# Workload in the Glass Cockpit

## *Increasing sophistication in electronic flight instrumentation and systems has redefined the role of the pilot.*

*by*
*Alan H. Roscoe, M.D.*
*Aviation Medical Consultant*
*Britannia Airways*

Increasing use of automation in the cockpit has resulted in much publicity about the changing role of the pilot, underscoring the fact that he is becoming more of a manager, or supervisor, than an active controller of an aircraft. However, his basic goal has remained the same: to fly an aircraft safely from point A to point B. It is only the way in which he carries out that role that has changed.

This change has become substantially greater since the introduction in the early 1980s of a new generation of aircraft equipped with sophisticated flight management systems, electronics displays and improved autopilots. A flight deck equipped with these systems is referred to as the "glass cockpit" because of the extensive replacement of single-function dials and gauges with multi-function cathode ray tube (CRT) displays. The integrated systems and displays were designed to improve performance and to reduce workload. In the case of newer wide-body aircraft, an additional objective was to reduce the flight deck crew from three crew members to two pilots, an objective that was reached in 1981 after considerable controversy.

The proposed introduction of the glass cockpit had stimulated considerable interest among human factors experts regarding the way in which a pilot performs his tasks, as well as several related issues. [1,2] One of the issues is pilot workload. It was argued that although workload in the glass cockpit might be different, it would not necessarily be less, and that it might even be increased — particularly during traditionally high workload phases of flight. The concern was expressed, sometimes strongly, that workload in new technology aircraft might be greater than expected by aircraft and systems manufacturers, and that it might become too great for safe operation by two pilots.

More realistically, the possible effects on performance by changes in the nature of workload in the glass cockpit, rather than the level, became an important issue. In 1971, it had been shown that in practice, the introduction of automation would not necessarily reduce workload, because if doubts existed about the reliability of the system, increased monitoring would minimize the expected benefit. [3] Moreover, it has been shown by many researchers that man is not a good monitor, as Beaty pointed out in "Monitoring Brings the Demise of Vigilance."[4] It was also suspected that the different workload components might have some influence on crew coordination.[2]

The theoretical advantages and disadvantages of flight decks fitted with sophisticated, computer-controlled automatic systems have been discussed by several authors, but it should be noted that much of the experimental data on which many opinions have been based was derived solely from laboratory studies. Extrapolation from data obtained in the laboratory to the operational world can sometimes be misleading. It is essential that such data are complemented by data obtained from the real world. In this respect, a field study involving only a small number of subjects is often of more value than a large-scale experiment carried out in the laboratory — especially if the findings are consistent with operational experience.

This discussion considers three aspects of workload in the glass cockpit: workload in normal operations, workload in abnormal operations and the relationship between workload and fatigue.

## Using the Glass Cockpit In Airline Service

Some of the advantages of new technology flight decks were demonstrated in a Britannia Airways study that began in 1984; it was designed to compare levels of workload experienced during routine passenger flights in the newly introduced Boeing 767 with those experienced in the older Boeing 737-200 — an accepted two-pilot airplane.[5,6] Workload was assessed by means of a specially designed, 10-point rating scale — the Bedford Scale[7] — augmented by recording the pilot's heart rate. An experienced observer, seated in the cockpit, recorded details of the flight and also rated the workload using the same scale. During the first phase of the study, 12 pilots were monitored in the 737 and then, after conversion and some experience in type, in the 767. A particularly effective comparison of workload levels was provided by two management pilots who alternated every six months between the two aircraft types. Data were recorded primarily during high-workload phases of flight — such as the takeoff and initial climb, and the approach and landing. Data were also recorded on a random basis at less demanding times.

Results from a total of 73 flight sectors strongly supported numerous anecdotal reports from company pilots that levels of workload in the 767 are almost always noticeably lower than in the 737. The advantages of a flight director integrated with the flight management system can be seen in the typical workload ratings and heart rate responses (shown in Figure 1) for hand-flown flight director approaches and landings in both aircraft by the same pilot.

**Graphic Unavailable**

**Figure 1**

Comparison of beat-to-beat heart rate responses and workload ratings (WLR) for hand-flown flight director approaches and landings. Boeing 737 and 767.

Most of the data have been recorded from the pilot flying (PF), but some have been obtained from the pilot not flying (PNF) to examine the distribution of workload. It was observed that the workload of the PNF can be increased by the automation that reduces the workload for the PF. For instance, a hand-flown flight director standard instrument departure (SID) in the 767 generates a lower workload for the PF than in the 737, but the workload for the PNF is increased by requirements to make frequent selections to the flight director system.

These findings have been reinforced by results from an extension of the main study in which five 767 first officers rated their workloads during departures and during approaches and landings, both as PF and as PNF, during periods of two or three months (Table 1).

**Table 1**

| | Departures | | Arrivals | |
|---|---|---|---|---|
| | Mean | Range | Mean | Range |
| PF (n =127) | 3.20 | 2-6 | 3.44 | 2-5 |
| PNF (n =132) | 3.36 | 2-5.5 | 3.22 | 2-6 |

(n = number of instances recorded)

The main ratings agree with those recorded during the main study. Twelve high individual ratings of 5 (n=6), 5.5 (n=3) and 6 (n=3) appear, from the pilots' comments, to indicate periods of high workload caused partly by relative lack of total experience.

In view of conflicting comments about the automated cockpit and workload, and, in particular, the findings of a much-cited U.S. National Aeronautics and Space Administration (NASA) field study [8,9] that automation failed to reduce the workload for about half the Boeing 757 pilots involved, it was decided to conduct a further study within Britannia. This consisted of one-on-one interviews with 37 Boeing 767 pilots (22 captains and 15 first officers), who had been flying the aircraft for a year or more, to assess the effect upon workload of experience on type. Thirty two pilots readily admitted that on converting to the aircraft from the 737-200 they found the workload often to be higher than in the 737, especially just prior to and during the departure, but occasionally at other times as well. After approximately six months in the 767, it was unusual for the pilots to experience greater levels of workload; in most cases they were appreciably lower than those experienced previously in the 737.

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Most of the captains who were interviewed confessed to having some difficulty during the 767 conversion, whereas the younger first officers had little trouble. However, once on the line there was no clear difference in their workload — presumably, the much greater overall piloting experience of the captains compensated for their slower progress in adapting to the glass cockpit.

As retrospective studies tend to be vulnerable to distorted recall, a prospective study is now in progress in which, using the Bedford Scale, workload ratings are given for departures and arrivals (and for any other high workload event) during the first six weeks following conversion from the 737 to the 767 or 757, and again for a similar period after six months experience in type.

In comparing workload between old and new aircraft types, it is worth noting the substantial anecdotal evidence from first officers reconverting to the 737 after being promoted to the left seat. (One-on-one interviews with 12 pilots provided more detailed evidence.) They report having more difficulty with instrument scan, speed control and situational awareness, and that their overall workload is much greater. Although reducing with time, it remains consistently greater than in the 767.

The different conclusions reached in the NASA study, [9] and in the airline study are worth considering. The NASA study, in which questionnaires were used to obtain the views of 757 pilots, determined that more than 90 percent of pilots considered the glass cockpit displays to be " ... a big step forward." However, approximately half of the pilots reported that the automation did not reduce their workload, and might have increased it. The involved aircraft have virtually identical cockpits, and many airlines operate both types with a common pilot rating. Britannia operates both aircraft, and early reports from pilots suggest little, if any, difference in workload. Different training methods or operating procedures are also unlikely to result in such contradictory findings.

