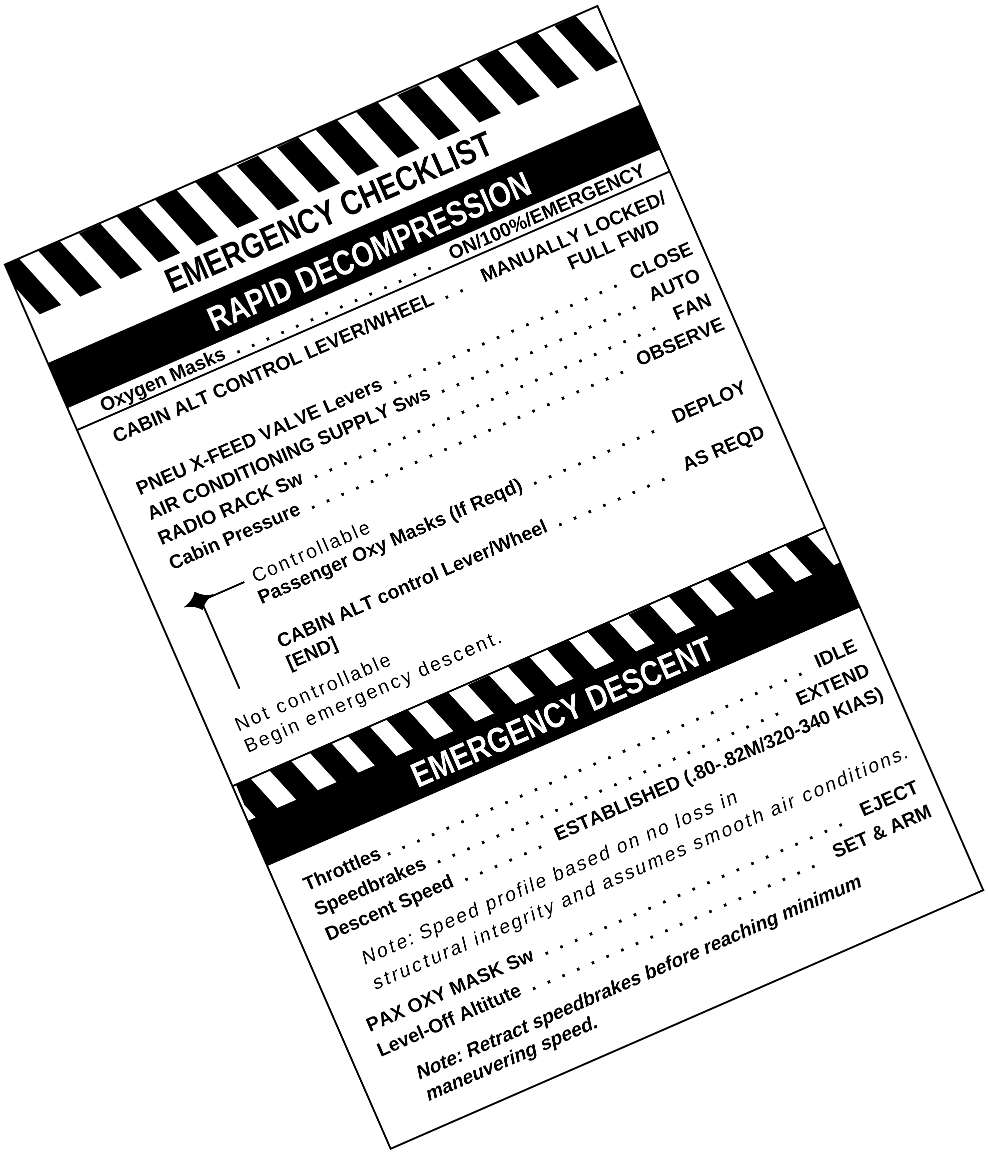
FLIGHT SAFETY FOUNDATION

MAY 1995

FLIGHT SAFETY
DIGEST

Studies Suggest Methods for Optimizing Checklist Design And Crew Performance



Flight Safety Digest

Vol. 14 No. 5 **May 1995**

In This Issue

Flight Safety Foundation is an international membership organization dedicated to improving aviation safety. Nonprofit and independent, the Foundation was launched in 1945 in response to the aviation industry's need for a neutral clearinghouse to disseminate objective safety information, and for a credible and knowledgeable body that would identify threats to safety, analyze the problems and recommend practical solutions to them. Since its beginning, the Foundation has acted in the public interest to produce a positive influence on aviation safety. Today, the Foundation provides leadership to nearly 650 member organizations in 76 countries.

Studies Suggest Methods for Optimizing Checklist Design and Crew Performance

Improved readability, color coding, listing steps in logical sequence, thoughtful indexing, convenient placement within the cockpit, attention to human factors and many other principles will help to ensure that checklists are used as intended.

Richard L. Gross, M.S.
and
Editorial Staff

The checklist is a classic response to a classic human-factors problem in aviation. The problem is the possibility of a flight crew neglecting an appropriate procedural step because of distraction, fatigue, task overload or complacency. The solution is elegantly simple: instead of relying on memory, a crew member reads the necessary steps from a written document — the checklist — that can never "forget" or "omit" an item that has been included in it.

There are separate checklists for different phases of flight and the tasks associated with those phases. Checklists are also classified as being for normal flight or for unusual flight situations, with "normal," "abnormal" and "emergency" the most common terms.

Procedures vary from one air carrier to another, but generally a crew member reads aloud each checklist item (the "challenge") and a second crew member verifies that the necessary action has been performed or that a control is in the correct position (the "response"). Some airlines require that both pilots confirm each item. The checklist may represent a "do list," that is, a signal for items to be accomplished as they are read aloud; or it may be a "verification list," providing redundancy by double-checking items that were accomplished before beginning the checklist.

The emergency checklist must counteract most of the same human-factors problems as the standard checklist, and other stresses as well. Complacency is not likely to be present in an emergency, but distraction, fatigue and task saturation may well be present, compounded by extreme urgency and some degree of anxiety. With all these factors as a backdrop, the Emergency Checklist must nevertheless enable the pilot to perform specific actions in response to specific conditions (e.g., engine fire, depressurization, hydraulic failure and other serious malfunctions) that are not encountered during routine operations.

The development of Emergency Checklists was largely stimulated by military aviation, especially during the World War II era. The Emergency Checklist was an attempt to lower the rate of accidents caused by systems failures and malfunctions — hence the common military aviation saying, "emergency procedures are written in blood."

The checklist is such a logical idea, and its benefits are so obvious, that it has been in universal use in aviation for many years. On the surface, it would hardly seem to present any grounds for controversy.

But while no one doubts the importance of checklists, there is disagreement about how checklists are best used and designed.

Checklist Type Definitions Vary

Aircraft manufacturers and operators do not fully agree on what should be included under each of the three basic classifications of checklists. "Normal" seems almost self-defining: it includes the equipment settings and actions needed for foreseeable, routine situations in operation of the aircraft.

But "abnormal" and "emergency" leave room for interpretation. The European Joint Aviation Requirements recognize six classifications of flight conditions, whose effect on aircraft and occupants ascends in seriousness from "normal" through "nuisance," "operating limitations," "significant reduction in safety margins" and "large reduction in safety margins" to "multiple deaths, usually with loss of aircraft."[1]

Aircraft manufacturers and operators do not fully agree on what should be included under each of the three basic classifications of checklists.

FlightSafety Canada Ltd. has created these definitions:

- **Abnormal.** " … foreseeable situations involving failures, in which the system's redundancy or selection of an alternate system will maintain an acceptable level of airworthiness."

- **Emergency.** " … foreseeable but unusual situations in which immediate and precise action may be required by the crew."[2]

Checklists are ultimately derived from flight crew operating manuals (FCOMs). In the United States, the FCOM — and checklists based on it — for an airplane flown by a major air carrier can evolve through a process that includes as many as four stages:

- Under U.S. Federal Aviation Regulations (FARs) Part 25.1581, the FCOM approved by the U.S. Federal Aviation Administration (FAA) is developed jointly by the manufacturer and the FAA's Flight Manual Review Board.

- Also under Part 25.1581, a manufacturer-developed FCOM may be developed that presents the material in a different format.

- Under FAA Order 8110.8, "Engineering Flight Test Guide for Transport Category Airplanes," Part 121 operators (major air carriers) who develop a "large amount of experience with a particular airplane" may write their own operating procedures, subject to FAA approval.

- The same order permits "scheduled air carrier operators only" to develop FCOM procedures with no FAA review, but only with the inclusion of language stating that the airline takes responsibility for its own procedures providing "equivalent safety" of the FAA-approved procedures.

The result, then, is that Part 121 scheduled air carriers can to some degree tailor the original manufacturer-FAA procedures, and thus the checklists, to their own operating philosophies.

The FARs have few specific requirements for checklists *per se*. Part 121.315 requires operators to provide a check procedure for each aircraft type, including all items necessary for safe operation. It requires that the procedures be "readily usable," and that the flight crew follow them. Air Carrier Operations Bulletin (ACOB) No. 8-88-4 requires FAA inspectors to review checklists for compliance with the FARs as well as with manufacturers' recommendations, type certificates (TCs) and supplemental type certificates (STCs).

The FAA has proposed a rule that will subject commuter airlines to Part 121 requirements beginning in December 1995, with most implementation completed the following year. Part 135.83 (which, meanwhile, applies to most commuter airlines) is similar to Part 121.315, although it describes in more detail what emergency procedures must be included in checklists. But FAA approval is not required. ACOB Part 135 No. 88-5 says that procedures should be "printed in clear, concise and legible form," without specifying that form further.

