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Inadequate Response to Flight-control Problem, Misuse of Autopilot Cited in Falcon 900B Upset

The aircraft was descending to land in Bucharest, Romania, when the autopilot disengaged and several pilot-induced pitch oscillations occurred. Seven passengers, who were not wearing seat belts, were killed; one passenger and the flight attendant were seriously injured.

FSF Editorial Staff

On Sept. 14, 1999, a Dassault Falcon 900B, operated by Olympic Airways for the Greek government, was descending over Romania when the pilot flying (PF) moved the control wheel to level off at Flight Level (FL) 150 (15,000 feet) with the autopilot engaged. The autopilot disconnected, and several pitch oscillations exceeding the aircraft's flight-load-factor limits occurred. The cabin was destroyed during the upset. Seven passengers were killed; one passenger and the flight attendant were seriously injured; two passengers received minor injuries; and the two pilots received minor injuries or no injuries.

The Romanian Civil Aviation Inspectorate (CAI) said, in its final report, that the following causal factors were identified during the accident investigation:

- "Inadequate risk assessments [of flight-control] 'PITCH FEEL' malfunctions;
- "Overriding of the [autopilot] on the pitch channel by the crew;
- "Inappropriate inputs on the control column at high speed with the Arthur unit [a flight-control artificial-feel-adjusting system] failed in the 'low-speed' position, leading to pilot-induced oscillations; [and,]
- "Seat belts not fastened during descent flight phase."

(The report said that a similar incident occurred in the United States on Oct. 9, 1999. The aircraft was descending at 355

knots when the PF "pulled back on the airplane control column to initiate the level-off without disengaging the autopilot." The autopilot disengaged, and the aircraft entered four pitch oscillations. [See "Improper Use of Autopilot Causes Falcon Upset in U.S."])

The aircraft involved in the accident in Romania was being flown from Athens, Greece, to Bucharest, Romania. Both pilots held airline transport pilot licenses, type ratings in the Falcon 900 and Boeing 737, and were qualified as Falcon 900 captains for Olympic Airways.

The designated pilot-in-command, 46, had 8,239 flight hours, including 270 flight hours in the Falcon 900 and 2,213 flight hours in the B-737. He had received recurrent training in the Falcon from FlightSafety International in June 1999. He was the PF on the accident flight.

The designated second-in-command, 44, had 7,465 flight hours, including 231 flight hours in the Falcon 900 and 1,209 flight hours in the B-737. He had received recurrent training in the Falcon from FlightSafety International in July 1999. He was the pilot not flying (PNF) on the accident flight.

Both pilots had received proficiency checks in the B-737 in June 1999, but neither pilot had received a proficiency check in the Falcon, which was the only aircraft of its type operated by Olympic Airways.

"All [other] Olympic Airways aircraft belong to a type-specific company fleet, and they are operated according to specific requirements and procedures set out in the HCAA [Hellenic Civil Aviation Authority] approved company flight operations manual," the report said. "The Falcon 900B aircraft, however, because of its own special mission and exclusive use for Greek government purposes, did not form a separate company fleet, nor did it belong to any other existing company fleets."

Accident-aircraft maintenance records showed that eight malfunctions involving illumination of the "PITCH FEEL" warning light occurred between Nov. 29, 1995, and March 15,

Improper Use of Autopilot Causes Falcon Upset in U.S.

At 1510 local time on Oct. 9, 1999, a Dassault Falcon 900B, operated by Amway Corp., was descending in visual meteorological conditions to land at Grand Rapids, Michigan, U.S., when several pitch oscillations occurred. The upset occurred after the first officer manually applied elevator-control input to level the aircraft at 11,000 feet without disengaging the autopilot. The flight attendant was seriously injured. The pilots and two passengers were not injured.

The U.S. National Transportation Safety Board, in its final report, said that the probable cause of the accident was "the copilot's improper use of the autopilot system while leveling the flight from descent, resulting in an inadvertent pilot-induced pitch oscillation of the airplane. A factor was the flight attendant not wearing a seat belt at the time of the occurrence."