In the NASA study, pilots were asked to state their degree of agreement or disagreement with a number of statements on a five-point scale. A possible explanation is the form of the relevant statement on workload: "Automation does not reduce total workload since there is more to monitor now." It is usually accepted that such a leading statement would bias the answer. And it might be inferred from the statement that the monitoring component of workload equates with other components — like manual control. This is not necessarily so, because evidence from the airline study suggests strongly that monitoring performance can be maintained at an adequate level with a lower workload than that associated with manual flight; ratings for example, averaging less than 2.5 for autolands compared with around 3.5 for hand-flown approaches and landings.

Another explanation may be worth considering. Two peaks in the responses for those pilots who agreed and those who disagreed occur in the NASA data on workload and they indicate two groups of pilots having different characteristics — in personalities or in natural abilities. Changes in the characteristics of pilots during the last few years have been noted by several experienced observers.[10]

## Operating in the Glass Cockpit During Abnormal Situations

In the mid-1980s there was growing concern that, in glass cockpit aircraft, the increased workload generated by abnormal operations and flight emergencies might become too great for two pilots. (These views were later reinforced following the accident in January 1989 with the Boeing 737-400 at Kegworth, United Kingdom, where confusion about proper identification of a failed engine contributed to an accident.)

In 1987, in response to this concern, a second phase of the airline study was started with the aim of assessing workload during abnormal operations using a 767 simulator.[11] The suitability of the simulator was demonstrated by obtaining similar workload ratings and heart rate responses from pilots flying normal departures and arrivals in both aircraft and the simulator. During this phase, volunteer 767 pilots, captains and first officers, were monitored during a wide range of emergencies both as PF and PNF. Abnormal flight conditions included engine failures and fires, various systems failures, pilot incapacitation and windshear (two or three normal flight conditions are included in each simulator session). Figure 2 shows heart rate responses and workload ratings for an engine fire shortly after takeoff, followed by a single-engine missed approach, and then a single-engine landing. (These data may be compared with those in Figure 1 for the same pilot).

**Graphic Unavailable**

**Figure 2**

Engine fire on takeoff (F), single-engine missed approach (M/A), and single-engine approach and landing.

A shortage of simulator time has delayed the completion of this part of the study, but sufficient data, from seven pilots, have been recorded to demonstrate that it is extremely unlikely that workload during emergencies would exceed the capabilities of two well-trained pilots following well-designed procedures and exercising good cockpit discipline. Consider this comment made in the U.K. Air Accidents Investigation Branch (AAIB) report on the Kegworth accident: "The performance of flight crew in emergency situations may be regarded as a product of their natural ability and their training."[12]

Table 2 shows the ranges of workload ratings for several different flight conditions.

**Table 2**

| **Boeing 767 Flight Condition** | | **Workload Ratings** | | |
|---|---|---|---|---|
| | | **Overall** | **Peak** | **Number of instances** |
| Normal instrument departure | PF | 2 1/2 - 3 | 3 - 4 | 9 |
| | PNF | 2 1/2 | 3 - 3 1/2 | 4 |
| Rejected takeoff | PF | 4 - 5 1/2 | 4 1/2 - 6 1/2 | 6 |
| | PNF | 2 1/2 - 3 | 2 1/2 - 3 1/2 | 3 |
| Engine fire during takeoff | PF | 3 1/2 - 5 1/2 | 4 - 5 1/2 | 6 |
| | PNF | 4 - 5 1/2 | 4 - 6 1/2 | 5 |
| Windshear during takeoff | PF | 3 - 4 1/2 | 3 1/2 - 6 | 4 |
| | PNF | 2 1/2 - 3 | 2 1/2- 3 1/2 | 2 |
| Normal approach and landing | PF | 3 - 3 1/2 | 3 1/2 - 4 1/2 | 8 |
| | PNF | 2 1/2 - 3 | 2 1/2 - 3 1/2 | 4 |
| Single-engine approach | PF | 4 - 4 1/2 | 5 - 7 | 4 |
| Landing in severe turbulence | PNF | 3 1/2 - 4 1/2 | 4 - 4 1/2 | 3 |

As can be seen in the table, the workload of the PNF can sometimes be greater than that of the PF. This change is particularly evident during such emergencies as an engine failure when automation can reduce the workload of the PF significantly, while increasing that of the PNF because of the number of items to be addressed. In an emergency, the captain may elect to take control so that, with a lower level of workload than that of the PNF, he would have more time for appropriate decision making.

It has frequently been suggested that a simulator does not reproduce all the elements of real flight — especially the element of risk. It could, therefore, be argued that responses to simulated emergencies might not be typical of those experienced in real flight. However, it has been shown in a number of studies that increased risk and the presence of danger do not normally influence heart rate in experienced pilots during real flight.[13] In simulated flight, heart rate responses and workload ratings appear to depend very largely on the realism of the simulator and the flight scenarios. The data recorded so far appear to be realistic because they seem to agree with what might be expected in the aircraft.

## The Glass Cockpit and Pilot Arousal Are Considered

The rationale for using heart rate to augment subjective ratings of workload is based on the fact that, in most pilots, it reflects the level of activity in the nervous system — or arousal. Although the concept of neurological arousal is probably oversimplified, it is of practical value when considering a pilot's performance. It is generally accepted that the relationship between performance and arousal is best expressed by a curve in the form of an inverted 'U'. In other words, there is an optimal level for reliably good performance. It has been hypothesized that a pilot, consciously or subconsciously, sets his level of arousal according to how he perceives the difficulty or demands of the flight task. This agrees with the following definition: "Pilot workload is the integrated mental and physical effort required to satisfy the perceived demands of a specified flight task."[7]

There is certainly evidence that underarousal and, possibly, complacency have been present in the cockpits of aircraft involved in accidents.[14] The fatal accident with a McDonnell Douglas DC-9 at Charlotte, N.C., U.S., in 1974 is one such example. The aircraft crashed short of the runway during an approach in marginal weather conditions. The NTSB report observed that the cockpit conversation was " … quite casual and completely unrelated to the flight task."

Heart rate responses, personal observations and reports from pilots suggest that during automatic flight in the 767 an element of underarousal may sometimes occur — mostly in cruise flight, especially at night, but occasionally during autolandings in clear weather.[15] Too much reliance on automated systems can encourage a pilot to move too far away from the control "loop" and by reducing his level of arousal, reduce his situational awareness. It has been shown that a pilot who is out of the loop is much less likely to diagnose and deal with unexpected faults.[16,17] Monitoring is much more likely to be effective if the pilot is in the loop or very close to it, with an appropriate level of arousal.

*… there has been an increasing number of reports of fatigue occurring in pilots flying advanced technology aircraft … .*

## The Glass Cockpit and Its Effects On Fatigue Investigated

Pilot fatigue is an emotive issue that deserves to be considered in a more objective and scientific manner than often is the case. The term fatigue (which is frequently used ambiguously) must be distinguished from the much more common feelings of drowsiness or tiredness. These feelings often follow inadequate preflight rest, circadian dysfunction and prolonged activity. But, more importantly, these feelings also tend to accompany boredom — especially at times when a person would normally be asleep. It is usually possible to overcome feelings of drowsiness when necessary, whereas physiological fatigue represents " … a real objective inability to continue at peak intensity, or even continue at all." [17]

During the past four or five years there has been an increasing number of reports of fatigue occurring in pilots flying advanced technology aircraft — with the implication, in many instances, that the glass cockpit is in some way responsible. During the same period, extended-range versions of these aircraft have been introduced on long-haul routes, and flights of more than eight hours are now commonplace. In addition, new two-pilot aircraft with even longer range capabilities — the Boeing 747-400 and the McDonnell Douglas MD-11 — are increasing the concern about fatigue in the glass cockpit.

