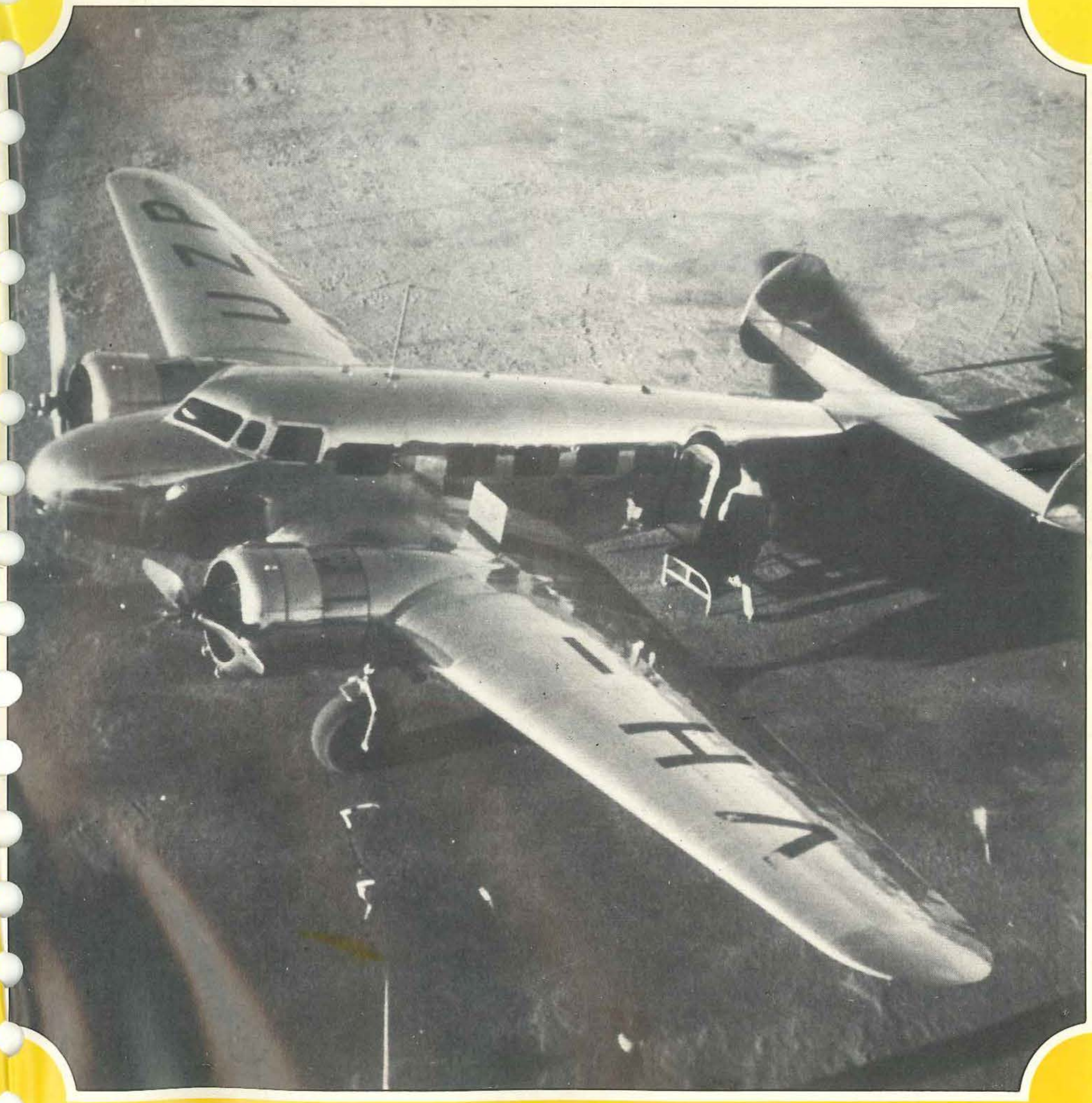
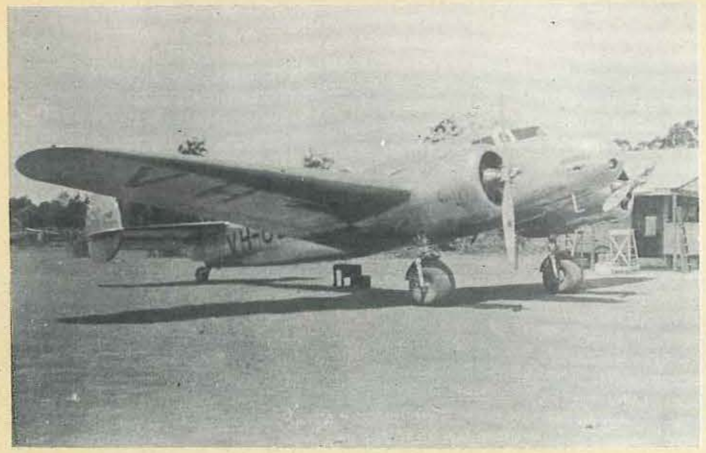
LOCKHEED "ELECTRA"

AUSTRALIAN DEPARTMENT OF TRANSPORT

Number 95 1976

AVIATION SAFETY DIGEST





LEARNING FROM EXPERIENCE— PAST AS WELL AS PRESENT

As with so many aviation accidents today, the message of the story on page 2 of this issue of the Digest is no fresh revelation. There is nothing new under the sun it seems, and the pitfall that claimed the Cessna 210 at Mount Dom Dom is one that has taken toll of unnumbered aircraft over the years.

The Digest has pointed out the fact before of course, but Australian civil aviation, in the years since its inception in the early twenties, has accumulated a great wealth of operational experience, much of it learnt in a very hard school. So much so that our air legislation and operational procedures as we know them today are largely the product of that hard practical experience. Indeed the Aviation Safety Digest itself, as a medium of safety education and accident prevention, is based on this very concept of taking what has been learnt from harsh and sometimes tragic reality and using it in a way that will make for safer operations in the future.

With very occasional exceptions, the Digest has consistently sought to fulfil this function with the latest accident and incident investigation data available. It has done this in the belief that the lessons of the most recent occurrences are those most relevant to today's operations. Yet it is obvious that this emphasis has not always produced the desired result, and nowhere is this more so than in the case of 'below VMC accidents' which have been featured almost ad nauseam for many issues past.

Why is this so? The reasons are probably manifold, but chief among them perhaps is the fact that, as practising pilots and active members of the aviation industry, we all find it difficult to be impartial in our assessment of recent operational object lessons. We are too close to them; some of us know the personalities involved; some of us may have been through very similar experiences ourselves but have happened to get away with them. And in many cases of course, long before the completed accident report has been reviewed in the Digest, its circumstances have been written up in the press and people have formed their own conclusions. Thus, by the time the Digest review appears, it is already stale as news, and its message is accordingly blunted.

What can be done to alleviate this situation? Undoubtedly, despite the problems, there is value in continuing to cover accidents which have a message for us and the Digest will continue to do so. But it is also evident that there is real safety education value in all that wealth of experience accumulated in years gone by. Readers' reactions to the coverage which the Digest has occasionally given to historical Australian accidents has established this fact beyond all doubt. And what is more, these are situations which we can all look at impartially — there is no personal or emotional involvement to cloud the issue and thus the safety message to be drawn from it can be a truly objective one.

For this reason, in addition to reviewing those recent accidents which have a clear safety lesson for us today, the Digest will endeavour to enhance and illumine these messages by comparing and contrasting them with some of the accumulated operational experience of our colourful past. In this way, it is hoped that today's object lessons will stand out in sharper relief and be more readily seen for what they really are.

This policy, begun in effect in the last issue with the publication of the Stinson story, is continued in this Digest, this time on the theme expressed in the title on page 2. It is thus not only the tragedy to the Cessna 210 at Mount Dom Dom which bears out that statement — the 30-year-old accident on page 6, involving the pioneer airline operation portrayed in this issue's Cover Story, makes precisely the same point.

AVIATION SAFETY DIGEST

Number 95 1976

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Editor: G. Macarthur Job, Assistant Editor: R. J. Maclean.
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IT'S GOT TO BE ONE THING... ...OR THE OTHER

IMC-VMC is a dangerous compromise

Weather accidents to light aeroplanes — those that happen in what, for want of better words, we call 'Below VMC', are regrettably still very much with us, notwithstanding all that has been said and done on the subject in the past.

Despite some improvement statistically during 1975, the problem is still a grave one and as many readers are already aware, it is a concern fully shared by the Department.

The latest accident of this type which it is the Digest's sad duty to review, is one that is already familiar to many readers. It is included because, like the lesson from the past on page 6, it shows irrefutably that while both VFR and IFR procedures, properly followed, provide extremely safe alternative methods for the conduct of a flight, any attempt to 'have a bit each way' can only result in a compromise which becomes extremely dangerous in unfavourable conditions.

The aircraft involved in this accident, a Cessna 210 with four women private pilots on board, was making a VFR flight from Archerfield, Queensland, to Moorabbin, Victoria. The pilot in command, who occupied the left hand seat, had over 1000 hours aeronautical experience, more than 100 of which had been flown in this type of aeroplane. The pilot occupying the right hand seat likewise had an endorsement for the Cessna 210.

The aircraft departed Archerfield at 0952 hours local time and landed at Mudgee for fuel some two and a quarter hours later. While on the ground there, one of the party, believed to be the pilot occupying the right hand seat, telephoned the briefing office at Moorabbin Airport and spoke with the meteorological officer on duty concerning the weather at their destination. She was told that conditions at Moorabbin were expected to remain suitable for VFR flight but because of low stratus cloud and fog in the ranges to the north-east of Melbourne, the Kilmore, Glenburn and Narbethong gaps in the Great Dividing Range were likely to be marginal.

Departing again from Mudgee at 1324 hours, the flight continued south-west in fine weather and subsequently reported over Albury at 1500 hours, cruising below 5000 feet, with an ETA for Moorabbin of 1551 hours. The aircraft then requested the actual Moorabbin weather and was advised that reports had been received during the afternoon of heavy cloud and showers which had closed the Kilmore gap. The current Moorabbin weather observations, five oktas strato-cumulus cloud at 2500 feet, and a visibility of 30 kilometres, were then passed to the aircraft.

At 1531 hours the aircraft reported 'Eildon Weir this time, CAVOK' and was again advised that marginal conditions south of this position had been reported by another aircraft operating in the area. The aircraft acknowledged this information but 13 minutes later, when Melbourne called it to request its present position there was no reply. All subsequent attempts to contact the Cessna 210 were in vain.

Meanwhile, a number of witnesses living in the Acheron River valley had seen the aircraft flying low, apparently following the Maroondah Highway southwards towards Healesville via Taggerty, Buxton and Narbethong. The sky at the time was completely overcast by low cloud which was obscuring the mountain tops on either side of the valley.

Two kilometres south-west of Narbethong, at the southern end of the valley, a number of forestry workers sighted the aircraft, now at only 300 to 500 feet above ground level, still apparently following the highway to where it rises to cross Black's Spur in the direction of Healesville. Black's Spur, elevation 1650 feet, forms a low saddle in this part of the Great Dividing Range and, lying as it does just to the south-west of Narbethong, is known in general aviation circles as the 'Narbethong Gap'. Ahead of the aircraft the forestry workers could see that the 2400 foot Mount Dom Dom, immediately to the east of the saddle, was enveloped in cloud except for its lowest slopes which were just visible above an intervening line of trees. As they watched, the engine noise increased as the aircraft entered the cloud and it became lost to their view. The noise of the aircraft then faded quite rapidly and those watching assumed that it had safely negotiated the gap.

* * * *

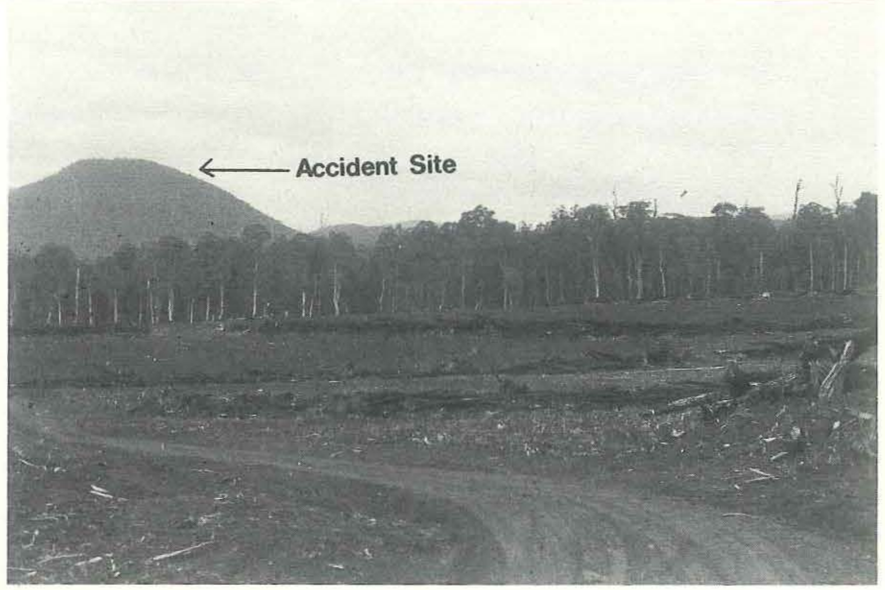
When the aircraft had failed to reply to further calls from Melbourne Flight Service and had not reported to the tower approaching Moorabbin, search and rescue procedures were introduced. A search was subsequently organised and at about 1550 hours the next day the crew of a searching helicopter sighted the wreckage of the Cessna on the densely timbered south-western slope of Mount Dom Dom, about 100 feet below its summit. A police ground party reached the site just over an hour later, and found that all four occupants had been killed in the crash.

* * * *

The aircraft had disintegrated and burnt on impact, but a detailed examination of the wreckage did not disclose any evidence of pre-impact structural failure, malfunction of systems, or other mechanical failure which could have contributed to the accident. Damage to the wings and tailplane indicated that the aircraft was in a climbing attitude at impact and damage to the propeller was consistent with a high power delivery.

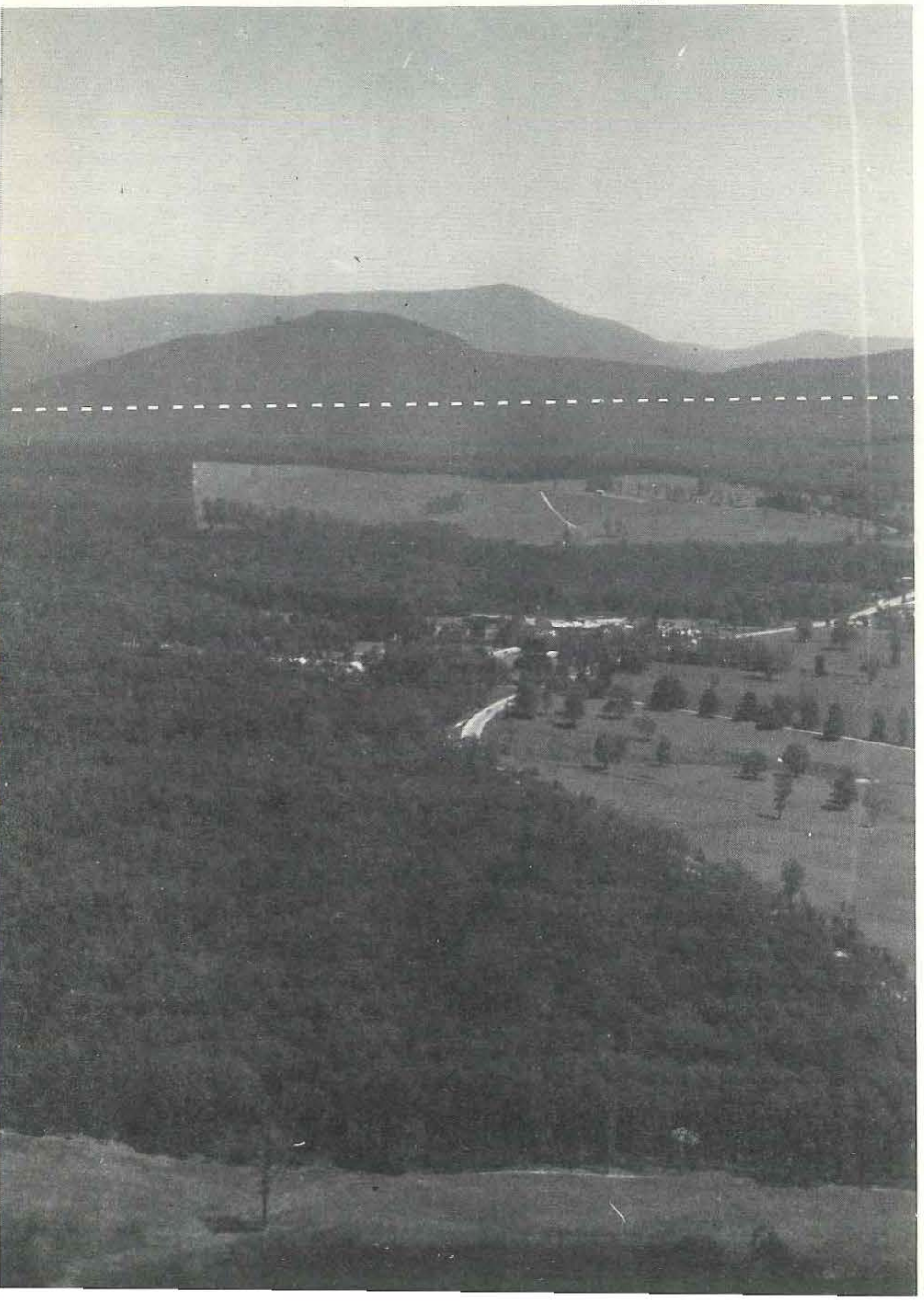
Almost half the aircraft's flight planned track from Eildon to Moorabbin lay across the mountainous and rugged terrain of this portion of the Great Dividing Range. Because the higher peaks of the range in this area rise to well over 4000 feet, the existence of cloud below about 5500 feet may well prevent VFR flight directly between Eildon and Moorabbin.

