselage section reconstructed by AAIB at Farnborough - Pan Am 103.

Lockerbie Air Disaster Friday 15/12/89

inspector and the author went directly to Lockerbie where the main impact sites in and near the town were pointed out by the police. At this stage the best information was of a wreckage trail some five miles long. Much of the time that night was spent walking the hills to the east of the town and it was fortunate that there was little cloud and adequate moonlight. It was an eerie experience looking at the scattered bodies and debris in such circumstances.

By dawn the three team members were back at the town looking at the accommodation within the Lockerbie Academy which was taken over for the initial phase of the investigation. Although the occurrence of such a tragic accident during the Christmas period was particularly poignant it did mean that school buildings were unoccupied and available for our use. Rooms were found for the AAIB team and for the US accredited representative and his advisers.

Initial Activities

The police had initially identified seven major wreckage sites in or near to the town and when the remainder of the AAIB team arrived from the hotel on that first

morning they were assigned to sites to work with the police and rescue teams. The reason for this was to record as much detail as possible on site and to advise the rescue teams on removing wreckage to gain access to bodies while at the same time preserving essential evidence. As this work continued throughout the day reports were coming in of the discovery of wreckage at progressively greater distances to the east of Lockerbie and the enormous scale of the accident became increasingly evident. It gradually became clear that this was an accident of far greater scale than had ever been seen in Britain.

There was a strong westerly wind at the time of the accident with the wind direction consistently from 250 degrees to 260 degrees at all altitudes and increasing progressively with altitude to a peak of 115kt at Flight Level 320. There was little associated turbulence and the only significance of the strong westerly wind was that it distributed the wreckage along the 80-mile trail to the east of Lockerbie. In fact following the loss of secondary radar contact the primary returns from debris falling over the east coast of England could still be seen on the radar more than one hour later.

The Lockerbie Aircraft Disaster *continued*

Personnel involved

During the afternoon of December 22 the first members of the accident investigation team from the USA began to arrive. The accredited representative, Mr Bob Benzon, did an excellent job looking after a US contingent which reached a maximum of over 30. Together with the AAIB team of typically 15 and a number of others assisting us the total number of personnel forming the aircraft investigation team at its peak exceeded 50. There were of course many additional Pan Am personnel present to look after the relatives of the victims. There were also representatives from the US Embassy and numerous other officials from the USA and Germany helping the police with the criminal investigation.

The accident occurred within the area of the Dumfries and Galloway Constabulary which has a total police strength of 330. The scale of this accident was such that reinforcements from adjacent police forces were drafted in to bring the total police strength dealing with the accident at its peak to over 1,000. To assist with the search for and recovery of bodies and wreckage, units from the Army, Royal Air Force and Royal Navy were brought in, and were greatly helped by many voluntary groups such as mountain rescue teams and the Search and Rescue Dog Association. The total number of personnel involved from all sources at one stage approached 2,500.

Pattern of working

Personnel were constrained to the hours of daylight for the actual field work and, being mid-winter, in effect this meant from 0900 to 1600hrs. The arduous nature of the task which involved much walking over terrain varying from rolling moorland to marsh and densely forested areas was particularly tiring and, even if there had been longer hours of daylight available, the teams would effectively have been limited to similar working hours because of fatigue. At 1800hrs on December 22 the first of many evening meetings took place, to allow everyone in the aircraft investigation team to meet each other, to review the progress made during the day and to assign tasks for the following day. From the beginning, a routine pattern of working was established with the teams deploying at 0900, returning at 1600 to 1630hrs and providing a summary of their day's results to one of our operations

inspectors before the formal evening meeting at 1800 hours. These meetings typically lasted for two hours during which everyone was able to hear the achievements of other teams and ask questions. It was then possible to make plans for the following day.

Police Liaison

Running in parallel with our evening meeting a similar meeting was being held by the police. AAIB sent a representative to this meeting which dealt, among other things, with requests for helicopter support for the following day. At the peak of activity on December 22, 16 military helicopters were involved but as the operation progressed there were more typically three available. Usually there were also two light helicopters available. Without knowing at the evening meeting exactly what the requirements for helicopters would be for the following day, the team put in a bid for and usually made use of one light helicopter every day during the initial ten days or so of the investigation. Constant liaison between the AAIB team, the Royal Air Force and the police ensured that the helicopters were used to good effect.

While on the subject of police liaison it should be noted that Scottish law is different from that south of the border and, in particular, their rules in criminal cases concerning the continuity, recording and preserving of evidence are especially stringent. Retrieving small items of wreckage was therefore a more cumbersome procedure and this did slow the pace of the investigation. However, the procedure was very thorough and minimised the possibility of evidence being lost.

The other thing for which the police, together with the Department of Transport press office are to be congratulated, is the way in which they controlled the media. All inquiries from the media were directed to the press office and any official statements and press releases were made in a controlled way. This ensured that the relevant Ministers were properly informed and that officials in the USA or UK were not embarrassed by unauthorised leakage of information.