Problems that have been addressed by several research groups [18,19] will not be considered here. These include disrupted patterns and circadian desynchronization that are associated with long-haul operations and, in particular, transmeridian flights.

The relationship between workload and fatigue is relevant to the discussion and will be covered briefly. It is difficult to accept that fatigue is more likely in the glass cockpit, especially in view of evidence from the Britannia study that workload is reduced by automation. In fact, the opposite is suggested by the results from an airline investigation into the effects of different flight patterns that cause tiredness in the cockpit. A seven-point fatigue rating scale developed for the U.S. Air Force (USAF) [20] was completed before and after each sector. Most of the study involved 767 pilots flying short-medium length flights in Europe, longer flights to West Africa, and extended-range operations to Australia and North America. But an early part of the study compared 737 and 767 flights of similar lengths. Graph 3 compares mean ratings for the inbound sectors of two-sector flights at night. The fatigue scores for the 737 indicate that the glass cockpit of the 767 induces less tiredness.

The increased likelihood of boredom and complacency occurring in the glass cockpit has been referred to by several authors.[19, 21] Undoubtedly, as mentioned earlier, the lower levels

**Graphic unavailable**

**Graph 3**
Mean fatigue ratings for night inbound flight sectors. (Short/Medium-haul routes) B-737 and B-767.

of workload associated with automation are accompanied by lower levels of arousal and, at times, underarousal. When flying at night, it is much more difficult to maintain an adequate level of arousal because of the natural reduction that accompanies the physiological changes that follow the body's biological clock. A well-known observation states that performance is lowest between the hours of 0300 and 0600 — body time.

Although the symptoms of tiredness and drowsiness resulting from sleep deprivation are similar to those accompanying boredom and underarousal, it is useful to distinguish between them because their prevention is somewhat different. For instance, it is possible to combat low arousal by following appropriate operating procedures, by exercising good cockpit discipline, and — most of all — by being aware that the problem exists. Many pilots know that they can increase their arousal by reviewing various aspects of the flight, and by contemplating possible problems at their destination.[15] Using heart rate as a measure of arousal, it has been shown that after a long night flight, pilots can increase their arousal before descending. Similar heart responses, for the same pilot, have been recorded during 767 autolands at the same airport following flights of different duration — from two hours to nine hours.[21] The two different causes of these symptoms may occur together, and at times probably have a synergistic effect on each other.

Finally, the glass cockpit not only generates a lesser workload but is also significantly less noisy than the older cockpit. Thus — the fatiguing effect of prolonged exposure to noise is reduced. But the quieter environment is more conducive to sleepiness when a pilot is bored and underaroused. As Graeber [19] has observed, with reference to the glass cockpit, " … when combined with increased flight deck comfort and long-haul operations, advanced automation produces an environment [that is] ripe for performance atrophy."

## Interim Findings Favor The Glass Cockpit

Unfortunately, there is insufficient data from the Britannia study to reach firm conclusions. But the findings give strong support to the large amount of anecdotal evidence regarding workload in the glass cockpit. In the 767, and probably in the 757, workload is almost always markedly lower than in the 737-200 for the pilot experienced on that type, although for a short period of time following conversion the glass cockpit workload may sometimes be higher.

During emergencies and abnormal flight, workload will almost always increase in any aircraft. But if the problem is approached in a systematic way without rushing, and automation is used in a sensible manner, the increase should be contained to an acceptable level. For example, in most emergencies the autopilot can be used to its full potential. The evidence from the airline study demonstrates that with appropriate training, well-designed operating procedures and good crew discipline, workload levels in the glass cockpit should not exceed the capabilities of two pilots.

With regard to the relationship between workload in the glass cockpit and fatigue or tiredness, the evidence available suggests that boredom and underarousal, associated with a lower level of workload, is the main problem. Flying during times when the pilot's biological clock indicates it is time to sleep aggravates the problem. Various strategies appear to be of value in maintaining adequate levels of arousal — especially for the more critical phases of flight — thereby helping to ensure an appropriate level of performance. ♦

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## *About the Author*

*Alan H. Roscoe, M.D., is a consultant in the United Kingdom to Britannia Airways and the Royal Aircraft Establishment (RAE) at Bedford, and is a visiting research fellow at the Cranfield Institute of Technology. He is executive advisor for flight safety to the Shuttleworth Collection of antique aircraft and to the Imperial War Museum airfield at Duxford.*

*Dr. Roscoe was the chief medical officer of Britannia Airways from 1983 to 1990. From 1969 to 1983,* *he was the establishment medical officer at RAE Bedford, with responsibilities for aviation and occupational medicine and for research into developing new techniques for assessing pilot workload during the flight testing of new aircraft and systems.*

*After serving as a navigator in de Havilland Mosquito aircraft for the Royal Air Force, Roscoe qualified in medicine at the University of Manchester in 1954. He then spent 13 years in clinical medicine.*

## Aviation Statistics

# Executive/Corporate Transportation
# 1970 - 1990

*by*
*Shung C. Huang*
*Statistical Consultant*

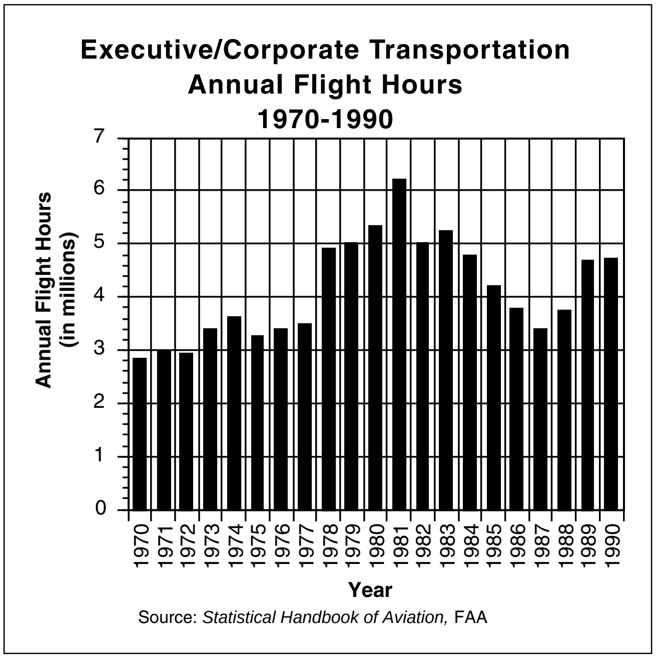
The segment of general aviation operations designated as corporate/executive transportation is defined as an aviation operation dedicated to corporation business. In the U.S. Federal Aviation Administration's (FAA) *1967 Statistical Handbook of Aviation*, executive transportation was defined as "any use of aircraft by a corporation, company, or other organization for the purpose of transporting its employees and/or property not for compensation or hire, and employing professional pilots for the operation of the aircraft." In the 1981 edition, executive transportation was redesignated as executive/corporate transportation but the definition remained the same.