Roughly following this track however, is the Maroondah Highway which, from a point only 20 km west of Eildon, runs almost due south through the Acheron Valley, a clearly defined 50 kilometre long corridor through this part of the ranges. The southern end of the valley, just south of the hamlet of Narbethong is 'blind' in the



Mount Dom Dom, as seen from position of forestry workers two kilometres south-west of Narbethong. At the time of the accident, the base of the cloud was just above the line of trees in the middle distance, almost completely obscuring the mountain.

Above: Aerial view of Mount Dom Dom looking south-east from over Black's Spur. The site of the crash is indicated.



Below: Low level aerial view of southern end of valley looking towards Mount Dom Dom and Black's Spur saddle. The Maroondah Highway and Narbethong can be seen in the foreground. The cloud base at the time of the accident is indicated by the dotted line.

sense that it is closed by the main ridge of the Great Dividing Range, but as already described a portion of this ridge, where it is crossed by the Maroondah Highway, is a low saddle only 1650 feet AMSL. The saddle, known as Black's Spur, is less than 2000 metres wide with high terrain flanking it on either side. The highway crosses the saddle in a south-westerly direction towards Melbourne and, once over the saddle, runs down over a distance of about 10 km to Healesville and the coastal plain which surrounds the Melbourne metropolitan area and Port Phillip Bay.

This saddle or gap in the Great Dividing Range thus provides, together with the Glenburn and Kilmore Gaps, a possible VFR route through the range when low cloud prevents direct flight over the range. Of the three alternatives however, though the route towards the Narbethong Gap is perhaps the most clearly defined and easiest to follow when approaching Melbourne from the north in conditions of low cloud and poor visibility, the terrain in the area of the gap itself is probably the least safe in marginal weather. There are several reasons for this:

- The orientation of the saddle at the valley's southern end, in relation to the prevailing moist south-westerly winds, frequently causes a build-up of low cloud around the saddle itself which is the route's highest terrain and most critical point.
- A pilot cannot finally determine whether the saddle is 'open' until he has flown some distance down the valley to its southern end in the vicinity of Narbethong.
- Because of the comparative narrowness of the valley at its southern end, a turn back on to a northerly heading, in the event of the saddle being closed by low cloud, can be difficult and dangerous at low level, especially in faster aircraft if they are not deliberately slowed for manoeuvring in such conditions.

In view of the pilot's experience, it has to be asked why, when she had already received advice that conditions for VFR flight in the vicinity of the gaps would be marginal, she persisted so far in her attempt to negotiate the Narbethong Gap.

Although it would obviously have been prudent to have turned back earlier, it seems that the pilot simply did not recognise the approaching danger until the aircraft actually passed Narbethong and she could see that the low cloud ahead was obscuring the gap and the range, as well as the surrounding higher terrain. By this time the only possible option still open to the pilot to avert the danger posed by the lower cloud, would have been to first slow the aircraft, extending the undercarriage and lowering the appropriate amount of flap, and then to execute a narrow-radius turn. At this late stage however, there was no margin of safety left even for a manoeuvre such as this, and in the event, the aircraft entered cloud. Whether this entry into cloud was inadvertent or forced upon the pilot by the terrain, cannot be known, but there remains the possibility that, faced with the situation in which she was now placed, the pilot might have felt she had sufficient competence and ability to handle the aircraft safely by reference to instruments and decided to continue into the cloud before climbing and turning.

Whatever was in the mind of the pilot at that late point, her earlier decision to continue into the gap rather than to turn back while she was still able to maintain VFR flight, proved a fatal mistake. As in the case of the accident to the Twin Comanche which climbed straight ahead into a cloud enshrouded mountain near Nimbin, New South Wales, a little over two years ago (see 'Why', Aviation Safety Digest No. 91), the limited visibility available beneath a very low cloud base gives little or no indication where high terrain lies. Certainly in the case of the Mount Dom Dom accident, the pilot was familiar with the area in the sense that she had flown over it many times coming and going to Moorabbin Airport. But, as it would be for any of us, knowledge of this sort is insufficient to be able to remember the precise location and elevation of the surrounding terrain in a particular area, especially in the extremely poor visual conditions that existed at the time of this accident.

CAUSE

The probable cause of the accident was that the pilot continued flight below a low cloud base and towards rising terrain beyond the point where the safe adoption of an alternative procedure was possible.

COMMENT

The question as to whether or not this pilot entered cloud intentionally, with the thought that she would continue flight on instruments, is one that has not been resolved, and never will be. Even so, it is possible that, having arrived at the situation where she was unable to proceed visually, she then decided to proceed in instrument conditions. The pilot did hold a Class 1 instrument rating and the aircraft, fitted with a full set of flight instruments, as well as with an ADF and VOR receiver, was approved for operations to night VMC standard. The aircraft however, was not approved for planned IFR flight.

In any case, were a flight in IMC undertaken on such insubstantial information as existed in this instance, it would cut directly across the whole philosophy of IFR operations and its basis of positive separation from terrain and other air traffic.

This philosophy and the way in which it is implemented in our airways system today, is by no means an arbitrary one. It has been evolved over years of actual operational experience and as a result, is designed to provide a safe margin for error in both control manipulation and navigation. Thus it is not merely the ability to fly an aeroplane accurately by reference to instruments that makes for safety in IMC. This factor is of course necessary and important. But of equal importance is proper flight planning and conduct which will ensure that prescribed IFR standards are met in respect to the navigation of the aircraft. To compromise these standards in any way, especially by attempting to adapt them to a method of flying which should be undertaken only in adequate visual conditions, is to enter upon a path which sooner or later can only lead to disaster.

Although it may have nothing at all to do with the circumstances of this accident, there is a message here and in the historic accident on page 6, which is worth re-stating: If you intend to fly in Instrument Meteorological Conditions, you must plan it properly in accordance with the Instrument Flight Rules and fly IFR only. Conversely, if you intend to fly visually, you must comply with Visual Flight Rules. And if you do encounter IMC or see that these conditions will prevail there is only one course of action — you must remain clear of those conditions and turn back or divert.

Aerial view from southern side of Mount Dom Dom, looking north up Acheron Valley in the direction from which the aircraft had come.

View looking south-west in direction of Moorabbin Airport from above Black's Spur saddle. Note how terrain drops away and opens out once clear of high ground at southern end of Acheron Valley.

'not quite contact . . .'

It is May, 1946. The war is not yet 12 months over, but civil aviation is getting back on its feet. Australian National Airways' fleet of DC-2s and DC-3s have shed their drab wartime camouflage and are gradually being replaced on the company's inter-capital routes by giant new DC-4 Skymasters which have recently been ferried across the Pacific from California. The executive of the embryonic TAA has been appointed and plans are in hand to recruit pilots from ex-RAAF aircrew; and an independent operator's Lockheed 10s, recently returned from military charter operations 'up north' are re-establishing their company's former routes between Sydney, Melbourne, and Adelaide.

The mid-afternoon Lockheed service to Adelaide this day is a notable one — the company's first direct flight from Melbourne. And with a capacity load of passengers, it seems an auspicious new beginning for the route. The weather, too, has smiled for the occasion — except for the final few miles in the vicinity of the Mt. Lofty Ranges, where there is a trough line, the forecast is excellent.

The cool autumn day is at its best as the Lockheed, its two Wright Whirlwinds howling in fine pitch and its polished metal gleaming in the sunlight, lifts off the grass to the side of Essendon's half-constructed north-south runway, and sets course to the north-west.

Twenty minutes later, as Daylesford slides slowly into view 8000 feet below the nose, the first officer levels the Lockheed into the cruising attitude and eases the engines back to 1875 rpm and 25 inches. On his left in the command seat, the captain, a veteran of Australia's biplane airliner era, writes up the navigation log and the instrument reading record, and replaces them in their folder.

Back in the compact but comfortably appointed passenger cabin, the paying customers tire of watching the now-distant landscape and the fluffy patches of cumulus, and settle down to read or doze. There is plenty of time for both, because Adelaide's Parafield airport is still nearly three hours beyond the gap in the mountain range that now lies ahead on the western skyline. Characteristically, as with most twin-engined Lockheeds, a faint aroma of high-octane aviation fuel persists, but the atmosphere is one of cool freshness and the travelling rugs provided by a thoughtful management add a feeling of modest indulgence.

The engines maintain their sonorous drumming as the late afternoon wears on and the checkpoints come and go — Murtoa, Nhill, the South Australian border. Now, directly ahead, the sun is setting behind the patchy cumulus on the horizon. Permission is obtained through Nhill Aeradio to descend to 6000 feet and the ground speed improves slightly. The sky above the Lockheed, now completely overcast by a layer of alto-stratus, darkens imperceptibly, and soon all that is left of the day is a brightness on the western horizon. In the fading light, the Lockheed's burnished metal wings take on the hue of pewter, and away off to port, the clustered lights of Tintinara twinkle brightly through a gap in the underlying cumulus. On board all is well, and in the calm evening air, the flight of the Lockheed seems almost perfect. In fact the only fault evident to the crew is a persistently flickering instrument lamp which defies all attempts to rectify the annoyance.

Now, with three-quarters of the flight gone, the crew have received two reports of deteriorating weather at Parafield and know what to expect ahead. For the passengers, basking in the friendly yellow light of the cabin reading lamps, the increasing cloud beyond their neatly curtained windows is hardly noticeable. But twenty minutes later, the crew's only sign of Tailem Bend is the abrupt reversal of the radio compass needle on the cockpit instrument panel.

Another twenty minutes flight in the darkness of the cloud and it is time to descend. The radio compass is already tuned to Parafield and as well they are now receiving the continuous tone of the radio range's eastern leg. The captain takes over, trimming the aircraft for a shallow descent. The first officer reports they are due overhead Parafield in 10 minutes . . .

It is raining and bumpy now and, at 3800 feet, the range's cone of silence, as well as the radio compass, signals station passage over Parafield. At a word from the captain, the first officer sets the altimeter to 29.77 and pulls the knob on the left of the control pedestal which will lower the undercarriage. The red 'up' lights go off and are replaced by a single amber as the electric motor whirs somewhere below the floor. There is a thump and two greens appear on the panel. The undercarriage is down and locked.

At an indicated 150 mph, with 1900 rpm and 25 inches set, the aeroplane is descending at 1000 feet a minute. From the blackness beyond the windscreen, squalls of rain intermittently fling themselves against the glass, and at 1500 feet, the captain begins a rate one turn to port, straightening out on a south-westerly heading to intercept the western leg of the range. At 1000 feet the cloud parts briefly and there is a glimpse of lights on the horizon. Now there is another light on the starboard side. The first officer reports again to Parafield: 'One thousand now, can see lights, not quite contact'.

The descent continues. The captain slides open his side window to look for lights and requests the first officer to ask Parafield for the cloudbase. As he is about to transmit, the first officer notices the altimeter. It is indicating 300 feet and unwinding fast! He grabs the control wheel in front of him to check the descent. Startled at the movement, the captain looks around but too late. Suddenly there is a tremen-

Flashlight photograph of inverted wreckage shortly after arrival of rescue party at scene of accident.

dous impact and a tearing of metal as the port landing wheel and wingtip gouge into the ground. For a moment there is a nightmare of confusion, violence and noise, then the aircraft is on its back, sliding upside down on the top of its fuselage. It skids to a stop in this attitude. In the pitch darkness there is a deathly quiet . . .

The silence is broken by a young girl, still hanging by her seat belt somewhere towards the rear of the cabin, crying out in alarm. Another passenger, just out of the Air Force and wearing his new 'civvies' for the first time, recovers himself quickly. Reaching for the cabin ceiling to take the weight of his body, he undoes his seat belt and lowers himself carefully. He is quite unhurt and feels his way to the rear cabin door. It has sprung open in the impact, and he crawls through on to the sodden ground.

Somewhere on the other side of the inverted fuselage there is a flickering reflection of light. Fire! He scrambles his way around behind the smashed tailplane. Fingers of blue flame are stabbing intermittently from the starboard engine nacelle. The engine itself is gone from its mountings, but there is still fuel and fumes in the wing tanks. Running around the shattered starboard wing to the front of the nacelle, he scoops up handfuls of mud and throws them on the darting flames. In less than a minute the crisis is over, the fire snuffed out before it could gain a hold.

Meanwhile, in the inverted cockpit, the pilots have found themselves trapped by the jammed bulkhead door. The first officer uses his flig.. bag to smash his side window, and he and the captain climb through.

By this time, the other passengers, credulous and slightly numbed by it all, have released themselves and each other from their inverted seats, and have clambered out into rain. Miraculously, only one woman is slightly hurt. Not much is said — the sudden shock of the crash and its outcome is almost unbelieva and has had a stunning effect.

It is very dark, but there is a light in the distance. The first passenger out borrows a torc and taking two others with him, sets off acr the muddy paddock. It is obviously a farmhouse some distance away and there are fences to climb through. By the time they are knocking the door they are drenched to the skin. Pools of water form on the floor as they explain their plight. A quick telephone call to Parafield, th the tension is over — and help is on the way.

* * * *

The fact that all on board a twin-engined a line aircraft could not only survive a major crash during an instrument letdown, but walk out of the wreckage almost unscathed, is an eve without parallel in Australian aviation histor

Yet it was these very circumstances that enabled the cause of this accident to be determined so positively and accurately; an accura that now, almost 30 years later, enables us to examine the reasons leading to that cause, and to learn something useful from them. And as is often the case, those reasons were simple and man enough.

It was found that the Lockheed's flight from Essendon to Parafield was normal in every spect until it passed over Parafield in cloud at 500 ft. But instead of following the instrument approach procedure laid down in the company's operations manual, which required a 500 fpm scent along the western leg of the radio range to a minimum night altitude of 1100 feet, the captain made an unorthodox descent to the rth-west of the aerodrome.

Although this was not the direct cause of the accident, it resulted in the captain being sufciently uncertain of his position to prompt him look for landmarks while descending through the minimum night approach altitude, still partially in cloud. Looking rearward through the rt side window, the captain failed to notice that the aircraft was losing height to a dangerous extent, thus setting the stage for it to fly into the ound. Although the first officer pulled the control column back in an attempt to check the aircraft's rapid rate of descent, it hit the ground efore level flight could be regained.

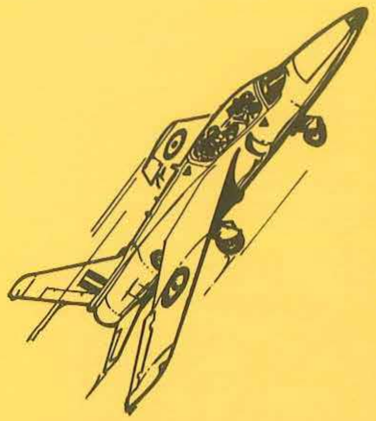
The cause of the accident was thus ascribed to the fact that the captain had not devoted his full attention to the flight instruments while flying at w altitude in poor visibility at night.

In other words it could be said the unfortunate captain was trying to have a bit each way. Yet is particular captain, it needs to be emphasised, had been an airline pilot since the very early thirties and had flown over 10 000 hours. His experience not only included early Bass Strait airne operations in all types of weather when radio navigational aids of any sort were but a dream for the future; much of it had been gained n wartime night charter operations between Brisbane and Townsville. It is abundantly clear that, if a man of this experience was unable to affect a safe compromise between IMC and VMC flying, then certainly it is unlikely that anyone else can!

It is to be hoped that this lesson from the past, together with others of much more recent experience, will establish the veracity of this point which is made again in the unhappy recent accident reviewed on page 2.

Bystanders taking a close look at the Lockheed's starboard engine, torn from its mountings during the impact. Damage to the propeller shows that the engine was developing considerable power at the time of the crash.

The scene of the crash the morning after the accident. Note the flat, low-lying nature of the terrain. The structural integrity of the wreckage, despite the severity of the impact, is testimony to the robustness of the aircraft's design and construction.



When I came to the end of my first tour on Canberras, I was posted, in common with all the other pilots leaving the squadron, to the course at CFS. 'Specially selected' they used to say. My first stroke of luck in my Training Command tour was that there were no ex-Hunter jocks on my course, which reduced the competition for the Gnat slots. So I was happy to join two other Canberra drivers and a Vulcan captain on the Gnat course. My second stroke of luck was that the designer-chappie had the Gnat built with enormous ailerons which provide an almost unrivalled rate of roll. How that saved my neck will become apparent.

By the middle of my tour I actually enjoyed teaching students and had acquired a relaxed (over?) confidence in my own ability and judgement. One lovely sunny morning I squeezed once more into the back seat of my mini-jet for a mid-course general handling sortie. My student was a competent individual who handled the required upper air work well, and we returned to base for circuit continuation.

On rejoining, we found that the only other aircraft in the visual circuit was a Vulcan. I restrained the obvious comment upon this unlooked-for complication, and allowed charity and pride to have their say, *viz:* I suppose we are all in the same air force, and anyway surely I can allow sufficient spacing for one four-jet! By the time we positioned downwind, the Vulcan was approaching short finals and I reminded my student that he should extend the downwind leg to allow plenty of time for any turbulence to clear away. Well he did, but only by 2 or 3 seconds instead of the 10 or 12 I had in mind.