Group System

The accepted international practice on major investigations is to break down the investigation work into a number of

'Groups' (Structures, Operations, Flight Recorders etc). The traditional group system of investigation was modified to some extent in that, with several hundred tons of wreckage spread over what eventually transpired to be about 845 square miles, the majority of personnel involved at Lockerbie formed one large structures group. This was split into smaller groups with each group being assigned to a different geographical area. The main task was to locate items of structure, identify if possible the part of the aircraft from which it had come and attach identifying tags to allow it to be recovered in due course.

Significant items, such as the nose section, were examined on site, both to glean what information was available from instruments and control positions but also to examine the nature of structural failures. Metallurgists from the USA and the Royal Aerospace Establishment were used as mobile experts for this task but found nothing of a suspicious nature. Likewise the AAIB team included experts on the effects of explosive devices from the UK and USA whose skills were used to examine pieces which were thought to exhibit unusual characteristics. By use of specialist personnel in this way the AAIB team was able to cover the possibilities that the accident had resulted from terrorist action, structural failure or from any other cause.

There was one false start on December 23 when one of the team found a piece of burnt wood some three miles east of Lockerbie, but this in fact turned out to be a piece of burnt window frame from the building obliterated by the wing impact and which had been carried aloft by the fireball and then blown downwind. It was not until December 26 (the fifth day of the investigation) that items of structure were found which exhibited clearer evidence of explosive damage and these were immediately taken to the Royal Armaments Research and Development Establishment (RARDE) for physical and chemical forensic examination during the following day. Confirmation was received during the day of December 28 that the items showed conclusive evidence of a detonating high explosive and a press release was prepared for issue that afternoon.

In addition to the major structures group a separate group was formed to examine the engines which had all fallen in different

locations within the town, fortunately causing minimal damage. There were also separate groups at AAIB HQ looking after the flight recorders, the personnel records and aircraft technical records.

By the beginning of 1989 those involved at Lockerbie were beginning to show signs of fatigue. The number of personnel attending from overseas was by this time steadily reducing and AAIB arranged for some of the inspectors to return to HQ and for relief staff to replace them on a rotational basis. However, it was on January 8 that the serious accident to a Boeing 737 occurred close to East Midlands airport and those personnel who returned for a rest were immediately faced with their second major investigation in two weeks.

Identification of Sites and Areas

One piece of essential information on the tag attached to items of wreckage in the field was the geographical position where it was found using the UK National Grid reference system. For example a position given as 'Sheet No 78 Grid Reference 135809' can be quickly and easily found on the map by anyone, but a description such as '550 metres east of the north-west corner of field D23' will take a lot more effort to pinpoint and, in particular, the position of field D23 (which was a designation given by the police at the time of the accident) must be known. A further great advantage of the grid reference system is that bearing and distance calculations can readily be made from one position to another and the system lends itself to computerisation.

After the first day the individual sites were expanded to defined geographical areas. The use of obvious features for boundaries, such as roads and rivers, was found to be preferable to the use of grid lines which were initially used. With the use of the grid lines there is a potential for confusion and the possibility that some areas might be searched twice with consequent wasted effort, or the even greater danger that some areas may be missed altogether. The wreckage was spread along two distinct trails which became known as the southern and northern trails. Largely because of poor visibility it was not until the end of the second day that the extent of the southern trail became clearer and even then it was not known that it continued as far as the North Sea.

Logistic support Maps

The huge area covered by wreckage and

the large number of personnel involved created an enormous demand for maps of the areas so that existing stocks were rapidly exhausted. The Dumfries and Galloway Regional Council activated their Emergency Plan within hours of the accident and, in addition to their other key activities, they set up a map production room and turned out maps in quantity. The area further east includes many large man-made forests – the Kielder Forest is reputed to be the largest man-made forest in Europe – and there are extensive areas elsewhere which have been planted relatively recently. As members of the team discovered, the maps did not in some cases show these new plantations and this made map reading all the more difficult.

Aerial photographs

The RAF were requested to provide aerial photographs of the wreckage trail by AAIB HQ on the first day of the investigation and the large scale photographs were available on the following day. These were ideal and enabled team members to update their maps with the boundaries of the newer forests. In addition, some sets of the photographs had been annotated by the photographic interpreters and various items of wreckage were marked, some with a tentative description. This again was invaluable particularly in the densely forested areas where progress on foot was near impossible and the wreckage could be located only from the air either using the photographs or by helicopter reconnaissance.

Communications

Considering the large area involved and the nature of the terrain it is hardly surprising that communications were initially rather difficult. The main communications network for the various agencies involved was provided by the RAYNET organisation. RAYNET is a voluntary body of licensed radio operators which is pledged to supply radio communications in times of disaster and whose members own their own radio equipment. They had established a communications network by 0800hrs on December 22 and had about 80 staff in post each day until the end of December. A RAYNET operator was provided for each of the teams in the field and the system worked very well. The only significant disadvantage was that the network was not secure and communications were in some instances intercepted by the media.