The aircraft was en route to Grand Rapids from Portland, Oregon.

Both pilots held airline transport pilot certificates and type ratings in the Falcon 900B and several other transport aircraft, and were qualified as Falcon captains for Amway.

The designated captain, 51, had 10,423 flight hours, including 191 flight hours in type. The designated first officer, 36, had 5,838 flight hours, including 3,625 flight hours in type. The first officer was flying the aircraft from the left seat.

The cruise portion of the flight was conducted at Flight Level 370 (37,000 feet). The autopilot vertical-speed mode was selected for the descent to Grand Rapids. The captain said that the rate of descent was 2,000 feet per minute (fpm) to 2,500 fpm.

Air traffic control cleared the crew to descend to 11,000 feet and to maintain 11,000 feet. As the aircraft descended through 11,400 feet at 355 knots, the captain observed that the primary flight display showed that the autopilot was in the pitch-hold mode. The captain told the first officer that he believed that the autopilot was not going to level the aircraft at the assigned altitude.

"I immediately grabbed the controls and pulled back on the yoke to level the aircraft," the first officer said. "I noticed at 10,900 feet [that] the aircraft had stopped descending and was starting a climb, so I reduced the back pressure on the yoke to level at 11,000 feet. The airplane pitched nose-down violently.

"I pulled the yoke back again and stopped the pitch-down and recovered to a nose-up attitude. Then the [captain] grabbed the controls with me, and the airplane proceeded to pitch down one more time. The autopilot disconnected, and we recovered for the final time to a level attitude without any further pitching oscillations."

The report said that three or four pitch oscillations had occurred within about five seconds, and that the crew regained control of the aircraft after reducing thrust.

The digital flight data recorder showed that peak vertical accelerations during the upset were +3.3 g (i.e., 3.3 times standard gravitational acceleration) and –1.2 g.

The pilots and the passengers had their seat belts fastened. The flight attendant was in the forward galley when the upset occurred.

A passenger said, "I felt a sudden dive of the aircraft, which was followed by a climbing feeling. This was repeated several times and was extremely violent. It felt as though I was in a boat that was jumping good-sized waves. I could see that [the flight attendant] was being thrown around the galley area violently. I know that she hit the ceiling of the aircraft at least once."

The report said that the flight attendant's injuries included a broken shoulder that required surgery.

After the upset occurred, the first officer hand-flew the aircraft, and the crew conducted a normal approach and landing at the Grand Rapids airport.

Both pilots said that the "PITCH FEEL" light, which warns of an artificial-flight-control-feel system malfunction, illuminated briefly during climb on the day before the accident and flickered twice during takeoff on the day of the accident, and that no flight-control problems were encountered until the upset occurred. They said that the "PITCH FEEL" light flickered three times when the flaps and slats were retracted after the aircraft was landed.

Postaccident examination of the elevator-control system and the artificial-control-feel system showed no anomalies. The aircraft's maintenance records showed no history of autopilot problems or flight-control problems.

The report said that the aircraft flight manual and the autopilot operating manual did not explicitly state that the autopilot should not be manually overridden.

Dassault Aviation on Oct. 18, 1999, issued Service Newsflash No. 52 for the Falcon 900. The document provided the following information:

> As we have previously reported, two Falcon 900 aircraft have recently experienced difficulties during descent which resulted in abrupt pitch movements.
>
> Although the root causes of these incidents have not yet been determined and may not be related, the French airworthiness authority has requested that Falcon operators be reminded of the following basic piloting techniques when flying with the autopilot engaged:
>
> - Do not manually apply control yoke forces in an attempt to control the aircraft.
> - If aircraft manual control is required or desired:
>   - Hold the control yoke and disengage the autopilot using any of the pushbuttons available for disconnection (refer to your model aircraft's documentation for pushbuttons to disconnect);
>   - Manually control the aircraft as required; [and,]
>   - Trim the aircraft and re-engage the autopilot if desired.♦

[Editorial note: This article, except where specifically noted, is based on U.S. National Transportation Safety Board report CHI00FA006. The 213-page report contains diagrams, illustrations and appendixes.]