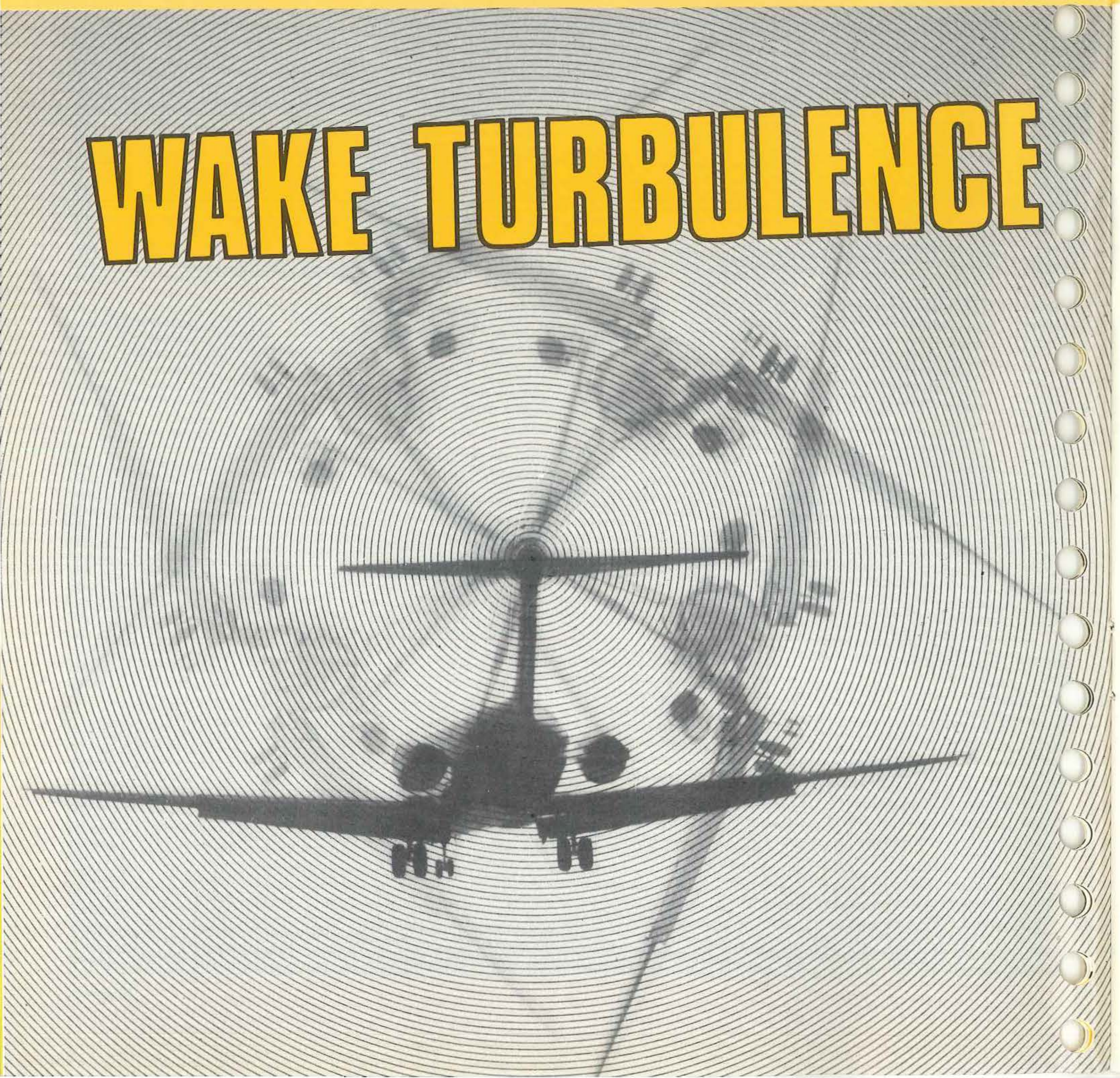
As we turned finals the Vulcan was climbing away and was, I reckoned, about 3 track miles ahead. Too close for comfort? Probably, but I expected that if there was going to be a problem, we would first encounter turbulence as we rolled out on finals. As this was a slightly extended circuit, our height at that point should be about 500 ft. So I let my student continue — first mistake! Everything was still going fine at 200 ft and I was curious but content that the wind must have drifted the wake away, and yet we had been passed the surface wind as less than 5 kt — second mistake!

Then at 50 ft, SLAM. Roll . . . Yaw . . . Grass . . . Caravan . . . Crh . . . throttle, aileron and rudder all at the stops simultaneously, but not before we were more upside down than right side up. What the student was doing I neither knew nor cared, but a fraction of a second later we came clear of the vortex, the aircraft rolled the right way up and climbed away from about 30 ft. I blurted out something about turbulence and retained my grip on the controls to fly the final circuit. At the time I justified this by thinking I should let the student get over the shock, but on reflection I needed something to take my mind off what had just happened. As it was, by the time I had completed the landing run, my knees were shaking to such an extent that I could no longer control the toebrake pedals. My student was able to taxi in while I recovered.

Back in the crew-room, where several chaps had had a good view of the incident, the usual ribaldry was replaced by a shocked seriousness in comments such as 'we thought you'd had it that time'. One thoughtful soul pushed under my nose a magazine open at an article on Wake Turbulence, which showed what I had just discovered — that the vortex core can be rotating at as much as 240 degrees per second. Some rate of roll!

—with acknowledgement and thanks to RAF 'Air Clues'.

WAKE TURBULENCE

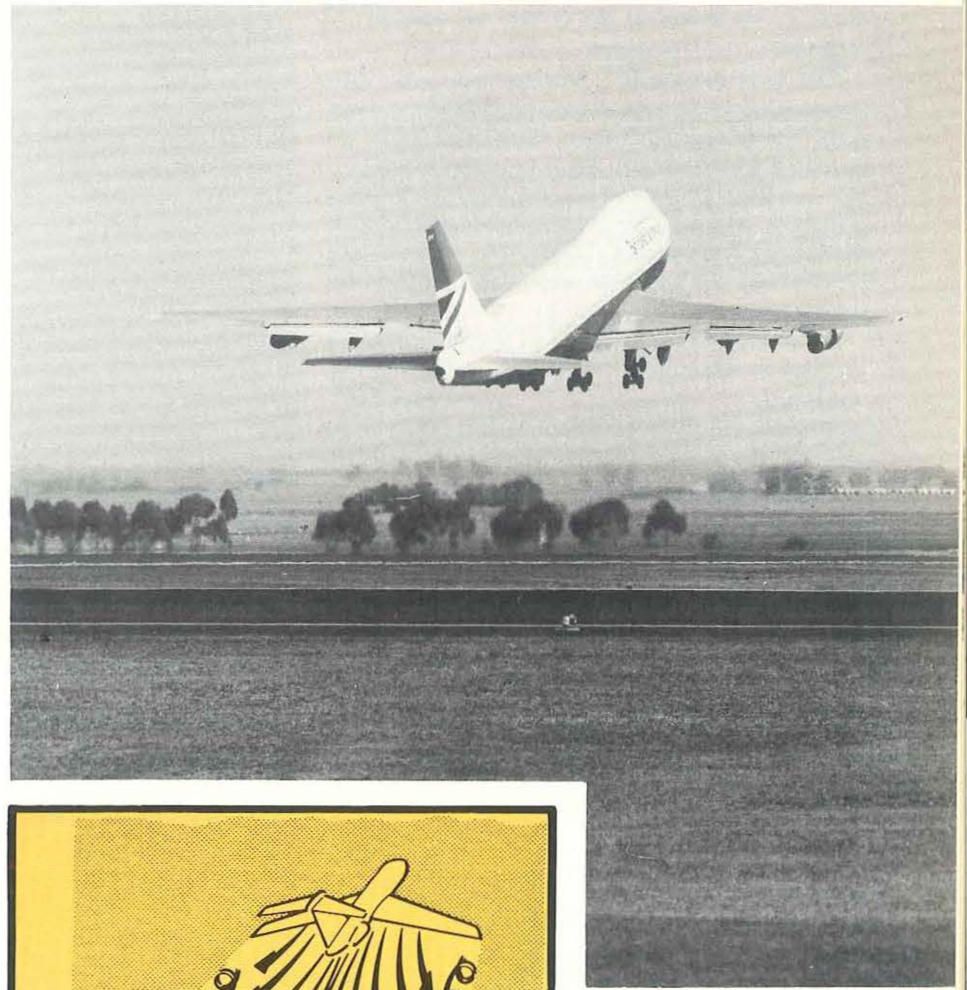


Every aircraft generates a wake in flight. In earlier days, when pilots encountered the wake of another aircraft, the disturbance was attributed to 'prop wash'. It is now known, however, that this disturbance is caused by a pair of counter-rotating vortices, trailing one from each wing-tip.

The vortices from large aircraft can present a hazard to other aircraft encountering them. For instance, the wake of these aircraft can impose rolling moments exceeding the roll control capability of smaller aircraft. In previous years it was thought that only light aircraft were likely to be endangered in a wake turbulence encounter but in 1972, a DC-9 crashed while making an approach to land behind a DC-10, killing all on board. The investigation concluded that the probable cause of this accident was an encounter with the trailing vortex generated by the preceding, heavier DC-10, resulting in an involuntary loss of control.

In addition to the possibility of accidents caused by loss of control, turbulence generated within the vortices can damage aircraft structures and equipment if encountered at close range.

To avoid wake turbulence encounters, pilots must learn to envisage the location of the vortex wake generated by large aircraft. In this way small aircraft can be manoeuvred clear of potentially hazardous areas, and larger aircraft may adopt alternative procedures when safety is likely to be prejudiced.



MAIN FEATURES OF TRAILING VORTICES

Vortex Generation

Lift is generated by the creation of a pressure differential over the wing surfaces of an aircraft. The lowest pressure occurs over the upper wing surface and the highest pressure under the wing. This pressure differential triggers a rolling motion in the airflow behind the wing, producing swirling air masses which trail downstream from the wingtips. As the rolling motion is completed, the wake develops as two counter-rotating cylindrical vortices.

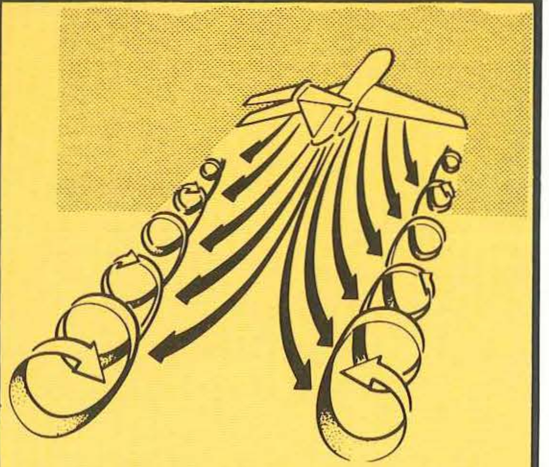


FIGURE 1 — VORTEX GENERATION

Vortex Strength

The strength of the vortices is governed by the weight and speed of the generating aircraft as well as the shape of its wing. Engines located on the fuselage, rather than suspended from the wing, may also significantly affect the aircraft's vortex characteristics.

The vortex characteristics of any given aircraft can be changed by the extension of flap or other wing configuring devices, as well as by a change in speed. However, the vortex strength may be taken as being approximately proportionate to the generating aircraft's size.

Trials conducted with Boeing 747 and 727 aircraft have shown that the vortex core may typically vary between a third of a metre to nine metres in diameter, and tangential velocities of up to 85 metres per second (166 knots) have been recorded. In theory however, the peak tangential velocities decrease logarithmically from the core centre so, typically, at a distance of 12 metres from the core centre, the tangential velocity is likely to be as low as six metres per second (12 knots).

The peak tangential velocity has also been shown to decrease significantly with flap extension. The reason appears to be related to the interaction of the wingtip vortices with supplementary vortices generated at the flap extremities. Typically, the vortex strength behind an aircraft in the approach configuration may be only half that behind the same aircraft in a holding configuration.

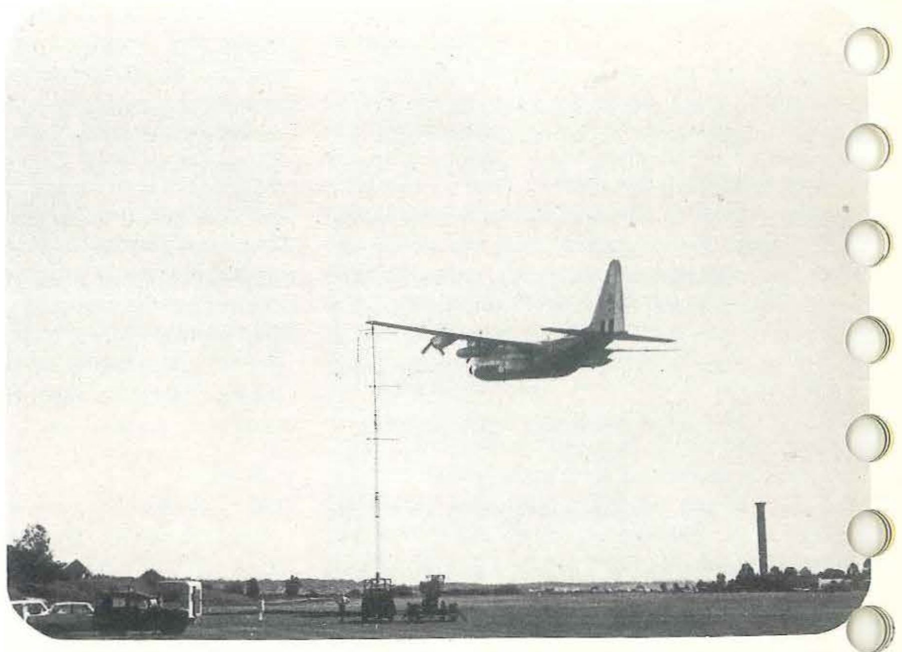
In summary, the strength of a wingtip vortex is likely to be greatest when the generating aircraft is:

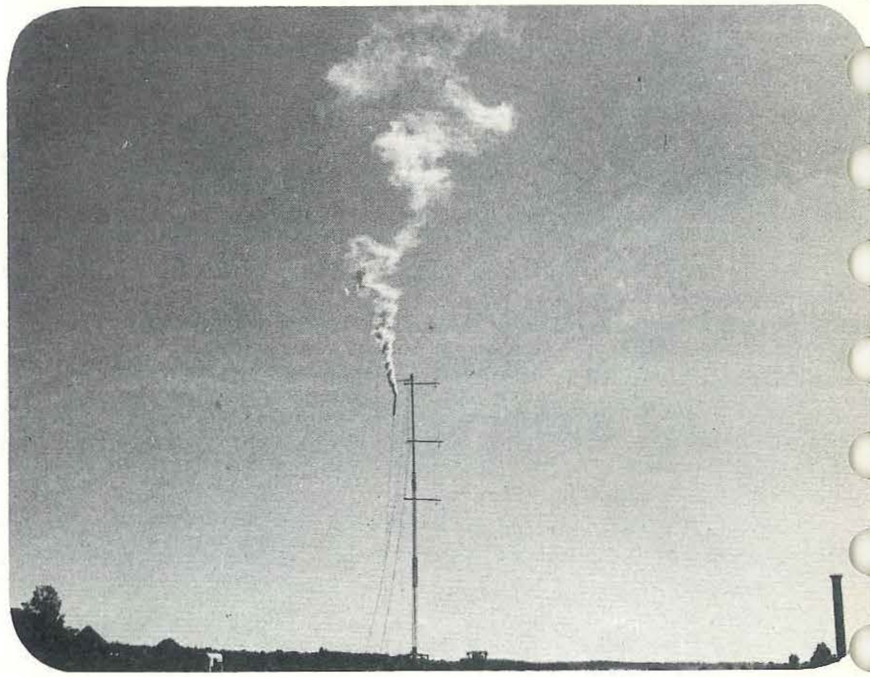
- **Large**
- **Flying slowly**
- **'Clean'** rather than with flap extended.

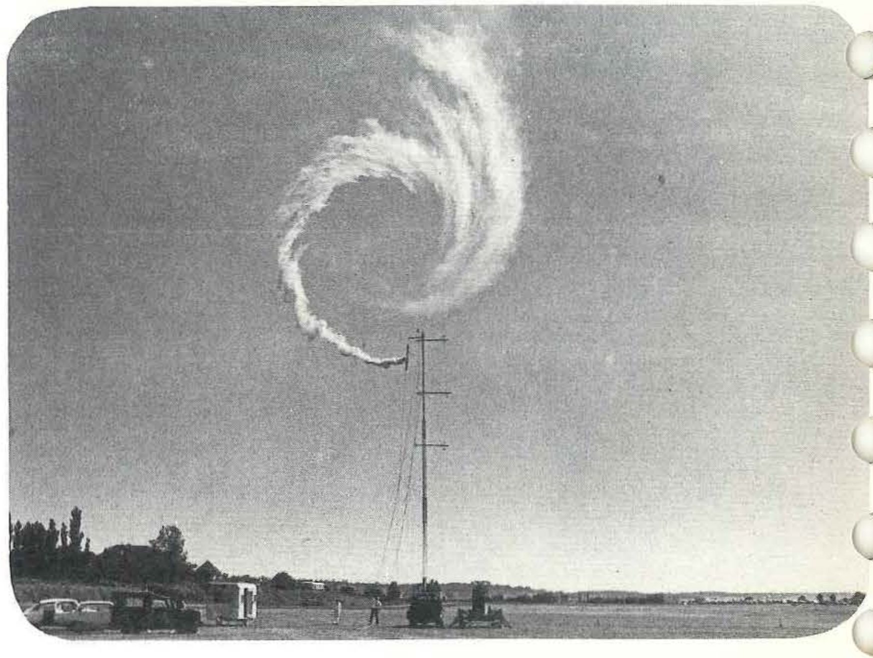
Nature of the Vortex

The following remarkable series of pictures was taken by a research team from the Aeronautics Department of the University of Sydney during a study of wake turbulence made for the Department. The aim of this experiment, conducted at the RAAF Base, Richmond, NSW, was to render a wingtip vortex visible by allowing it to drift across a smoke source. The smoke source was provided by a smoke generator mounted on the steel mast in the foreground of the pictures.

To begin the experiment, a Lockheed Hercules aircraft was flown at low level past the mast (Picture 1). A few seconds later, the smoke generator was ignited (Picture 2). As the vortex from the port wing of the aircraft drifted over the mast, the rising smoke was suddenly whipped into the rapidly rotating horizontal column of air (Picture 3). The smoke was rapidly drawn into the core of the vortex as well as into the more open, induced airflow spirals surrounding the core itself (Picture 4). In Picture 5, showing the final stage of the smoke development, the compact spiral character of the core is clearly visible.







Effects of a Vortex Encounter

A wake encounter is not necessarily hazardous. It can be experienced as one or more jolts of varying severity, depending upon the direction of the encounter and the distance from the generating aircraft. Naturally, the degree of hazard varies with the height above the ground, since this determines the time available to correct for any unusual attitude induced by the encounter.