Initially there was a considerable problem with the availability of telephone facilities and British Telecom isolated some 50 domestic telephone lines and transferred

them to the academy. Telephones were installed in the individual offices in the academy as required and after about two days the system became relatively trouble free. The AAIB team also deployed with a number of cellphones which proved to be an invaluable addition to teams in the field for more secure messages although there were not initially enough cellphones to provide one for each team. These were supplemented by additional cellphones from AAIB HQ and by renting them locally. Considering the circumstances the communications were remarkably good.

Women's Royal Voluntary Service (WRVS)

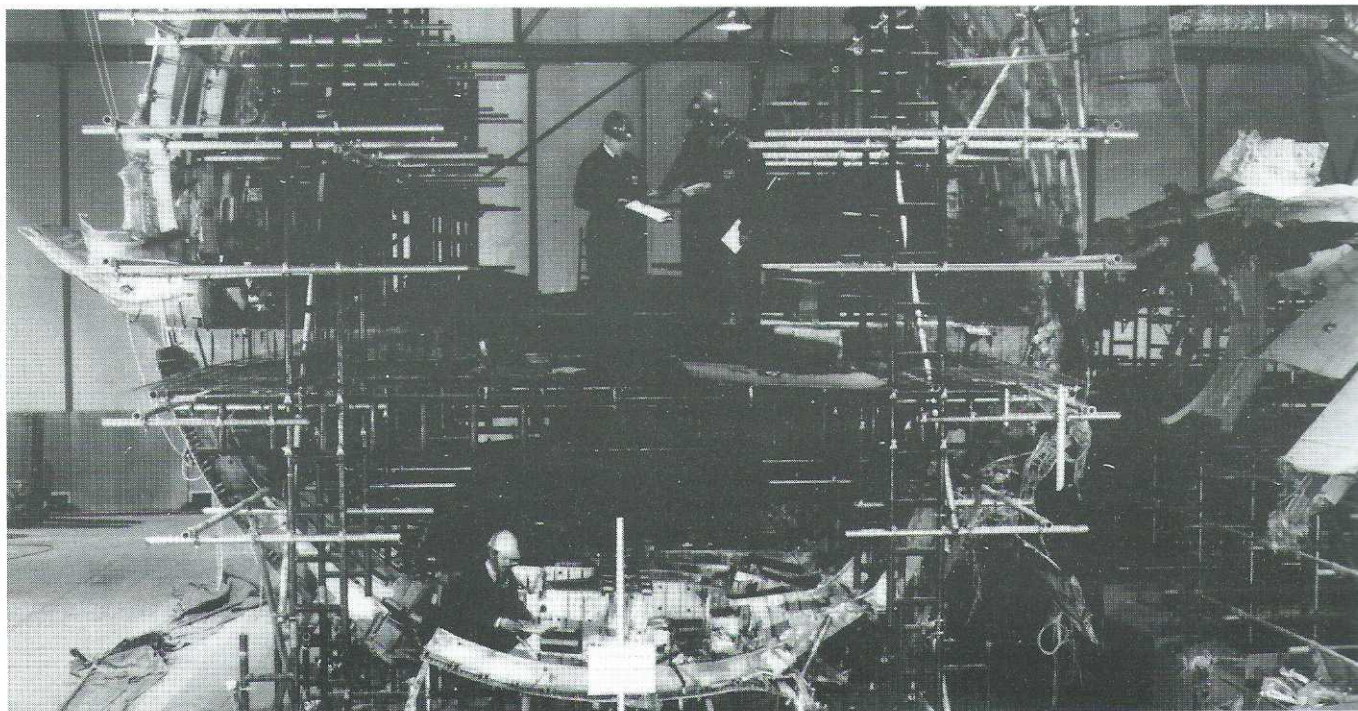
The many hundreds of people involved in the operation all needed feeding. By midday on December 22 WRVS, (a voluntary organisation created in 1938) were manning the canteen in the Lockerbie Academy. A total of 200 WRVS staff were involved in the operation to work a three shift system from 0400 to 2000hrs serving the meals prepared by the school kitchen staff.

Wreckage recovery Aircraft structure

From the outset it was clear that the wreckage would have to be recovered to a location where it could be examined in detail. Fortunately there was, about 20 miles down the road from Lockerbie, an Army Depot, CAD Longtown, where a large empty hangar was available consisting of over five acres of covered space. The only disadvantage was that contractors were due to start refurbishing the hangar roof on April 1 and it would therefore only be available for three months. It was decided to use the hangar and postpone the decision on the long term future of the wreckage. Wreckage was recovered from the field by the Aircraft Salvage and Recovery Flight of RAF Abingdon using cranes and vehicles. Where necessary the wreckage was cut into smaller pieces to enable it to travel along the country lanes. Some of the items were carried by helicopters as underslung loads directly from the field to Longtown.

