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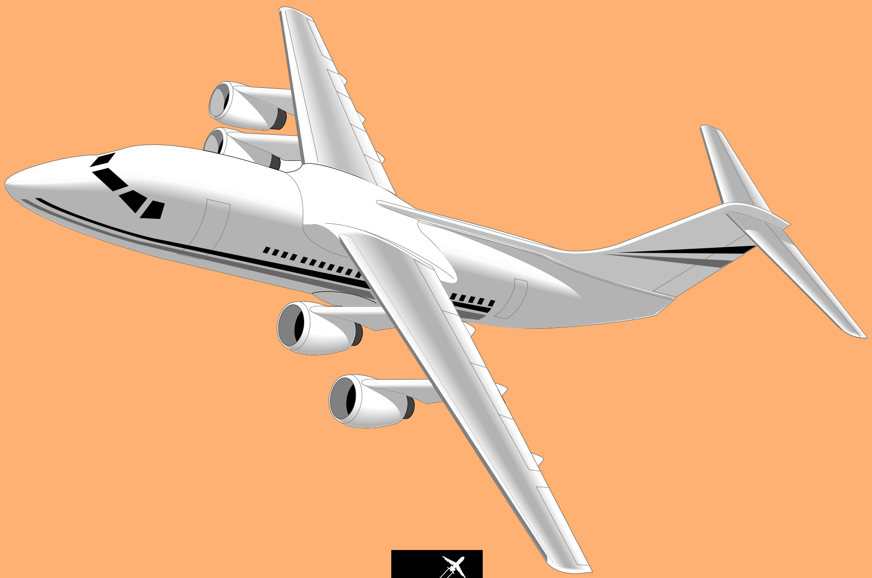

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FLIGHT SAFETY FOUNDATION

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On the cover: British Aerospace BAe 146

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Omission of Oil-plug Seals Leads to In-flight Engine Shutdowns

The incident inquiry concluded that maintenance error caused oil to be lost from all four engines on a British Aerospace BAe 146. The aircraft, which often is used to transport Britain's royal family, was on a training flight when the incident occurred.

—

Bart J. Crotty
Aviation Consultant

On Nov. 6, 1997, the crew of a U.K. Royal Air Force (RAF) 32 Squadron British Aerospace BAe 146 saw indications of significant oil depletion in all four engines. Subsequent low-oil-pressure indications prompted the crew to immediately shut down one engine and later to shut down another engine during an emergency landing at London Stansted Airport.

The U.K. Ministry of Defence, in its incident-inquiry report, said that the incident was caused by maintenance error.[1] The report said that magnetic chip-detector plugs (MCDPs) had been installed without oil seals (O-rings) in all four engines of the BAe 146.

"The aircraft had an experienced crew on board and was close to a suitable airfield when the incident occurred," the report said. "The crew reacted quickly, and the aircraft was landed safely at Stansted. Had the circumstances not been so fortuitous, the incident may have had graver consequences."

The BAe 146 incident was similar to an event on May 5, 1983, involving an Eastern Air Lines Lockheed L-1011. The three-engine jet transport was en route from Miami, Florida, U.S., to Nassau, Bahamas, when the no. 2 engine low-oil light illuminated. The crew shut down the engine and diverted the flight to Miami. The no. 1 engine low-oil light and the no. 3 engine low-oil light then illuminated, and both engines later flamed out. The crew was able to restart the no. 2 engine and conduct a successful single-engine landing in Miami. No one was hurt, but the event was classified as an accident because all three engines required replacement. The U.S. National Transportation Safety Board (NTSB) said, in its final report on the accident, that oil seals had been omitted from the MCDPs during maintenance on the engines.[2] The report said that the mechanics who worked on the engines did not follow procedures for installing the MCDPs and that supervisory personnel failed to require the mechanics to follow the installation procedures.

The report on the BAe 146 incident said that FRA SERCo, a civilian maintenance contractor at RAF Northolt air base, performed routine maintenance on the aircraft's Textron Lycoming (now AlliedSignal) ALF502 turbofan engines two nights before the incident.