Accidents have called into doubt the adequacy and the usage of some checklists. Nearly within a year of each other two airplanes — a Northwest Airlines McDonnell Douglas DC-9 in Detroit, in 1987, and a Delta Air Lines Boeing 727 in Dallas, in 1988 — crashed when their crews attempted to take off without extending the flaps and slats. Neither accident could have happened if the crews had accomplished their pretakeoff checklists.

Between the beginning of 1983 and October 1986, 21 accidents or incidents investigated by the NTSB raised questions about defective checklists or improper use of checklists.[3] A safety study of 37 flight crew–involved major accidents of U.S. airlines from 1978 through 1990 said that six of the eight takeoff accidents studied involved procedural checklist failures during the taxi phase.[4]

As a result of the 1978–1990 study, the U.S. National Transportation Board (NTSB) issued, in a February 1994 letter to the FAA, two recommendations:

- Recommendation A-94-001 stated; "Apply the results of research conducted to date on the design and use of checklist procedures for taxi operations by enhancing [flight crew] monitoring/challenging of checklist execution, providing cues for initiating checklists, and considering technological or procedural methods to minimize the omission of any items on a checklist. Provide specific guidance to air carriers for implementing these procedures."

- Recommendation A-94-003 urged the FAA to require Part 121 air carriers to provide simulator training for newly qualified flight crew that would improve crew member skills in observing and challenging errors made by other crew members. The recommendation included "practice in monitoring and challenging errors during taxi operations, specifically with respect to minimizing procedural errors involving inadequately performed checklists."

A recent accident suggests that failure to follow checklist procedures still occurs despite the massive evidence that such violations have had severe consequences. On March 2, 1994, a Continental Airlines McDonnell Douglas MD-82 overran the runway as a result of a rejected takeoff and came to rest nose-down on a mud flat at LaGuardia Airport, Flushing, New York, U.S. [*Accident Prevention*, Vol. 52, No. 5, May 1995]. In its report, the NTSB concluded that "the pilots failed to conduct a prestart checklist properly" and that this was one of the "direct causes" of the accident.[5] The report cited 11 specific violations of the airline's checklist procedures.[6] The report noted that special FAA en route inspections had previously disclosed "checklist deviations" and "suggest[ed] that the problems involved in this accident regarding improper checklist procedures were systemic at [Continental Airlines]. If pilots fail to adhere to procedures during en route inspections by FAA inspectors, they most likely behave in a similar manner when no inspector is present."

Each significant interruption creates a dilemma for the pilot: how can he or she be certain at what point in the list the interruption occurred?

The NTSB also criticized the airline's Normal Checklist policies: " … [The policies] for managing checklists do not consistently specify which [flight crew member] is responsible for initiating or accomplishing each item on the checklist, do not define [flight crew member] responsibilities for bringing to the attention of the pilot in command any observed deviation from prescribed procedures, do not include a policy for management of interrupted checklists, and do not specify that in the taxi and pretakeoff phases, specific aircraft configuration items, such as flaps, should be confirmed and responded to by both [flight crew members]."[7]

"How is it that reading of a checklist, which requires no special skill but only an appropriate, responsible attitude, seems to give so many problems within certain operational cultures?" asked Frank H. Hawkins, a British researcher of aviation human factors.[8] Could the contents, organization or design of certain checklists make them difficult to use or even discourage their use?

NTSB Recommended Checklist Study

Following the 1987 Detroit accident, the NTSB was concerned enough about checklist misuse and nonuse to recommend that the FAA take steps "to determine if there is any type or method of presenting checklists that produce better performance on the part of user personnel."

This article draws primarily on two studies that have appeared since — and in the first case, in response to — the NTSB recommendation. They are by Turner and Huntley, *The Use and Design of Flight Crew Checklists and Manuals*[9] and by Degani and Wiener, *Human Factors of Flight-deck Checklists: The Normal Checklist.*[10]

Both studies note important behavioral issues related to checklist use. Among those issues are the following:

- Many pilots use personal cues to remind them that it is time to begin a particular checklist; for instance, beginning the Taxi Checklist after receiving the taxi clearance, or the Before-takeoff Checklist when the aircraft reaches the hold line before the runway. But a problem arises when the normal cue is absent or is overlooked. It is believed that the crew of the accident aircraft in Detroit was interrupted before completing the Taxi Checklist, and by the time they might have completed it, the airplane's position at the airport was such that the environment no longer provided the cues that normally triggered the Taxi Checklist.[11]

- Accomplishing the checklist is subject to numerous interruptions and distractions — from air traffic control (ATC), ground crew, flight attendants and other sources. In a survey of airline pilots' views on checklists, reported by Turner and Huntley, one pilot responded: "*Try* and read checklist between CIVET (52.4 miles NE of LAX [Los Angeles International Airport]) and LAX on a VFR [visual flight rules] day. Typical to have six frequency changes, a dozen transmissions while ['setting up'] bugs and radios for two different approaches, and being assigned to side-step to land on a third runway."[12]

Each significant interruption creates a dilemma for the pilot: how can he or she be certain at what point in the checklist the interruption occurred? Some operators require the pilot to go back to the beginning of the checklist, and others do not. Many pilots have a system devised by themselves, but some rely on what Degani and Wiener call the human brain's "low-capacity short-term memory" that "has a very limited retention time for stored information."[13]

- Conversely, performing a checklist can be a distraction from other necessary cockpit tasks. One study of pilot-reported distractions found 22 reports labeled as distractions caused by checklist procedures.[14]

Some Pilots Take 'Short Cuts'

Because of the inconvenience occasioned by the checklist, some pilots have found "short cuts." Checklist items are sometimes skipped or "forgotten." Pilots may perform the checklist from memory. In a high-workload phase of flight, the pilot flying may offer the proper response to the call from the pilot not flying, only looking later to check whether the response affirming a setting or completion of a task was accurate. Some pilots perform the challenge-and-response items in "chunks" rather than one item at a time.[15]

These methods are adopted not out of indifference to safety but as a practical response to a busy and high-pressure cockpit environment. To one degree or another, however, such strategems defeat the checklist's purpose, which is to eliminate the reliance on the flight crew's memory or their *perception* that all items are properly configured.

In some cases, the size and formatting of Emergency Checklists makes them more difficult to read than Normal Checklists.

It may be that poorly written, organized and designed checklists encourage pilots to circumvent their use. Of course, crews are responsible for using the checklist as required, regardless of their opinion of it. But if some checklists are dysfunctional, it is clearly better to note their inadequacies and find improvements than merely to insist on crews using those checklists as they are.

Among the checklist deficiencies that have been identified are the following:

- Checklists that are difficult to locate in a flight manual or booklet. One NTSB accident investigation report commented on the checklist booklet from an accident airplane: "Locating a specific checklist requires the user to identify the desired checklist in the table of contents, note the number of the divider at which the checklist is filed, and turn to the desired checklist which is inserted before (forward of) the numbered divider"[16];

- Checklist procedures that are not in the order in which the steps should be accomplished;

- Checklist items that are not carried over from the airplane flight manual (AFM), or are inconsistent with actions prescribed in the AFM (Turner and Huntley found one case of "opposing actions being prescribed by the AFM and the operating checklist … ")[17];

- Checklist procedures that are incomplete;

- Checklists that suffer from poor organization, design and typography. "Often," Turner and Huntley found, "print was blurred, and contrast of print to background poor, despite the obvious fact that if … checklists are difficult to read, they will be difficult to use" [18]; and,

- Wide variations among operators concerning types of items included.

Some anomalies were found that applied specifically to Emergency Checklists:

- There is no standard definition for "emergency." One non-U.S.-manufactured aircraft had a checklist including 39 sets of emergency procedures, most of which would be considered "abnormal" by U.S. manufacturers. "[In-flight] events that are classified as emergencies (for example, low-level unpressurized flight) in one aircraft type but not another in the same fleet reduces the flight crews' respect for the term and contributes to their confusion regarding their priorities for action," said Turner and Huntley[19];

- Emergency Checklists are sometimes difficult to locate when needed, because they are contained in manuals that are stowed in flight bags;

- Some Emergency Checklists do not include procedures for all common emergencies; and,

- In some cases, the size and formatting of Emergency Checklists makes them more difficult to read than Normal Checklists. "The practice of using smaller, less legible type for [Abnormal] and [Emergency Checklists] was found [among] both major and regional carriers. Since these are checklists [that] are used under conditions of stress, and often with poor illumination, they should be as legible as possible, and surely not smaller than the [Normal Checklists]," said Turner and Huntley.[20]

Turner and Huntley also found instances of what they decried as a "lack of clarity of purpose of the checklist … ," citing items in checklists that would have been more appropriate in a training manual. "Pilots at the career stage of flying for an airline should not need basic flying lessons," they wrote. "Including training information in … checklists only increases their size and detail, and makes them more difficult to use for their intended purpose."[21]

Checklist Length Is Disputed

How long and how complete should a checklist be? Arguably, the checklist should include most of the items needed to configure the aircraft properly, but this can result in a long checklist. Degani and Wiener wrote, "The opponents of the above approach argue that a long and detailed checklist is no guarantee of absolute safety. Indeed, it carries the risk that some pilots might choose not to use the checklist or conduct it poorly because of its length."

But Degani and Wiener, who found no simple answer, also acknowledged that "this approach [of accommodating human nature by shortening the checklist, to reduce the temptation to skip or misuse it] may also subsequently produce problems. The plane may not be configured correctly in the setup phase, but this will pass unnoticed." Degani and Wiener appear to suggest that all that can be done is to think critically about the philosophy behind any given checklist and consider whether each item needs to be on it.[22]

If checklists that are easy to use will reduce cockpit workload and help avoid errors, what are the principles of designing such checklists? The basic theme was suggested by Hawkins: "The technical writer and designer of [specialized] documents … is responsible … for writing in a way to ensure accuracy and comprehension, to avoid ambiguity and to maintain motivation of the reader. He needs to be responsive to the practical needs of his reader and understand exactly how the document will be read and used."[23] The last phrase is particularly important, because a checklist may be technically accurate but still out of touch with practical realities — for instance, if a checklist designed for a high-workload phase of flight includes items that could be checked at another, less pressured, time.