The hangar floor was painted with a grid corresponding to the aircraft stations so that as soon as items of wreckage arrived and were identified they could be placed on the grid in their correct relative position to other items of structure. Around the edge of the building bays were marked corresponding to geographical search areas so that items not immediately identifiable could be stored until we were able to examine them further. Well in excess of 90 per cent of the aircraft

The Lockerbie Aircraft Disaster *continued*



**End section of reconstructed lower fuselage section of Pan Am 103 showing lower cargo hold and three AAIB Inspectors on passenger deck. (Roof section right of photograph.)
Lockerbie Air Disaster Friday 15/12/89**

structure was finally recovered.

When the fuselage and empennage were arranged in a flat layout it highlighted the fact that the structure which showed visible evidence of bomb damage was limited to an area of skin approximately 20 inches by 20 inches and to the structure immediately inboard. Considering that these relatively few small items were spread over a distance of at least 20 miles well to the east of Lockerbie, the probability of finding such evidence on the sea bed, if the device had detonated over the sea, is remote.

Containers

In addition to laying out the wreckage at Longtown the pieces of baggage container were segregated into a separate store and pieces of two critical containers were identified and then reassembled on to wooden frameworks in order to reconstruct each container as fully as possible. The position of the device within the container was identified to within inches. The damage to this container was also related to the airframe damage from which it was possible to confirm that the container had been loaded into the position in the forward hold as stated in the aircraft loading records. During the process of reconstruction a piece of the improvised explosive device was found, by an AAIB Inspector, trapped within a

section of buckled metal from the container. This item was identified by forensic experts as being part of a radio/cassette player.

Engines

All four engines had been extensively damaged during the break-up and particularly by the ground impact. The number one, two and three engines were assessed as potentially containing debris from the device and were therefore taken to the British Airways Engine Overhaul facility near Cardiff for closer examination by AAIB in conjunction with two representatives from Pratt and Whitney. Numbers one and three engines were found to show no evidence of ingestion and a strip examination was considered to be unwarranted. Number two engine was found to show evidence of ingestion. This engine was pulled apart as far as was possible and small items of debris were recovered and sent to RARDE for forensic examination.

Three dimensional reconstruction

In early March the decision was taken to transport the section of fuselage corresponding to the forward hold area to AAIB at Farnborough in order to carry out a three dimensional reconstruction. The

remainder of the wreckage was removed for safe storage elsewhere and by the beginning of April the hangar at CAD Longtown was vacant and the Army were able to begin their refurbishing of the roof without delay.

The reconstruction of the 50 feet long fuselage section began during the first week in April and was completed in just over two months.

The reconstruction has greatly contributed to the AAIB's understanding of the mechanism and sequence of the disintegration following the detonation of the device.

Conclusion

Lockerbie was without doubt the largest aircraft accident which AAIB have had to investigate in the UK and it was also an enormous tragedy in human terms. There was, however, one outstanding characteristic of the Lockerbie investigation and that was the willing and cheerful co-operation of all the hundreds of people involved.

The author would like to pay tribute to the many voluntary organisations who gave so freely of their time and energy to support the operation and he would also like to thank, on behalf of the AAIB, all of those from the UK and overseas who provided invaluable assistance during the early stages of the investigation.

In February 1985 a Boeing 747SP was flying 300nm north-west of San Francisco on a trans-Pacific flight from Taipei to Los Angeles, when its number four engine lost power.

In the next four and a half minutes, as the crew attempted to relight the engine, the aircraft went into an uncontrolled rolling descent from cruising level at 41,000ft to 9,500ft before the captain managed to regain control and restore the aircraft to stable flight.

After diverting to San Francisco International Airport, the captain landed the aircraft safely.

Although the Jumbo suffered major structural damage during the incident, only two persons among the 274 passengers and crew on board were seriously injured.

As the aircraft was US registered, the incident was investigated by the US National Transportation Safety Board (NTSB). It determined that the probable cause of the accident was the captain's preoccupation with the engine malfunction and his failure to properly monitor the flight instruments, which resulted in his losing control of the aircraft.

Contributing to the accident was the captain's over-reliance on the autopilot after the loss of thrust on the number four engine.

Flight progression

Flight 006 was flying in a polar jet stream and encountering light clear air turbulence (CAT). The captain had therefore turned the 'fasten seat belt' lights on.

Two automatic flight systems were engaged when the incident occurred: the performance management system (PMS) and the autopilot. When coupled, they provided pitch steering inputs into the aircraft's pitch control system. The PMS provides thrust control above 2,500 ft AGL to maintain pilot selected altitudes and speeds. When PMS is selected, the autothrottle servomotor is controlled by the PMS computer. Roll guidance to the autopilot was provided by the inertial navigation system (INS).