The aircraft was one of three BAe 146s based at RAF Northolt and used to transport members of the royal family and government officials. Although the aircraft are operated by the military, they are maintained according to civilian maintenance programs, documentation, procedures and standards.

In its contract proposal to the RAF, FRA SERCo said that the night-shift maintenance staff would comprise 12 workers: one chargehand (general foreman), two senior leading hands (senior supervisors), three leading hands (supervisors) and six fitters (technicians). The company, however, had a personnel shortage. When the maintenance was performed on the incident aircraft, the night shift comprised nine workers; the staff did not include the two senior supervisors and one of the three supervisors.

The general foreman told one of the supervisors on duty to draw spectrometric oil-analysis program (SOAP) samples and to change the MCDPs in all four engines. This is a routine BAe 146 maintenance procedure that is conducted every 50 engine cycles or 50 flight hours, whichever occurs sooner.

The supervisor was a former military-airframe technician who had received no engine-maintenance training. Nevertheless, he was authorized by the company to perform some engine work.

The supervisor searched for MCDP change kits in the maintenance hangar, but found none. MCDP change kits — which include oil plugs, plug seals and SOAP sample bottles — normally were assembled by technicians who worked in the company's engine bay. Because of the personnel shortage, however, the engine-bay night shift had been eliminated. The engine-bay day shift assembled change kits upon request.

"The engine bay [day-shift staff] had not been advised of the requirement for an MCDP change, and there were no prepared kits available," said the report.

The supervisor consulted with the general foreman and then went to the engine bay to assemble kits from items available there. The supervisor found MCDPs in an area of the engine bay that he believed contained BAe 146 engine parts that were ready for use. The area, however, contained MCDPs that had been cleaned but had not been inspected or fitted with seals. The supervisor assembled four change kits with MCDPs from this area.

When the supervisor returned to the hangar, he found that none of the technicians was available to obtain the SOAP samples and install the MCDPs. The supervisor elected to do the work himself.

The supervisor did not consult the aircraft maintenance manual (AMM), which said that SOAP samples must be obtained from the engine oil tanks within 15 minutes of engine shutdown, that MCDPs must be installed with new seals and that the engines then must be operated to check for oil leaks and satisfactory engine operation. The supervisor did not comply with these requirements.

"He was not conscious of checking the plugs for seals prior to fitting them to the engines," said the report. "[The supervisor said that he] was unaware of the existence of the AMM procedure and confirmed that engine ground runs were not carried out. … [He] took the SOAP samples from the MCDP housings, not the engine oil tanks. The engines had not been run in the 15 minutes prior to the [SOAP] samples being collected."

The report said that FRA SERCo normally did not conduct engine ground runs after MCDP changes.

"The terms 'historical' and 'common practice' [were] used to explain the reason for tasks not being carried out [in compliance with] the AMM," said the report. "This undermines engineering standards and perpetuates bad practice."

The job card required that the work be signed off by the person who performed the work and by the person who supervised the work. The supervisor asked a technician to sign the job card as the person who performed the work, and the supervisor signed the job card as the person who supervised the work.

"There was, therefore, no supervision of the SOAP samples and MCDP change," said the report.

Before the incident flight, the aircraft crew chief confirmed that each engine contained at least three-fourths of its total oil capacity of 12.1 quarts (11.5 liters). Ground crewmembers saw no oil leaks and noticed no engine abnormalities when the engines were started and when the airplane taxied to the runway.

The airplane departed RAF Northolt at 1510 local time. Fifteen minutes later, while climbing at about 5,000 feet in instrument meteorological conditions, the crew saw that the oil-quantity gauges for the no. 2 engine, no. 3 engine and no. 4 engine indicated empty, and that the oil-quantity gauge for the no. 1 engine indicated less than one-fourth full.

The crew began flying the airplane back to RAF Northolt. The low-oil-pressure warning light for the no. 3 engine then illuminated. At 1527, the crew shut down the engine, declared an emergency and requested — and received — immediate clearance to land at Stansted.