The following guidelines emerged from the two major studies cited, as well as criteria based on research by Morris Bolsky and Chris Yuhas of Bell Laboratories[24]:

- Number procedural steps;
- Use simple, clear language and the fewest words that will convey the required meaning;
- Use words, symbols and abbreviations that are consistent with accepted aviation terminology;
- Use active voice ("set XYZ" or "XYZ set" rather than "XYZ is to be/will be/shall be set");
- List steps in a logical sequence. This may mean the order in which actions must occur for technical reasons, or where there is no technical requirement for a sequence, the natural "eye-and-hand" order based on the proximity of gauges, switches and levers in the cockpit;
- Place sublists such as Before-taxi and After-takeoff on the checklist in the order in which they will be used; and,
- Duplicate critical checklist items such as flaps/slats and trim on different checklists, because they may have been reset based on new information, or perhaps not set while awaiting new information. In its report on the Detroit DC-9 accident, the NTSB speculated that while "anticipating a different flap setting due to the runway change, the first officer might have elected to delay the deployment of the flaps until a specific runway would be assigned."

Some Checklist Items Need Special Attention

The two main studies cited in this article agreed that special treatment must be given in the checklist to safety-critical ("killer") items — for instance, fuel quantity and flaps before takeoff or gear down before landing. But the studies took different approaches to increasing the safety margin for these important items.

Turner and Huntley advocated including safety-critical steps as the final items on checklists, even if they were already included earlier. "This," they wrote, "will facilitate fast and last-minute reference to these items."[25]

Degani and Wiener believed that the best strategy is that "[very] critical items should be completed first on the task-checklist, and not last." Their reasoning is that the pilot flying has some degree of choice about when to call for checklists to be performed, and whenever possible will begin the checklist when the workload is low. For instance, the captain will call for the Taxi Checklist after the plane is clear of ramp obstacles, systems are working and the taxiway sequence has been assigned. At this point, it is likely that at least the first few items of the checklist can be accomplished without interruption or distraction, a probability that diminishes with time.[26] Although Degani and Wiener did not say so, crew members' alertness will probably be greatest at the beginning of a checklist, especially if it is a long one.

Turner and Huntley found in their survey of checklist usage that many checklists — even Emergency Checklists — were contained in manuals, often stowed in crew members' flight bags. This placement made the checklists awkward to find and use. The researchers recommended that all checklists be contained on a single $8^1/_2$-inch x 11-inch [21.59 centimeter x 27.94 centimeter] page, trifold or laminated. Among the reasons that they cited were:

- "Many pilots clip the checklists to the yoke or parts of the window apparatus for use. This is easy with one page — more than one page becomes too bulky;

- “A checklist of one page can be found more easily and quickly;
- “A single-page checklist is easier to stow and retrieve when needed; [and,]
- “We feel that anything that promotes ease of use with a checklist will discourage misuse, or neglect, of checklists.”

On that premise, Turner and Huntley recommended the following design guidelines:

- For headings, use 12-point type; for text, use 10-point type. This is a compromise specification aimed at keeping the one-page limit. If space permits, use 14-point type and 12-point type, respectively [As an illustration, the headings in this article are set in 14-point type, and the text is set in 10-point type];
- Use color coding. “Throughout the industry the use of color-coded annunciator lights is standard — red indicates ‘WARNING’ or danger, yellow indicates ‘CAUTION,’ green indicates safety. FlightSafety Canada Ltd. and some air carriers have carried this color coding through in checklist use. [Abnormal Checklists] are identified by headings of yellow, and [Emergency Checklists] by headings of red, with the ‘IMMEDIATE ACTION’ items boxed in red.” To fully carry through the scheme, Normal Checklists could be identified by green headings; and,
- Although black type on white paper is the usual specification, consider black type on a bright lemon-yellow background. A regional carrier–sponsored study indicated that the color combination is optimum for readability. Some fire departments have adopted yellow rather than the traditional red as a color for their fire engines, for similar reasons.

In keeping with the single-page concept, Turner and Huntley recommend printing the Normal and Emergency Checklists for each phase of operation on opposite sides of a single sheet or card, if possible within their print-size specifications. Otherwise, they say, Normal and Emergency Checklists should be kept in an easily accessible location in the cockpit — the former because they are used frequently, the latter because they must be immediately available when needed.

Other design specifications suggested by various sources include the following:

- Use Roman (non-italic) type, upper and lower case (i.e., avoid using all capital letters);
- Use consistent type, formatting and charts throughout the checklist; and,
- Leave adequate margins and spacing between lines of text and paragraphs.

Emergency Checklists Have Special Requirements

Emergency Checklists should generally follow the previously mentioned guidelines, but they have their own specialized requirements.

A prerequisite is that the Emergency Checklist must be arranged so that whatever section of it is needed can be located immediately. The 1980 Lockheed L-1011 accident in Riyadh, Saudi Arabia, illustrates why. All 301 occupants of the aircraft died from smoke inhalation and thermal injuries, even though the accident was in principle survivable because the aircraft landed safely and came to a controlled stop. But three minutes had been lost by the crew trying to locate the procedure for the aft cargo compartment smoke-warning procedure. Abnormal procedures were distributed among emergency, abnormal and additional sections, and the time lost in the search may have turned what could have been a minor accident into a tragedy.[27]

Emergency Checklists must be accessible to both the captain and the first officer. If it is practical, each pilot should be provided with a copy of the Emergency Checklist.

Emergency procedures are best grouped according to major aircraft systems, further divided into procedures for subsystems. If all the emergency procedures are in one binder rather than on separate pages or cards, the optimum design criteria are these:

- Use tab dividers to separate major divisions (e.g., aircraft systems), with smaller tabs separating subdivisions (e.g., engines, flight controls). Color code the tab dividers, page edges or both;
- Place the complete table of contents on the front of the binder, directly under the checklist title. Place the table of contents for each subdivision on the first page of each subdivision following the tab; and,
- Place page numbers in large type in a uniform location on each page.

Turner and Huntley, observing the checklist practices of various air carriers, found one of the best examples in the checklist booklet from FlightSafety Canada [Ltd.], for use in the Canadair Challenger 601. They wrote: “This [checklist booklet] included color-coded, laminated tabs, well-indexed [abnormal] and [emergency] sections, and heavy, hard-finished paper pages with 10-point type or larger. It was easy to use and very legible. Moreover, the aircraft for which it was designed had a convenient storage slot for it; its compactness would make it easy to adapt other aircraft to accommodate [such a checklist].”[28]

Regardless of the format of the Emergency Checklist, the following guidelines also apply:

- Ensure that all titles for specified emergencies are clear and unambiguous;
- In general, provide only the information needed to respond to the emergency, but ensure that the information is complete on the Emergency Checklist. Never require a pilot to consult another checklist for a specific emergency procedure;
- Consider including abbreviated normal descent, approach and landing checklists into Emergency Checklists, so that a crew handling an emergency in one of these phases of flight need not experience the additional strain of working from two separate checklists;
- In a procedure for responses to a cascading-failure event (e.g., low hydraulic pressure leading to a single-system loss, redundant-system loss and all-related-systems loss), incorporate a reference to related emergency procedures into the procedure for the precipitating-event procedure. This will allow the pilot to quickly access other procedures that may be required in a cascading failure. The associated emergencies' procedures should be bidirectional so that the pilot can quickly refer back to the procedure for the precipitating emergency; and,
- Before it is adopted, have the checklist reviewed by a human-factors specialist and thoroughly tested using line crew members in simulated abnormal or emergency conditions.

Turner and Huntley quoted with approval from a U.S. military specification an instruction that " … abbreviation is to be accomplished by omitting explanatory material and reducing the check item to the minimum necessary to describe the required action. For example, the step 'Reduce airspeed to 130 knots IAS [indicated airspeed] for best glide' can be abbreviated 'Airspeed — 130 KIAS Glide.'"[29]

But although brevity and simplicity are virtues in a checklist, it is necessary to bear in mind Hawkins' dictum that the writer of a specialized technical document "needs to be responsive to the practical needs of his reader and understand exactly how the document will be read and used."

Under routine conditions, a pilot is likely to have no difficulty supplying missing words in a much-condensed checklist item and mentally converting it into a full sentence. But in an emergency, the pilot is in a very different frame of mind. He or she is concentrating on one critical problem and what to do about it, and has little mental energy left for verbal interpretation. "Reduce airspeed to 130 knots IAS for best glide" might require a second longer to read than the proposed alternative, but it says unambiguously what to do and why.

Hawkins, in a discussion of documentation in general but with application to Emergency Checklists, said that "[keeping] sentences short does not mean using telegraphese, the kind of language used in telexes and newspaper headlines where cost or space are overriding. Leaving out words such as which, that or who can shorten a sentence but only at the cost of comprehension … ."[30]

Memory Items Raise Another Issue

An established air carrier has the right to decide whether or not to use memory items (also known as immediate-action items) in its Emergency Checklist. The rationale for memory items is that in certain emergencies no time can be lost when responding, even by consulting a checklist. Examples of procedures that require immediate action include explosive depressurization and runaway stabilizer trim.

The argument against memory items is that hasty action can be based on a mistaken diagnosis of the emergency, and lead to the wrong response. For an engine-fire warning in flight, a memory-item procedure might dictate shutting down the engine instantly. But a significant number of fire warnings result from faulty warning systems and bleed-air leaks. If the throttle lever is retarded, the fire warning may cease, especially in the case of a bleed-air leak. On short final or in a power-critical situation, it may be prudent not to secure the engine if no secondary indications of engine fire are observed.