The number four engine had a short history of earlier malfunctions, but despite rigorous testing, nothing abnormal was found.

The PMS was set for the aircraft to cruise at 0.85M (254 KIAS), and when the CAT was encountered the airspeed began fluctuating between 0.84M (251 KIAS) and 0.88M (264 KIAS). Therefore the PMS began moving the throttles fore and aft to maintain the commanded cruise

mach number.

Engine pressure ratio (EPR) is the turbine discharge total pressure divided by total pressure at the compressor inlet: the higher the EPR, the greater the engine thrust output. Thus when the mach number increased to about 0.88 the PMS retarded the throttles to about 1.0 EPR and the Jumbo decelerated. When 0.84M was reached the PMS advanced the throttles and the EPR on engines one, two and three increased to 1.5. However, number four engine showed no sign of response and the EPR remained at 1.05. The engine had 'hung' and the aircraft decelerated.

Number four engine relight attempt

The flight engineer was directed by the captain to try to relight the engine at 41,000ft, notwithstanding the fact that the maximum relight altitude was 30,000ft. The attempt was unsuccessful and the aircraft continued to decelerate. By this time the co-pilot had requested a clearance from ATC to descend to a lower altitude, but no emergency was declared. Despite at least six attempts by ATC to pass the clearance to descend, no acknowledgement was received from the aircraft.

As the aircraft decelerated past 240 KIAS the captain turned the autopilot's speed mode selector switch off, thus releasing it from the hold altitude command. This switched the autopilot to the pitch attitude hold mode while maintaining INS track in the autopilot roll mode without any pilot input. The captain then rotated the autopilot pitch control wheel 'nose down' in order to commence a descent to stop the aircraft losing further speed. When the pilot disengaged the autopilot, the aircraft immediately yawed and rolled right. The captain did not use any rudder to prevent the yaw.

Aircraft non VMC

Almost immediately the 747 entered cloud and the captain stated that he was unable to recover to normal flight: he was

uncertain of the roll attitude and was moving the control wheel to the left and to the right. However, as the aircraft accelerated during its departure from controlled flight the captain pulled the control column back and the airspeed decreased. He therefore lowered the nose and the Jumbo accelerated again. Finally, the captain and co-pilot between them managed to pull the control column back. The aircraft reduced speed and came out of the bottom of the cloud at 11,000 ft.

Sequence of departure from controlled flight

For about four minutes of flight the Jumbo carried out some most uncommercial manoeuvres and in the process lost about 30,000ft of altitude. The sequence of aerodynamic events was as follows:

- Time 1013:43. The roll angle of the aircraft was constant at about three degrees left wing down, but the left wing down deflection of the control wheel increased as the IAS decreased. By now, the control wheel deflection had reached 22.9 degrees, the maximum available from the autopilot, so the aircraft started to roll slowly to the right.
- Time 1014:33. The airspeed had reduced to 225 KIAS, and despite the 22 degree control wheel deflection the aircraft had rolled 23 degrees right wing down and slightly (1.8 degrees) nose up. The airspeed slowly decreased as the aircraft continued rolling right at an increased rate. The rate of descent reached 1,200 ft/min.
- Time 1014:50. The aeroplane had descended to 40,442ft at an airspeed of 221 KIAS in a 64 degree right wing down and four degree pitch down attitude, and was now 60 degrees off heading.
- Time between 1015:00 and 1015:23. During descent over the next 10,000 ft, the aircraft nose down pitch angle increased to 68 degrees and then reduced to 11 degrees. The aircraft rolled over on its back and continued rolling right until it had reached 25 degrees right wing low, essentially completing a 360 degree aileron roll.

• Time between 1015:23 and 1017:15. The aircraft descended from about 30,000ft to approximately 9,500ft when straight and level was recovered. The vertical acceleration forces reached 4.8g at 30,552ft and 5.1g at 19,083ft. Minimum speed reached was 54 KIAS—the aircraft has a usual stalling speed of 155 KIAS.

Control regained at 9,500ft

Most of the gyrations of the aircraft occurred in cloud and the pilot only completed effective recovery action when 'visual' beneath the cloud at 9,500ft.

Miraculously, only two people on board were seriously injured, but the aircraft sustained major damage. The wings were bent two to three inches upwards at the tips. The left outboard aileron upper surface panel was broken. The trailing edge wedge was cracked in several places. The left and right undercarriage assemblies had separated from their attachment points. The auxiliary power unit (APU) too, had separated from its mounts and was resting on the two lower cone access doors.

Some 10-11ft of the left tailplane, including the left elevator, had separated. The right tailplane lost five feet of the tip and a further section in the box beam area. No engines were damaged.

Flight crew performance

The US NTSB report indicates that the co-pilot performed satisfactorily during the emergency and that the engineer performed in a correct and timely manner, except that during the attempted relight of number four engine he did not close the bleed air valve switch before advancing the throttle.

