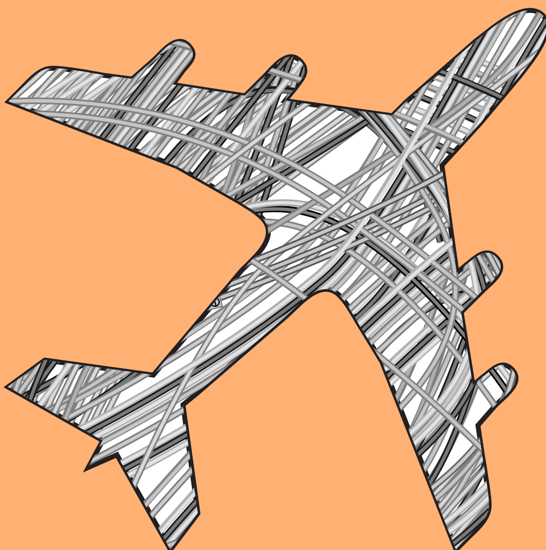
FLIGHT SAFETY FOUNDATION
Aviation Mechanics Bulletin

JULY–AUGUST 1998

Age-related Failures of Aircraft Wiring Remain Difficult to Detect



FLIGHT SAFETY FOUNDATION
1947–1997

FLIGHT SAFETY FOUNDATION

Aviation Mechanics Bulletin

Dedicated to the aviation mechanic whose knowledge, craftsmanship and integrity form the core of air safety.

Robert A. Feeler, editorial coordinator

July–August 1998 **Vol. 46 No. 4**

Staff: Roger Rozelle, director of publications; Rick Darby, senior editor; Mark Lacagnina, senior editor; Wayne Rosenkrans, senior editor; John D. Green, copyeditor; Karen K. Ehrlich, production coordinator; Ann L. Mullikin, assistant production coordinator; and David Grzelecki, librarian, Jerry Lederer Aviation Safety Library.

Subscriptions: US$35 (U.S.-Canada-Mexico), US$40 Air Mail (all other countries), six issues yearly. • Include old and new addresses when requesting address change. • Flight Safety Foundation, Suite 300, 601 Madison Street, Alexandria, VA 22314 U.S. • Telephone: (703) 739-6700 • Fax: (703) 739-6708

What's Your Input?

In keeping with FSF's independent and nonpartisan mission to disseminate objective safety information, Foundation publications solicit credible contributions that foster thought-provoking discussion of aviation safety issues. If you have an article proposal, a completed manuscript or a technical paper that may be appropriate for *Aviation Mechanics Bulletin*, please contact the director of publications. Flight Safety Foundation assumes no responsibility for submitted material. The publications staff reserves the right to edit all published submissions. The Foundation buys all rights to published manuscripts. Payment is made to authors upon publication. Contact the Publications Department for more information.

Age-related Failures of Aircraft Wiring Remain Difficult to Detect

FSF Editorial Staff

Maintenance technicians are familiar with the types of aircraft-wire failure caused by chafing, cutting and other visible forms of damage. When such damage is observed, the wire usually is repaired or replaced.

Most maintenance technicians believe that unless there is visible damage to wire, maintenance is not necessary.

"The assumption is that wiring is good for the life of the aircraft," said George Slenski of the Air Force Research Lab, Wright Patterson Air Force Base, Dayton, Ohio, U.S.[1]

There is, however, another type of aircraft-wire failure that usually is not detectable by visual inspection and is caused by age-related degradation of wire insulation, said Armin M. Bruning, Ph.D., president and technical director of Lectromechanical Design Co. of Sterling, Virginia, U.S.[2]

"The second type of failure is not widely recognized in the wiring fraternity, nor [is it] aggressively addressed in the specification world," said Bruning.

"[This type of failure] has some interesting characteristics. It is so small that it usually cannot be [detected] by visual inspection. The effect on operations usually shows up as an intermittent fault of connected operating equipment, although in rare cases it can cascade into an arc which becomes dramatically visual."