## Executive/Corporate Transportation Reviewed

In 1970, executive/corporate transportation flew a total of 2.8 million hours, accounting for approximately 11 percent of the total general aviation hours flown. During the 1970-1980 period, the annual growth rate for executive/corporate air transportation in flying hours was approximately nine percent. In 1981, the annual hours flown reached 6.2 million, or 17 percent of the total hours flown by general aviation. Historically, this was the highest number of annual hours flown in executive/corporate transportation. Following the downtrend of overall general aviation activity in the 1980s, these transportation activities began decreasing in 1982 and continued until 1989. Graph 1 delineates the annual variations in executive/corporate transportation hours flown and the trend.

## The Executive/Corporate Aircraft Fleet Changes

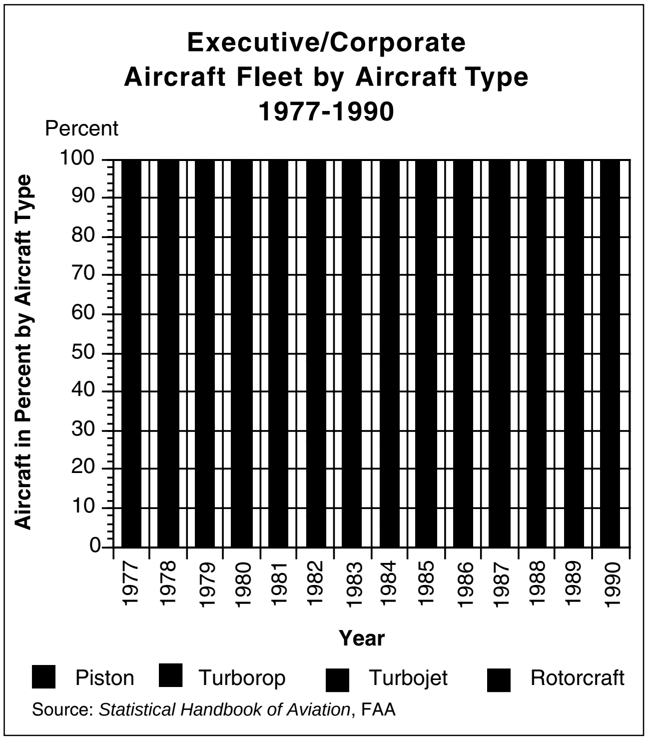
The type of aircraft in the executive/corporate fleet has changed significantly over the years. In the 1970s, more than 60 percent of



**Executive/Corporate Transportation Annual Flight Hours 1970-1990**

Source: *Statistical Handbook of Aviation,* FAA

**Graph 1**

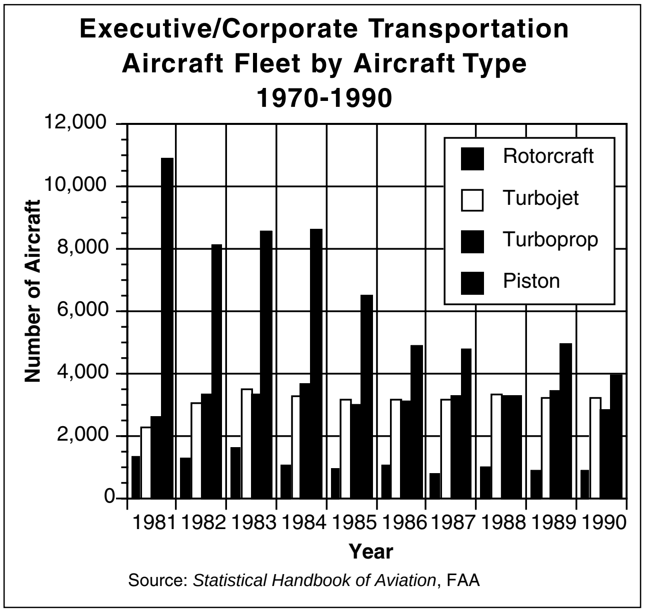


**Executive/Corporate Aircraft Fleet by Aircraft Type 1977-1990**

Source: *Statistical Handbook of Aviation*, FAA

**Graph 2**

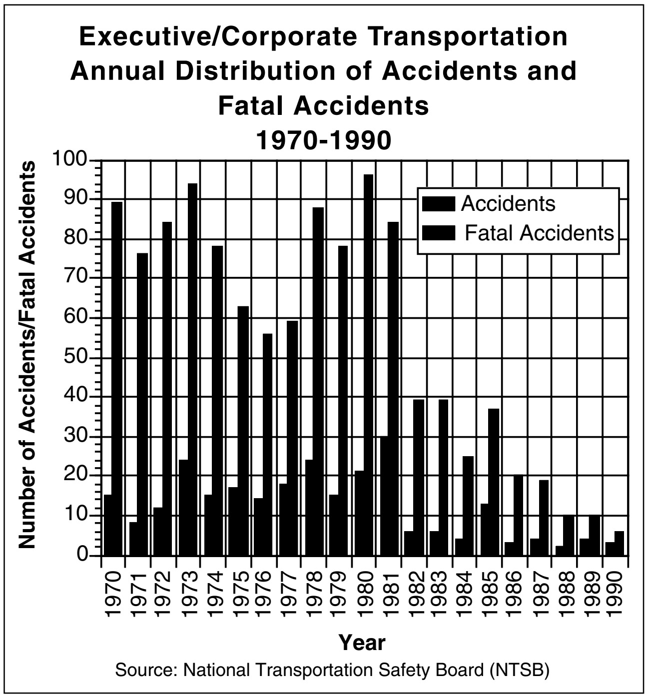
the fleet was represented by fixed-wing, piston-engine aircraft. The number of fixed-wing turboprop and turbojet aircraft accounted for 15 percent and 18 percent, respectively. Beginning in the early 1980s, fewer piston-engine aircraft were used for executive/corporate flying and more fixed-wing turboprop and turbojet aircraft were brought into the fleet. In 1990, piston-engine aircraft represented only 36 percent of the fleet while turbojet and turboprop aircraft numbers increased to 29 percent and 26 percent, respectively. However, the use of rotorcraft in this segment of general aviation remained fairly constant, accounting for approximately 10 percent. Graph 2 shows the aircraft fleet by type for the 1977-1990 period.