The low-oil-pressure lights for the no. 2 engine and the no. 4 engine then began to illuminate intermittently. The crew conducted an instrument landing system approach to Stansted with the thrust levers for the no. 2 engine and the no. 4 engine at flight idle, and the thrust lever for the no. 1 engine at maximum thrust. When the crew was sure that the aircraft was in position for a safe landing, they shut down the no. 2 engine. They shut down the no. 4 engine during the landing roll and taxied clear of the runway using the no. 1 engine.

The captain watched as the crew chief checked the engines. The engine cowls were covered with oil, and oil spilled to the ground when the cowls were opened. The MCDPs were removed and found to have no seals.

Maintenance Errors Analyzed

An analysis of the Ministry of Defence incident-inquiry report suggests events and factors that could have influenced the events that led to the depletion of engine oil and to the emergency landing of the aircraft. The codes appearing in parentheses, in order of priority assigned by the author, are explained in Table 1.

- Half of the normal complement of supervisory personnel was available on the night shift. Despite the reduction in supervisory resources, the general foreman did not reduce the amount of

Table 1
Factors and Elements Involved in Individual and Organizational Maintenance Error

Code	Factor	Related Elements
C	Communications	Verbal, written, visual, direct, indirect, flight crew, work assignment, shift turnover, etc.
D	Design	Original, modification, STCs, SBs
E	Environment	Weather, lighting, indoor/outdoor temperature, noise
G	General maintenance manual, AMO	Organization or company policies, procedures, rules, requirements, issued authorizations and approvals
H	Hardware	Equipment, tools, parts, materials, GSE, etc.
I	Inspection	Preliminary, progressive, final, NDI, duplicate
L	Limitations	Weight, reach, sight, access
M	Manufacturer manuals, data	Maintenance and service, NDI, SBs, AFM, MEL, SRM, IPC, LLP
O	Organizational structure, top management	Division of or shared responsibility, support resources, quality/safety commitment, planning
P	Paperwork, record systems	Technical logbooks, forms/job cards, records, documents, etc.
Q	Quality management/audit	AMO/AOC formal programs, requirements, effectiveness
R	Regulations	Airworthiness design, maintenance organization, personnel, programs, ADs, AMO/AOC, health/environment, workplace safety
S	Supervision and middle management	Work assignment, oversight, major decision making
T	Training	Basic skills, product technical, special program requirements, initial, recurrent, records
W	Worker	Aircraft maintenance, ground support, fueling, technical administration staff, licensed, unlicensed, line, hangar, shop
X	Physiological, psychological	Stress, fatigue, drugs, alcohol, mental illness

ADs = Airworthiness directives
AOC = Air operator certificate
GSE = Ground support equipment
LLP = Life-limited parts
NDI = Nondestructive inspection
SRM = Structural repair manual
AFM = Aircraft flight manual
AMO = Aircraft maintenance organization
IPC = Illustrated parts catalog
MEL = Minimum equipment list
SBs = Service bulletins
STCs = Supplemental type certificates

Source: Bart J. Crotty

maintenance work planned or expected that night (O, S);

- The elimination of the engine-bay night shift was not planned adequately by management. The inadequate planning resulted in the unavailability of serviceable MCDP kits for the maintenance-hangar night shift (O, S);
- Despite the risks involved in performing identical maintenance on all aircraft powerplants, MCDP changes were scheduled to be conducted simultaneously on all four of the BAe 146 engines (C, Q, S);
- The supervisor exceeded his capability and experience, and exercised poor judgment in attempting to assemble serviceable MCDP kits from items obtained in the engine bay (S, W, M, T);
- The supervisor had not been trained to perform the routine engine-maintenance task and performed the task without consulting the AMM (S, W, T, M, R);
- The supervisor did not comply with AMM procedures (O, S, M, R);
- The supervisor asked a technician to sign for work that the technician had not performed. The supervisor performed the work, but he signed as having supervised the work (R, P);
- Ground operation of the engines was not conducted after the maintenance was performed (M, T, R); and,
- The general foreman did not adequately monitor the work performed by the night-shift personnel and did not ensure that their work was performed according to safety standards (C, O, S, R).♦