Although age-related failure of aircraft wire usually cannot be detected by visual inspection, there are methods to test aircraft wiring systems and predict when age-related failure will occur, said Bruning.

Destructive and nondestructive testing methods to predict age-related wire failure are relatively new. Bruning believes that end-of-life predictions can be incorporated in aircraft-wire design and production standards, and in aircraft maintenance.

Bruning defines "end of life" as the time when a break or fracture sufficient to cause arcing first occurs in insulation. He said a microfracture usually is sufficient to cause arcing.

"Note [that] we do not use the ultimate failure manifestation of an electric arc or [intermittent] failure of connected equipment as the marker of wire failure," said Bruning.

Bruning said that some aircraft designers and wire manufacturers do not consider an insulation microfracture to be an indication that the wire has failed.

"I appreciate that many will not agree with [our] approach, saying that as long as the equipment operates OK, the presence of leaking insulation is acceptable," said Bruning. "On the other hand, it can be demonstrated that such fractures may allow generation of radio-frequency EMI [electromagnetic interference] and can lead to arcing flashover.

"We know of no standard that says how much and what form of wire current leakage is acceptable. We know of an extreme case of an aircraft in which 20 percent of one-foot [0.3-meter] sections of 126 feet [38 meters] of flight-critical wiring [had] the types of trauma [illustrated in] the photograph on page 3. This aircraft was being used in flight."

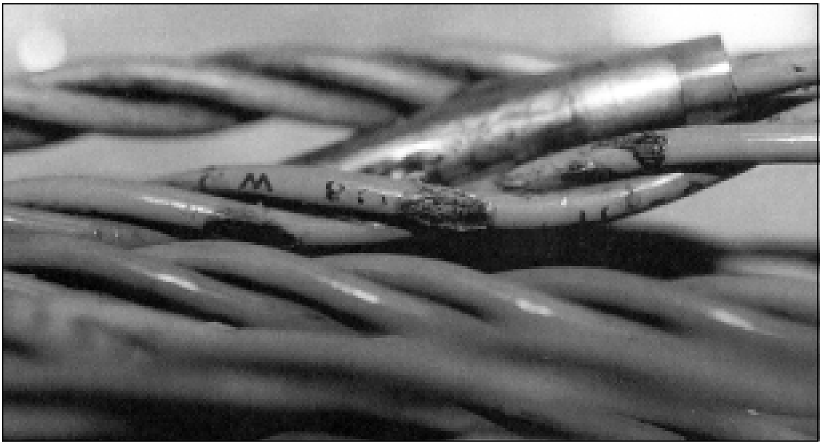
Bruning said that regardless of how end of life is defined, four variables should be considered when testing aircraft wire:

- Form of wire- insulation failure;
- Environmental effects on the physical properties of the insulation;
- Forces that cause the structure and material of the insulation to fail; and,
- Variations in wire-insulation properties.

Forms of failure. Bruning said that there are two forms of failure: traumatic failure and gradual-aging failure.

"The 'traumatic failure' is the one with which those of us in the maintenance world routinely cope," said Bruning. "Usually, in an aircraft-operational mode, this physical form of failure brings itself to our attention by faulty aircraft operation. We locate it by 'visual inspection.' For the front-line operating electrician, the repair is a well-practiced routine."

Gradual-aging failure occurs when wire insulation degrades to the point



Trauma failure of wire insulation usually is detectable by visual inspection.
(Source: Armin M. Bruning)

that microfractures occur. Bruning said that because insulation microfractures usually cannot be detected by visual inspection of wire, gradual-aging failures are reported seldom. Therefore, the extent of gradual-aging failure of aircraft wire is not known.

Bruning said that there is anecdotal evidence that age-related failure of aircraft wire causes intermittent failure of electronic equipment. Such failures are referred to informally as "gremlins" and "glitches," and usually cannot be detected through visual inspection of the wiring and equipment.