In rare instances a wake encounter in flight could cause catastrophic structural damage, but the usual hazard is associated with loss of control in the rolling plane. The high tangential velocities surrounding the vortex core can induce rolling moments which exceed the counter-rolling capability of the encountering aircraft. The probability of induced roll increases when the encountering aircraft's heading is generally aligned with the vortex trail or flight path of the generating aircraft.

During inflight experiments, aircraft have

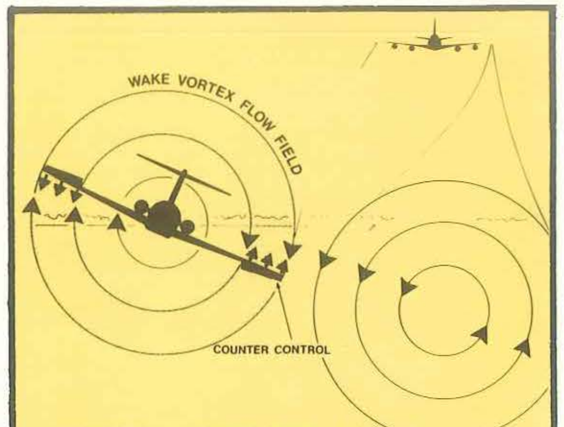


FIGURE 2 — INDUCED ROLL

been intentionally flown into and along the trailing vortex cores of large aircraft. As a result it has been found that the capability of an aircraft to counteract a roll induced by wake vortices depends primarily on the wingspan and counter-control responsiveness of the encountering aircraft.

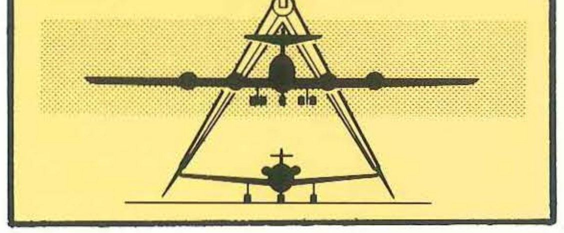
Counter control is usually effective, and induced roll minimal, in cases where the wingspan and ailerons of the encountering aircraft extend beyond the rotational flow field of the vortex. It is more difficult for aircraft with short wingspans relative to the generating aircraft, to counter the roll induced by vortex flow. For this reason, **pilots of short span aircraft, even high performance types, must be especially alert to the possibility of vortex encounters.**

The wake of large aircraft demands the respect of pilots of all aircraft.

Vortex Life

Vortices obviously have a finite life. Instead of gradually decaying to zero velocity, it has been

FIGURE 3 — RELATIVE SPAN



found that they break up at distinct intervals. The break-up may be of two types: Sinuous instability, or interaction between the two vortices, causing the formation of separate vortex rings or loops; or a 'bursting' of either or both vortices, thought to be the result of an internal reaction within the individual vortex.

The lifespan is also affected significantly by ambient atmospheric conditions and break-up is hastened by atmospheric turbulence. Experiments have shown that vortices close to the ground will typically last from less than one to approximately two minutes. At higher altitudes, the vortex life may be as long as five minutes. Depending on the generating aircraft's speed, this could produce a vortex trail from less than two, to up to 15 nautical miles long.

Vortex strength before break-up also diminishes with time. The trials conducted with the Boeing 747 and 727 aircraft suggest that the peak tangential velocity varies as the elapsed time in seconds, in accordance with the formula, $V_{\theta\ max} = K(t)^{-\frac{1}{2}}$. In general, the peak velocity reduces by half after about 45 seconds.

Vortex Behaviour

Trailing vortices have certain behavioural characteristics which can enable a pilot to visualise the wake location and take avoiding action. The vortices have different but reasonably predictable paths, depending on whether or not they are in contact with the ground.

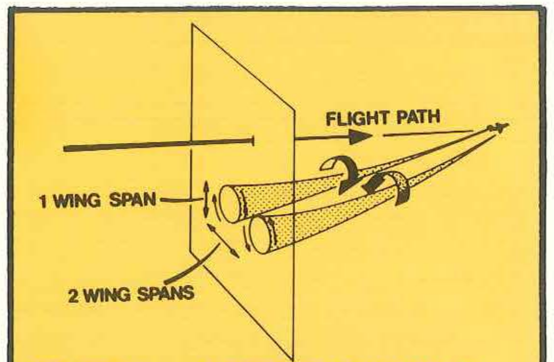


FIGURE 4 — VORTEX FLOW FIELD

Vortices Not in Ground Effect

As already indicated, vortex circulation is upward and around the wingtips when viewed from either ahead or behind the aircraft. In the case of vortices behind aircraft which are well clear of the ground, research has shown that the vortex flow field, in a plane cutting through the wake at any point downstream, covers an area about *two wingspans wide* and *one wing span deep*. The vortices remain so spaced, about a wingspan apart, sinking and drifting with the wind.

Flight tests have shown that the vortices from large aircraft sink initially at a rate of about 400 to 500 feet per minute then gradually become 'buoyant', tending to level off at a height generally not more than *900 feet below* the flight path of the generating aircraft. They then tend to remain at this altitude, with the vortex strength diminishing with time and, therefore, with distance behind the generating aircraft. Eventually the vortices break up; the process being hastened by atmospheric turbulence.

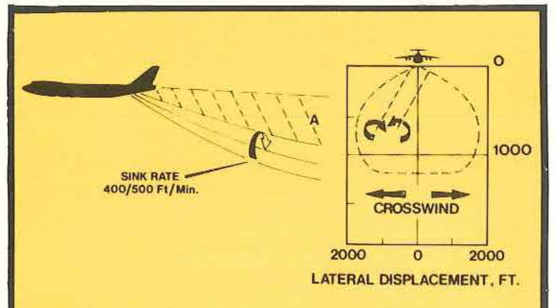


FIGURE 5

To avoid a wake encounter therefore, pilots should fly at, or preferably above, the large aircraft's flightpath. If committed to fly below a large aircraft, an upwind flight-path should be chosen and the area behind, and at least 1000 feet below the generating aircraft, avoided.

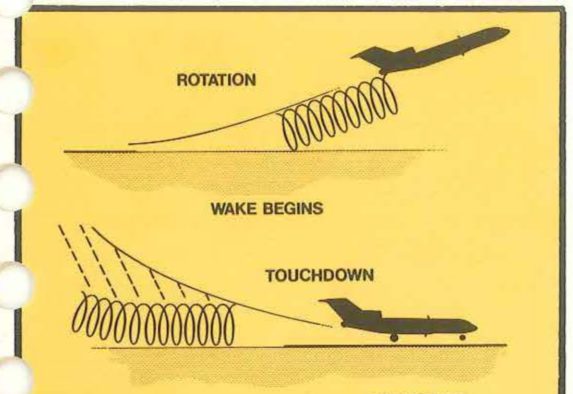


FIGURE 6

Vortices in Ground Effect

Wake vortices are generated from the moment an aircraft leaves the ground. On nosewheel aircraft, the commencement of the vortex on take-off can be visualised as the point where the nose is rotated clear of the ground. This of course is normally some distance along the runway.

When the vortices of large aircraft sink to within about 200 feet of the ground, they tend to spread outwards moving laterally over the ground at a speed of about five knots. This phenomenon is often described as 'vortices in ground effect'.

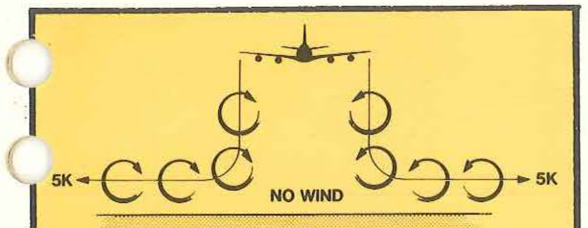


FIGURE 7

Effect of Crosswind: A crosswind will decrease the lateral movement of the upwind vortex and increase the movement of the downwind vortex (Figure 8). Thus a light wind of three to seven knots could result in the upwind vortex remaining in the touchdown zone for a period of time — sometimes called 'stalling' of the vortex (Figure 9), and hasten the drift of the downwind vortex, perhaps towards another runway. Observations have shown that the upwind vortex may ascend when in ground effect.

A tailwind condition can drift the vortices of a preceding aircraft forward into the touchdown zone. Experience and flight tests have shown this to be the most hazardous situation for following aircraft. Thus, **the light quartering tailwind requires maximum caution** (Figure 9).

A monitoring programme to determine the life and location of wake vortices in the final approach 'window' has been conducted at a number of major international aerodromes outside Australia. Records compiled from over

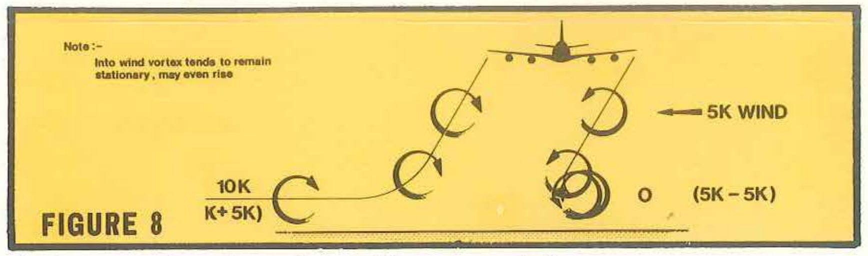


FIGURE 8

9000 approaches show that, with a crosswind between 5-10 knots, the 'residence' of a vortex in the final approach window in excess of 80 seconds occurred in less than 0.3% of the cases. 'Residence' in this sense means that the wake had neither dissipated nor moved out of the approach window. With a crosswind of 10-15 knots, there were no cases where the residence time was in excess of 60 seconds. And there were no cases of a residence greater than 40 seconds with crosswinds of 15-20 knots. This can be shown in tabulated form:

EFFECT OF CROSSWIND ON 'RESIDENCE' OF VORTEX IN APPROACH WINDOW

Crosswind (kts)	Maximum Residence Time (Secs)	Likelihood of Encounter at Greater Time
5-10	80	0.3%
10-15	60	Nil
15-20	40	Nil
20	None Recorded	

NOTE: This information is to assist pilots to visualise the nature of the wake behaviour. It is not intended as an authoritative statement on safe separation standards.

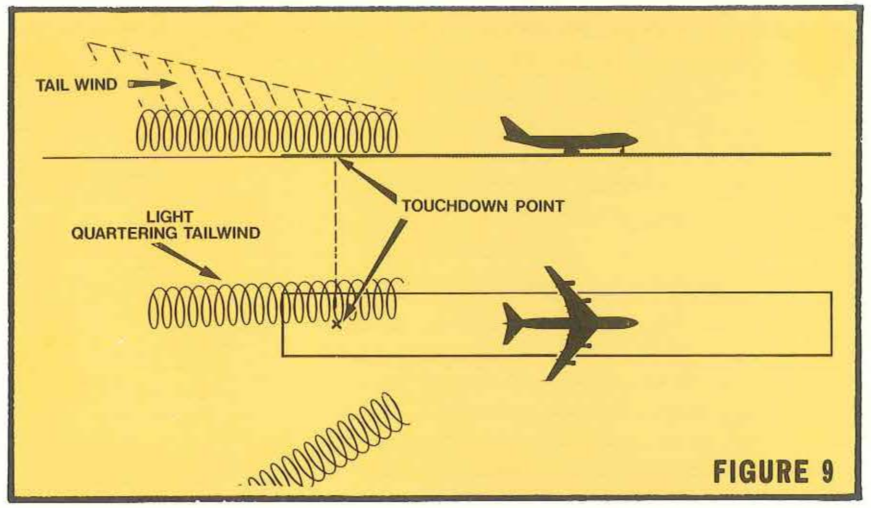


FIGURE 9

WAKE TURBULENCE AVOIDANCE

It is important that all pilots should be able to visualise the location of the vortex trail behind large aircraft and adjust their operations to avoid this area. In controlled airspace, Air Traffic Control will assist by applying appropriate separation in certain circumstances. Both Air Traffic Control and Flight Service may issue advisory warnings to pilots.

Generally, where mixed classes of aircraft are using the same runway and commencing take-off from the same point, there is little chance of a vortex encounter on take-off, since the normal performance of the aircraft likely to be endangered would put its flight path above that of the generating aircraft. However, the landing situation, the intersection take-off, and take-offs and landings on crossing runways require especial caution if wake encounters are to be avoided.

During approaches to land behind heavy aircraft, ILS and VASIS guidance can provide assistance in avoiding a wake encounter. Pilots should take particular care not to descend below the glide-slope indication in these circumstances.

Pilots should be particularly alert in calm wind conditions and in situations where the vortices could:

- Remain in the touchdown area
- Drift from aircraft operating on a nearby runway
- Sink into take-off or landing paths from a crossing runway
- Sink into the flight path of aircraft flying at a lower altitude.

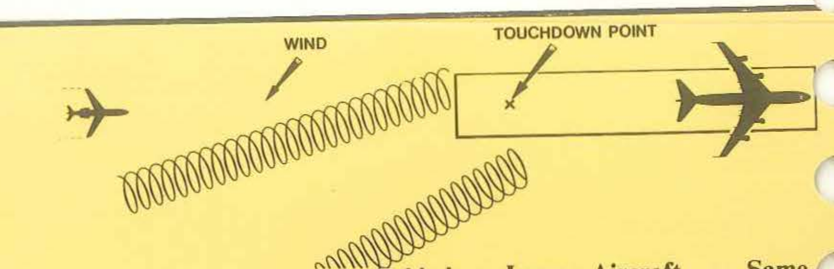
As already mentioned, the light quartering tailwind produces the most hazardous conditions for aircraft approaching to land behind a larger aircraft. **Always avoid the area below and behind larger aircraft, especially at low altitude, when even a momentary wake encounter could be hazardous.**

Separation Standards in Controlled Airspace

It is important to note firstly that, because wake vortices are not generated on take-off *until* rotation, special separation procedures between landing aircraft and preceding aircraft taking off are *not* considered necessary. In such a case, the preceding aircraft's point of rotation is a long way beyond where the landing aircraft could be expected to touch down.

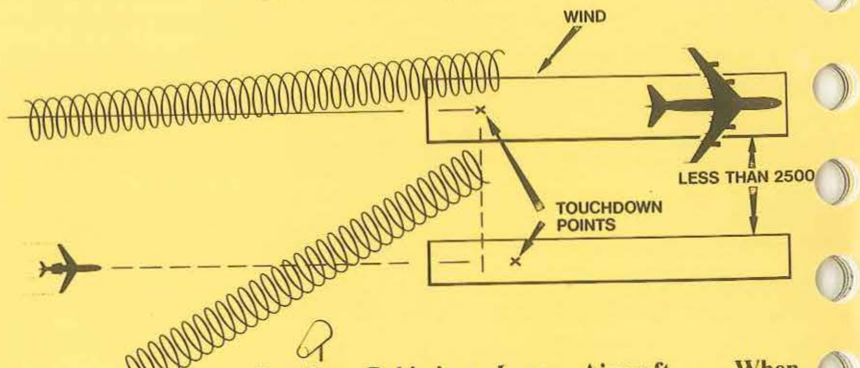
In all other cases however, separation standards have been devised which aim to protect aircraft from active vortices generated by preceding heavier aircraft. For this purpose aircraft are grouped according to their certificated maximum take-off weight, and an appropriate longitudinal distance or time separation is specified. Some appreciation of accepted minimum safe standards can be gained from the fact that time separations of two to three minutes, or distance separations of five to six nautical miles, are applied to operations behind wide-bodied jet aircraft.

IFR Category Aircraft: In controlled airspace, ATC will apply appropriate separation to



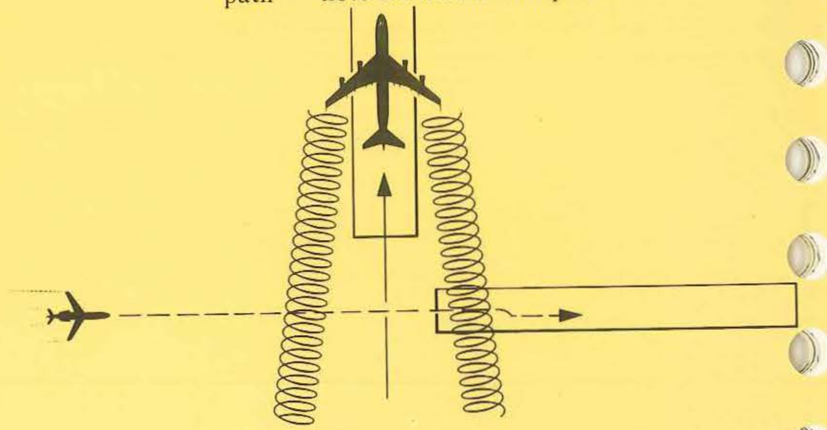
Landing Behind a Large Aircraft — Same Runway: Stay at or above the large aircraft's final approach flight path — note its touchdown point — land beyond it.

FIGURE 10



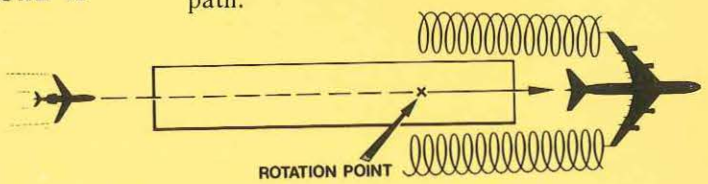
Landing Behind a Large Aircraft — When Parallel Runway is Closer than 750 Metres: Consider possible drift to your runway. Stay at or above the large aircraft's final approach flight path — note its touchdown point.

FIGURE 11



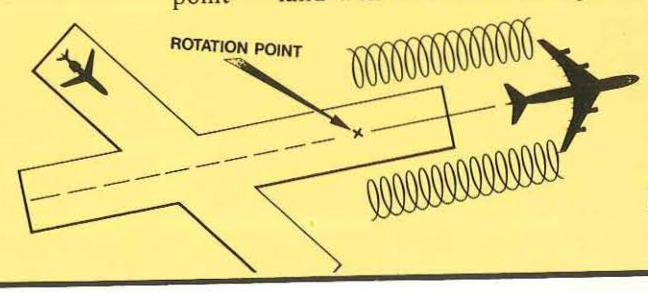
Landing Behind a Large Aircraft — Crossing Runway: Cross above the large aircraft's flight path.