1999. Corrective actions included resetting the air data computer (ADC), replacing the ADC, resetting the box Arthur pitch (BAP) system and replacing the BAP system.

"The manufacturer was not involved [in determining] the proper corrective action," said the report.

The Falcon 900B has hydraulically powered primary flight controls and an artificial-flight-control-feel system.

"The control inputs originate from the cockpit, where a system of rigid rods and bellcranks link the control wheels and rudder pedals to the servoactuators of the rudder, the elevators and the ailerons," the report said.

Artificial flight-control feel is provided by a system of springs that comprise the artificial-feel unit (AFU). An automatic spring-load-adjusting system, called the "Arthur Q" (Arthur) unit, adjusts the artificial feel of the elevators according to airspeed and horizontal-stabilizer position (see Figure 1, page 4). At low airspeeds, the Arthur unit adjusts control feel so that relatively low control-wheel force is required to move the elevators. As airspeed increases, the unit adjusts control feel so that more control-wheel force is required to move the elevators; the unit also limits elevator travel. (The Arthur unit also adjusts aileron control feel according to airspeed.)

The BAP system monitors the position of the Arthur unit actuator and the position of the horizontal stabilizer.

"If the difference between [the position of the Arthur unit actuator and the position of the horizontal stabilizer] passes a certain threshold, one lock will operate, causing the 'PITCH FEEL' light to illuminate on the warning panel, and the [Arthur unit actuator] will return to its low-speed position, provided that the [actuator] is not jammed," said the report.

The report said that the "PITCH FEEL" light also illuminates if the BAP malfunctions, an electrical fault occurs, or a hydraulic fault occurs. The light can indicate that the Arthur unit has failed in the high-speed position.

"The 'PITCH FEEL' light will go out as soon as the slats are extended and airspeed is less than [210 knots] or equal to 210 knots, provided that the Arthur is in the 'low-speed' position," the report said. "Otherwise, 'PITCH FEEL' keeps on illuminating."

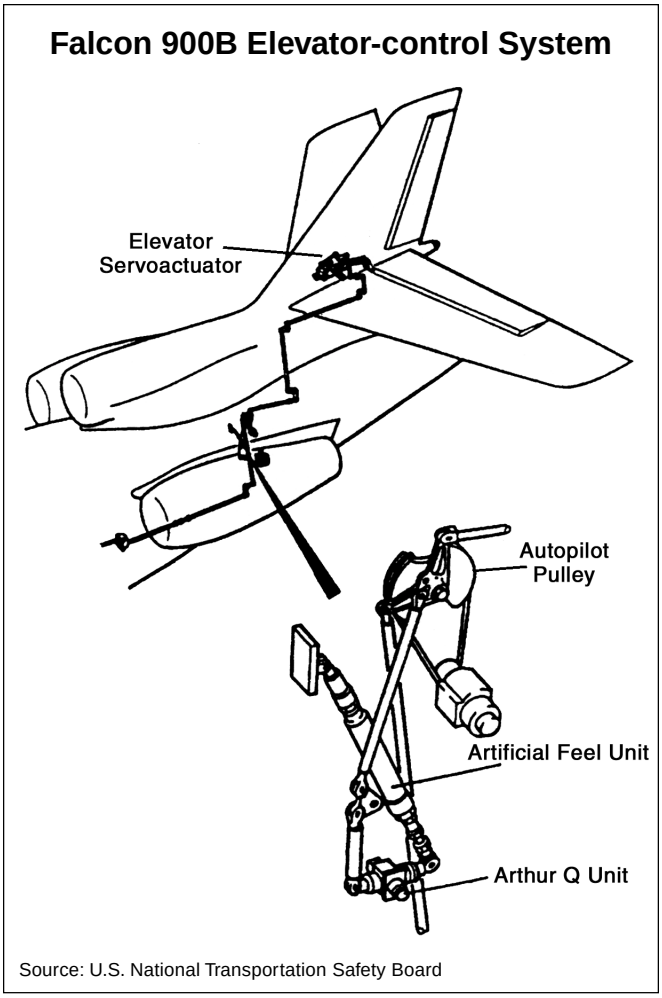


Figure 1

The accident aircraft's "PITCH FEEL" light illuminated soon after the aircraft took off from Athens at 1816. The aircraft was climbing at about 210 knots with the flaps and slats retracted when the light illuminated. (The report said that defective potentiometers in the horizontal stabilizer and in the Arthur unit caused the unit to fail in the low-speed position.)