Although the hand-held paper checklist remains the most common type among air carriers, other means of presenting the checklist have been adopted, especially by Part 91 (corporate) operators. These alternate means are intended to overcome some inherent problems associated with conventional hand-held paper checklists, especially the problem of remembering at what point in the checklist an interruption occurred. Table 1 (page 8) summarizes the advantages and disadvantages of each checklist format.

Among the alternative checklist presentation techniques are:

- **Mechanical devices.** A mechanical checklist uses plastic slides, each of which moves to cover or uncover checklist items printed on a panel. As the item is accomplished the slide is moved to cover the item's display. Electromechanical checklists use a similar principle. Item names are illuminated from behind, and a toggle switch is mounted beside each; as the item is accomplished, the switch is flipped to the "off" position, extinguishing the back-lighting for the item. In both cases, the system can display visually whether each checklist item has been accomplished.

One major U.S. airline uses mechanical and electromechanical devices for the Before-takeoff and Landing Checklists, but other task checklists are still performed from paper cards.

Table 1
Advantages and Disadvantages of Various Checklist Formats

Advantages	Disadvantages
Paper	
• Easy to use and to remove as the checklists are accomplished.	• Easy to mark and to deface.
• Easy to stow.	• Becomes worn and torn.
• Inexpensive to reproduce.	• Easy to misplace or to remove from the airplane.
• Inexpensive to update.	• May be difficult to use under poor lighting conditions.
Laminated Card	
• Rugged and difficult to destroy.	• More expensive to produce than paper lists.
• Difficult to mark and to deface.	• Bulky in comparison to a folded paper checklist.
• Fairly easy to stow.	
• Remains legible longer than paper checklists.	
Checklist "Booklet"	
• Groups all checklists together, including the Abnormal and Emergency Checklists.	• Can be bulky on aircraft with a large number of lengthy checklists.
• If properly tabbed, makes it easy to find any specific checklist.	
Mixed, Paper-slide or Paper–illuminated display	
• Positive check on checklist progress for those lists on the mechanical portion.	• Necessitates the use of two sets of lists.
• The lists on the mechanical device can be interrupted without losing track of progress.	• Slide or light switch combination requires cockpit space.
Cathode-ray Tube (CRT)	
• Cannot be lost.	• May displace another display such as radar.
• Can present systems schematics in the case of Abnormal or Emergency Checklists.	• Requires a lot of "heads-down" time.
• Color-coded for ease of use.	• Requires cockpit space.
• Presents no stowage problem.	• Can be cumbersome to find a list or to go back to a point in a list.
Scroll	
• Cannot be lost.	• Can be difficult to read because of size of print and distance from the viewer, and some are not lighted at night.
• Promotes "heads-up" posture.	• Difficult to go back to a prior item on a list.
• Relatively easy to make changes to checklists.	
• Stows out of the way on the glare shield.	
• Easy to mark progress.	

Source: Turner and Huntley[1]

- **Cathode-ray tube (CRT) checklists.** It is now technically feasible to display checklist items on a CRT screen. This type of display can be provided in two distinct categories. The first is a display and pointer system; the second incorporates the checklist display into a feedback loop with the aircraft's computerized monitoring system.

  In the display and pointer system, an index "page" for either Normal or Emergency Checklists appears onscreen, and via a cursor the pilot selects the desired checklist. After checklist items appear, the color of each item changes as the cursor moves to it, and when the item is executed, the color changes again. Skipped items remain in the original color.

  The second type of CRT checklist is used in the Airbus A320, which integrates the checklist with the airplane's electronic centralized aircraft monitoring (ECAM) computers. The critical items of the Takeoff and Landing Checklists appear onscreen before the corresponding phases of flight. The screen displays accomplished items and the status of each checklist item. Here, too, the technique is used only for takeoff and landing phases; other checklists are performed from paper cards.

- **Scroll checklists.** The scroll checklist is a narrow strip of paper that scrolls between two reels, and is contained inside a box fitted with a window and a linear position indicator. The scroll is advanced by the pilot as each checklist item is accomplished. This type of checklist is widely used in U.S. Air Force transport aircraft.

Although each of the alternative checklist forms offers some advantages, each has its own drawbacks. A CRT checklist display, for instance, may have to share a screen with weather radar, making it impossible to monitor weather in the flight path while performing a checklist. It also requires "heads-down" time for the pilots while using the system.

Optimizing the concept, design and format of checklists can be expected to overcome many of the behavioral problems associated with them. Other strategies for further reducing failure to conform to checklist discipline include:

- Pilot training should emphasize the importance of using standard phraseology in the checklist procedure. Like any other repetitive task, a checklist that uses precisely the same wording each time can be boring, and there is a temptation to vary the monotony by devising idiosyncratic phrases and using them in place of the standard ones. But as Hawkins noted, "As soon as check airmen begin to respond *boost pumps* instead of the printed *fuel pumps*, the door has been opened to [personalization] of the checklist."[31]

Minor modifications to the prescribed wording, which appear certain to be understood by other pilots, may seem innocuous. But, especially if the deviations are by the captain, the result is to diminish the importance and the seriousness of checklist procedures in other crew members' minds. More significant modifications, such as skipping items or indicating verification without actually verifying the item, then may acquire a semblance of legitimacy.

- Standard operating procedures should eliminate ambiguous or generalized responses such as "set," "checked," "completed" and "as required." Degani and Wiener concluded that "whenever possible, the response should always portray the actual status or the value of the item (switches, levers, lights, fuel quantities, etc.)."[32] This policy counteracts the normal psychological tendency to perceive what one expects to see, and makes it nearly impossible to go through the motions of verification without actually verifying an item's status.

- The captain should practice checklist management. Initiating a checklist should not be isolated from situational context. According to Degani and Wiener, the captain must make his call for a checklist in light of such considerations as: Is the other pilot overloaded with tasks? What are the consequences of the other pilot performing the checklist rather than other tasks? On the other hand, what are the likely consequences of delaying the checklist because of other considerations?

The captain must also constantly evaluate the quality of the checks performed by himself and the other pilot. If, because of interruptions, distractions, workloads or time pressures, the checklist performance seems to be substandard, it is the captain's responsibility to intervene and to create the conditions for proper execution of the job.

- Emphasizing crew resource management (CRM) helps maintain checklist-performance discipline, among other benefits. CRM promotes good interaction among the pilots in the cockpit. Because CRM recognizes that anyone is capable of a lapse, it encourages each crew member to raise questions if it appears that any aspect of standard procedures, including checklist procedures, has been violated.

Human Factors Can Weaken or Strengthen Checklist Procedure

The human-factors dimension of checklist performance can be where the system breaks down, as the Detroit and Dallas accidents appear to confirm. Yet human judgment and self-discipline can also provide the cement that binds together and thus strengthens a disparate mixture of regulations, procedures and technology.

Although much can be learned from existing studies, it is also important to recognize that much research remains to be done in improving the man/checklist/machine interaction. Other factors, perhaps extremely important factors, have yet to be explored. In checklist studies, as in aviation safety research generally, the focus must consider not only the aircraft but the most complex system on board the aircraft — the human mind and body. ♦

References

1. Joint Aviation Requirements, JARs-25, Large Aeroplanes. Advisory Material Joint (AMJ) 25.1309, System Design and Analysis.

2. Turner, John W.; Huntley, M. Stephen Jr. *The Use and Design of Flight Crew Checklists and Manuals.* A special report for the U.S. Federal Aviation Administration. Report No. DOT/FAA/AM-91/7. April 1991, p. A-6.

3. *Ibid*., p. 2.

4. U.S. National Transportation Safety Board (NTSB). *Safety Study, A Review of Flightcrew-Involved, Major Accidents of U.S. Carriers, 1978 Through 1990.* Report No. NTSB/SS-94/01.

5. U.S. National Transportation Safety Board (NTSB). *Runway Overrun Following Rejected Takeoff, Continental Airlines Flight 795, McDonnell Douglas MD-82, N18835, LaGuardia Airport, Flushing, New York, March 2, 1994.* Report No. NTSB/AAR-95-01, p. 48.

6. *Ibid*., p. 41–43.

7. *Ibid*., p. 56.

8. Hawkins, Frank H. *Human Factors in Flight*. Aldershot, England and Brookfield, Vermont, United States: Ashgate Publishing Co., 1987, p. 218.

9. Turner and Huntley, op. cit.

10. Degani, Asaf; Wiener, Earl L. *Human Factors of Flight-deck Checklists: The Normal Checklist.* A special report for the U.S. National Aeronautics and Space Administration (NASA). Contractor Report 177549. May 1990.

11. U.S. National Transportation Safety Board. *Aircraft Accident Report, DC-9-82 N312RC, Detroit Metropolitan Wayne County Airport, Romulus, Michigan.* Report No. NTSB /AAR-88/05, p. 58.

12. Turner and Huntley, *op. cit.*, p. 15.

13. Degani and Wiener, *op. cit.*, p. 35.

14. Monan, W.P. *Distraction — A Human Factor in Air Carrier Hazard Events.* Moffett Field, California, United States: U.S. National Aeronautics and Space Administration (NASA) Technical Memorandum 78608. 1979.

15. Degani and Wiener, *op. cit.*, p. 30.

16. Turner and Huntley, *op. cit.*, p. 22.

17. *Ibid.*, p. 13.

18. *Ibid.*, p. 24.

19. *Ibid.*, p. 24.

20. *Ibid*., p. 7.

21. *Ibid.*, p. 11 *et seq*.