"One of the most insidious aspects of this aging failure … is … that this silent, slow-to-happen fracturing is associated with a progressive deterioration of other stress-supporting characteristics of a polymer," said Bruning.

"In other words, as the material ages and moves toward the 'silent-fracturing' stage of its life, it also becomes susceptible to overt failure from milder forces *that produce the same proximate failure appearance as normal 'abusive' trauma*. But, in fact, these gross failures can be the result of minor stresses which existing specifications had ensured the new wire could sustain.

"Older wire — like aging people — becomes more delicate. Field data and laboratory tests [are required] to distinguish between [traumatic and age-related] failures."

Bruning said that although traumatic failure and age-related failure of aircraft wire appear identical, the preventive measures are very different.

Environmental effects. Bruning said that tests have shown substantial changes in the aging rates of aircraft wiring from variations in exposure to two environmental factors: moisture and temperature.

"Because of the sharp change in aging rate at different values, the frequently asked question — 'Which ages [aromatic] polyimide [insulation] more: water or temperature?' — is a non sequitur [an inference that does not follow the evidence]," said Bruning.

"Classical test specs for wire performance are commonly at some extreme condition which will occur only at [a] few locations in an aircraft for short periods of time. It is clear that longer times at [which aircraft wiring is exposed to] more moderate conditions may have a more damaging effect than [exposure to] an extreme condition for a short time."

Bruning said that an example is the degradation of wire in an aircraft exposed to an environment of 90 percent relative humidity 10 times longer than the aircraft is exposed to an environment of 100 percent relative humidity; the temperature in both environments in this example is 70 degrees Celsius [158 degrees Fahrenheit].

"The degradation of the [aircraft's wire-insulation] polymer at the lower humidity will be twice as much as at the higher humidity," said Bruning.

Types of forces. Many types of mechanical forces are applied either continually or intermittently to aircraft-wire insulation, said Bruning. Among the most common types of forces are bending, flexing, torsion, vibration, chafing (abrasion), cutting, impact and crushing.

Bruning said that the ability of aircraft-wire insulation to resist these forces decreases as the wire ages. The rate at which damage resistance degrades varies according to the types of forces applied to the wire.

For example, Bruning said that tests showed that the ability of aromatic polyimide insulation to resist chafing decreases more quickly than the insulation's ability to resist strain.

"We have data indicating that chafing resistance deteriorates about twice as fast as bending-failure resistance," said Bruning.

Variation in insulation properties. The ability of aircraft wire to resist damage is affected substantially by variation of the chemistry and structure of the insulation, said Bruning.

Changes in the physical characteristics of aircraft-wire insulation can be caused by stresses applied to the wire during installation, said Bruning. But Bruning said that he also has found significant variations in the chemistry and structure of insulation along lengths of wire before the wire was installed in aircraft.

"We [have found] this variation in the same production run [of wire] on the same reel," said Bruning. "The variations existed in aircraft wire manufactured to the same specifications.

"We have thousands of tests of specimens that show such results. Such variation is the rule, not the exception."

Bruning said that testing aircraft wire for the purpose of predicting age-related failure presently is performed on a very limited basis worldwide on military aircraft and not at all on commercial aircraft.[3]

Bruning said, however, that attention to potential problems caused by the aging of aircraft wire was increased recently in the United States by the White House Commission on Aviation Safety and Security.

The commission directed the U.S. Federal Aviation Administration (FAA) to expand the activities of its Airworthiness Assurance Working Group (AAWG) to consider age-related problems in aircraft nonstructural systems, including wiring. The AAWG is responsible for ensuring safe operation of aging aircraft in the United States.