However, the report is critical of the captain's performance. He did not disengage the autopilot when the engine 'hung' as recommended in the training manual, and relied on the autopilot which he merely monitored. Had he disengaged the autopilot, he would have been required to perform the physical, more difficult, and more time and attention consuming tasks involved with flying the aeroplane manually. The captain then became preoccupied with the decreasing airspeed and his instrument scan broke down to the extent that he was not aware of the departure from normal flight. Finally, he became spatially disorientated and did not reorientate himself until clear of cloud. Although the board cited distraction and over reliance on the autopilot as causal factors, it also noted that the aircraft had been airborne for about 10 hours, had crossed several time zones and that the incident had occurred at about 0214 hours

Taiwan local time, some four to five hours after the captain's normal bed time. Thus his ability to obtain, assimilate, and analyse all the data presented to him could have been impaired by the effects of monotony, boredom and fatigue, even though he had had two hours sleep during the flight. However, the board did not accept these factors as facts, and circumstances showed that he was alert to the situation as it developed. As an experienced 747 commander, it said, he should have known how loss of thrust of an outboard engine would affect controllability and that the autopilot control did not include rudder so the net effect of the autopilot would be a left wing down roll, which would induce sideslip, increase drag and decrease speed.

In summary, the board concluded that the accident was not caused by the number four engine malfunction. Indeed, an engine failure in the cruise for a B-747 does not place the aircraft in immediate jeopardy and even the airline's operating manual does not classify such an event as an emergency. However the malfunction did cause the captain to be distracted from his normal instrument scan, by his participation with the flight engineer in the evaluation of the engine malfunction and his desire to overcome the reducing airspeed. He did not deselect the autopilot as he was taught in training; the autopilot effectively masked the impending loss of control of the aircraft. During his attempt to relight number four engine the flight engineer did not close the air bleed valve switch before advancing the number four throttle.

The automatic flight systems of the B-747 SP are such that the aircraft can be programmed for automated flight for the whole route. This reduces the physical workload for the pilot but increases the task of computer supervision, shifting total pilot workload from performing tasks to monitoring. The pilot is therefore only in the system monitoring mode and needs to get into the system controlling mode as soon as possible after a malfunction. There is ample evidence the board noted, from both research and accident statistics, that people are poor monitors.

Flight crew experience

Because the aircraft was US registered, the flight deck crew members had special purpose certificates issued by the FAA. The captain, first officer and flight engineer all had considerable flying experience on B-747s.

The Captain, aged 55, had logged 15,494 hours, including 3,748 on B-747s. He had passed his last two simulator proficiency checks in February and

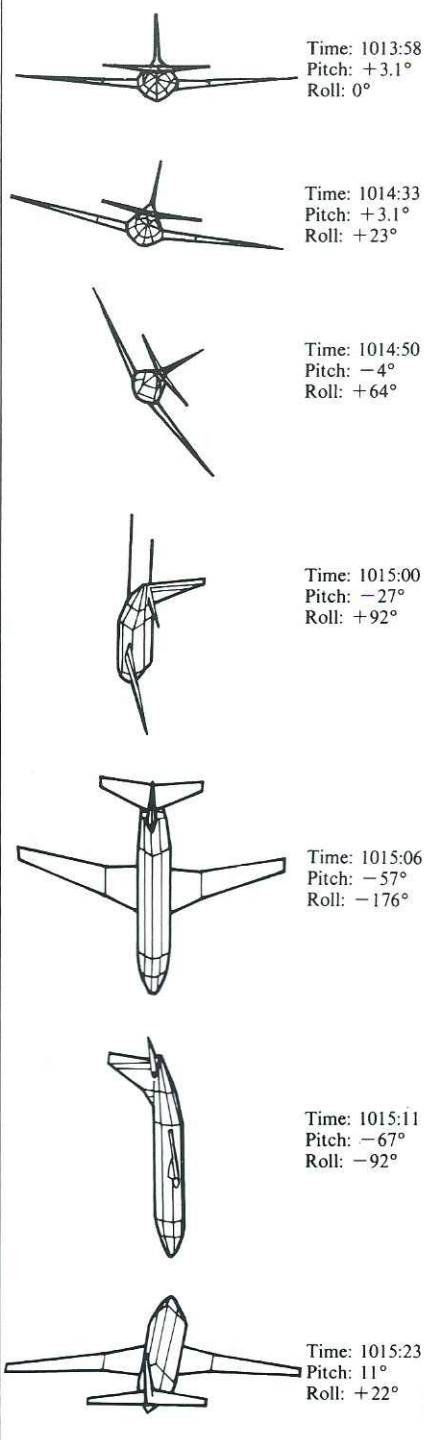
November 1984, and his last route check in April 1984.