FIGURE 12



Landing Behind a Departing Large Aircraft — Same Runway: Note large aircraft's rotation point — land well before rotation point.

FIGURE 13



FIGUR

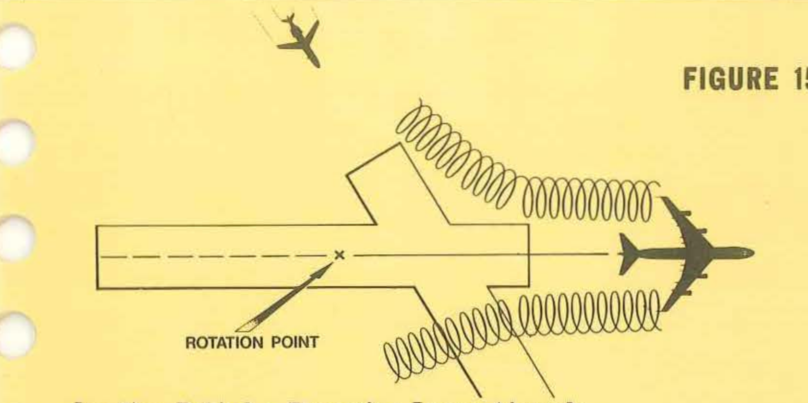


FIGURE 15

Landing Behind a Departing Large Aircraft — Crossing Runway: Note large aircraft's rotation point — if past the intersection — continue the approach — land before reaching the intersection (Figure 14). If large aircraft rotates before reaching the intersection, avoid flight below the large aircraft's flight path. Discontinue the approach unless a landing is assured well before the intersection (Figure 15).

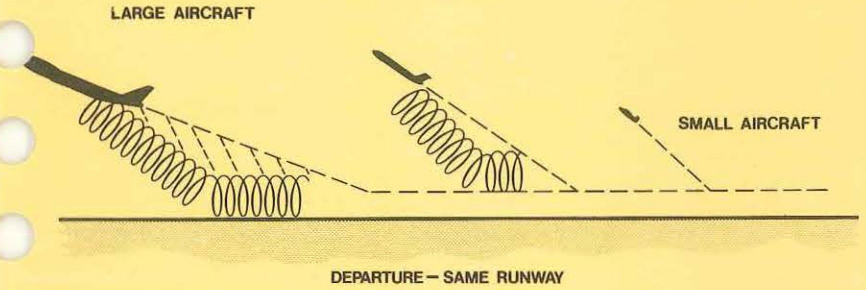


FIGURE 16

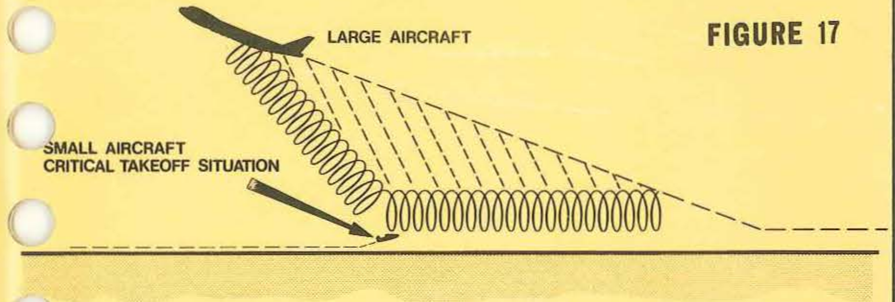


FIGURE 17

Departing Behind a Large Aircraft: Note large aircraft's rotation point and rotate prior to this point — continue climb above its flight path and, if there is a crosswind, stay upwind of the large aircraft's climb path until turning clear of its wake (Figure 16). Avoid subsequent headings which will cross below and behind a large aircraft (Figure 17). Be alert for any critical take-off situation which could lead to vortex encounter (Figure 18).

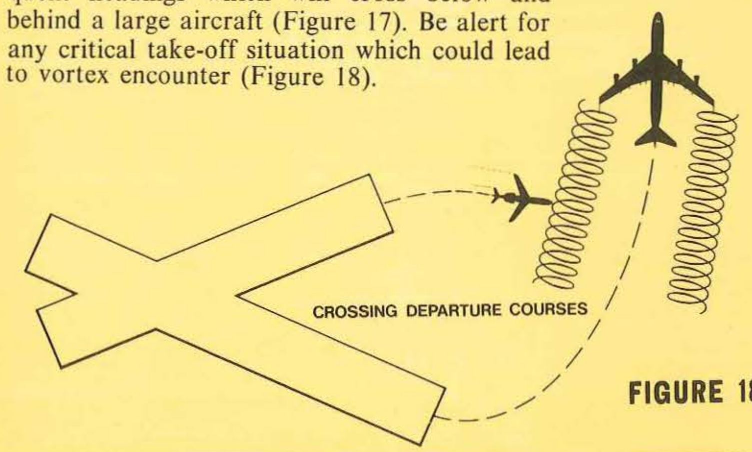


FIGURE 18

aircraft operating under IFR procedures, without reference to the pilot.

VFR Category/VFR Procedures: IFR Category aircraft cleared to approach and land under VFR procedures, i.e. aircraft cleared for a 'visual approach', and aircraft in VFR category will be given clearances designed to achieve the required separation. In these circumstances separation is a joint responsibility and, especially in the circuit area, pilots *must* ensure that their aircraft are manoeuvred, for example by extending the downwind leg, to maintain the minimum safe separation. ATC will provide every assistance, including the use of radar, where available, to maintain this separation.

Additional Precautions: It is expected that the longitudinal separation currently being applied will avoid flight through a preceding aircraft's wake, but pilots are warned of two situations in which the chances of a wake encounter are significantly increased:

- When a preceding heavy aircraft has gone around from its approach to land; and
- When, on take-off, the lift-off will be achieved at a point *further* along the runway than the point of rotation of a preceding heavy aircraft.

If doubt exists on the separation necessary to avoid wake turbulence, pilots should forgo their approach or delay their take-off and request an alternative clearance. **Pilots are especially warned against requesting intersection take-offs when an immediately preceding heavier aircraft has used the full runway length.**

Caution

Whenever Air Traffic Control or Flight Service are aware of the likelihood of a wake turbulence hazard, the phrase 'CAUTION — WAKE TURBULENCE' will be given to arriving and departing aircraft. Pilots should note however, that because of the difficulty in predicting the occurrence of hazardous vortices, this caution may be omitted. It is the pilot's responsibility to adjust his operations or flight path, or to obtain an alternative clearance, if he considers a wake turbulence encounter likely. **If in doubt do not continue an approach behind a heavy aircraft.**

At non-controlled aerodromes, Flight Service will warn lighter aircraft of the movements of other aircraft whose certificated maximum taxiing weight exceeds 45 500 kg.

VORTEX AVOIDANCE PROCEDURES

Recommended vortex avoidance procedures are given in the accompanying diagrams:

NOTE: Whenever these recommendations conflict with aircraft performance requirements (e.g. by limiting runway length), or with specified aircraft operating procedures, these will naturally take precedence. In such circumstances, wake turbulence must be avoided by applying time separation.

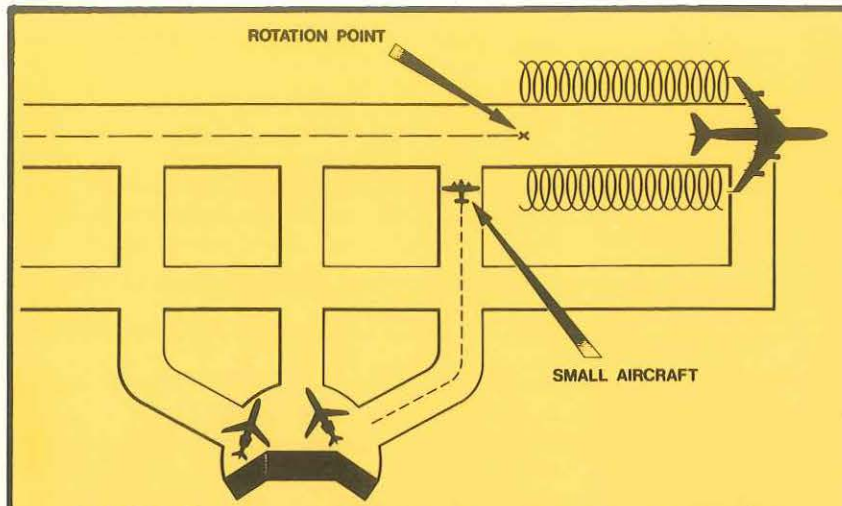


FIGURE 19 **Intersection Take-offs — Same Runway:** Be alert to adjacent large aircraft operations, particularly upwind of your runway. If an intersection take-off clearance is received, avoid subsequent headings which will cross below a large aircraft's path.

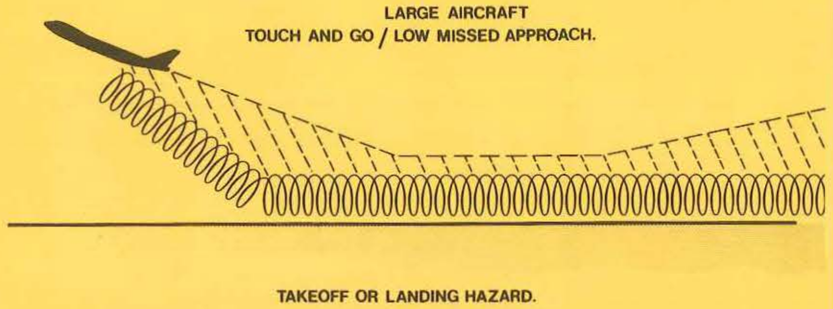


FIGURE 20 **Departing or Landing Behind a Large Aircraft Executing a Low Missed Approach or Touch-And-Go Landing:** Because vortices settle and move laterally near the ground, the vortex hazard may exist along the runway and in your flight path after a large aircraft has executed a low missed approach or a touch-and-go landing, particularly in light quartering wind conditions. You should ensure that an interval of at least two to three minutes, according to the preceding aircraft type, has elapsed before you take-off or land.

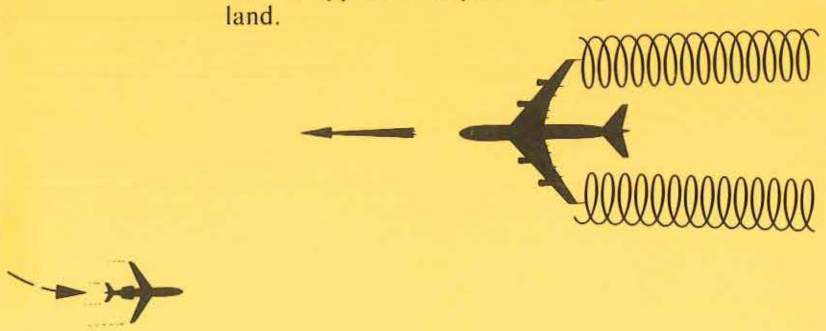


FIGURE 21 **En Route or in the Holding Pattern:** Flight below and behind large aircraft should be avoided. If wake turbulence is experienced when in a holding pattern, request increased vertical separation to 2000 feet below any heavy aircraft. Outside controlled airspace, pilots of lighter aircraft should arrange their flight path to avoid the wake danger area depicted in Figure 5.

HELICOPTERS

A hovering helicopter generates a downwash from its main rotor, similar to the propeller wash of a conventional aircraft. However, in forward flight, this energy is transformed into a pair of trailing vortices similar to wingtip vortices of fixed-wing aircraft. Pilots of small aircraft should avoid the vortices as well as the downwash.

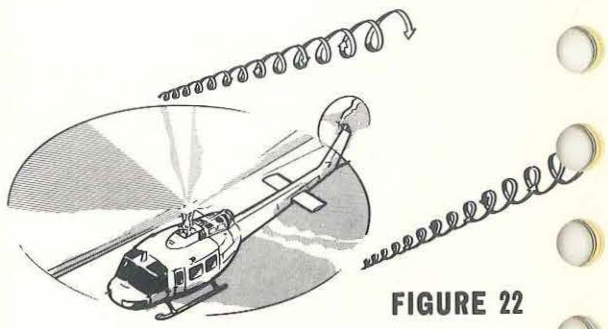


FIGURE 22

FUTURE DEVELOPMENTS

It is known that the life of a wing-tip vortex, particularly near the ground, is significantly affected by atmospheric turbulence. This in turn is dependent upon the local wind velocity, temperature and the presence of temperature inversions. Studies are under way to determine those meteorological parameters which are conducive to the longevity of vortices and which indicate the need for extreme caution.

Research is also being conducted on methods of detecting the presence of active vortices on runway approach paths. A reliable method of detection would enable existing separation standards to be reduced in particular circumstances, thereby increasing the traffic capacity of the airport concerned.

NEAR-DISASTER AT NAIROBI

During a coupled ILS approach in instrument conditions into Nairobi Airport (elevation 5327 feet), 5000 was dialled into the Altitude Selector of a Boeing 747 aircraft and a descent to capture this altitude was initiated. The aircraft descended through the actual cleared altitude (7500 feet) just before it became established on the localiser. Although it was still below the glide-slope, the descent was continued to within sight of the ground at approximately 200 feet. During the subsequent overshoot the aircraft came to within 70 feet of the ground approximately six and three-quarter nautical miles from the airport.

Reproduced from report issued by Department of Trade, United Kingdom.

THE FLIGHT

The aircraft was operating a scheduled service from London to Johannesburg with intermediate stops in Zurich and Nairobi. The flight from London to Zurich was uneventful and after a crew change, the aircraft departed Zurich at 2136 hours on 2 September, 1974, 11 minutes behind schedule, with an ETA at Nairobi of 0513 hours (0813 hours local Nairobi time).

When the aircraft was approximately 150 nm from Nairobi, the commander briefed the co-pilot and the flight engineer for the approach and landing. Following normal company procedures he reviewed the aerodrome approach charts and noted the height of Nairobi above sea level (5327 feet) and the appropriate safety heights for the area. Anticipating that runway 06 would be in use and that procedure 'A' would be followed, the commander declared his intention of carrying out a coupled-approach on the ILS with a manual landing once the runway had been sighted. Having obtained the weather minima appropriate to both a manual approach and an auto-approach from the company manual, the crew set the movable indices on the pressure altimeters appropriate to 5627 feet (manual minimum altitude above sea level) and those on the radio altimeters to 200 feet (coupled-approach minimum height above aerodrome elevation).

Shortly after this briefing, radio communications were established with the Nairobi radar controller on 119.5 MHz and the aircraft was cleared to the 'Golf Golf' NDB at FL 150 with no delay expected for an ILS approach to runway 06. The 0430 hours Nairobi weather observation, reporting two oktas of cloud at 800 feet, was also passed on to the aircraft. At approximately 0455 hours, when the aircraft was about 90 nm from Nairobi, the descent to FL 150 was commenced. During the descent a message was received informing the aircraft that a pilot who had just landed at Nairobi had reported that the cloud base was then at 300 feet.

The aircraft was re-cleared to FL 120 on a revised heading of 160°M after it had been positively identified by radar at a distance of 46 nm from Nairobi. After it levelled off at FL 120 at 0504:00 hours and with 30 nm still to run to the 'Golf Golf' beacon, it accelerated gradually to 338 knots IAS. At this time the skies were clear and the Ngong range of hills, on whose summit the 'Golf Golf' beacon is installed, was clearly visible. Beyond the hills, however, the plateau surrounding the airport was covered by low cloud.

At 0505:47 hours when the aircraft was about 16 nm from the 'Golf Golf' beacon, it was re-cleared to descend to FL 100. This descent was made with the throttles closed and at a rate of about 1000 feet per minute with the airspeed gradually reducing. At 0508:13 hours the aircraft was instructed by radar to turn left on to a heading of 105 degrees. During this turn the aircraft reached FL 100 and began to level off automatically under the control of the autopilot. The speed at this stage was 263 knots IAS and was still reducing. (The maximum speed for lowering one degree of flap, i.e. the first increment, was 265 knots IAS and the maximum speed for zero flap at the aircraft's weight was 213 knots IAS.)

The turn on to 105°M was completed at 0508:49 hours, and the commander engaged the autothrottle seven seconds later when the speed was about 235 knots IAS.

The No. 1 VHF navigation receiver had been set to the runway 06 ILS frequency by this time and the Nairobi VOR frequency left on the No. 2 set. Both ADF receivers were tuned to the 'Golf Golf' beacon.

At 0508:59 hours, the radar controller advised the flight: '. . . YOU ARE PASSING THE GOLF GOLF BEACON THIS TIME DESCEND SEVEN FIVE ZERO ZERO FEET THE QNH IS ONE ZERO TWO ZERO DECIMAL FIVE.'

The crew noticed that they were passing the beacon both visually and by reference to the RMI needles. Neither pilot heard the clearance correctly and believed they had been cleared to descend to 'five zero zero zero feet'. The co-pilot accordingly read back without hesitation: 'ROGER . . . CLEARED TO FIVE THOUSAND FEET ON ONE ZERO TWO ZERO DECIMAL FIVE'. This message was not acknowledged by the radar controller. It was also missed by the flight engineer. He has stated that although he thought the word 'SEVEN' was indistinct, he was nevertheless in no doubt that the aircraft had been cleared to 7500 feet, a height that he was expecting as it was given on the airfield approach chart as the intermediate approach altitude. However, he remained unaware that the pilots had interpreted the clearance differently.

A reconstruction of the events on the flight deck subsequent to this point has been made using the information obtained from the flight data recorder, the RTF transcript and recording, simulator studies and crew statements. No information was available from the cockpit voice recorder. From the studies, it has been deduced that as soon as the clearance was received, the commander disconnected the autothrottle and put the aircraft into a descent. At the same time, the co-pilot dialled 5000 in the Altitude Selector on the autopilot/flight director mode selector on the pilots' light shield. The flight engineer saw this action but did not see the altitude selected as he was engaged in checking the ILS coding at the time.