"The programs in existence under the AAWG have been effective and are considered adequate to deal proactively with the structural problems associated with aging commercial aircraft," said the White House Commission on Aviation Safety and Security.[4]

"However, much less is known about the potential effects of age on nonstructural components of commercial aircraft. Nonstructural components include: electrical wiring; connectors, wiring harnesses and cables; fuel, hydraulic and pneumatic lines; and electromechanical systems such as pumps, sensors and actuators."

The commission said that "existing procedures, directives, quality assurance and inspection may not be sufficient to prevent safety-related problems caused by the corrosive and deteriorating effects of nonstructural components of commercial aircraft as they age."

The FAA has an Aging Aircraft Plan to solve structural problems and is developing an Aging Systems Plan to solve nonstructural problems, including aging of aircraft wiring systems. "One thing we expect to address is wiring-inspection intervals," said Les Dorr, a public affairs spokesman for the FAA.[5]♦

References

1. Slenski, George. Interview by Lacagnina, Mark. Alexandria, Virginia, United States, 9 June 1998. Flight Safety Foundation, Alexandria, Virginia, United States.

2. Bruning, Armin M. "Aging Measurements of Operating Aircraft: Implications for Specification Writing and Aircraft Reliability." Paper presented at Society of Automotive Engineers Aerospace Electrical Interconnect System Conference, Williamsburg, Virginia, United States, October 1997.

3. Bruning, Armin M. Interview by Lacagnina, Mark. Alexandria, Virginia, United States. 3 June 1998. Flight Safety Foundation, Alexandria, Virginia, United States.

4. Gore, Al. *Final Report to President Clinton*. White House Commission on Aviation Safety and Security. 1997.

5. Dorr, Les. Interview by Lacagnina, Mark. Alexandria, Virginia, United States. 3 June 1998. Flight Safety Foundation, Alexandria, Virginia, United States.

MAINTENANCE ALERTS

NTSB Wants Inspections of Wiring In Boeing 747 Fuel Tanks

The U.S. National Transportation Safety Board (NTSB) has recommended inspections of the fuel-quantity-indication system (FQIS) wiring in Boeing 747 (B-747) center-wing fuel tanks and modifications of the system to eliminate potential ignition sources. The NTSB also said that fuel-tank electrical surge-protection systems should be required in all transport airplanes.

The NTSB found damaged FQIS wiring in the B-747 that exploded during initial climb in New York, U.S., on July 17, 1996 and in three other B-747s that were retired from airline service. The damage included cuts in wire insulation from contact with the knurled surfaces and edges on Honeywell Series 1-3 fuel-probe and compensator terminal blocks, and chafing of wire insulation under strain-relief clamps and at points of tight contact between wires.

"The damaged wiring at the terminal blocks was found only after the wiring had been removed," said the NTSB. "A close visual inspection in the [center-wing fuel] tank without removing the wires would have been insufficient to disclose damage that is concealed between wires or under wire clamps. These types of damage could create spark gaps that are very small and that could become latent failures in the wiring systems."

The NTSB also found deposits of copper, silver and sulfur on fuel-probe wiring connections. "The deposits … were determined to be similar to copper sulfide deposits found in previous examinations of fuel probes from military aircraft. The [U.S. Air Force research] laboratory had previously found that the deposits gradually reduced resistance between [fuel probe] electrical connections."

The laboratory said, "Residue formation is most likely the result of a long-term degradation or corrosion process. Exposed silver-plated copper wiring and other silver-containing surfaces (electrodes) are apparently reacting with the sulfur in the fuel."

The NTSB said that copper sulfide deposits on FQIS wires could become ignition sources in B-747s and other aircraft with similar fuel tanks. "Although the design for the B-747 [center-wing fuel tank] FQIS provides for limited electrical power in the fuel tank, the FQIS wires are routed in bundles with nearly 400 other wires, some of which carry up to 350 volts."