22. Degani and Wiener, *op. cit.*, p. 20.

23. Hawkins, *op. cit.*, p. 209.

24. Bolsky, Morris I. and Yuhas, Chris M. *Performance Aids for Greater Productivity: How to Plan, Design, Organize and Produce Them.* Private communication, August 1975.

25. Turner and Huntley, *op. cit.*, p. 25.

26. Degani and Wiener, *op. cit.*, p. 51.

27. Hawkins, *op. cit.*, p. 209, 225.

28. Turner and Huntley, *op. cit.*, p. 22.

29. *Ibid.*, p. A-4.

30. Hawkins, *op. cit.*, p. 213.

31. *Ibid.*, p. 222.

32. Degani and Wiener, *op. cit.*, p. 41.

About the Authors

Richard L. Gross, M.S., is an aviation, human factors and systems safety consultant based in Dallas, Texas, U.S. He has investigated and analyzed numerous aircraft accidents and incidents, and is an expert witness. Gross is also a former Air Safety Investigator for the U.S. National Transportation Safety Board (NTSB) and served as engineering manager–flight test safety for Douglas Aircraft Co. He holds an airline transport pilot (ATP) certificate and has logged more than 5,750 flight hours.

The Flight Safety Foundation editorial staff, using the resources of the FSF Jerry Lederer Aviation Safety Library facilities, coauthored this article.

ASRS Data Show TRACON Most Often Involved In Reported Facility-related Incidents

Incidents in terminal airspaces are most often reported in "airspace-related" category.

Editorial Staff Report

U.S. incidents involving terminal radar approach control (TRACON) and air route traffic control centers (ARTCCs) made up the largest proportion of incidents involving facilities both in 1993 and in the 1987 through 1993 period, according to figures released by the U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS). Data are compiled by ASRS from voluntary reports by pilots and air traffic controllers, and are reported in de-identified form to the U.S. Federal Aviation Administration (FAA) for use in policy guidance.

For the one-year period and the seven-year period, TRACON incidents comprised the same percentage — 37 percent — of total incidents (Figure 1, page 12). The next largest group was incidents related to ARTCCs (32 percent in 1993, 35 percent in 1987–1993). Less frequently reported were incidents involving airport facilities during 1993 and 1987–1993 (25 percent and 23 percent, respectively) and control tower facilities (22 percent and 20 percent, respectively). Reports of incidents involving navigational aids, and FAA and other facilities, were negligible.

(Reported incidents could fall into more than one category, so percentages of the total among categories are more than 100 percent.)

The data base for incidents involving airspaces shows a somewhat different picture for 1993 alone vs. 1987–1993 (Figure 2, page 12). In 1993, incidents involving terminal airspace (including terminal control areas [TCAs, now Class B airspace] and airport radar service areas [ARSAs, now Class C airspace]) had the highest percentage of reports in the category (31 percent of the total incident data base); in the longer period, although the percentage was little different (29 percent), these incidents represented the second highest percentage in the category.

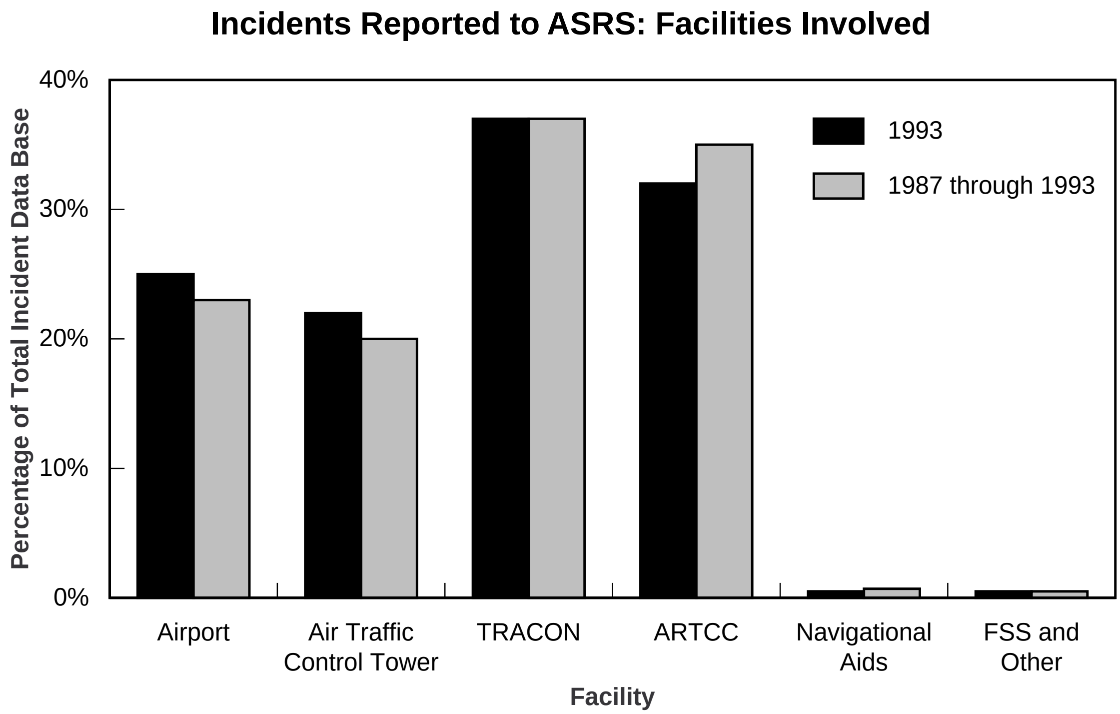
For 1987 through 1993, incidents involving ARTCC and other controlled airspaces represented the largest portion of the category (37 percent of the total incident data base). For 1993, the corresponding figure was 29 percent. There was also a significant number of reports for incidents involving airways (17 percent and 15 percent for 1993 and 1987–1993, respectively).

"Ground incidents" (Figure 3, page 13) represent a relatively small number of incidents among the total incident data base. "Runway transgression/other" incidents in both periods analyzed comprised 4 percent of the total incident data base, followed by "runway transgression/unauthorized landing" (3 percent in both periods).

"ATC [air traffic control] handling anomalies" that were reported represented 3 percent of the total incident data base for 1993 and 5 percent for 1987–1993 (Figure 4, page 13). Within that category, the largest number of reports concerned "ATC operational errors," 2 percent of the 1993 total incident data base and 3 percent of that for 1987–1993.

Because incidents are voluntarily reported to ASRS, they are subject to what is known as "self-reporting bias." The figures do not reflect the number of incidents in each category that actually occurred, nor are they a precise guide to the relative frequency of incidents among different categories. ASRS statisticians emphasize that about 96 percent of reports come from pilots rather than air traffic controllers, an imbalance that "causes the ASRS data base to have many more records describing pilot errors … than controller errors … ."

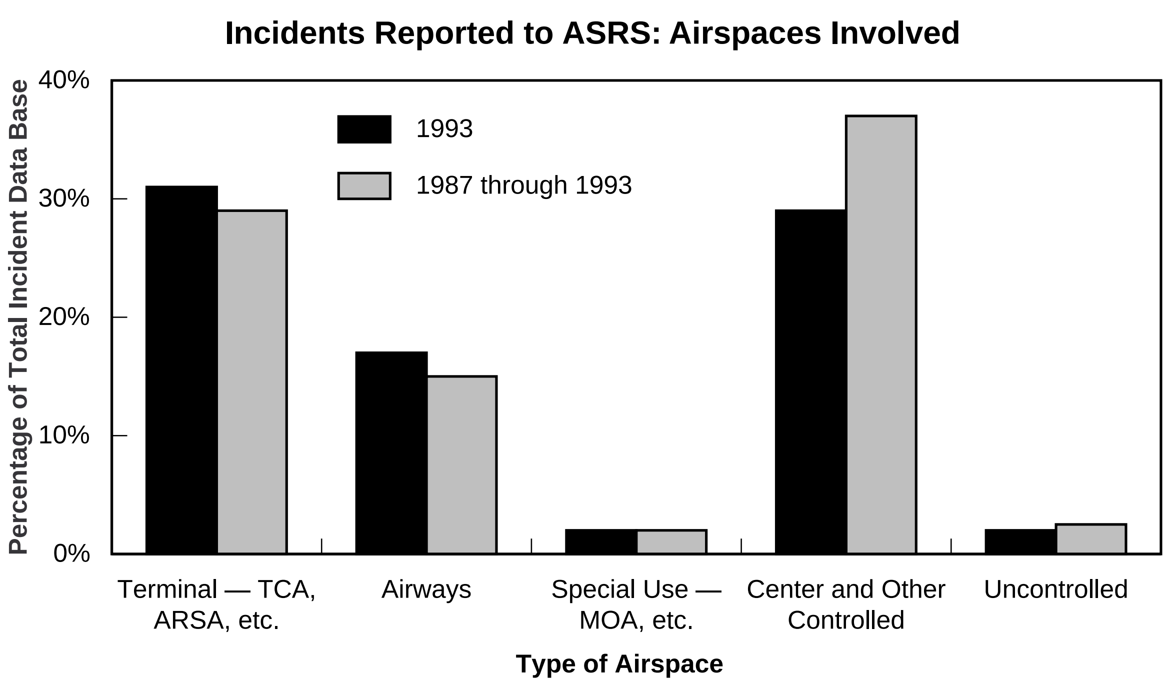
Nevertheless, ASRS reports do provide reliable estimates of the minimum numbers of incidents that occurred in each category, and can indicate problems that need attention.