**Executive/Corporate Transportation Aircraft Fleet by Aircraft Type 1970-1990**

Source: *Statistical Handbook of Aviation*, FAA

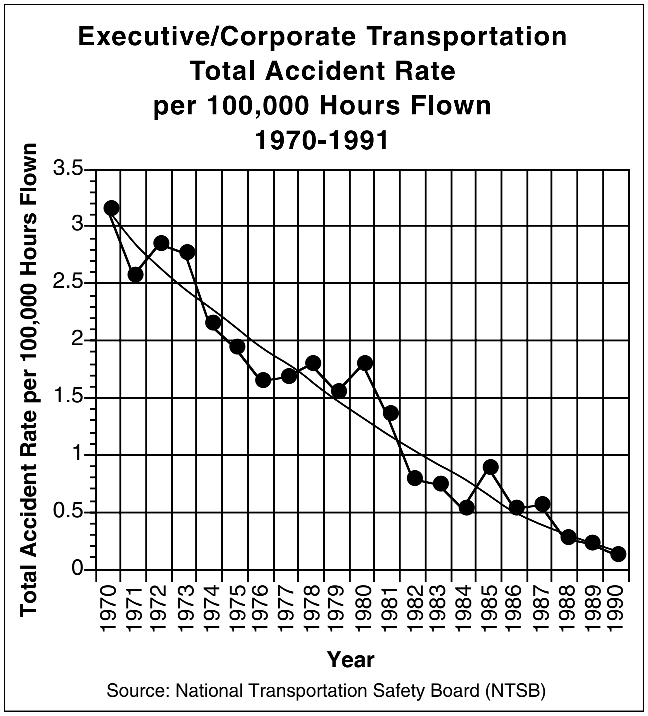
**Graph 3**



**Executive/Corporate Transportation Annual Distribution of Accidents and Fatal Accidents 1970-1990**

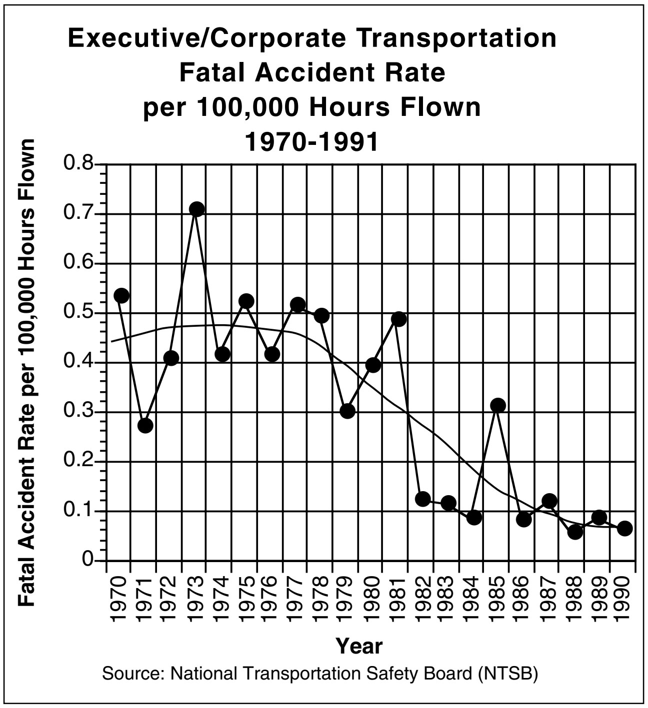
Source: National Transportation Safety Board (NTSB)

**Graph 4**


Executive/Corporate Transportation
Total Accident Rate
per 100,000 Hours Flown
1970-1991

Source: National Transportation Safety Board (NTSB)

**Graph 5**


Executive/Corporate Transportation
Fatal Accident Rate
per 100,000 Hours Flown
1970-1991

Source: National Transportation Safety Board (NTSB)

**Graph 6**

Fleet size has changed dramatically. Graph 3 shows the changes in fleet size by aircraft type between 1981 and 1990. The total fleet size dropped from as great as 18,580 aircraft in 1981 to 10,906 aircraft in 1990 — a decline of 41 percent. The most significant decrease was in fixed-wing, piston-engine aircraft, which dropped from 12,280 to 3,933, a decrease of 67 percent. The fixed-wing turboprop and jet aircraft numbers show a slight increase in the early 1980s and have changed little since 1985.

**Table 1**
**Most Prevalent First Occurrences in All Accidents**
**Executive/Corporate Transportation**
**Calendar Year 1980-1988**

| Year | 1980-1984 | | 1985-1988 | |
|---|---|---|---|---|
| Type of Occurrences | Mean | Percent | Mean | Percent |
| Collision with Object/Terrain | 16.2 | 28.6 | 4.8 | 22.3 |
| Loss of Power | 11.6 | 20.0 | 5.0 | 23.2 |
| Loss of Control-on Ground | 5.0 | 8.8 | 4.0 | 4.6 |
| Loss of Control-in Flight | 4.6 | 8.1 | 0.8 | 3.5 |
| Airframe/Component/System Failure | 4.0 | 7.1 | 3.0 | 14.0 |
| Gear Collapsed/Retracted | 3.6 | 6.4 | 1.5 | 7.0 |
| Encounter with Weather/Turbulence | 2.4 | 4.2 | 1.8 | 8.1 |
| Hard Landing | 2.4 | 4.2 | 0.0 | 0.0 |
| Miscellaneous | 2.2 | 3.9 | 0.5 | 2.3 |
| Undershoot/Overshoot | 1.8 | 3.2 | 2.5 | 11.7 |
| Fire/Explosion | 0.8 | 1.4 | 0.2 | 1.2 |
| Propeller/Rotor Contact | 0.8 | 1.4 | 0.5 | 2.3 |
| Midair Collision | 0.6 | 1.1 | 1.2 | 5.6 |
| (All Other Type) | 0.6 | 1.1 | 0.2 | 1.2 |
| Total | 56.6 | 100.0 | 21.5 | 100.0 |

**Table 2**
**Most Prevalent First Type of Operation in All Accident**
**Executive/Corporate Transportation**
**Calendar Year 1980-1988**

| Year<br>Phase of Operation | 1980 - 1984<br>Number of Accidents | Percent | 1985 - 1988<br>Number of Accidents | Percent |
|---|---|---|---|---|
| Landing | 78 | 27.5 | 20 | 23.3 |
| Approach | 53 | 18.7 | 17 | 19.8 |
| Takeoff | 49 | 17.3 | 14 | 16.2 |
| Cruise | 48 | 17.0 | 14 | 16.2 |
| Decent | 20 | 7.1 | 2 | 2.3 |
| Climb | 11 | 3.9 | 5 | 5.8 |
| Standing | 8 | 2.8 | 1 | 1.2 |
| Taxi | 8 | 2.8 | 6 | 7.0 |
| Maneuvering | 7 | 2.5 | 3 | 3.5 |
| Other | 1 | 0.4 | 4 | 4.7 |
| Four-Year Total | 283 | 100.0 | 86 | 100.0 |

Source: NTSB

## Executive/Corporate Transportation Reflects Good Safety Record

The safety record of executive/corporate transportation has improved significantly during the past 20 years. The annual distribution of total accidents and fatal accidents declined from an average of 84 accidents in the 1970-1974 period to an average of 13 accidents in the 1986-1990 period, a decrease of 85 percent. The reduction of fatal accidents during the years was equally significant; it dropped from an average of 13 fatal accidents in the 1970-1974 period to an average of three fatal accidents in the 1986-1990 period, a reduction of 77 percent. Graph 4 shows the distribution of accidents and fatal accidents during the past two decades. Graphs 5 and 6 show the total accident rate and fatal accident rate per 100,000 hours flown. The fatal accident rate of 0.71 fatal accidents per 100,000 in 1973, the greatest during the period, decreased to 0.06 in 1990, the least of the period, a decline of 92 percent.