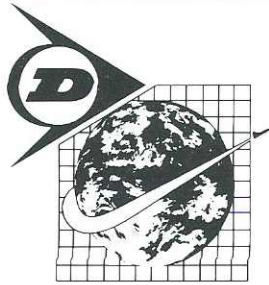
The First Officer, 53, had 7,734 hours of flying experience, of which 4,553 hours were on Jumbos.

The Flight Engineer, 55, had flown 15,510 hours, with 4,363 hours on 747s.

There were two additional crew members, a captain and a flight engineer, however they were not on the flight deck at the time of the incident.

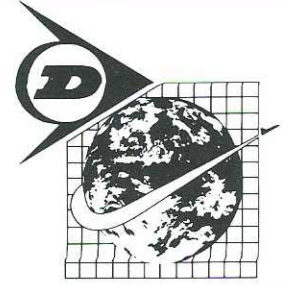
Sequence shows how aircraft descended from about 40,000ft to 30,132ft, during which it completed a 360 degree right-hand roll and then pitched upwards. The 4-5 g forces later prevented the flight data recorder from functioning properly.





Good Housekeeping

(This article was contributed by Dunlop Aircraft Tyres Division)



Perhaps the two most important words regarding the care of aircraft tyres are good housekeeping. Without it, the best will never be obtained from the product. Cleanliness is essential from wheel assembly to front line servicing; and dispersal areas, taxi ways and main runways should be kept free of foreign objects and assorted debris.

It should not need to be stated that tyre inflation pressures should always be checked using an accurate, regularly calibrated dial-gauge. The best place for the ever popular, but notoriously inaccurate, stick-gauge is the scrap bin.

Tyre Performance

Dunlop operates a sophisticated computer programme for its customers. Given the data, we can analyse performance by landings, by total carcase life potential to a confidence level better than 95 per cent and plot performance trends as aircraft weights increase, or operations change. For the short haul operators, for example, there can be very significant performance variations between the summer (hot and dry) and the winter (cold and wet) seasons. An extreme example is given by a Scandinavian DC9 operator. 385 landings in summer; 1,100 plus landings in winter. This variation has led a number of civil operators whose records are good enough, to measure their tyre life in total cycles rather than the more common method of the number of retreads achieved. The RAF no longer maintains

tyre landing records per se and statements made from time to time may best be described as an educated guess. We imply no criticism by this as we understand fully that their personnel have better things to do. Neither does the RAF advance so far down the retread stages as some civil operators. This is a position driven partly by logistic considerations plus the fact that RAF front line aircraft have tyre performance spectra which are at the top end of the severity range. Nevertheless we do retread up to three times for the RAF, at which stage they have achieved 100 per cent value for money.

Tread Wear

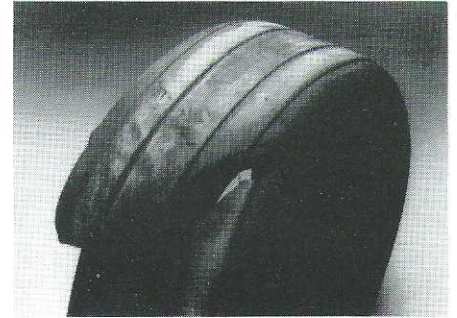
It is not generally recognised what vast strides have been made in the last decade or so with regard to tyre wear rate. We have better tyre shapes, improved tread patterns and rubber compounds, such that tread life has, in very many cases, more than doubled. 500 landings is not unusual on many civil aircraft whereas 250 was a good number some years ago. Statistically, 85 per cent of tyre removals are for normal wear to the base of the centre groove(s). The remaining 15 per cent are described in our parlance as premature removals, the vast majority of which are for cuts or punctures – FOD. The Dunlop sin-bin contains many and varied articles which have ruined tyres: nuts, bolts, nails and rivets, the odd metal biro together with suitcase clips and catches and several pairs of servicing pliers.

Tyre Inflation Pressure

Correct inflation pressure is essential for optimum tyre performance.

It cannot be overemphasised that underinflation is the greatest enemy of satisfactory tyre performance because it leads to overheating and vastly accelerated carcase fatigue.

Think of a tyre as a body with a memory. You may abuse it a couple of times with no recognisable effect. But it will remember the maltreatment and possibly let you down when you least expect it. In all probability the tyre failure will take the



Cut and burst

form of a blow out from the lower sidewall or a tread strip. Aircraft damage can occur as a result of flying debris which can be several pounds in weight.

Question: Is a tubeless tyre airtight?
Answer: No.

The little green dots around the bead area identify vents placed in the tyre at the time of manufacture. The inner liner of the tyre is naturally permeable and these vents are necessary to allow the permeating air to escape to atmosphere. Without them there would be a build up of pressure within the tyre carcase which would lead to ply separation or blistered sidewalls.