TRACON: Terminal Radar Approach Control
ARTCC: Air Route Traffic Control Center
FSS: Flight Standards Service

Source: U.S. National Aeronautics and Space Administration, Aviation Safety Reporting System (ASRS)

Figure 1



TCA: Terminal Control Area
ARSA: Airport Radar Service Area
MOA: Military Operations Area

Source: U.S. National Aeronautics and Space Administration, Aviation Safety Reporting System (ASRS)

Figure 2

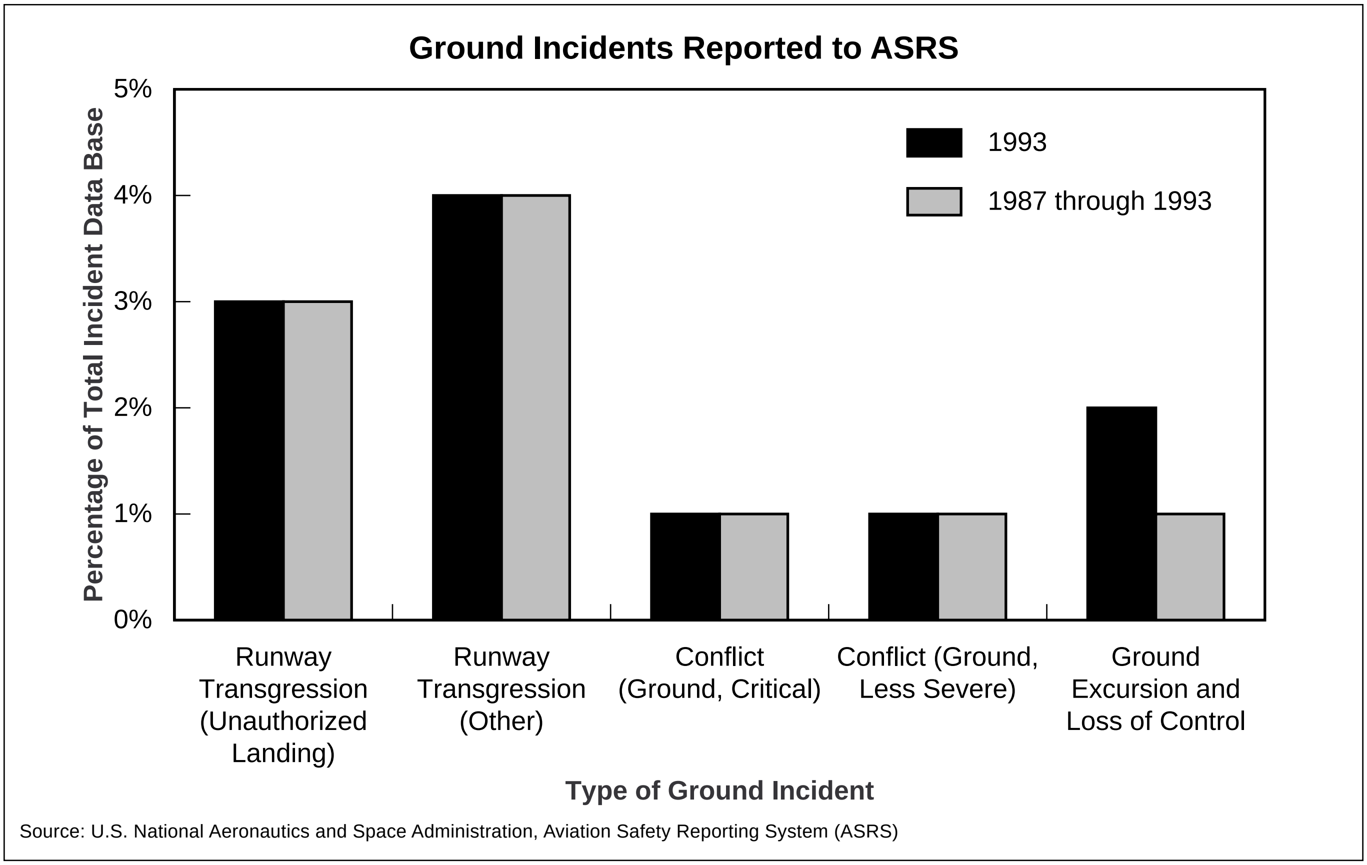


Figure 3

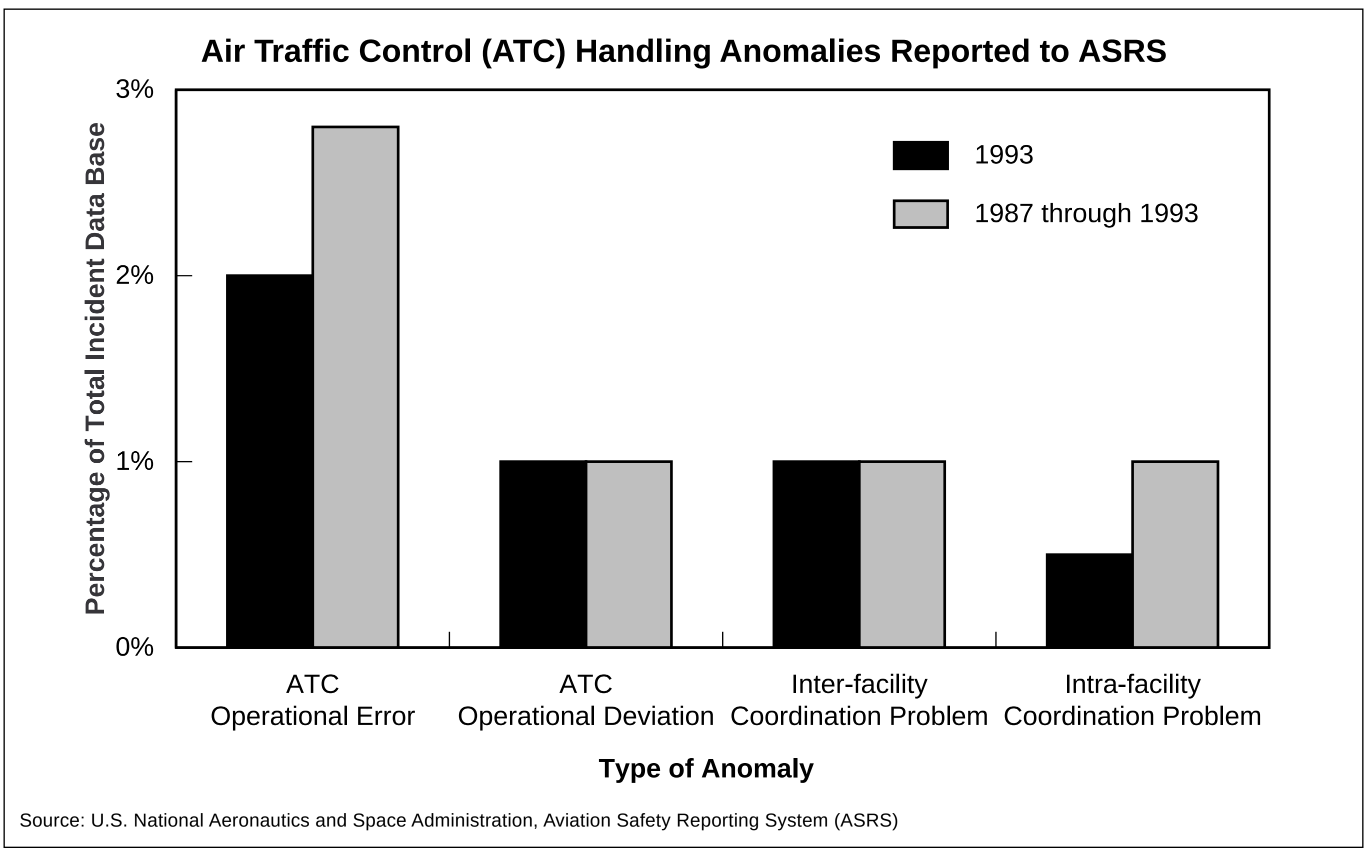


Figure 4

Publications Received at FSF Jerry Lederer Aviation Safety Library

Advisory Circular Announces Availability of Training Aid to Minimize Probability of Rejected-takeoff Accidents

Fatal Words *analyzes danger of miscommunication in aviation.*

—

Editorial Staff

Advisory Circulars (ACs)

Takeoff Safety Training Aid Announcement of Availability. U.S. Federal Aviation Administration (FAA). Advisory Circular (AC) No. 120-62. September 1994. 10 p.

This AC announces the availability of a joint FAA/industry Takeoff Safety Training Aid. The AC says that the goal of the Takeoff Safety Training Aid is to minimize the probability of rejected takeoff (RTO)-related accidents and incidents by improving pilots' ability to maximize takeoff performance margins; improving pilots' ability to make appropriate go/no-go decisions; and improving crews' ability to effectively accomplish RTO-related procedures.

According to the AC, the training aid is organized under four sections: Takeoff Safety — Overview for Management; Pilot Guide to Takeoff Safety; Example Takeoff Safety Training Program; Takeoff Safety — Background Data.

Helicopter Simulator Qualification. U.S. Federal Aviation Administration (FAA). Advisory Circular (AC) No. 120-63. October 1994. 58 p.; appendices.

This AC provides one acceptable means to qualify helicopter simulators for use in training programs or for airmen checking under various parts of the U.S. Federal Aviation Regulations (FARs). The guidelines in the AC are not mandatory.

The FAA has been involved in flight-simulator evaluation and approval since the mid-1950s, when air carriers were permitted to perform limited proficiency check maneuvers in airplane simulators. Since that time, however, simulators have reduced flight training costs for operators and made flight training safer. Although the FARs have been developed to permit the increased use of airplane simulators for flight training, they have not addressed the training and checking of crew members in helicopter simulators.

The AC says that helicopter simulators in use today have been approved on a case-by-case basis, but that it is expected that their use will expand rapidly and that applicable regulations will be amended to extend formal credit to the use of helicopter simulators in approved training programs.