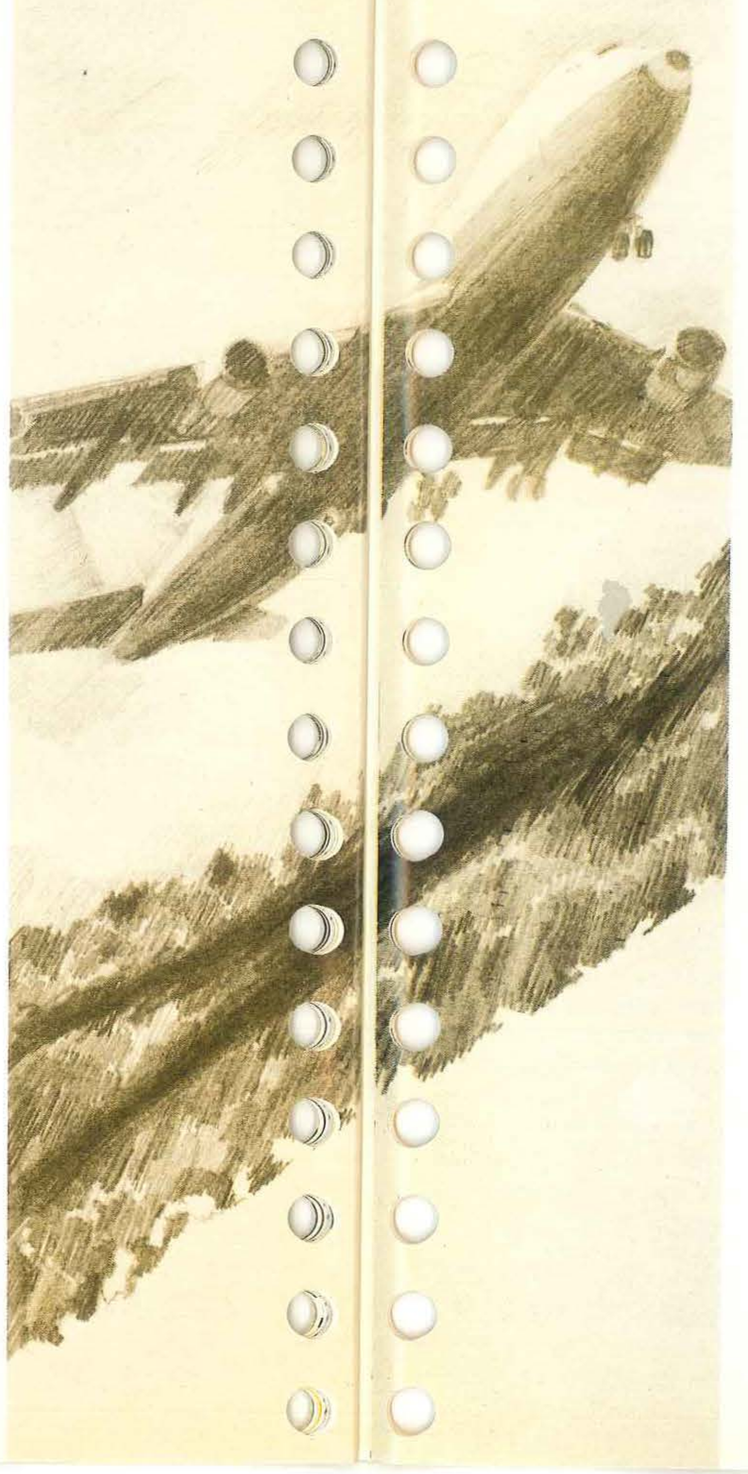
At 0509:07 hours, when the airspeed was 228 knots IAS, the commander called for one degree of flap and whilst this was being selected by the co-pilot, the flight engineer started the approach check. This occupied him for well over a minute and whilst he was engaged in doing this, both pilots reset their pressure altimeters to the QNH of 1020.5. The commander continued to control the aircraft through the autopilot whilst the co-pilot retuned both the ADFs to the outer and inner locators respectively. Both pilots then checked the locator beacon identifications. At this point, the co-pilot advised the commander that in accordance with the airfield approach chart, it was permitted to descend to below the sector safe altitude as the aircraft's position had been positively established over the 'Golf Golf' beacon by radar.

The flight engineer continued with the approach checks and encountered one short delay only when he found the pilots too pre-occupied with other duties to respond to his altimeter challenge until he had repeated it three times. As the aircraft passed through 8600 feet AMSL he checked the cabin differential pressure in order to cross check the aircraft's altitude.

The aircraft continued descending at about 1900 feet per minute and soon entered the bank of low cloud when all visual reference to the ground was lost. When it passed through 2500 feet above ground level the terrain clearance audio warning sounded and was duly noted by the crew.

At 0509:26 hours, when the airspeed had been reduced to 220 knots, the co-pilot selected five degrees of flap and this took 28 seconds to achieve. At 0509:53 hours the radar controller advised the aircraft that it had 15 nm to run to the runway and that it was cleared to lock on to the localiser which it was approaching and descend on the glide path. The commander then selected the ILS frequency on the No. 2 VHF NAV receiver himself, set the inbound QDM and switched the navigation mode switch to LAND. He then engaged the Nos. 2 and 3 autopilots in preparation for a coupled approach and at 0510:20 hours he called for 10° flap.

At 0510:38 hours the automatic capture of the localiser was initiated and the aircraft banked



into a left turn. It was probably descending through about 7700 feet AMSL at this time at a descent rate of about 2000 feet per minute and with the airspeed temporarily steady at 225 knots. The aircraft passed through the localiser and had to continue the turn and make further adjustments in heading before it stabilised on the inbound course. At this stage the flight engineer made a further check on the aircraft's altitude by cross reference to the cabin differential pressure.

At 6000 feet AMSL the co-pilot called 'One thousand to go' and shortly afterwards there was an audio warning alerting the crew that they were approaching their selected altitude. The ILS deviation warning light on each pilot's instrument panel then illuminated but, because it was unexpected, the commander's initial reaction was that the warning was probably false. The flight engineer also noticed the warning on resuming his instrument scan after checking the pressurisation and, when he saw that the aircraft was still descending with the glide-slope pointers out of view in the up position although on the localiser centre line, he called 'We have no glide-slope'. The commander replied 'We have'. (Later he explained that he understood the flight engineer to mean that the glide-slope had failed and that he could see no failure flag to confirm this.)

At 0511:42 hours, whilst the aircraft was still descending at 217 knots and at about 1650 feet per minute, it reached 270 feet AGL and the Decision Height audio warning tone began to sound. A few seconds earlier, ATC had advised the aircraft that it was eight and a half nm from touchdown and that it was cleared to land. The co-pilot began to acknowledge this message but his transmission was abruptly cut off in mid-word. At this moment the flight engineer called: 'Two hundred feet decision height' and almost immediately afterwards, the aircraft broke out of the bottom of the cloud. The flight engineer called 'Give full power — give full power' followed by 'Check height — check height'. The commander, on sighting the ground, checked the rate of descent on the elevators, disconnected the autopilots and applied power for the overshoot. The time was then 0511:50 hours. From the flight recorder readout, it was established that at its lowest point, the aircraft came to within 70 feet of the ground.

At 0512:26 the aircraft called ATC that it was overshooting and it was subsequently cleared to climb to 7500 feet. When the crew came to set this figure in the Altitude Selector they saw the figure 5000 which had been previously set and realised the error that had caused the premature descent and near collision with the ground. The aircraft was subsequently given radar guidance back on to the ILS and made a successful automatic landing.

The commander remained convinced that he had been cleared to 5000 feet and after landing he went with his crew to ATC to find out why he had been given an incorrect clearance. This was denied by the controller and the flight crew were allowed to hear a replay of the ATC tape. This initially appeared to them to confirm that the figure 5000 had been given in the descent clearance but after the third playback it was agreed that the words spoken by the radar controller were 'seven five zero zero feet'.

The commander completed a company incident report form which was immediately transmitted to the company's base in London. The company immediately suspended the crew from flying duties and carried out an investigation into the circumstances. The Accidents Investigation Branch was also informed of the incident by the company, although the occurrence did not fall within the definition of a notifiable accident. However, in view of its apparent seriousness, the Chief Inspector of Accidents ordered a full Inspector's investigation to be carried out, following consultation with the East African authorities.

Subsequently, the responsible licensing authority suspended the flight crew's licences pending their own investigation. The licences were later restored conditionally upon the flight crew demonstrating their proficiency on the aircraft and the co-pilot resumed his duties after further re-training. The flight engineer also returned to flying duties after successfully completing company proficiency checks. The commander, however, did not return to flight duties with the company and has since left its employ.

INVESTIGATION

Operational Equipment

The aircraft was equipped with a triple-channel autopilot/flight director system which among other functions has the capability for automatic capture of a preselected altitude; in addition it has the capability of holding airspeed, vertical speed and altitude. With this equipment it is possible to carry out either a coupled approach with one or more autopilots engaged or a fully automatic landing with either two or three autopilots engaged. However, before more than one autopilot can be engaged at the same time it is necessary to have both VHF NAV receivers tuned to the same ILS frequency and the navigational mode switch selected to LAND.

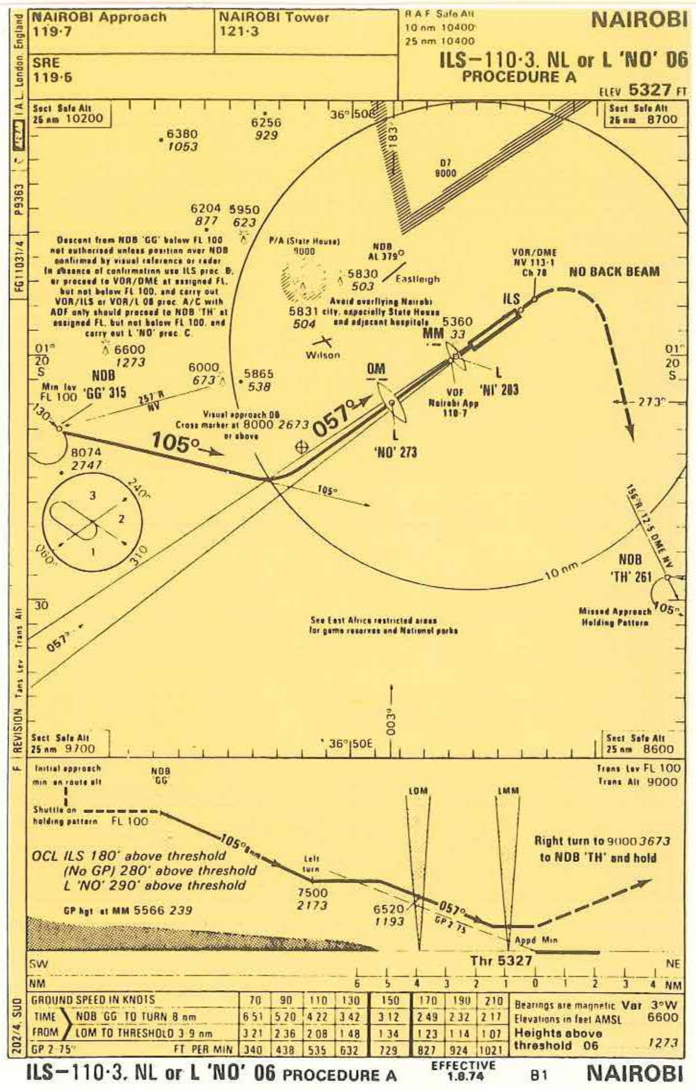
The autopilot/flight director mode selector panel which contains most of the control functions is situated on the pilot's light shield above the centre instrument panel and is accessible to both pilots. To pre-select an altitude, it has first to be inserted in the Altitude Selector on this panel and the system then has to be armed. The height at which altitude capture commences depends on the aircraft's actual rate of descent or climb. The barometric pressure setting to which the altitude is referenced is that set on the aircraft's left hand pressure altimeter.

There is an annunciator panel on each pilot's instrument panel which among other functions indicates either by a white or a green light when a selected facility is armed and when capture has been achieved. The functions covered by the annunciators are the Altitude Selector, and localiser and glide-slope capture.

Navigation Warning Systems

(a) Altitude alert

The altitude select facility has an associated alerting system which provides both an aural and



Nairobi ILS approach chart for procedure being used at time of accident.

a visual warning whenever the aircraft is approaching or deviating from the pre-set altitude. This alerting system is referenced to the barometric setting which has been selected on the co-pilot's pressure servo altimeter.

An aural tone of approximately two to three seconds duration sounds when the aircraft is approaching (900 feet above or below) the selected altitude and at the same time the amber alert light on each pilot's panel comes on and remains on until 300 feet above or below the selected altitude, when it goes out. The lights remain off when the aircraft is within 300 feet above or below the selected altitude. When the aircraft deviates outside this range the lights flash and the two second aural tone sounds. The lights continue to flash until 900 feet above or below the reference height, when they go out.

(b) Terrain warning

A terrain aural warning is incorporated in the Low Range Radio Altimeter system. Provided that the Decision Height pointer is set at or below 2500 feet and is not below zero, the aural tone will be heard in the headsets and the cockpit speakers when the aircraft descends through 2500 feet on the radio altimeter.

(c) Decision Height warnings

These warnings, both aural tone and lights, are also incorporated in the LRRA system and the aural tone is the same as that used in the terrain warning. The tone sounds when the radio altimeter indicates between 75 feet above DH altitude and DH. When descending towards DH the note gradually increases in volume.

An amber DH warning light is positioned on each pilot's Attitude Director Indicator and illuminates when the radio altimeter indicates at or below the altitude at which the DH pointer is set.

(d) ILS Deviation warning lights

There are two red warning lights on each pilot's instrument panel which are operative when at least one autopilot is engaged and when either ILS or LAND mode is selected. Both illuminate if the aircraft deviates from the ILS localiser by a quarter dot or more, or from the glide-slope by one dot or more, or when 500 feet or less is indicated on the radio altimeter.

Altimeters

(a) Pressure Servo altimeters

There is a pressure servo altimeter on each pilot's instrument panel. These altimeters are of the digital pointer type in which the digital counter displays the height in hundreds and thousands of feet. Heights between each thousand are indicated by a pointer which makes one revolution of the instrument per thousand feet. There is a movable index (bug) which can be moved by hand around the periphery of the dial to indicate any height between zero and one thousand. It is impossible to reference thousands on the digital counter and therefore a height such as 5627 can only be indicated as 627 on the pointer scale. The range of the sub-scale setting is 950-1050 mbs. It would therefore be impossible to set the QFE on the altimeter when operating into a high level airfield such as Nairobi, where the QFE is normally in the order of 830-840 mbs.

(b) Low Range Radio Altimeters

There is an LRRA indicator on each pilot's instrument panel between the ADI and the pressure altimeter. A third LRRA is positioned below the pressure altimeter on the right hand instrument panel.

The LRRA pointer indicates height above ground level from 2500 feet down to zero on an expanding scale. A movable index serves as a reference for the aural and light warning systems associated with the radio altimeters.

Meteorological Information

The incident occurred in daylight about one and three quarter hours after sunrise and throughout this period the sun was shining into the flight deck through the captain's side and front windows.

The plateau immediately surrounding Nairobi Airport was covered in low stratus with a varying base and with tops which have been estimated to be about 8000 feet AMSL. Beyond the area of the low cloud the weather was clear and the aircraft was flying in visual contact with the ground from the latter part of its descent until after leaving the 'Golf Golf' beacon when it entered cloud during its final descent.

Aids to Navigation

The airport was equipped with an ILS on runway 06, a VOR station co-located with Distance Measuring Equipment, and radar. All the appropriate radio navigational aids were serviceable and in use at the time of the incident. The radar unit was not equipped with Secondary Surveillance Radar or Height Finder equipment nor could it monitor the aircraft's height on its final approach path. The DME was frequency paired with the VOR station and not the ILS.

There were two alternative approach procedures published for an ILS approach from the 'Golf Golf' beacon to runway 06. Procedure 'A' included the following warning in a printed note on the chart:

'Descent from NDB "GG" below FL 100 not authorised unless position over NDB confirmed by visual reference or radar.'

Since the aircraft's position over 'Golf Golf' was confirmed both visually and by radar it was permitted to use procedure 'A'. This procedure allows for a descent to 7500 feet AMSL after leaving the beacon and then further descent only after the glide-slope has been intercepted. The altitude over the outer marker when on the glide-slope should be 6520 feet AMSL.

The glide-slope angle of the 06 ILS was 2.75°. This angle suitably extended would intercept the vertical plane over the 'Golf Golf' beacon at an altitude of approximately 10 300 feet AMSL. This compares with the aircraft's actual altitude over the beacon of 10 347 feet AMSL (FL 100).

The company's progress log listed the minimum safe altitude for each sector of flight, and that given for the sector Nakuru direct to Nairobi was 15 200 feet. However, it is permissible for an aircraft intending to land at Nairobi to descend below this altitude if its position has been established by Nairobi radar. It can then be directed to descend in steps to FL 100 which must be maintained until passing the 'Golf Golf' beacon. The approach chart which the crew were using gave 10 200 feet as the minimum safe altitude within 23 nm of Nairobi Airport in the north-west sector.

Communications and Air Traffic Control

(a) Air Traffic Control

The aircraft first established radio contact with Nairobi Control on the radar control frequency 119.5 MHz. As there was very little other traffic it was decided to keep the aircraft on that frequency in order to give experience to a controller who was under supervision and receiving radar training. Initially the aircraft was given the normal procedural clearance to proceed to the 'Golf Golf' beacon and descend to FL 150. The aircraft was identified on radar when it was 46 nm from the airport and was given vectors to the beacon and further progressive descent clearances to FL 120 and FL 100.

At this point the supervising controller left the radar room for about four minutes in order to go to the tower. He returned after the aircraft had passed over the 'Golf Golf' NDB and had been given further descent clearance to 7500 feet, and was therefore not present when the aircraft read back this altitude incorrectly. The trainee himself did not notice the incorrect read-back. His duties required him to inform the tower controller when the aircraft had left the beacon and this he did using the internal intercom system. The aircraft was retained on the radar frequency during the approach according to normal procedure and at eight and a half nm from touchdown, was passed the surface wind and clearance to land.

The trainee radar controller carried out all the communications with the aircraft with the exception of two transmissions by the supervisor after the incident had occurred. There was no other traffic on the frequency during the approach and there appeared to be no difficulty in communications between the controller and the aircraft, apart from the misunderstanding of the clearance to 7500 feet.