References

1. U.K. Ministry of Defence. *Conclusions of the Inquiry*. A special report prepared for the station commander, Royal Air Force (RAF) Northolt, regarding the incident involving RAF 32 Squadron British Aerospace BAe 146, Nov. 6, 1997.
2. U.S. National Transportation Safety Board. *Aircraft Accident Report: Eastern Air Lines, Inc., Lockheed L-1011, N334EA, Miami International Airport, Miami, Florida, May 5, 1983*. NTSB/AAR-84/04. March 9, 1984.

About the Author

Bart J. Crotty is an airworthiness, maintenance and safety consultant. He is a former U.S. Federal Aviation Administration (FAA) airworthiness inspector and trainer, and designated airworthiness representative. Crotty

has worked for repair stations, airlines, an aircraft manufacturer, law firms, consulting firms, safety organizations and several non-U.S. national civil aviation authorities. His career spans 39 years, approximately half of that period in non-U.S. locations. He has an FAA airframe and powerplant mechanic certificate and a bachelor of science degree in aeronautical engineering. Crotty resides in Springfield, Virginia, U.S.

MAINTENANCE ALERTS

NTSB Recommends Actions to Prevent Cracked Cases in JT8D Engines

The U.S. National Transportation Safety Board (NTSB) cited a McDonnell Douglas MD-88 in-flight engine failure in recommending actions to prevent cracking of the combustion chamber outer case (CCOC) of certain Pratt & Whitney (P&W) JT8D engines.

NTSB recommended that the U.S. Federal Aviation Administration (FAA) require that all P&W JT8D-1 through -17AR and JT8D-200 engines have a one-piece integral-boss CCOC installed "at the next shop visit [in which] the engine's CCOC becomes accessible."

NTSB also recommended that FAA take several interim actions, noting that so many of the engines are in service that it will take several years for all of them to be retrofitted with the one-piece integral-boss CCOC.

The recommended interim actions include:

- Requiring P&W to identify all JT8D-1 through -17AR and JT8D-200 engine CCOCs that had boss welds reworked during manufacture, requiring repetitive on-wing inspections of the affected CCOCs for boss weld cracks, and, if cracks are found, requiring replacement of the CCOC;
- Requiring JT8D engine CCOCs that did not have boss welds reworked during manufacture to undergo repetitive on-wing inspections for cracks in the welds and, if cracks are found, requiring replacement of the CCOC; and,
- Requiring one-time inspections to identify any P&W JT8D-1 through -17AR and JT8D-200 COCCs with magnetic bosses and, if such bosses are found, requiring replacement of the CCOC with a one-piece, integral boss CCOC.

The incident cited by NTSB in issuing its recommendations involved an Oct. 15, 1998, Delta Air Lines flight that experienced an uncontained failure of the no. 2 (right) engine immediately after takeoff from Logan International Airport in Boston, Massachusetts, U.S. The pilots declared an emergency and returned to Boston.

Examination of the engine "revealed that the rear sections of the upper and lower forward cowl doors were deflected away from the engine and that the rear cowl doors were missing," NTSB said. "Subsequent disassembly of the engine revealed [that] the … CCOC had ruptured axially from the fuel drain boss at the bottom of the case."

As a result of the incident, Delta inspected JT8D-200 engines with CCOCs similar to the one that ruptured. The inspections identified 12 more CCOCs with cracks in and around the boss welds, but Delta said that there was no visual evidence of mechanical thinning adjacent to the cracks, as was found on the ruptured CCOC.

In March 1999, P&W issued an alert service bulletin calling for an initial on-wing inspection procedure for CCOC fuel-drain boss-weld cracks. Nearly two months later, the company said that it had received no reports from JT8D-200 operators of CCOC inspections accomplished in accordance with the bulletin.