Reports

Aviation Safety: FAA Can Be More Proactive in Promoting Aviation Safety. Mead, Kenneth M. Testimony before the Committee on Commerce, Science and Transportation, U. S. Senate. U.S. General Accounting Office (GAO). Report No. GAO/T-RCED-95-81. January 1995. 12 p. Available through GAO.**

Keywords:
1. Aeronautics — Safety Measures
2. Aeronautics, Commercial — Safety Measures — United States

Kenneth Mead, director, Transportation Issues, Resources, Community and Economic Development Division, GAO, said that the U.S. Federal Aviation Administration (FAA) has a key role, as regulator, to play in promoting aviation safety, and that the U.S. air transport system has achieved a high level of safety. Nevertheless, he added that GAO's work had identified several longstanding problems that handicap the FAA's oversight and its ability to proactively promote aviation safety. Mead noted the FAA's difficulty recruiting, training and retraining staff and said that GAO had found several occasions when the FAA had not effectively collected and analyzed data needed to target its inspection resources. He added that the FAA lacks a good system for obtaining complete, reliable data on problems experienced by aircraft.

International Aviation: DOT Needs More Information to Address U.S. Airlines' Problems in Doing Business Abroad. U.S. General Accounting Office (GAO). Report No. GAO/RCED-95-24. November 1994. Available through GAO.**

Keywords:
1. Airlines — United States
2. Aeronautics, Commercial — United States
3. Competition, International
4. Competition, Unfair

This report examines problems faced by U.S. airlines operating abroad, particularly in Europe and the Pacific Rim, and efforts by the U.S. Departments of State and Transportation to eliminate those problems. Obstacles identified in the report include limited access to landing and takeoff reservations, inadequate terminal facilities, restrictions on an airline's performance of ground services and restrictions and delays in processing cargo. These types of obstacles, the report notes, usually affect all airlines except the national carrier. The report also notes that non-U.S. carriers face fewer problems in the United States than U.S. airlines face abroad.

International Trade: Long-term Viability of U.S.–European Union Aircraft Agreement Uncertain. U.S. General Accounting Office (GAO). Report No. GAO/GGD-95-45. December 1994. Available through GAO.**

Keywords:
1. Aircraft Industry — Government Policies — United States
2. Aircraft Industry — Government Policies — Europe
3. Commercial Treaties — United States
4. Commercial Treaties — Europe

This report to the U.S. House of Representatives reviews details and implications of the 1992 U.S.–European Union bilateral aircraft agreement, which aimed to reduce government support to manufacturers of civil aircraft with 100-passenger or more capacity. The report says that the agreement has not been in effect long enough to note any changes in government support to the large civil aircraft industry.

The report says that the United States and the European Union have tried to encourage other countries with aerospace industries, such as Japan, Russia and China, to agree to limits similar the U.S.-European Union agreement, but the GAO does not believe that such an agreement will be reached in the near future.

An Assessment of Aviation Accident Risk of Aphakic Civil Airmen by Class of Medical Certificate Held and by Age: 1982–1985. Nakagawara, Van B.; Montgomery, Ronald W.; Wood, Kathryn J. A special report prepared for the U.S. Federal Aviation Administration (FAA) Office of Aviation Medicine. Report No. DOT/FAA/AM-95/11. 13 p.; tables, references. Available through NTIS.*

Keywords:
1. Vision
2. Aviation Accidents
3. Aphakia
4. Lens, Intraocular
5. Certification

Aphakia is a condition in which the eye's crystalline lens has been removed (often because of the removal of a cataractous lens). Opthalmologists usually use one of three methods to correct aphakia: eyeglasses, contact lenses and artificial or intraocular lens (IOL) implants. Implanting IOLs is the primary therapy for aphakia in the United States, the report says.

In the fiscal year (FY) "1992–1993 Annual Program Guidance and Current Policy Statement," the U.S. Federal Air Surgeon requested an investigation of these treatments as they relate to medical certification. The researchers compared the accident frequency of aphakic and nonaphakic airmen (with or without IOL) by medical certificate (first-, second- or third-class) and by age (more than or less than 50).

Weather Forecasting: Unmet Needs and Unknown Costs Warrant Reassessment of Observing System Plans. U.S. General Accounting Office (GAO). Report No. GAO/AIMD-95-81. April 1995. 49 p.; appendices. Available through GAO.**

Keywords:
1. Weather Forecasting — United States — Cost Effectiveness
2. United States — National Weather Service — Management — Evaluation

The GAO examined the U.S. National Weather Service's (NWS's) US$351 million automated surface observing system (ASOS) with the intention of determining what ASOS problems exist and how effectively NWS is resolving them; the cost of resolving them; and whether NWS's plans for implementing ASOS make sense in light of these problems.

ASOS automates observing and disseminating data on temperature and dew point, visibility, wind direction and speed, pressure, cloud height and amount, and types and amounts of precipitation. NWS intends to have ASOS replace human observers at many airports and most NWS weather service offices.

As of December 1994, NWS had bought 617 ASOS units, and accepted 491 of them; 47 of the 491 had been commissioned, and they provided the official weather observation. Nevertheless, thus far, no human observers have been released; they provide observations that ASOS cannot provide, such as of thunderstorms and tornadoes.

The GAO concluded that ASOS meets many but not all of its specified requirements, and that it does not provide some capabilities that some users say are crucial to ensuring safe aviation, effective weather-related decision making and accurate climatological analysis. Because of the volume and severity of these problems, NWS has temporarily halted further ASOS commissionings. NWS corrective actions are under way, the report said, but the service has not determined the range of problems that it will address, or how much the corrections will cost.

Functions of External Cues in Prospective Memory. Vortac, O.U.; Edwards, Mark B.; Manning, Carol A. A special report prepared for the U.S. Federal Aviation Administration (FAA) Office of Aviation Medicine. Report No. DOT/FAA/AM-95/9. February 1995. 17 p.; references. Available through NTIS.*

Keywords:
1. Automation
2. Air Traffic Control
3. Flight Progress Data
4. Cognitive Psychology
5. Memory
6. Applied Psychology

Prospective memory can be characterized by the phrase “Do not forget to ... .” External cues, such as an alarm, often trigger prospective memory. Nevertheless, triggers often indicate that it is time to take action, but not what action. Triggers can be combined with content components (e.g., putting something next to the door to remind you to take it with you when you leave) to indicate that it is time to take action and what the action to take is.

This study used a simulation of an air traffic control task as the setting to investigate the functions of external cues in prospective memory. The researchers performed two experiments that came to the same conclusion: the primary function of an external cue was to support retrieval of the to-be-performed action. The report also discusses implications for the design of a computer interface to present cues.

Bibliography of Lewis Research Center Technical Publications Announced in 1993. U.S. National Aeronautics and Space Administration (NASA) Technical Memorandum No. 106666. November 1994. 470 p.

Keywords:
1. Bibliographies
2. Abstracts
3. Documentation
4. Indexes (Documentation)

This compilation of abstracts indexes and describes 733 technical publications and 283 additional contractor-authored research reports published by NASA’s Lewis Research Center in 1993. All reports were first announced in the 1993 issues of *Scientific and Technical Reports* (STAR) and/or *International Aerospace Abstracts* (IAA).

Relationships of Type A Behavior with Biographical Characteristics and Training Performance of Air Traffic Controllers. Nye, L.G.; Schroeder, D.J.; Dollar, C.S. Report No. DOT/FAA/AM-94/13. A special report prepared for the U.S. Federal Aviation Administration (FAA) Office of Aviation Medicine. July 1994. 14 p.; appendix; references. Available through NTIS.*

Keywords:
1. Air Traffic Control
2. Type A Behavior Pattern
3. Health Behavior
4. Personnel Training

Data concerning the importance of personality factors in the performance of an air traffic control specialist (ATCS) are limited. This study was part of an expanded research program: selective personality measures and biographical questionnaires were administered to ATCSs upon entry to the FAA Academy Nonradar Screen Program. At the beginning of the nine-week screening program, the Jenkins Activity Survey (JAS) and a biographical questionnaire were given to 474 ATCS students, and scored on the JAS, Achievement Striving (AS) and Impatience-Irritability (II) scales. Analyses of the JAS questions confirmed the presence of AS and II factors, but correlations between achievement at the academy and AS were not significant. Previous research had recorded a positive relationship between AS and academic achievement in college.

Johnson Space Center Research and Development Annual Report 1994. U.S. National Aeronautics and Space Administration (NASA) Technical Memorandum 104787. August 1994. 216 p.; ill. Available from the NASA Center for Aerospace Information, 800 Elkridge Landing Road, Linthicum Heights, MD 21090-2934, United States.

Keywords:
1. Research Projects
2. Research and Development
3. NASA Programs
4. Technology Utilization
5. Space Technology Experiments

This report complements the *Johnson Space Center (JSC) Research and Technology Annual Report* and is intended to communicate the JSC’s accomplishments in research and technology development. Topics covered are Computer Hardware and Software; Medical, Life and Space Sciences; and Space Systems.

Simultaneous Gas-chromatographic Determination of Four Toxic Gases Generally Present in Combustion Atmospheres. Endecott, Boyd R.; Sanders, Donald C.; Chaturvedi, Arvind K. Report No. DOT/FAA/AM-94/18. A special report prepared for the U.S. Federal Aviation Administration (FAA) Civil Aeromedical Institute (CAMI). September 1994. 9 p.; ill. Available through NTIS.*

This study describes the development of a method suitable to analyzing carbon monoxide (CO), hydrogen sulfide (H_2S), sulfur dioxide (SO_2) and hydrogen cyanide (HCN). Toxic effects of individual gases depend on the gases' concentration and the duration of exposure to the gases. Nevertheless, rapid, precise and simultaneous measurement of gases present in combustion atmospheres is limited; most quantitation methods are primarily limited to quantitating one gas at a time. The method described in this report is suitable for measuring CO, H_2S, SO_2 and HCN individually, in mixtures and in combustion atmospheres at two-minute intervals.