The crew consulted the "Arthur Unit Inoperative" checklist.

The report said that all the checklists used by the flight crew during the accident flight were inappropriate, because they were published by FlightSafety International for training purposes.

"However, the 'Arthur Unit Inoperative' checklist [published by FlightSafety International for training purposes] was similar to the checklist contained in the [Falcon 900B] aircraft flight manual [AFM]," the report said.

The AFM "Arthur Unit Inoperative" checklist provides the following information:

> The pitch [control forces] and roll control forces may be higher or lower than normal, depending on whether the Arthur unit has failed in the high-[speed] or low-speed position.
>
> - Light forces: avoid large displacements and rapid movements of the control surfaces, to avoid inducing high load factors.
>
> - High forces: use normal [trim system] or emergency trim system and execute an approach:
>
>   – [with] "PITCH FEEL" light on: at V_{REF} [reference landing speed] + 10 knots, and increase the landing distance by 800 feet/244 meters (1,335 feet/407 meters added to the landing field length); [or,]
>
>   – [with] "AIL [aileron] FEEL" light on: at V_{REF}.

The report said that the checklist did not include information on how to determine whether the Arthur unit failed in the high-speed position or low-speed position.

The PF disengaged the autopilot and perceived that control feel was "normal."

"The [PF] was not able to determine that the Arthur unit had failed in the low-speed position," the report said. "He [perceived] the forces experienced as normal. This estimate was probably influenced by the fact that this malfunction ('PITCH FEEL' light on) [had occurred during] previous flights and was classified as an indication error of the system.

"A perception error was made in determining the Arthur unit position, and this had an important influence on the encountered airplane upset."

The cruise portion of the flight was conducted at FL 400. At 1903, the crew began a descent to FL 150. The autopilot was operated in the vertical-speed mode. During the descent, vertical speed remained constant at 2,200 feet per minute, and indicated airspeed increased from 240 knots to 332 knots. (The applicable maximum operating airspeed [V_{MO}] was 370 knots.)

The Falcon 900B AFM says that the "SEAT BELTS" sign should be illuminated at the top of descent. Olympic Airways' policy was that the "SEAT BELTS" sign be illuminated five minutes before landing "unless there are special reasons such as turbulence, emergency situation, etc." for illuminating the sign earlier.

The report said, "Based on flight crew statements, during the accident, the 'SEAT BELTS' signs were not activated because there were no special reasons [for them] to be switched on."

The sky was clear at the time, and clear-air turbulence was not forecast or reported.

The PF obtained updated weather information for the Bucharest airport as the aircraft was descending through FL 170. He then told the PNF to request clearance for further descent (below FL 150).

The aircraft was nearing FL 150 at 1915 when the PNF requested and received clearance from air traffic control (ATC) to continue the descent to FL 50. At the time, the PF and the flight attendant were discussing the estimated time of arrival in Bucharest.

"When speaking with the PF, [the flight attendant] could see Bucharest through the cockpit windows," the report said. "She was seated on her jump seat with the upper part of her body turned to the cockpit."

The report said that, at 15,500 feet, the autopilot would have begun to arrest the descent to achieve level-off at FL 150. The digital flight data recorder (DFDR) showed that, while the PF was talking with the flight attendant, the elevator moved "very rapidly" in a nose-up direction. The rate of elevator movement was greater than the autopilot-control limit.