The CCOC rupture on the Delta flight was the first in a JT8D-200 engine, but the JT8D-1 through -17AR engines, with similar CCOCs, have had at least 10 CCOC ruptures that initiated from boss welds and at least nine from rear-flange-bolt holes, NTSB said. Because of past ruptures and cracking, and in response to NTSB recommendations, FAA has issued a series of airworthiness directives involving the CCOC bosses.

Engine Fire Prompts NTSB Call for Changes In Fire-detection Systems

The U.S. National Transportation Safety Board (NTSB) has recommended modifications of the engine and auxiliary power unit (APU) fire-detection systems in the Airbus A300-600 and A310 airplanes in the wake of an in-flight engine fire last year on an American Airlines flight from San Juan, Puerto Rico, U.S.

NTSB asked the U.S. Federal Aviation Administration (FAA) to issue an airworthiness directive (AD) calling for changes in fire-detection systems and flight-crew procedures for dealing with in-flight engine fires.

The recommendation followed investigations of the fire in the no. 1 engine of an American Airlines Airbus A300B4-605R shortly after takeoff from San Juan on July 9, 1998. The flight crew declared an emergency, followed in-flight engine-fire procedures and returned to San Juan, where the fire was extinguished and emergency procedures were used to evacuate passengers and crewmembers from the aircraft. Twenty-eight passengers received minor injuries during the evacuation; the other 224 occupants were not injured.

Examination of the aircraft showed that the fire had damaged the no. 1 engine's fan cowls, thrust reverser, core cowls, the engine core compartment outside the engine cases and the fire-detection systems. Damage to the airframe was minimal.

The investigation found that the flight crew received the engine-fire warning shortly after takeoff. In response, they immediately retarded the no. 1 engine throttle, and after 88 seconds, the fire warning ceased.

"The flight crew subsequently selected the no. 1 engine's fuel lever to 'off' and discontinued the engine-fire procedures without discharging the fire-extinguishing bottles," NTSB said. "During the airplane's final approach, the flight crew was unaware that the engine was still on fire until alerted by the flight attendants. After landing, the flight crew discharged the fire bottles."

NTSB said that it supports actions taken by General Electric Aircraft Engines, which manufactured the aircraft's CF6-80C2A5 engines, and FAA to address the cause of the engine fire. But, the agency said, "This incident raises broader concerns about the A300-600 and A310 fire-detection systems and in-flight engine-fire-emergency procedures that … FAA should also take action to address."

NTSB asked that FAA issue an AD to require operators of A300-600 and A310 airplanes to modify engine and APU fire-detection systems so that, in case of a single-loop fault in the engines or APU, the remaining loop would automatically be armed for fire detection.

NTSB also called for issuance of a flight standards information bulletin that would require principal operations inspectors to emphasize that flight crews should deactivate the faulted fire-detection loop if a fire warning on an engine or APU changes to a loop fault. For operators of aircraft not modified to automatically arm the remaining loop for fire detection in case of a loop fault, the inspectors also should emphasize proper methods of identifying a failed fire-detection loop, NTSB said.

NTSB said that Airbus should be required to include supplementary information in the in-flight engine-fire procedure outlined in flight-crew operating manuals for the A300-600 and the A310 to indicate an appropriate amount of time that flight crews should wait after the throttle is retarded to idle before the fuel lever is selected to "off."♦

Portable Pumps Power Torque Wrenches

Pumps designed for Enerpac's hexagon cassette torque wrenches and square drive wrenches are available as electric and air-driven models. The pumps have reservoir capacities of one-half gallon to two gallons (1.9 liters to 7.6 liters) and pressure ratings of 11,600 pounds per square inch (816 kilograms per square centimeter). Flows at rated pressure range from 20 cubic inches to 60 cubic inches (328 cubic centimeters to 984 cubic centimeters) per minute, said the manufacturer.

The two-speed electric pump weighs 53 pounds (24 kilograms) and operates on standard 50/60 Hz power. Features include an adjustable pressure-relief valve for accurate torque adjustment and an internal pressure-relief valve to prevent overpressurization. The unit is available with a heat exchanger and comes with a standard remote control.