The NTSB made the following recommendations to the U.S. Federal Aviation Administration:

- "Issue, as soon as possible, an airworthiness directive to require a detailed inspection of [FQIS] wiring in Boeing 747-100, -200 and –300 series airplane fuel tanks for damage, and [to require] the replacement or the repair of any wires found to be damaged. Wires on Honeywell Series 1-3 probes and compensators should be removed for examination;
- "Issue an airworthiness directive to require the earliest possible replacement of the Honeywell Corporation Series 1-3 terminal blocks used on [B-747] fuel probes with terminal blocks that do not have knurled surfaces or sharp edges that may damage [FQIS] wiring;
- "Conduct a survey of [FQIS] probes and wires in [B-747s] equipped with systems other than Honeywell Series 1-3 probes and compensators, and in other model airplanes that are used in Title 14 Code of Federal Regulations Part 121 service to determine whether potential fuel tank ignition sources exist that are similar to those found in the [B-747]. The survey should include removing wires from fuel probes and examining the wires for damage.

Repair or replacement procedures for any damaged wires that are found should be developed;

- "Require research into copper sulfide deposits on [FQIS] parts in fuel tanks to determine the levels of deposits that may be hazardous, how to inspect and clean the deposits, and when to replace the components;
- "Require in [B-747] airplanes, and in other airplanes with [FQIS] wire installations that are corouted with wires that may be powered, the physical separation and electrical shielding of FQIS wires to the maximum extent possible; [and,]
- "Require, in all applicable transport airplane fuel tanks, surge-protection systems to prevent electrical power surges from entering fuel tanks through [FQIS] wires."

Plastic Shipping Plug Causes Fuel-heater Leak and Engine Fire

Transport Canada (TC) said that the failure of a shipping plug in a replacement fuel heater caused an engine fire while a DeHavilland Dash-8 was being taxied for a post-maintenance inspection.

"Normally the [fuel-heater] port is plugged with a locked steel plug; in this case, the heater had been installed [on the left engine] with the plastic shipping plug in place, rather than the steel replacement," said TC. "The engine had been motored with the starter after the heater installation, and observers had reported no evidence of leaks."

The maintenance crew then started both engines and began taxiing the aircraft for a postmaintenance check. The plastic shipping plug in the fuel-heater port failed, and fuel leaked into the engine and engine compartment. The crew turned on the auxiliary fuel pump when they saw the low-fuel-pressure light. The auxiliary pump did not restore fuel pressure, and the crew turned the pump off. The left-engine fire-warning light then illuminated; the airport ground controller confirmed that the engine was on fire.

"The crew exited the aircraft after shutting down the engines, but the aircraft continued to burn, owing to the large amount of fuel that had pooled in the engine's hot section because of the leaking fuel heater," said TC. "The flames burned through the aircraft belly skin and the intense heat severely damaged the aircraft interior.

"After this occurrence, the company reported that it was inspecting its entire fleet to look for signs of this error and to ensure that the correct plugs were in place. The manufacturer distributed a notice to all operators concerned, advising them of the occurrence and method of prevention. Also, the engine maintenance manual is being revised to clarify the installation requirements for the fuel heater."

Speed-Brake Pin Checks Required in DC-9 and MD-80 Series Airplanes

The U.S. Federal Aviation Administration (FAA) ordered inspections of the speed-brake latching-lever pins in McDonnell Douglas DC-9 series 10, 20, 30, 40 and 50 airplanes, and in MD-81, MD-82 and MD-87 airplanes.

The FAA said that the inspections, required by Airworthiness Directive 98-11-10, will prevent the speed-brake latching-lever pin from jamming and preventing full advancement of the left throttle and retraction of the spoilers during a go-around.

The airworthiness directive requires compliance with repetitive inspections and maintenance procedures in McDonnell Douglas Service Bulletin DC9-27-346, Revision 01.

Tail-Rotor Spindle Failure Leads to Forced Landing

A Sikorsky S-58 helicopter was engaged in a logging operation when a heavy vibration began. The tail-rotor blade and tail-rotor hub assembly then separated from the helicopter. The three occupants of the helicopter were seriously injured in the subsequent forced landing.