It follows, therefore, that a permissible daily pressure loss must be established. These limits are as follows:

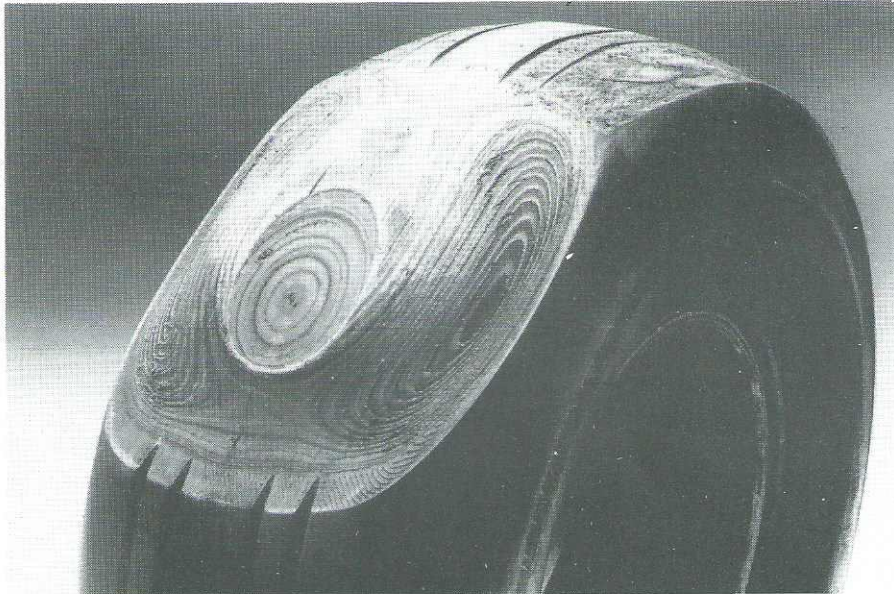
- a) In the first 24 hours after initial fitment 10 per cent. This takes account of tyre growth or stretch.
- b) Each 24 hour thereafter 5 per cent.

The greater the inflation pressure, the closer to these maxima will you approach. It also follows that in the case of an alleged leaking tyre, a quick water immersion test will not necessarily confirm a leak. Bubbles from the vents might only serve to confirm that they are doing their job. While we recognise the constraints of supply and demand and operational readiness, nevertheless it remains the case that the only proper way to confirm a leak is by a 24 hour check in the tyre bay. It is a matter of your own records that a significant number of aircraft tyres have been rejected on a Monday.

It is perhaps worth reminding all concerned that the other arch enemy of tyre performance is fuel contamination. Natural rubber tread compounds are



Deep cut



Braking flat – tyre deflated and on a dry runway

permanently and irreversibly damaged after exposure to aircraft jet fuel for only two or three minutes.

What of the Future

It is perhaps worthwhile correcting a popular misunderstanding that most tyres are of radial construction. They are not. They are cross ply (bias) construction. It

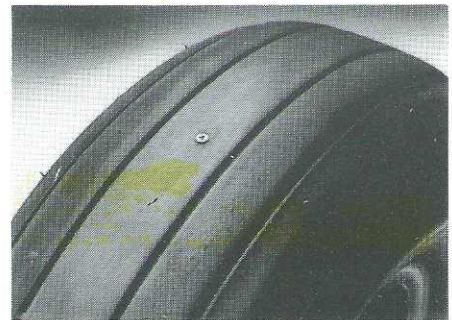
is not unnatural for the layman to assume that the radial tyre can do for aircraft what it has done for the car and commercial vehicles, namely vastly improve tread life.

But will it?

Dunlop is proud to be the supplier of radial tyres for the AV8B and Harrier GR5 aircraft and is happy to predict a potential

increase in tread life of some substance, due to the car-like construction of these particular tyre sizes.

Suffice it to say in this particular article that the author maintains serious reservations regarding the future of the radial tyre for general application to aviation. The type of radial construction necessary to satisfy the stringencies of the front line military aircraft and large civil transport requires vastly different physical properties from the car tyre. The question of retrofit opens up the whole field of wheel, brake, antiskid and undercarriage performance and current design criteria. The question of application to future projects may be overshadowed by cost of ownership. We shall see what we shall see.



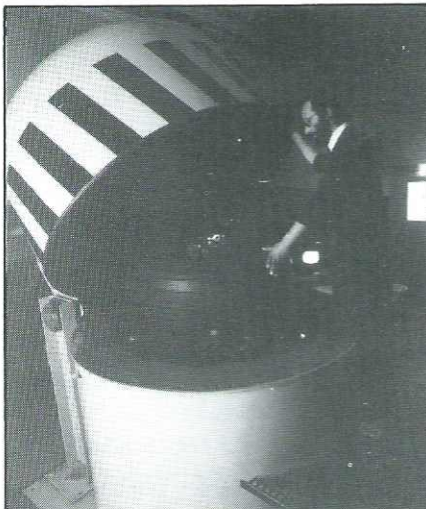
Foreign object in casing



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