The air-driven model features a high-output, air-driven, two-stage pump and an air-operated valve with remote control. The model is suitable for use under circumstances that require explosion-proof equipment, said the manufacturer.

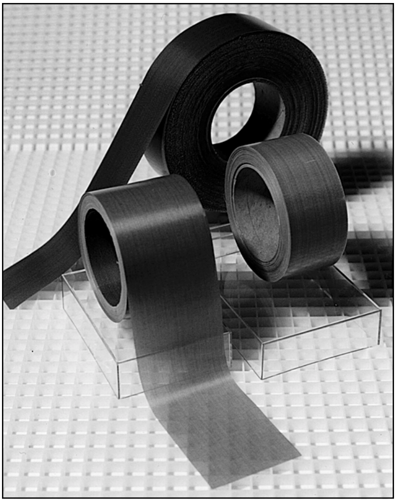
For more information: Enerpac, 6101 North Baker Rd., Milwaukee, WI 53209 U.S. Telephone: +1(414) 781-6600.

Enerpac Portable Pump

Double-duty Tape Withstands Heavy Use

Plasma Flame Spray Tapes from C.S. Hyde Co. withstand heavy-duty grit blasting and protect from overspraying and intense heat and abrasion, said the manufacturer. The two-ply/double-duty tapes eliminate the need for a second taping operation when multiple layers are required.

A high-temperature silicone adhesive provides heat resistance, high



C.S. Hyde Co.
Plasma Flame Spray Tape

adhesion and ease of removal without adhesive residue. The tapes are suitable for HVOF (high-velocity oxygen fuel), metal or ceramic plasma spraying and grit blasting.

For more information: C.S. Hyde Co., 461 Park Ave., Suite 300, Lake Villa, IL 60046 U.S. Telephone: +1(800) 461-4161 (U.S. and outside U.S.).

Hearing Protection System Balances Noise Attenuation, Useful Sound

Dalloz Safety's Real World Solutions hearing protection program incorporates Bilsom Natural Sound Technology to provide proper protection from noise while maximizing the wearer's ability to hear useful sounds such as speech, said the manufacturer.

Hearing protectors now available include two over-the-head earmuff models and one cap-mounted earmuff model. The earmuffs do not need to be removed for wearers to understand speech in a noisy environment, said the manufacturer.

For more information: Dalloz Safety, 2nd & Washington Streets, P.O. Box 622, Reading, PA 19603-0622 U.S. Telephone: +1(610) 376-6161.

Training Program Probes Maintenance Human Factors

Error management is the subject of *Engineering Solutions to Human Problems*, a new training program for maintenance technicians, maintenance managers, safety managers, engineers, maintenance apprentices and maintenance trainees.

The program helps to fulfill requirements for human factors training of licensed engineers, said the International Federation of Airworthiness (IFA), which provided technical support and financial support for production of the program.

The requirements for human factors training of licensed engineers are in

International Civil Aviation Organization Annex 1 amendment no. 161. The amendment requires all licensed engineers to have knowledge of "human performance and limitations relevant to the duties of an aircraft maintenance holder," said IFA.

The program comprises 11 elements, including four videotapes, briefing and training materials, cases histories and human factors study materials.

The program was produced by TVC Television Communications. The program costs US$5,500.00; IFA members receive a 10 percent discount.

For more information: Julian Dinsell, Managing Director, TVC Television Communications, 15 Greek Street, London WIV 5LF. Telephone +44 171 734 6840.

Firm Opens Online Technical Bookstore

CCSINFO has opened an online technical bookstore offering publications on nearly 500 subjects, including aerospace and aeronautical engineering.

Books and industry standards can be ordered online, and a number of standards can be downloaded instantly. Users can conduct a single search to find both technical books and industry standards.

For more information: CSSINFO, 310 Miller Ave., Ann Arbor, MI 48103 U.S. Telephone: +1(734) 930-9277. Web site: www.cssinfo.com.