Because of the flight crew's difficulty in interpreting the altitude to which they were cleared, this part of the recorded transmission was carefully examined. There is no doubt that the controller spoke the words 'SEVEN FIVE ZERO ZERO FEET'. However, certain observations could be made on the manner in which the phrase was spoken. The word 'SEVEN' was pitched at a slightly lower volume than the rest of the transmission, whereas the word 'FIVE' was stronger and received more emphasis.

(b) Company Communications Policy

On Boeing 747 aircraft, communications and the tuning of radio navigation aids are the responsibility of the two pilots. However, the flight engineer, as part of his integration into the flight crew, was expected to listen in to the radio and check the identifications of the selected aids. This the flight engineer did. He heard the descent clearance given by the controller after 'Golf Golf' and, though he found that the word 'seven' in the clearance was indistinct, he assumed the controller had said 'seven five zero zero' as this was the clearance he was expecting because it was published as part of the ILS approach procedure. For some reason, which may have been that he switched to a beacon identification, he did not hear the co-pilot's read-back.

Aerodrome and Ground Facilities

The elevation of Nairobi Airport is 5327 feet. The aerodrome lies on a fairly level plateau which is surrounded by hills. The terrain to the west-south-west of the airport is open savannah type countryside which rises gradually for about 12 nm, then quickly to the Ngong Hills, a steep ridge of high ground running approximately north and south. The ridge is about six nm long and is 8074 feet at its highest point. The 'Golf Golf' NDB is installed on top of the ridge at its northern end.

The elevation of the ground in the area where the aircraft reached its lowest point during the overshoot is about 5400 feet AMSL.

Flight Recorders

The Flight Recorder read-out showed that there was nothing abnormal in the operation of the aircraft during the approach with the exception of the height to which it was allowed to descend. Once the descent had been started after passing 'Golf Golf', the rate at which the aircraft lost height was fairly constant, averaging about 1800 feet per minute, and this was maintained until the aircraft was about 110 feet above the ground when the overshoot was commenced. The aircraft continued to descend momentarily during the overshoot and came to within about 70 feet of the ground at its lowest point.

The aircraft's Cockpit Voice Recorder operated on a 30-minute cycle and would run while there was electrical power on the aircraft. In order therefore to preserve the recording of the incident, it would have been necessary for the crew of the aircraft to have pulled the appropriate circuit breaker to stop the recording. This was not done and neither was there any legal requirement or company procedure which required this to have been done.

Medical Information

The three members of the flight crew had a rest period of approximately 24 hours before commencing duty for the flight to Nairobi. They had a good night's sleep in a hotel in Zurich the night before their departure and additionally the individual crew members had slept for varying periods, the minimum being two hours, during the day before being called for the flight at 1850 hours.

There was no medical evidence in the case of the commander and the flight engineer which could have had a bearing on the incident. The co-pilot however, was still suffering from the effects of a bowel infection which he initially contracted over a month before the incident. He had lost nearly a stone in weight and according to the commander looked pale when he reported for duty in London.

(a) The Co-Pilot's Illness

The co-pilot became ill with a stomach disorder in New Delhi on 29 July, 1974, and after feeling very ill and feverish for about two days, during which time he received medical treatment, he returned as a passenger to London. In London he reported to the company's doctor and, after stating that he felt much better, was declared fit on 1 August. On 2 August he flew to New York and again experienced a stomach upset which however, was much milder and did not incapacitate him. He subsequently operated a week-long trip to Johannesburg, followed by another Atlantic crossing and felt fit although still suffering from a low grade gastro-enteritis. He then began to feel very lethargic with a tendency to sleep longer than normal and so, realising that he needed further medical assistance, he consulted his own private doctor on 28 August. He was prescribed some medicine in tablet form for the treatment of his illness but nothing was said to suggest that he should not fly. In any case he was, at this time, expecting to have a number of days off before being required to fly again. He completed a training detail in the company's Boeing 747 simulator on 30 August and although he still felt tired, his performance was satisfactory.

The co-pilot took one of the tablets prescribed by his doctor in Zurich on the morning of 2 September but could not remember whether he took another one just prior to the incident flight.

On returning to London after the incident at Nairobi the co-pilot was examined by the company doctor. The cause of the disorder was diagnosed as Oiardia, a tropical infection, and the co-pilot was taken off flying duties while he received further medical treatment.

(b) Medical Treatment

The opinion of the Civil Aviation Authority's Medical Branch was sought on the effects that the medicine which was being taken by the co-pilot might have had on his performance.

The preparation used was Lomotil, a drug which is commonly used in the treatment of mild diarrhoea. The drug has side effects which vary widely in their nature and magnitude and which has been quoted as including depression of the central nervous system, slow respiration, drowsiness, insomnia, dizziness, restlessness, euphoria, and nausea.

The drug has been used widely in aviation and has been prescribed for astronauts on space missions. Opinion varies on its usebutthe Royal Air Force has apparently had no problems with it. The Federal Aviation Administration in the United States however, suggests that 'airman duties are contra-indicated for 24 hours' after its use.

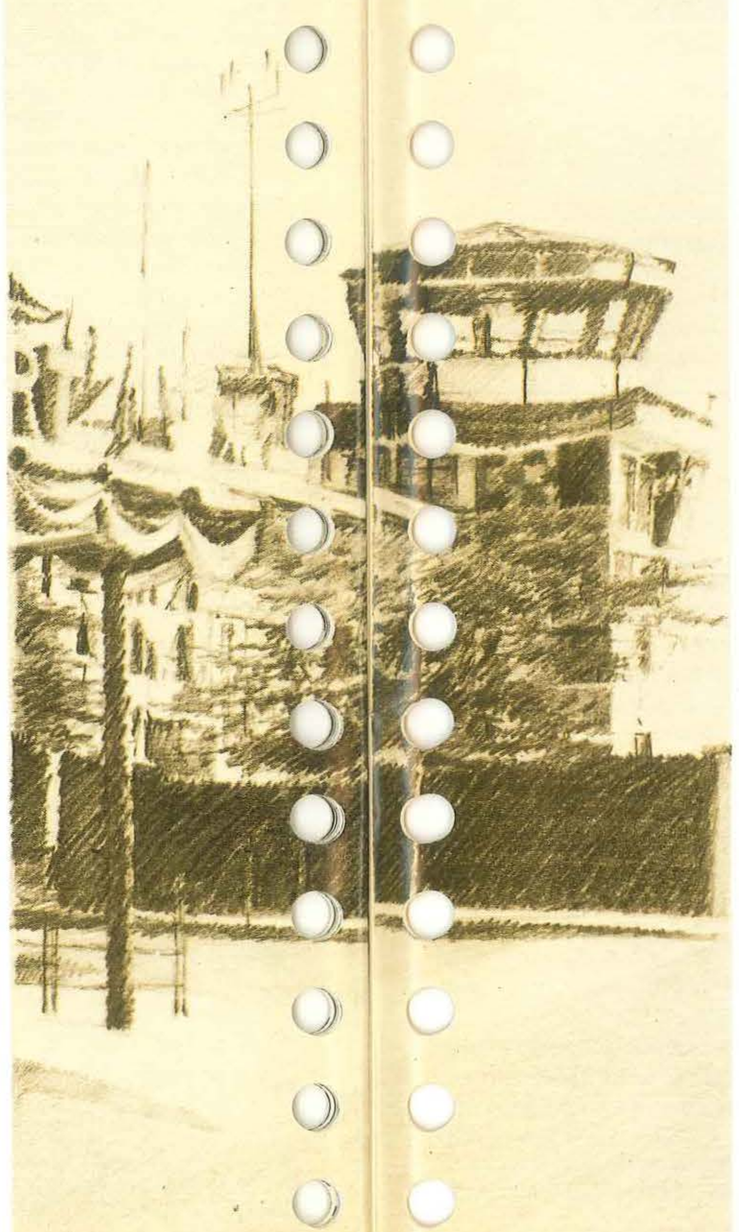
It was the opinion of the Civil Aviation Authority's doctors that the medicine could have affected the co-pilot's alertness and that the combination of this and the effects of his debilitating illness and the physiological state of low arousal which normally exists at the time of the day when the incident occurred, could have resulted in a level of performance well below his normal. This opinion was shared by the company doctor who examined him on his return to London.

Tests and Research

(a) Simulator tests

A test programme was carried out in the company's Boeing 747 simulator to try to evaluate the circumstances of the incident. The simulator tests confirmed that there was a high level of flight deck activity during the approach, especially in the period immediately following the receipt of the descent clearance. It was shown that there was a peak in the work load of both pilots at this time and that very little delay could be tolerated in starting the descent if the aircraft was to remain ideally below the glide-slope. The approach checks took on average about one minute to perform even with no delays or interruptions and during this time the flight engineer's attention was diverted from the operation of the aircraft.

Although the automatic pilot was flying the aircraft, a high degree of concentration was still required to supervise its progress and monitor the correct operation of the automatic systems such as the localiser capture and the acquisition of the selected altitude. This particularly applied



in the case of the commander who, in addition to regulating the rate of descent and monitoring the decaying airspeed, also made the requisite selections for programming the system for an autoland. There appeared to be little time for referring to the aerodrome approach chart and cross checking the approach procedure against ATC clearances. There were no conspicuous clues or warnings during the approach to alert the crew to the fact that they had mis-set the Altitude Selector and had passed through both the correct procedure altitude (7500 feet) and the outer marker altitude (6520 feet).

The tests showed that when the aircraft was approaching ground level, the illumination of the ILS deviation lights, and the audio warnings from the altitude alerting system and the radio altimeter decision height, followed one another in rapid succession. A confusing situation developed which would have been difficult to analyse by somebody who was unaware of the danger of his position.

Other approaches were made during the test programme in which the initial speed was reduced and stabilised with the flaps lowered and approach checks commenced before reaching the 'Golf Golf' beacon. This served to reduce the peak load which occurred at the start of the final descent and generally gave the crew more time in which to carry out their duties. The simulator programme however, revealed nothing that would have prevented a satisfactory approach from being completed if the correct procedure had been followed.

(b) Recommended speeds

In the company's Flying Manual, the following advice is given as regards the speeds that should be flown during the descent and approach phases:

With the flap at zero, one or five, the quoted minima of V_{REF}+80, 60 or 40 are comfortable speeds to maintain; minima for flap 10 and 20, i.e. V_{REF}+20 and V_{REF}+10, are both well below Vmd and, although safe in terms of stall margin, they are uncomfortable speeds. For the intermediate approach procedures a speed of V_{REF}+30 is recommended for both configurations.'

At the time of the incident the V_{REF} for the aircraft's weight was 134 knots IAS.

Consequently, the recommended speed during the intermediate approach phase after 10 degrees of flap had been selected was 164 knots IAS.

ANALYSIS

This was a very serious incident which only avoided becoming a major catastrophe by the narrowest of margins. Superficially, the incident occurred simply because both pilots misheard an ATC instruction to descend to 7500 feet. In all probability, had they not done so, the approach and landing would have been a well planned and well executed manoeuvre involving the minimum wastage of time and fuel; or at least would have appeared so. But on closer examination it is apparent that there was present a number of inter-related factors, involving environmental conditions, sickness, operational procedures and flight deck management, which made it highly likely that the crew would not be alert to errors made by themselves or others.

Obviously the central question is why the mistake over the clearance was not noticed in good time by the crew or the ATC. This aspect will be fully explored later, but first, an attempt is made to establish the reason for the error itself.

Air Traffic Control

The way in which the clearance was given, that is 'DESCEND SEVEN FIVE ZERO ZERO FEET' was quite correct and wholly in accordance with international procedures. Probably the pilot's hearing of the clearance as 'five zero zero zero feet' was because the word 'seven' was apparently received so indistinctly as to be unheard and the word 'five' appeared to be given greater emphasis. By concentrating on the number of zeroes being given in the clearance, the pilots obviously overlooked the first figure. The fact that the co-pilot's read-back was unchallenged by the ATC may well have submerged any subconscious doubts that he may have had about the correctness of it.

According to the ICAO Annex 10 Volume 2, the controller's instruction to the aircraft to descend was one for which a read-back was required. This implies that the controller should therefore have listened for the read-back and challenged it when he heard that it was incorrect. Equally the pilots should have also requested an acknowledgement if they were in any doubt. It is self-evident that, had the controller picked up the incorrect read-back, the incident would not have happened, but his failure to do so cannot be explained solely on the grounds that he was under training. He was, in fact, a fully qualified air traffic controller who was simply being checked out in that particular position. The most probable reason for his failure to pick up the incorrect read-back was that at the time, he was talking to the tower on the internal intercom to report that the aircraft had left the 'Golf Golf' beacon. Also, as the read-back was spoken confidently and without hesitation, there was nothing in the co-pilot's tone of voice to alert the controller that there was any doubt about the clearance.

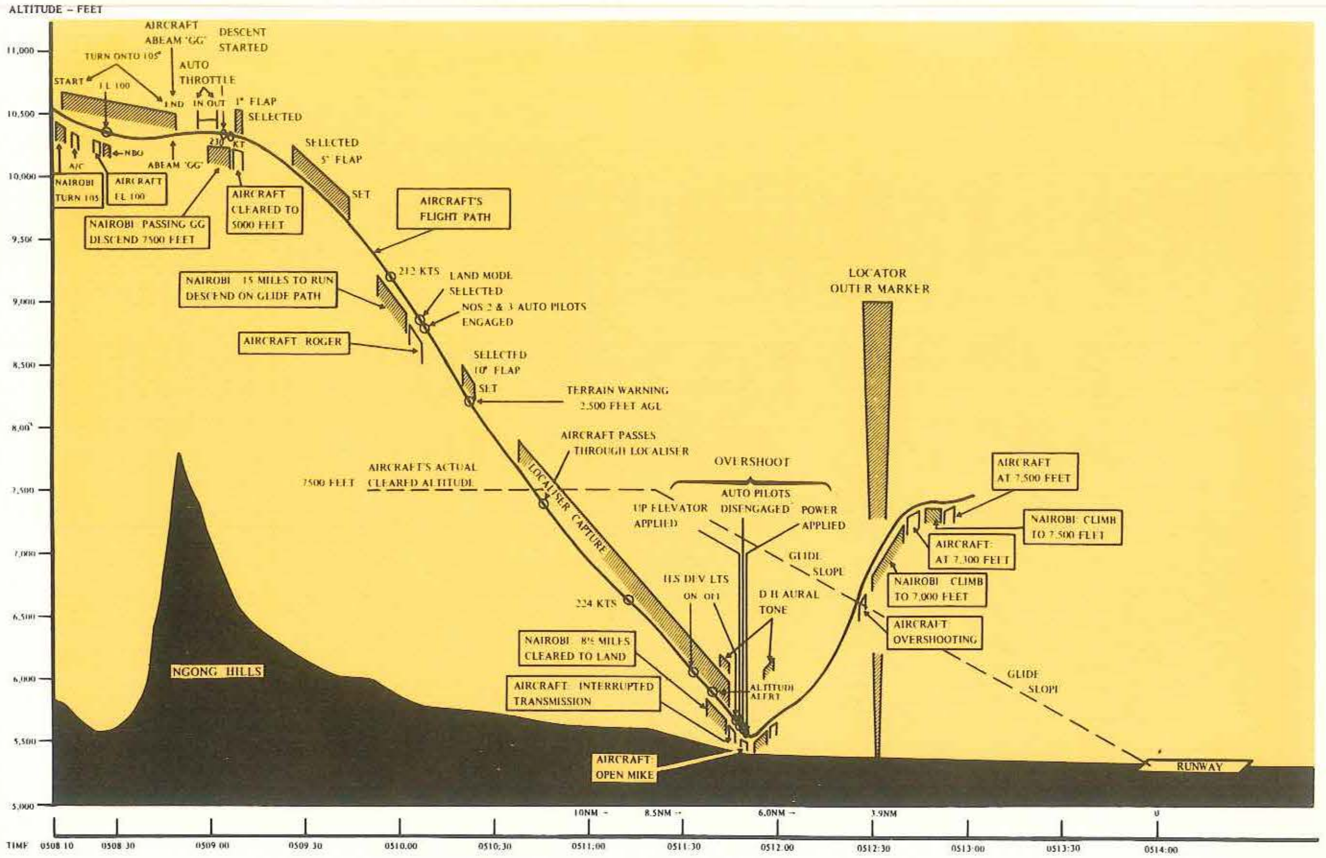
Terrain awareness

The reason why the pilots saw nothing wrong with a supposed clearance to descend to 5000 feet in the Nairobi area is more difficult to determine. Presumably they both believed that the aircraft had been cleared to descend to 5000 feet above ground level. This could possibly have been because they momentarily overlooked that Nairobi is not a sea level airfield.

This possibility would have been considerably lessened, as would any possible confusion over altitude clearances, had the crew been provided with log sheets on which to record QNH and other ATC instructions in a way that would enable a direct comparison to be made with airfield elevation and local safety heights.

Environmental factors affecting the crew

By the time of the incident, the crew had been on duty for nine hours during what was



Diagrammatic reconstruction of aircraft's approach to Nairobi Airport based on flight data recorder and ATC transcripts.

otherwise their normal sleep period. Moreover, at 0500 hours their biochemical, physiological and psychological functions would have been at their lowest point on the normal circadian rhythmic cycle. Thus each of them would have been in a lower state of arousal than normal and therefore less likely to notice errors, particularly if made by one of themselves.

In the case of the co-pilot, there were additional factors which undoubtedly would have affected his overall performance, foremost among which was his state of health. It seems clear that he was more affected by his bowel infection than he himself realised which, coupled with the medication he was taking, most probably lowered his general level of alertness and his ability to assimilate the normal amount of information. There is no doubt that the co-pilot should not have been flying in this condition, but the reason for his doing so can be appreciated. Not only did he believe that the infection was clearing up, but also he had been given no indication by his local doctor that he should not fly. When he was called out at the last moment over the weekend for the flight, which he was keen to make, he did not consider it necessary to let the company know that he had been prescribed medication for his condition. It has since transpired that the drug he was using can have side effects, which the United States Federal Aviation Administration, for one, consider incompatible with flying duties.