**Table 3**
**Broad Cause/Factor Assignment in All Accidents**
**Executive/Corporate Transportation**
**Calendar Year 1980-1988**

| Year | 1980-1984 | | 1985-1988 | |
|---|---|---|---|---|
| Broad Cause/Factor | Mean | Percent | Mean | Percent |
| Pilot | 38.2 | 67.5 | 16.8 | 78.1 |
| Weather | 20.4 | 36.0 | 5.0 | 23.2 |
| Terrain/Objects | 12.0 | 21.2 | 6.2 | 27.9 |
| Power plant | 11.0 | 19.4 | 4.2 | 19.5 |
| Personnel | 10.4 | 18.4 | 4.2 | 19.5 |
| Landing Gear | 8.4 | 14.8 | 3.5 | 16.5 |
| Miscellaneous | 7.4 | 13.1 | 2.5 | 11.6 |
| Airport/Airways/Facilities | 5.4 | 9.5 | 1.5 | 7.6 |
| Instruments/Equipment/Systems | 4.4 | 7.8 | 2.0 | 9.3 |
| Undetermined | 2.8 | 4.8 | 0.8 | 3.7 |
| Airframe | 2.4 | 4.2 | 1.2 | 5.5 |
| Rotorcraft | 1.2 | 2.1 | 0.2 | 1.0 |
| Four Year Mean | 56.6 | | 21.5 | |

## Accidents Analyzed

An analysis of accidents involving executive/corporate transportation for the period 1980-1988 by type of accident, phase of operation and cause/factor is shown in Tables 1, 2 and 3. As in other segments of general aviation operations, pilot errors and weather were cited in approximately 90 percent of the accidents, and approximately 60 percent of the accidents occurred during takeoff and landing. ♦

## Reference

1. *Annual Review of Aircraft Accident Data, U.S. General Aviation,* U.S. National Transportation Safety Board (NTSB), calendar years 1970-1988.
2. *Preliminary Monthly Civil Aviation Accident Summary,* U.S. National Transportation Safety Board (NTSB), January 1989-December 1990.
3. *FAA Statistical Handbook of Aviation*, U.S. Federal Aviation Administration, 1968-1990.

# Reports Received at FSF
# Jerry Lederer Aviation Safety Library

## Reports

*Air traffic Control Specialists in the Airway Science Curriculum Demonstration Project, 1984-1990:* Third Summative Report. Final Report / Dana Broach (Civil Aeromedical Institute). — Washington, D.C.: U.S. Federal Aviation Administration, Office of Aviation Medicine ; Springfield, Virginia, U.S.: Available through the National Technical Information Service*, [1991]. Report No. DOT/FAA/AM-91/18. 20 p. : charts.

Key Words
1. Aeronautics — Study and Teaching (Higher) — United States.
2. Air Traffic Controllers — Selection and Appointment — United States.
3. United States. Federal Aviation Administration — Officials and Employees — Selection and Appointment.

Summary: The objective of this summative evaluation of the Airway Science Curriculum Demonstration Project (ASCDP) was to compare the performance, job attitudes, retention rates, and perceived supervisory potential of graduates from recognized Airway Science programs with those of individuals recruited through traditional means in the Air Traffic Control Specialist (ATCS) occupation. Previous evaluations ... described institutional and organization benefits that accrued to the agency, participating institutions, and industry. In this technical evaluation, differences between Airway Science hires and a random, stratified sample of traditional ATCS hires on eight program objectives were evaluated according to: (1) interest in an aviation-related career; (2) attrition; (3) technical competence; (4) attitudes toward technological change; (5) managerial potential; (6) human relations skills; (7) female and minority representation; and (8) perceptions of the FAA. Controllers hired from the Airway Science register expressed significantly more interest in an aviation-related career (Objective 1). There were no significant differences between traditional hires and Airway Science hires on the remaining criteria. Overall, the performance of Airway Science hires was about the same as that of traditionally hired controllers. [Abbreviated author abstract]

*Computer Operations: FAA Needs to Implement an Effective Capacity Management Program.* Report to the Chairman, Subcommittee on Transportation and Related Agencies, Committee on Appropriations. U.S. Senate / United States General Accounting Office. — Washington, D.C.: May be ordered from GAO, P.O. Box 6015, Gaithersburg, MD 20877 U.S.: also U.S. General Accounting Office**, [1991]. Report No. GAO/IMTEC-92-2, b-245307. 33 p. : ill.

Key Words
1. Air Traffic Control — United States — Evaluation.
2. Computer Capacity — Management — Evaluation.
3. United States. Federal Aviation Administration — Data Processing — Evaluation.
4. United States. Federal Aviation Administration — Evaluation.

Summary: Management of computer capacity is critical to the FAA's meeting its missions, such as ensuring safe air travel. Although the FAA has recently made some limited improvements, it has not implemented a comprehensive capacity management program for its major automated systems because such a program is not a priority. As a result, the FAA lacks adequate computer capacity management policies, procedures, expertise, and tools. Without a comprehensive program, the FAA does not know how long current systems, such as those used to assist controllers in separating aircraft, will continue to meet capacity requirements, nor does it know the future capacity needs. [Results in Brief]

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*Human Factors in Aviation Maintenance: Phase 1, Progress Report* / William T. Shepherd ... [et al.]. — Washington, D.C. : U.S. Federal Aviation Administration, Office of Aviation Medicine; Springfield, Virginia, U.S.: Available through the National Technical Information Service*, [1991]. Report No. DOT/FAA/AM-91/16. x, 158 p. : charts.

Key Words
1. Aeronautics — Human Factors.
2. Airplanes — Maintenance and Repair.
3. Aviation Mechanics (Persons) — Psychology.

Content: Executive Summary — Maintenance Organization — The Maintenance Technician in Inspection — Advanced Technology Training for Aviation Maintenance — Job Performance Aids — List of Tables.

Summary: This human factors research in aviation maintenance addresses four tasks including studies of organizational behavior, job and task analysis in maintenance and inspection, advanced technology for training, and the application of job aiding to maintenance. The first phase of a three phase research program describes extensive preliminary investigation of airline maintenance practices. Each chapter describes the Phase I investigation and problem definition followed by the plan for the Phase II demonstrations.

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*Inhalation Toxicology, XII. Comparison of Toxicity Rankings of Six Polymers By Lethality and by Incapacitation in Rats*. Final Report / Donald C. Sanders, Boyd R. Endecott, Arvind K. Chaturvedi (Civil Aeromedical Institute). — Washington, D.C. : U.S. Federal Aviation Administration, Office of Aviation Medicine; Springfield, Virginia, U.S.: Available through the National Technical Information Service*, [1991]. Report No. DOT/FAA/AM-91/17. iii, 7 p. : ill.

Key Words
1. Carbon Monoxide.
2. Gases, Asphyxiating and Poisonous — Toxicology.
3. Polymers.
4. Respiratory Organs — Effect of Chemicals On.

Summary: Polymeric aircraft cabin materials have the potential to produce toxic gases in fires. Lethality in animal models is a standard index to rank polymers on the basis of their combustion product toxicity. However, the use of times-to-incapacitation may be more realistic for predicting relative escape times from a fire environment. Six pure polymers of different chemical classes were determined and compared for lethality and times-to-incapacitation. The two toxicological end points, lethality and times-to-incapacitation, did not exhibit the same relative toxic hazard rankings for these polymers. Also, times-to-incapacitation were not equal at the lethality concentrations, a condition of equal lethality. These findings demonstrate the possible involvement of different mechanisms of action for the combustion products of these polymers at the selected end points. [Abbreviated author abstract] ♦

*U.S. Department of Commerce
National Technical Information Service (NTIS)
Springfield, VA 22161 U.S.
Telephone: (703) 487-4780

**U.S. General Accounting Office (GAO)
Post Office Box 6012
Gaithersburg, MD 20877 U.S.
Telephone: (202) 275-6241

# Accident/Incident Briefs

*This information is intended to provide an awareness of problem areas through which such occurrences may be prevented in the future. Accident/incident briefs are based upon preliminary information from government agencies, aviation organizations, press information and other sources. This information may not be accurate.*

Air Carrier

## Poor Communications Prevent Timely Warning of Ground Collision

*Boeing 747: Minor damage. No injuries.*

*Lockheed L-1011: Minor damage. No injuries.*

The Lockheed L-1011 had been towed to one of the outer gates of the terminal, but it could not be parked fully into the gate area because a ground vehicle was stalled adjacent to the building. Ramp control had not been advised of the stalled vehicle. The control tower was not advised that the aircraft could not be parked fully into the gate.