Books

Fatal Words: Communication Clashes and Aircraft Crashes. Cushing, Steven. Chicago, Illinois, U.S.: The University of Chicago Press, 1995. 174 p.; appendices, notes, glossary, index.

Keywords:
1. Aeronautics — Terminology
2. Airplanes — Piloting — Terminology
3. Air Traffic Control — Terminology
4. Aeronautics — Accident Investigation
5. Communication of Technical Information

Steven Cushing is associate professor of computer science at Boston University. Miscommunication, he writes, has led to many aircraft disasters. Miscommunication can result from colloquialisms being used instead of accepted phraseology, from a pilot not listening closely to repeated instructions or from homonyms (e.g., "to" and "two") being mistaken for each other. As a short-term solution, Cushing suggests a visual communication system, including a touchscreen interface, that would supplement voice communication. The appendix is a technical description of such a system. As a long-term solution, he outlines a voice interface to filter conversations and to provide real-time feedback to make confusing language more understandable.♦

* 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)
P.O. Box 6015
Gaithersburg, MD 20884-6015 U.S.
(202) 512-6000
(301) 258-4066 (fax)

Federal Aviation Regulations (FARs)

Part	Date	Subject
Part 135	3/6/95, 4/23/95	*Air Taxi Operators and Commercial Operators* (incorporates Special Federal Aviation Regulation [SFAR] 38-9, "Certification and Operating Requirements," adopted 6/18/93; SFAR 38-10, "Public Aircraft Definition and Exemption Authority," adopted 1/6/95; Amendment 135-55, "Improved Flammability Standards for Materials Used in the Interiors of Transport Category Airplane Cabins," adopted 1/24/95; Amendment 135-56, "Improved Flammability Standards for Materials Used in the Interiors of Airplane Cabins," 3/6/95).

Advisory Circulars (ACs)

AC No.	Date	Title
120-51B	1/3/95	*Crew Resource Management Training* (cancels 120-51A, *Crew Resource Management Training*, dated 2/10/93).

Accident/Incident Briefs

Tight, Fast Turn onto Taxiway Sends Nose Wheel into Mud

Pilot flies in marginal weather, aircraft impacts mountain in heavy snowfall.

Editorial Staff

The following information provides an awareness of problems through which such occurrences may be prevented in the future. Accident/incident briefs are based on preliminary information from government agencies, aviation organizations, press information and other sources. This information may not be entirely accurate.

Air Carrier

Fast Turn Ends in Mud

McDonnell Douglas MD-80. Minor damage. No injuries.

After a daylight landing, the pilot initiated a 135-degree turn off the runway onto a taxiway when the aircraft's speed was 38 knots.

Nose-wheel steering became unresponsive about two-thirds through the turn and the nose wheel went off the taxiway and into deep mud. There were no injuries among the seven crew members and 142 passengers. An investigation found no anomalies with the nose-wheel steering or brakes.

Reverser Cowling Separates During Landing Roll

Airbus A300. Minor damage. No injuries.

After a normal landing, the pilot engaged reverse thrust. There was a bang and vibration in the throttles.

On clearing the runway, the engine thrust reverser would not stow and the amber panel light would not extinguish. It was determined that the right half of the No. 2 engine reverser cowling had separated from the aircraft during the landing roll. The cowling section measured about 12 feet (3.7 meters) long and four feet (1.2 meters) wide. There were no injuries among the crew of 11 and 152 passengers.

Air Taxi Commuter

Worn Part Causes Horizontal Stabilizer Trim Failure

De Havilland DHC3 Otter. No damage. No injuries.

The aircraft was in daylight cruise flight when it suddenly pitched nose down. The crew maintained control by applying strong back pressure on the control wheel and adding nearly full engine power.

After an otherwise uneventful landing, it was determined that the horizontal stabilizer trim actuator jack screw had failed. The actuator was found to be excessively worn and it had not been lubricated properly.

NTSB Makes Commuter Safety Major Priority

The U.S. National Transportation Safety Board (NTSB) has added commuter aviation safety to its list of top 10 "Most Wanted" transportation safety improvements.

The NTSB said May 16 that statistics indicate that the number of passengers flying on regional and commuter air carriers will nearly double from the 1995 estimate of 58 million to more than 109 million passengers in 2005.

"While both the FAA [U.S. Federal Aviation Administration] and aviation industry are moving to require one level of safety for both large carriers and smaller commuter operations, [this] action publicly emphasizes the NTSB's desire to see these safety upgrades implemented as soon as possible," said NTSB Chairman Jim Hall.

Corporate Executive

Pilot Defies Marginal Weather, Aircraft Crashes into High Terrain

Piper PA-31. Aircraft destroyed. Six fatalities.

The pilot of the twin-engine PA-31 was advised of marginal weather conditions, including low ceilings and snow showers. He did not file a flight plan for the night flight.

The aircraft was last depicted on radar as flying about 2,500 feet (763 meters) above mean sea level (MSL) and heading toward high terrain. The aircraft struck a 3,400-foot (1,037-meter) mountain at 2,500 feet in heavy snowfall.

The aircraft was located four days after the crash. It had been destroyed by impact and a postimpact fire. The pilot and five passengers were killed.

Improperly Installed Part Causes Engine Failure

Piper PA-60. Aircraft destroyed. Five fatalities.

After a daylight takeoff, the right engine failed during initial climb. The pilot lost control of the twin-engine aircraft and it collided with terrain. The aircraft was destroyed by impact and a postcrash fire. The pilot and four passengers were killed.

An investigation determined that a modification kit for the fuel injector air control was installed incorrectly and that it allowed an unfiltered air source. Spectral analysis of residue from the right engine's turbocharger compressor revealed that it had the same composition as the alternate air door seal.

Other General Aviation

Engine Power Loss, Power Lines Thwart Local Flight

Cessna 172. Substantial damage. No injuries.

The aircraft departed a Canadian airport for a short, local flight. About 30 minutes after the airplane's departure, the engine lost power.

The pilot applied full carburetor heat and set up for an emergency landing in a field. As the aircraft approached the field, the engine regained power and the pilot executed a go-around. As the aircraft approached power lines at the end of the field, the engine lost power again.

There was insufficient altitude to clear the power lines and the aircraft struck the top of a power-line pole. The pilot was able to maintain control of the aircraft and land the aircraft in a nearby field.

Low Clouds Prove Fatal for High-performance Single

Mooney M-20E. Aircraft destroyed. Three fatalities.

The Mooney was observed to enter low clouds during a daylight flight. A short time later, the aircraft struck tall trees and collided with rocky ground at an elevation of 3,000 feet (915 meters).

The aircraft was destroyed by impact and a postcrash fire. The pilot and two passengers were killed.

Rotorcraft

Survey Flight Ends in Collision With Power Lines

Bell 206B. Aircraft destroyed. One fatality. Three serious injuries.

The helicopter was conducting a wildlife population survey below 200 feet (61 meters) above ground level (AGL) when it struck power lines unmarked by warning devices. The power lines were depicted on the sectional chart and the pilot was familiar with the area.

Investigators determined that the unmarked span of $^{7}/_{16}$ inch (11.1 millimeters) wire was about 3,000 feet to 4,000 feet (915 meters to 1,220 meters) between towers. Other pilots had reported that the wires were difficult to see.

The helicopter was destroyed by the impact and a postcrash fire. The pilot and two passengers received serious injuries. A third passenger was killed. Weather at the time of the accident was reported as visual meteorological conditions with clear skies.

Tangled Cables Cripple Helicopter

Bell 47-G3B1. Substantial damage. One minor injury.

The helicopter was stringing power lines when a long line used to string the cables caught in the guy wires of one of the transmission towers. The aircraft became uncontrollable and impacted the ground.

The pilot, the sole occupant, received minor injuries. Weather at the time of the accident was reported as visual meteorological conditions with clear skies and winds at 10 knots.

Steam Cloud Disorients Pilot

Hughes 369D. Substantial damage. Two minor injuries.

The helicopter was operating in daylight in the vicinity of a volcano when it flew into a steam cloud. The aircraft was flying at about 40 feet (12.2 meters) above ground level (AGL) when it became enveloped in the cloud.

The pilot lost control of the helicopter and it collided with terrain. The pilot and a passenger suffered minor injuries in the crash. Rescue efforts and access to the helicopter were made difficult because of sulfuric fumes from the steam. Weather at the time of the accident was reported as visual meteorological conditions, clear skies and four miles (6.4 kilometers) visibility.

Load Net Snares Tail Rotor

Hughes 369D. Substantial damage. No injuries.

The helicopter was lifting construction supplies to a power-line tower in a mountainous area when the daylight accident occurred. A load of dry cement had just been delivered in a cargo net above a staging area.

As the helicopter established a 20-foot hover at the staging area, the net rose upward into the tail rotor. The tail-rotor assembly and gearbox separated from the tail boom and the helicopter began to spin. The pilot entered an autorotation and landed hard. The pilot was not injured, but the aircraft sustained substantial damage. Weather at the time of the accident was reported as visual meteorological conditions with 2,500 feet broken and visibility seven miles. ♦

FLIGHT SAFETY DIGEST

Staff: Roger Rozelle, director of publications; Girard Steichen, assistant director of publications; Kate Achelpohl, editorial assistant; Rick Darby, editorial consultant; and Karen K. Bostick, production coordinator.

Subscriptions: US$95 (U.S.-Canada-Mexico), US$100 Air Mail (all other countries), twelve issues yearly. • Include old and new addresses when requesting address change. • Flight Safety Foundation, 2200 Wilson Boulevard, Suite 500, Arlington, VA 22201-3306 U.S. • Telephone: (703) 522-8300 • Fax: (703) 525-6047