Transport Canada said, "A metallurgical analysis of the [tail-rotor] spindle concluded that the failure was a result of progressive fatigue cracking … [that could have been caused] by incorrect heat treatment."♦

NEWS & TIPS

Color-coded Labels Are Reusable

Write On/Wipe Off Magnetic Labels from D&G Sign and Label can be used for color-coding inventory. The tape rolls, one inch (2.5 centimeters) wide and 50 feet (15.2 meters) long, can be cut to any length.

The rolls are available in yellow, white, orange, green, blue and red. Each roll comes with a soluble-ink pen, and the wipe-off surface allows reuse of labels.

For more information: D&G Sign and Label, P.O. Box 157, Northford, CT 06472 U.S. Telephone: (800) 356-9269 (United States and Canada); Fax: (800) 824-4511 (United States and Canada).

Reusable Magnetic Labels from D&G Sign and Label

Aircraft-structural-Integrity-program Conference Will Examine "State-of-the-Art" Technology

The 1998 USAF [United States Air Force] Aircraft Structural Integrity Program Conference, to be held Dec. 1–3, 1998, in San Antonio, Texas, U.S., is designed to bring together practitioners in the aircraft-structural-integrity field to examine "state-of-the-art technologies for the design and acquisition of new aircraft systems and the maintenance and repair of aging aircraft systems in both the military and civilian fleets."

Papers will concern subjects including:

- Corrosion;
- Fatigue;
- Fracture mechanics;
- Short and small cracks;
- Widespread fatigue damage;
- High-cycle fatigue; and,
- Nondestructive evaluation and inspection.

For further information: 1998 USAF Aircraft Structural Integrity Program Conference, c/o Universal Technology Corp., 1270 North Fairfield Road, Dayton, OH 45432-2600. Telephone: +(937) 426-2808; Fax: +(937) 426-8755.

Battery Charger-Analyzer Meets European Committee Standards

The Christie RF80-K Aircraft Battery Charger-Analyzer has been designated "CE compliant," meeting safety and compatibility requirements of the European Committee for Electrotechnical Standardization. The CE-compliance rating is intended to promote international standards in electrical interference; wiring color codes; language-independent graphics; component flammability; hazard labeling; and sufficient component ratings.

Battery Charger-analyzer from Christie Electronic Corp.

The RF80-K charges and analyzes all common nickel-cadmium and lead-acid aircraft battery types, ranging from three ampere-hours to 55 ampere-hours. The unit incorporates technology for both rapid charging and reconditioning of nickel-cadmium batteries, and circuitry that displays the battery condition during charging.

For more information: Christie Electric Corp., 18120 South Broadway, Gardena, CA 90428 U.S. Telephone: +(310) 715-1402; Fax: +(310) 618-8368.

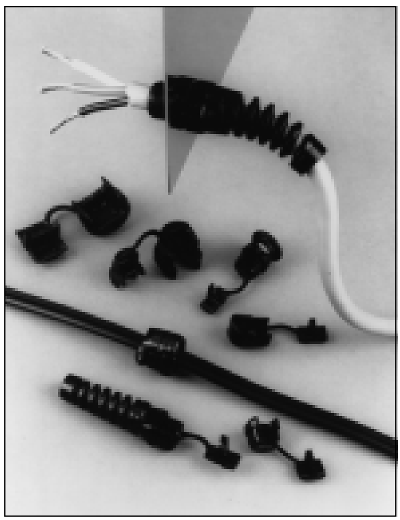
Strain-relief Bushings Designed for Easy Installation

Power cords and cables passing through openings can be anchored and insulated by fitting them with a new line of strain-relief bushings from Nelco Products.