The Boeing 747, meanwhile, had been cleared to taxi past the gate at which the L-1011 was parked, and its left wingtip struck the outboard tip of the other aircraft's right elevator and rode over it. The minor collision was not noticed by the 747 crew but several witnesses on the ground saw the contact and a brakeman sitting in the L-1011 cockpit felt the impact. However, no one reported the incident to the control tower and the 747 took off.

After the L-1011 was towed to a maintenance hangar, an inspection revealed scrape marks and a tear on the upper surface of the L-1011 right elevator. At that point, the control tower was notified of the collision. By that time, the 747 was too far away for the control tower to communicate by VHF radio and a message was relayed via company radio; the captain was made aware of the incident one hour and 15 minutes after it had occurred. Inflight visual inspection by the flight crew revealed no damage to the wingtip or fuel leaks. There were no compass problems with the wingtip-mounted sensor and the aircraft was handling normally.

The 747 made an uneventful landing at its destination. After inspection by maintenance personnel, the aircraft was found to have a broken outboard navigation light on the left wingtip, a flattened air scoop and some scrape marks on the wingtip fairing.

## Who Left the Window Open?

*Boeing 757: No damage. No injuries.*

The aircraft had accelerated to 80 knots on takeoff for a regularly scheduled trip when the first officer heard excessive noise from his side window panel. He saw the manual handle move to the rear and the window being opened by the window winder.

The first officer attempted to stop the opening of the window by opposing the movement of the manual handle. The clutch mechanism slipped during this action and the captain was notified that the window could not be closed. The captain aborted the takeoff.

The window was closed securely and the aircraft was taxied back to the beginning of the runway for another takeoff. There was no repeat of the earlier incident and the flight was uneventful. After landing at the destination, the captain demonstrated how the first officer's side window could be made to appear that it was closed properly when it was not closed. He closed the manual handle in the fully forward position with the "closed" decal in view while the rear edge of the window was open approximately one inch.

Prior to the earlier takeoff when the window had opened, the crew had been on the flight deck for a period of three hours while maintenance crews corrected a number of defects. There was no air conditioning and the first officer's side window had been opened to provide some ventilation. Because there was a drizzle, the window was closed occasionally to prevent the rain from coming in. This was the sixth such occurrence involving this model aircraft.

## Wrong Date, Wrong Winds, Wrong Flight Plan

The captain extracted his flight information from the flight planning computer and mistakenly entered the previous day's date. The computer obliged and provided the wind analysis for the day before. Consequently, the computer provided incorrect flight plan information for fuel required for the alternate airport. The captain failed to follow the instructions on the checklist adjacent to the flight planning computer terminal regarding procedures for entering dates and requesting information on alternate airports.

## Flight into Thunderstorm Results In Loss of Control

*Beechcraft C99: Aircraft destroyed. Fatal injuries to 13.*

The aircraft, operating as a scheduled commuter flight on an instrument flight plan, was making an instrument approach to an airport in an area that was experiencing thunderstorm activity. The pilot had been advised to expect summer thunderstorms during a weather briefing, and an automatic terminal information service (ATIS) broadcast heard by the flight crew from the destination airport also mentioned thunderstorms.

According to the U.S. National Transportation Safety Board (NTSB), the aircraft encountered a thunderstorm cell at a height of approximately 1,600 feet while on final approach. The NTSB concluded that the cell produced very strong vertical air shafts and associated turbulence. Attitude control was apparently lost and the flight crew was unable to regain control.

The aircraft crashed prior to reaching the airport. The aircraft was destroyed by the impact and post-crash fire. The first officer and 12 passengers were fatally injured; the captain and one passenger survived. Two homes and two automobiles were also destroyed.

The NTSB determined that the probable cause of the accident was the decision of the captain to "initiate and continue an instrument approach into clearly identified thunderstorm activity, resulting in a loss of control of the airplane from which the flight crew was unable to recover … ."

The flight crew had not received instruction in unusual attitude recognition and recovery, a factor the NTSB considered a possible reason why they were unable to control the aircraft after it encountered the upsetting action of the thunderstorm cell. The severe weather phenomenon that the aircraft encountered lasted only minutes and was contained within a small geographic area.

As a result of its investigation, the NTSB recommended that the U.S. Federal Aviation Administration (FAA):

- Develop criteria through a joint government/industry effort that can help flight crews to evaluate thunderstorm hazards and make go/no-go decisions.
- Require that airline airborne weather radar training programs include information on the specific types of equipment crews will use and that manufacturer information on limitations and procedures be incorporated in training.
- Require that recurrent training and proficiency programs for instrument-rated pilots include unusual attitude recognition and recovery.

The board also reiterated an earlier recommendation that aeronautical decision-making techniques be disseminated more aggressively to all categories of civil pilots.

## Taxiing in Close Quarters Leads to Mishap

*Hawker Siddeley HS 748: Minor damage. No injuries.*

After the aircraft had landed at its destination, it was directed by the control tower to backtrack along the runway and turn at the intersection with another runway, and to hold there for taxi instructions. There was some confusion about where the aircraft was to be parked before instructions were given for it to taxi to a maintenance hangar.

The sky was overcast and the captain had no shadows to help judge the aircraft's wingtip position relative to the edge of the taxiway, along which several aircraft were parked on the left side. Consequently, he relied upon keeping the nosewheel on the taxiway centerline to ensure clearance along the side. After passing several parked aircraft, the captain heard a thud sound and stopped the aircraft immediately.

Suspecting that the aircraft might have encountered some soft ground along the side of the taxiway, the captain directed the first officer to make a visual inspection. It was found that the taxiing aircraft had struck the tail of a parked Shorts SD 360 commuter aircraft with its left wingtip. The captain reported that the Shorts was nearer the taxiway than the other parked aircraft and that the right main wheel of his aircraft had crossed over the taxiway edge into the grass opposite the position where the Shorts was parked.

A published warning for the airport cautioned that the taxiway was limited to light single- and twin-engine aircraft and that other aircraft should use it with extreme caution because of reduced obstacle clearances.

## Fog Shrouds Three Approaches

*McDonnell Douglas DC-8-63F: Aircraft destroyed. Fatal injuries to four.*

The cargo aircraft, loaded with approximately 53,000 pounds of aircraft parts, printed material, computer hardware and mineral spirits, had made two missed approaches while attempting to land at its destination. The time was approaching 0330 hours and the winter weather included rain and fog. Winds were reported as 10 knots on the ground and 40 knots above the airport. Visibility was reported as two miles in rain and fog. On board were a flight crew of three and a pilot for another company who was riding as a passenger.

The aircraft crashed in a field two miles north of the airport during the third approach attempt. The aircraft was destroyed by impact and fire, and all occupants aboard sustained fatal injuries. Fumes from burning mineral spirits affected rescue workers and area residents.

Corporate
Executive

## Wrong Lever Selected During Landing Roll

*Ted Smith (Piper) Aerostar PA-60-601: Substantial damage. No injuries.*

The pilot and one passenger were aboard the twin-engine aircraft. The pilot made a visual approach and the aircraft touched down without incident.

As the aircraft was rolling out after the landing, the pilot decided to raise the flaps for better braking effectiveness. He inadvertently selected the wrong lever and placed the landing gear lever in the up position.