Last but by no means least was the co-pilot's relationship with the commander as an additional stress factor. They had not flown together before, and the co-pilot would therefore have been keen to make a good impression, particularly in view of the commander's considerable seniority. As a consequence of this, it is likely that the co-pilot tried to convey the appearance of alertness by carrying out his duties briskly, but due to his physical condition did so without much thought as to the implications of what he was doing.

From the foregoing therefore, it is reasonable to deduce that the physical and mental state of the crew was such as to make them prone to error, especially when faced with a sudden demand for activity after a longer period in a state of relatively low arousal. This would have been particularly so in the case of the co-pilot.

Crew Activity

The clearance to descend from FL 100 appears to have triggered off a period of intense activity by all three crew members, who were left with a considerable amount to do in the time available. The result of this was that each crew member became wholly absorbed in his own task to the exclusion of all else. The flight engineer was engaged in reading out the approach check list, which not only occupied him for well over a minute, but also required him to turn away from the pilots' panels in order to attend to his own. The co-pilot also participated in the approach check as well as monitoring the extension of the flaps and talking to ATC. It was also at about this time that he inserted 5000 in the Altitude Selector. The commander appears to have been mainly pre-occupied with initiating the descent. It therefore seems likely that he reacted as soon as he heard the word 'Descend . . . . .' and did not pay the same regard to the second part of the clearance. A further indication of the extent to which each crew member was occupied with his own tasks was when, a short while later, the commander found it necessary to tune the No.2 VHF Navigation Receiver to the ILS frequency himself, which he needed to do in order to engage Nos. 2 and 3 autopilots. Similarly the flight engineer states that he had repeatedly to request the pilots to check their altimeter settings.

Aircraft Speed

The unusually high work load of the crew after the aircraft had passed the 'Golf Golf' NDB was undoubtedly related to the speed of the aircraft during the descent from FL 100. This seems to have been unnecessarily high and considerably above the recommended speeds appropriate to each flap setting (though not, it should be said, in excess of the relevant limitations). The speed could in fact have been reduced progressively to 164 knots as the flap was lowered in stages to 10 degrees but in fact the commander never allowed it to fall below 210 knots IAS and most of the time it was higher than that. This resulted in the crew having considerably less time than they might otherwise have had for preparing the aircraft for the approach and monitoring the progress of the flight.

In view of the deteriorating weather conditions that were reported by the pilot of a preceding aircraft, it might have been expected that the commander would have considered it prudent to have slowed the aircraft down and perhaps have started the approach check before reaching 'Golf Golf'. Admittedly this check would not have progressed beyond the altimeter check whilst the aircraft was still above FL 100, but at least it would have spread the work load and given the crew more time to monitor the progress of the flight after the aircraft had passed 'Golf Golf'. As it was, the commander allowed the speed to build to as high as 338 knots when the aircraft levelled off at FL 120, so that when the aircraft reached 'Golf Golf' at FL 100, he had only managed to reduce the speed to 235 knots. He then had to initiate the descent immediately at a fairly high rate, thus making any further speed reduction more difficult to achieve.

The commander's decision to keep the speed higher than desirable appears to have been based on commercial considerations as it appeared to him that by so doing, the aircraft would arrive at Nairobi on or within five minutes of the scheduled time. It is not uncommon practice for commercial or ATC reasons for the speed to be kept close to the maximum for small flap extensions during the initial and intermediate approach phases. There can of course, be no objection to this, provided that the consequences in terms of increased workload on the flight deck are appreciated.

Monitoring procedures

The main reason why the commander did not properly evaluate the supposed clearance to 5000 feet seems to have been because he was attempting to do too much himself. He appears to have placed too much reliance on the system of monitoring used by the company, not realising that this system had in fact ceased to function during a period of increased crew activity. If any of the crew gave any thought as to who was monitoring the flight after it had passed the 'Golf Golf' beacon, it can only be supposed that each thought the other was. The disturbing conclusion to be drawn from this is that there could well be other occasions when, without the crew realising it, no monitoring takes place.

The company lays great stress on monitoring and has gone to considerable lengths to ensure that its B747 pilots and flight engineers operate as integrated crews. It must therefore be of some concern that the system of monitoring allowed a comparatively simple error to remain undetected whilst the crew was under pressure, especially as that pressure was neither exceptional nor sustained.

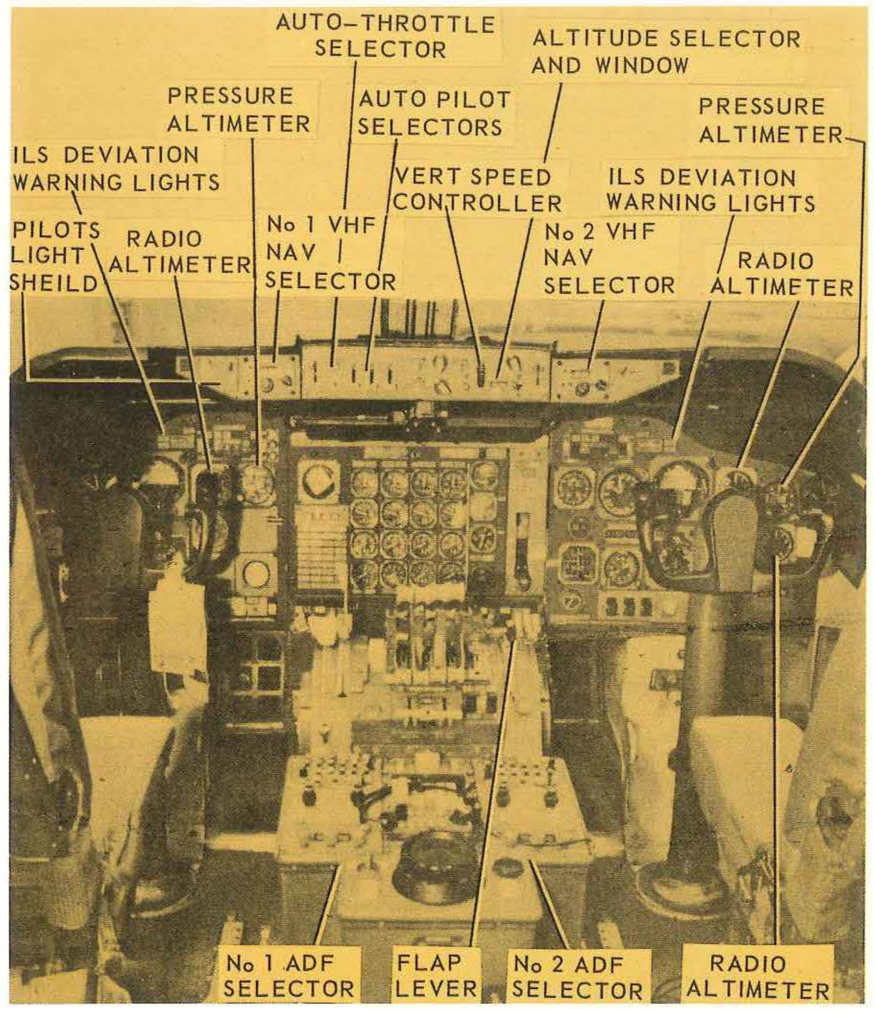
In the light of this incident, it would seem therefore that re-examination by the company of its monitoring procedures is called for, particularly to ascertain if any measures can be taken that would enable the commander to devote more of his attention to his overall supervision of the flight during an approach in instrument conditions.

The company's decision, made since the incident, to introduce a procedure for monitoring all changes of setting to the Altitude Selector will obviously go a long way towards preventing a recurrence of this type of incident.

Failure of the crew to respond to warnings and other indications

The greater part of this analysis has of necessity been concerned with examining the possible reasons for the clearance being misheard and why it was not noticed by the crew. It is also necessary to examine why, once the error was made, various warnings and other indications did not alert them to the fact that the

Pilot's instrument panel showing instruments and controls referred to in text.



aircraft had been programmed to descend into the ground.

Firstly it is necessary to appreciate that most probably both pilots were utterly convinced of the correctness of their actions thus far. Their conviction was quite unshaken by the terrain audio warning which occurred at 2500 feet above the ground (i.e. at an indicated altitude of 8200 feet) and they did not in any way relate this warning to the intermediate approach altitude of 7500 feet given on the approach chart and which they must have discussed at the top of the descent. It transpires that this warning makes comparatively little impact on crews, because it occurs on each approach at least once. In particular it appears to have little significance when it is heard at the time it is expected, as happened on this occasion. It is thus understandable why no action was taken when the warning sounded. However, from this point on, the radio altimeters were indicating, but only the flight engineer appears to have paid them any attention. He states that though he was concerned by the aircraft's apparent deviation from its expected flight path, he could not see the reason for it. Subconsciously, he was probably trying to relate the inconsistency of the aircraft's low altitude with the fact that the landing check had not been carried out and that the aircraft was not on the glide-slope. His inability to understand what was happening was probably due to his having been out of the monitoring loop for a period of a minute or more whilst he was reading out the approach check. He was probably reluctant to communicate his unease to the commander when he suspected that it may have been himself that was wrong and not the pilots. He clearly thought it best to say nothing until he had re-orientated himself to the approach.

The next two warnings came within two seconds of each other, namely the ILS deviation lights and the altitude alert. Also coincident with these warnings was a call from ATC clearing the aircraft to land. At this stage the aircraft was descending through 500 feet above the ground and it was also at this point that the flight engineer advised the commander that there was no glide-slope and received the commander's denial of this.

The altitude alert does not indicate proximity to the ground but only that the aircraft is approaching the selected altitude, which in this case was 5000 feet. As both pilots were convinced that there was nothing wrong with descending to 5000 feet, although it was in fact 327 feet below airport elevation, the warning that the aircraft was approaching that altitude clearly had no implications of danger for them. The pressure altimeter bug was similarly of no value, even though it had been set to the minimum decision height, as it can only be set to between 0 and 999 feet.

The ILS deviation lights illuminate when the aircraft is displaced from the localiser or glideslope and when it is below 500 feet above the ground, though terrain warning is not their function. The pilots' immediate reaction to the illumination of the ILS deviation lights was that it was a false warning. This was doubtless because it did not conform to what they believed the aircraft to be doing at this stage, namely, descending to the intermediate approach altitude. The co-pilot's reaction may well have been conditioned not only by the fact that there was very little time in which to determine the reason for the warning, but also because he had only once before seen the lights operate and that was at a very late stage in the approach during a simulator detail in circumstances totally different to that of the incident.

From the foregoing it can be seen that the reason why the crew apparently ignored the three indications of the aircraft's close proximity to the ground was because only one of these specifically related to aircraft height, namely the terrain warning at 2500 feet AGL, and that this occurred when it was expected. The other two were not primarily intended to warn when the aircraft was coming close to the ground and therefore did not cause the crew any undue concern. When the Minimum Decision Height warning sounded at 270 feet AGL, the flight engineer seemed to be the first to realise what was happening, probably because he had just previously been alerted by the operation of the ILS deviation lights. He immediately responded by calling that the aircraft was at a low altitude. Even then, it was only when the aircraft broke cloud that the commander at last appreciated the aircraft's danger and took overshoot action.

The investigation would have been considerably aided had the CVR recording for the period of the incident not been subsequently lost due to the recorder being erased during the normal shutdown procedure after the aircraft had landed. It is considered that every effort should be made to encourage crews when practicable, to pull the CVR circuit breaker as soon as possible after an incident or accident when the aircraft is on the ground, so that essential evidence may be preserved.

The incident first came to light because the commander reported it immediately. This was clearly a highly responsible action on his part and one which he took without thought of the possible consequences to himself. It is, of course, impossible to predict what effect the action taken against the crew will have on the future of incident reporting by flight crews, but it would seem likely that it may well be discouraging.

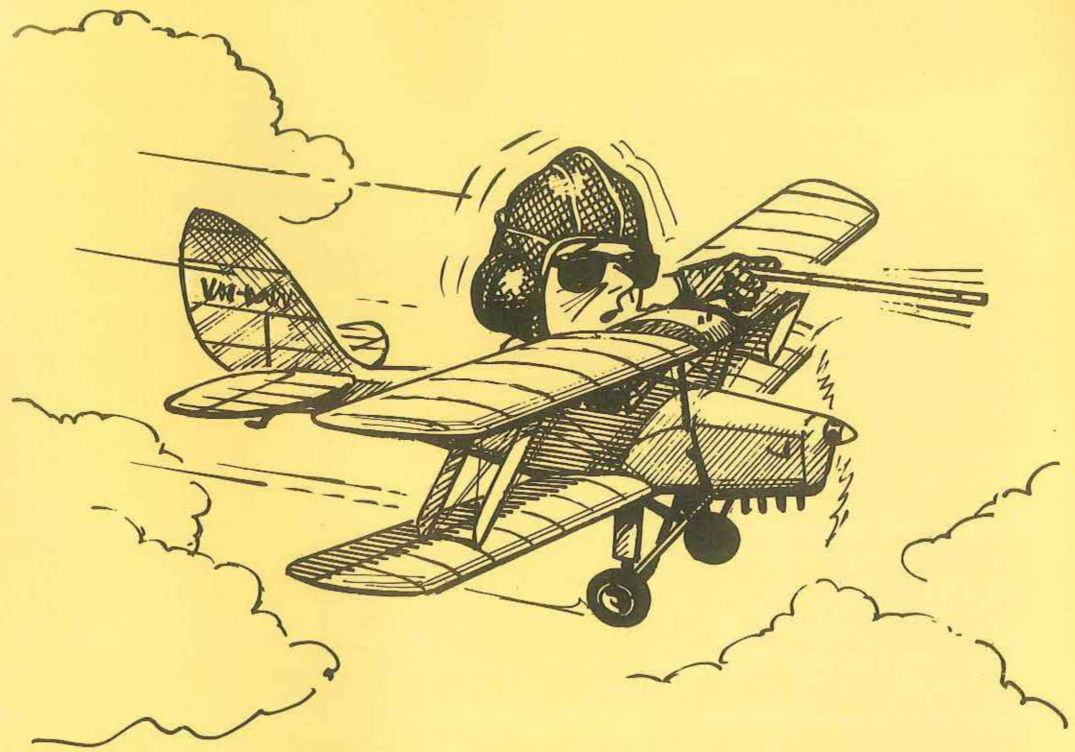
CAUSE

The incident was caused by the pilots' acceptance of a height to which they mistakenly believed the aircraft had been cleared by ATC to descend and which was below the level of the surrounding terrain. Contributory factors were: The failure of the ATC controller to challenge the incorrect read-back of the descent clearance by the co-pilot; inadequate crew monitoring; the relatively high speed of the aircraft's approach; the crew's low arousal state and the ill health of the co-pilot.

FLYING BLIND?

Be careful with photochromic glasses

A pilot, wearing anti-glare spectacles, was flying towards the setting sun above a cloud layer. After making an instrument descent through cloud approaching his destination, he found the light intensity to be much lower than he expected. He experienced some difficulty in seeing, but because his radio earpiece was attached to the spectacle frame and he had to maintain radio contact, he did not have time to take the spectacles off. As a result, his landing was well below standard.



The lenses of the glasses this pilot was wearing were 'photochromic'. There are two main varieties of these lenses, one being darker in appearance than the other, but both have a variable tint which changes with the amount of sunlight available. Photochromic lenses are now used in about one-fifth of prescription spectacles, as well as for non-prescription anti-glare or sunglasses.

The 'automatic' change of tint of photochromic lenses in response to light is brought about by micro-crystals of silver halides locked in the glass. The ultra-violet content of sunlight darkens the halides but — unlike a photographic film — the process is reversible. Thus, when the level of light is reduced, the silver halides tend to become colourless again and the tint becomes lighter.

Photochromic lenses in both sunglasses and prescription glasses are claimed to have certain advantages. There is the convenience of having a tint which varies with the ambient light, and a person who has to wear prescription glasses is able to save the cost of buying a second pair with tinted lenses.

Unfortunately however, photochromic lenses also have serious drawbacks for flying or driving. To protect the eyes from glare, a tinted lens should transmit no more than 25 per cent of visible light, but a number of photochromic lenses cannot achieve this figure. As well, the cockpits of many aircraft and the interiors of many motor vehicles are well shaded, and this, together with the ultra-violet filtration effect of the windscreen, may not allow sufficient light penetration to activate the photochromic effect.

When exposed to a brighter or dimmer light, the change in the tint of photochromic lenses is far from rapid. Under test conditions, lenses removed from sunlight may be only 50 per cent clear in five minutes, and 75 per cent clear after 20 minutes. And even after hours in darkness, the lenses may never achieve more than 80 per cent clarity. In some varieties of lens, the tint is not intended to clear beyond a certain density.

The human eye can maintain a constant acuity of vision over a wide range of light intensities. But below a certain level — about moderate room illumination — visual acuity falls steeply with reduced light. Also, any transparency placed between the eyes and the object being looked at, has the effect of reducing the effective illumination in proportion to its optical density.

For these reasons, any material of reduced transparency, such as sunglasses or a tinted windscreen, between the pilot and the exterior of the aircraft, will reduce his visual performance somewhat in cloud, and significantly more at dusk or at night.

Thus, a pilot who has been wearing photochromic glasses in sunlight will find his vision impaired if he flies into cloud or deteriorating weather, because the external light intensity will fall much faster than his lenses can clear. At dusk, too, the light intensity from the sky diminishes faster than the lenses can recover. The pilot who wears prescription photochromic lenses at night, believing that they are truly clear, is also at a visual disadvantage, though he may not realise it.

Pilots buying anti-glare glasses, whether prescription or not, should ensure that their lenses are of non-polarising material and the tint dark and neutral. If a pilot uses a headset for flying, he should wear it while trying on the glasses to ensure a match and avoid discomfort.

In the case of pilots who insist on having photochromic glasses, the lenses should be of the dark variety. But as with sunglasses of any kind, they should not be worn at night or in conditions of reduced illumination, such as at dusk, or on heavily overcast days or in cloud. In fact, for all practical purposes, anti-glare spectacles should be used only in bright sunlight.

For pilots who need to wear prescription glasses, the best solution to the problem is to have a clear set, and if so desired, a second set with an anti-glare tint.