An Endorsement of Red Tape

A report in the March-April issue of *Aviation Mechanics Bulletin* on the use of brightly colored tape to cover the alternate static port during a leak test of a helicopter's pitot-static system prompted a related suggestion from a reader.

Charles Lester of IBM Flight Operations in White Plains, N.Y., U.S., said that he began using colored tape after he visited a general aviation shop that had put the product to good use.

"They were using brightly colored surveyor's tape to mark work that was incomplete or presented some hazard of being forgotten," Lester wrote. "The tape is available in any hardware store and costs next to nothing. It can be tied or taped in place. The surface is made to be written on, so notes can be left on it. If something needs to be marked inside an aircraft, a piece can be made long enough to hang outside the area so anyone walking by will notice it. Every one of our mechanics has a roll of it.

"We have been using this with great success for several years now and have prevented numerous situations that could have compromised safety."♦

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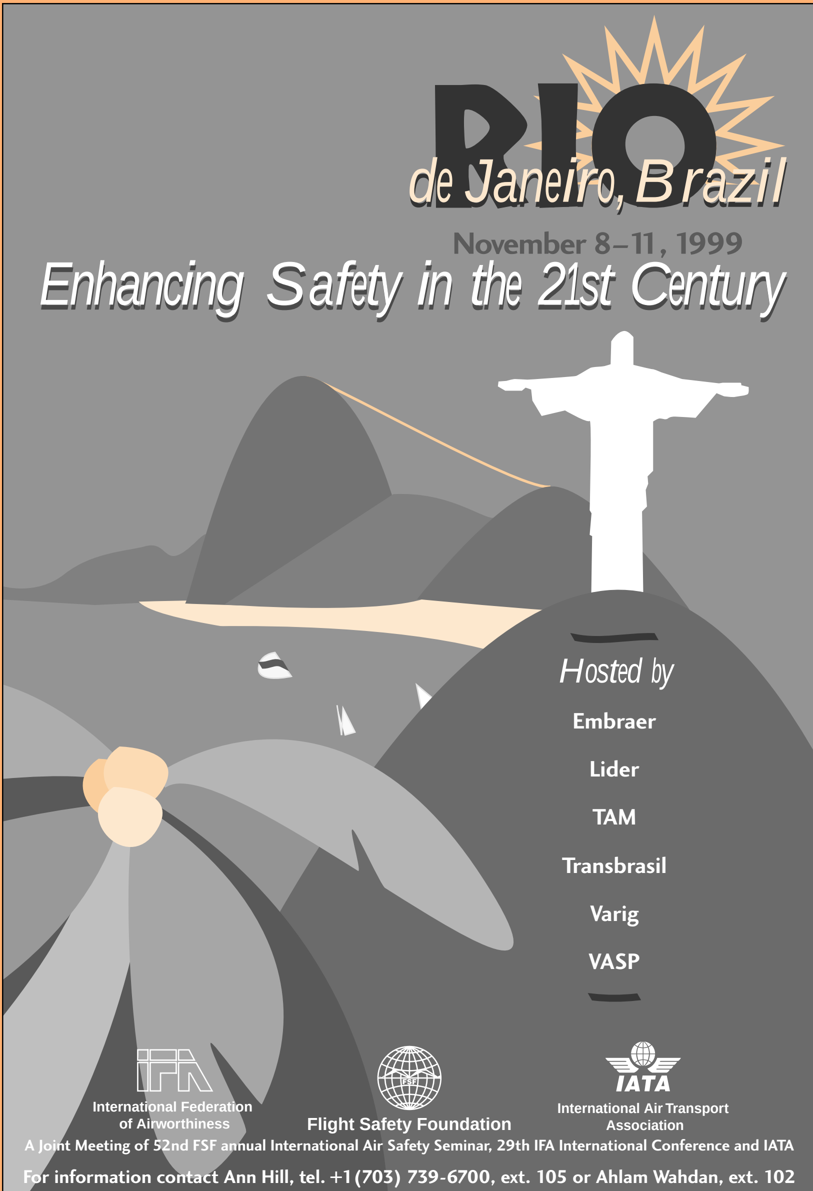

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