The first indication the pilot had that a mistake had been made was when the nosewheel slowly retracted. The aircraft skidded to a stop on the underside of the nose area and the tips of the right propeller struck the hard surface of the runway. There was no fire and the two occupants were able to evacuate the aircraft without injury. However, the aircraft sustained substantial damage.

## Fuel Siphoning Leads to Nighttime Accident

*Beech D55 Baron: Aircraft destroyed. Fatal injuries to one.*

The aircraft was flying at 10,000 feet at night and the pilot made an en route flight plan amendment because of unsuitable weather along his original route. The pilot was the only occupant of the twin-engine aircraft.

Shortly before midnight, the pilot advised air traffic control (ATC) that the aircraft had experienced a partial engine failure and, approximately four minutes later, stated that he had regained power in the affected engine. The pilot elected to continue the flight toward his original destination and was subsequently cleared to a lower altitude of 8,000 feet. When approximately 20 miles away from the airport, he was cleared to begin descending in preparation for landing. While descending from 4,000 feet to 3,000 feet, the pilot transmitted a Mayday message advising that both engines had failed. He was given radar headings to a small airport that was closer to his position than the destination airport.

At 0029 hours, the pilot radioed that he was at an altitude of 1,000 feet and he was advised that the alternate airport was five miles away. He reported that he would be unable to reach the airport, after which radar contact with the aircraft was lost. The aircraft's wreckage was found where the aircraft had impacted heavily against a slope along a road. The aircraft had been destroyed and the pilot had been fatally injured.

Investigators determined that both engines failed because of fuel exhaustion, although it was found that the aircraft had departed with sufficient fuel to complete the planned flight. A fuel stain on the left wing indicated a possible loss of fuel from the left main fuel tank cap, and further examination disclosed that a wire clip attached to the fuel cap securing chain had caught in the seal and prevented the cap from sealing properly. Fuel was siphoned from the tank and the bottom of the bladder-type fuel tank lifted, resulting in false indications that there was sufficient fuel in that tank.

Investigators theorized that, when the pilot first experienced partial engine failure it was because the left engine was not getting fuel, fed by the then-empty left main tank. By crossfeeding from the right tank, the pilot would have been able to regain power on the left engine. However, with both engines feeding from the right tank, the fuel would have run out approximately at the time the pilot reported the double engine failure.

Factors considered significant in the accident included the design of the tank clip, undetected deformation of the clip, the inadvertent lodging of the clip where it interfered with the cap seal, undetected loss of fuel from the left tank in flight and the pilot's decision to continue toward his original destination rather than divert to an alternate landing site. The final causal factor was the double engine failure following fuel exhaustion.

Other
General
Aviation

## Icing Ends Spring Flight

*Piper PA-28-161 Warrier: Substantial damage. Minor injuries to one.*

The pilot was flying solo on a local pleasure flight. Weather was not a factor on the late afternoon flight in early spring.

After approximately a half hour of flight, the pilot followed his routine practice of switching fuel tanks from the left fuel tank to the right fuel tank. After a few minutes of operation on the right tank, the engine began to run roughly. Shortly afterwards, it stopped.

The pilot selected full carburetor heat, checked that the electric fuel pump was on and followed the engine failure checklist. Engine restart attempts were unsuccessful and the pilot chose a forced landing site. The field he selected had recently been plowed and readied for seeding and, when the aircraft touched down, the soft surface caused the nose gear to collapse. The aircraft came to rest on its nose and a wingtip causing the pilot to hit his head on the top of the instrument panel and wrench his back. There was no fire, however, and the pilot evacuated the aircraft with no further injury.

Investigation revealed that there was sufficient fuel in both tanks for the flight to have continued and there was no evidence of fuel contamination in the tanks. The engine was operated with no evident abnormalities that could have interfered with operation. However, maintenance personnel reported that the lower spark plugs were found to have been wet with water — a possible result of melted ice deposits from the fuel/air induction system. A weather aftercast for the area at the time of the accident revealed that meteorological conditions below 5,000 feet were conducive to serious induction icing at any power setting.

## Unfamiliarity with Systems Leads to Gear-up Landing

*Mooney Mark 20: Moderate damage. No injuries.*

The purpose of the flight was for the pilot to gain an endorsement for flying aircraft with constant-speed propellers and retractable landing gear. It was only the second flight in this type of aircraft for the flight instructor and the first flight in it for the pilot being instructed.

During one landing approach, the pilots had checked that the gear-down and locked light was illuminated and rechecked it again during final approach. During a roundout that seemed normal to the occupants, the aircraft settled on its underside and slid to a halt gear-up.

Examination revealed that the gear had been up during the landing attempt and no fault was found with the systems. The red and green post lights on the instrument panel that indicate high and low vacuum pressure were of the same type as the landing gear position lights and the green vacuum light was located approximately three inches from the green gear-down light at its two o'clock position.

Significant factors considered by investigators included the unfamiliarity of both pilots with the aircraft type, the failure to extend the gear and the possibility that the pilots mistook the green vacuum light for the gear-down light and assumed that the gear was down and locked.

## Rotorcraft

### Student Loses Control as Helicopter Drifts

*Schweizer 269C: Aircraft destroyed. No injuries.*

The instructor was standing close to the touchdown point of the active runway. His student was flying the helicopter solo. Temperature in mid-afternoon of the summer day was 66 degrees F (19 degrees C) and the wind was light and variable. The student had completed three successful solo traffic pattern circuits and landings.

As the student completed the fourth traffic pattern and was approaching to hover for another landing, the instructor bent down to pick up his kneeboard and radio headset. At that time he heard a sudden change in the engine sound and looked at the helicopter to see it rotating rapidly to the right and pitching violently. The instructor watched as the aircraft impacted the ground tail first and broke up. After the helicopter came to rest on its left side, the instructor helped the student pilot escape from the wreckage. The aircraft was a total loss but the student pilot was not injured.

According to the student, he had been turning the aircraft into the wind while hovering when it began to drift sideways. He said he was unable to control the helicopter despite applying the corrective action he had practiced during dual instruction earlier that day.

### Water and Fuel Do Not Make A Combustible Mixture

*Hughes 500: Substantial damage. No injuries.*

The helicopter passenger had several stops to make, and the pilot had loaded five, five-gallon plastic fuel containers from which to refuel if necessary between scheduled fuel stops. At a point where he considered the fuel level insufficient to reach the next fuel facility, the pilot landed in a clearing and added the fuel from two of the cans.

Shortly after taking off, at a height of approximately 150 feet and a speed of 25 knots, the engine failure horn sounded. The pilot immediately initiated an autorotation and the helicopter was force-landed in an area of small trees where it sustained substantial damage. The occupants both evacuated without injury. Investigation revealed that the engine was not running on touchdown.

Teardown inspection of the fuel system revealed water in it. A small amount of water also was found in one of the cans that had been used to refuel the aircraft. The filled cans had been obtained from a company storage shed and the pilot had poured a sample into a clear container and a visual check had not disclosed any water. As a further precaution, he had left some liquid in each can so that any water would remain settled to the bottom. However, the pilot had not considered the possibility that the vibrations during the previous flying could have mixed the fuel and water to the point that some water could have been added to the helicopter's fuel tank along with the fuel.

As a result of the accident, the company supplied water detection kits to all its pilots and made it a practice to store fuel cans empty and to fill them from regularly tested underground tanks immediately prior to flight. ♦