Nelco/Heyco® Strain Relief Bushings are said to be easily installed by wrapping them around the cord or cable, tightening them with pliers and inserting them in the opening. The nylon bushings then absorb pressure caused by pulling, pushing, flexing and twisting.

The bushings are available in several designs and for flat and round cables. They are available in a wide variety of sizes appropriate for different hole diameters and cable thicknesses.

Contact Nelco Products Inc., 22 Riverside Drive, Pembroke, MA 02359 U.S. Telephone: (800) 346-3526 (United States and Canada); +(781) 826-3010; Fax: +(781) 826-7344.



Strain-relief Bushings from Nelco Products

Aircraft Tire/Wheel Balancer Makes Process More Efficient

Reducing the time, effort and expense of maintaining correct tire and wheel balance is the aim of the D755-1 Aircraft Tire/Wheel Balancer from T.J. Karg.

The tool, which requires one square foot (0.09 square meter) of storage space, accommodates tire sizes as large as 34 x 9.25-16 and wheel sizes as large as 16 inches (40.6 centimeters). The D755-1 balances the tire and wheel as a unit rather than separately, eliminating demounting and mounting.

For more information: T.J. Karg Co. Inc., 1055 Evans Ave., Akron, OH 44305 U.S. Telephone: +(330) 630-2225.

Pneumatic Hand-held Tool Facilitates Cutting Metal Straps

Simonds Shear-Action Strap Band Cutter

Cutting metal-strap banding normally requires heavy-duty shears and repetitive manual squeezing. But the Simonds Shear-Action Strap Band Cutter eliminates strenuous effort from the task.

The ergonomically designed air-powered cutter features tapered cutting jaws that slip under even tightly bound, one-inch- (2.54-centimeter-) wide flat metal straps. Pressing a thumb trigger activates the steel cutting edges.

The cutter is powered by shop air and can be reconfigured with specialty jaws for pin insertion, punching and other applications.

Contact Simonds Inc., 248 Elm Street, P.O. Box 100, Southbridge, MA 01550-9921 U.S. Telephone: +(508) 764-3235; Fax: +(508) 765-5125.♦

BLANK
INSIDE
BACK
COVER

A Joint Meeting of

51st FSF International Air Safety Seminar (IASS)
28th IFA International Conference, and IATA

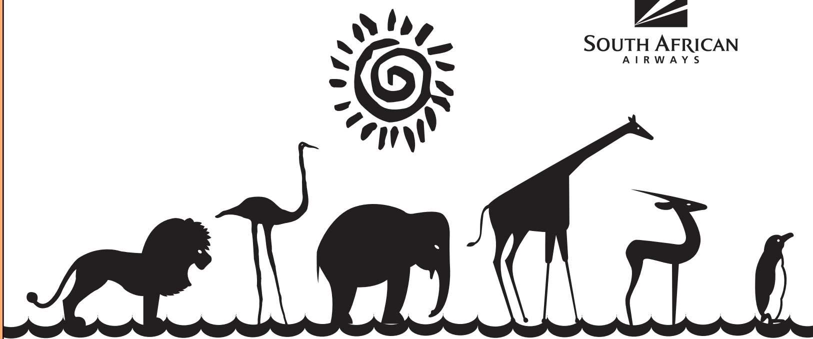
Aviation:
Making a Safe System Safer

Monday, 16 November — Thursday, 19 November 1998

CAPE TOWN, SOUTH AFRICA

Hosted by

SOUTH AFRICAN AIRWAYS



For additional registration information contact:

Flight Safety Foundation, Suite 300, 601 Madison Street, Alexandria, VA 22314 U.S.
Telephone +(703) 739-6700 Fax +(703) 739-6708
Susan M. Hudachek, membership services manager, ext. 105, or Joan Perrin, director of marketing and development, ext. 109

International Federation of Airworthiness 28th International Conference

Flight Safety Foundation

International Air Transport Association

Visit our World Wide Web site at http://www.flightsafety.org