"This [rate of elevator movement] and the absence of any external stimuli to the aircraft which would have led to such a rapid motion indicate that the [PF was] overriding the autopilot servo in the nose-up direction," said the report.

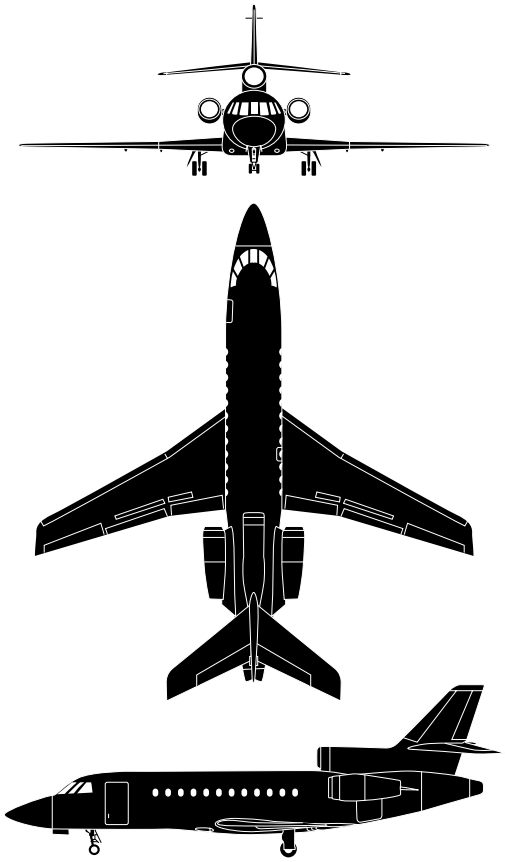
The autopilot changed from the vertical-speed mode to the pitch-hold mode, which is the autopilot's default vertical mode.

The report said, "The possible ways for the autopilot to change from vertical-speed mode to pitch-hold mode are the following:

- "By deactivating the vertical-speed mode;
- "By entering a new altitude selection while the aircraft [is] in altitude-selected-capture mode; or,
- "By moving the pitch (thumb) wheel located on the flight-guidance controller [when] the altitude-selected-capture mode [is engaged]."

The report said that available data did not show why the mode change occurred, but that the "most-probable scenario" was that a new altitude (FL 050) was selected when the autopilot was in the altitude-selected-capture mode (with FL 150 as the altitude selected). With the autopilot in pitch-hold mode, the aircraft continued to descend.

"Noticing that no level-off to FL 150 had started, the [PF] moved the control column gently, commanding a nose-up movement of the aircraft, probably with the intention of



Dassault Falcon 900B

Deliveries of the Dassault Aviation Falcon 900 three-engine intercontinental business transport began in 1986. The 900 has a larger cabin and larger wings than the three-engine Falcon 50. The Falcon 900B, which has 5.5 percent more powerful engines than the 900, was introduced in 1992.

The Falcon 900B has accommodations for two pilots, a flight deck jump-seat occupant and up to 18 cabin passengers.

With a maximum differential of 0.64 bar (9.3 pounds per square inch), the pressurization system can maintain cabin pressure at sea level when the airplane is flown at 25,000 feet and at 8,000 feet when the airplane is flown at its maximum cruising altitude: 51,000 feet.

Each of the three Garrett TFE731-5BR turbofan engines is rated at 21.13 kilonewtons (4,750 pounds static thrust). The center engine is equipped with a thrust reverser.

The fuel system comprises two wing tanks, a center-section tank and two tanks under the fuselage floor. Total usable fuel capacity is 10,825 liters (2,860 gallons).

Maximum takeoff weight is 20,640 kilograms (45,503 pounds). Maximum landing weight is 19,050 kilograms (41,998 pounds). Maximum cruise speed is 0.84 Mach. Economy cruise speed is 0.75 Mach. Range with fuel reserves and eight passengers at economy cruise speed is 7,116 kilometers (3,843 nautical miles).

Source: *Jane's All the World's Aircraft*

assisting the [autopilot] with its expected capture of FL 150," the report said.

The report said that possible explanations for the PF's attempt to manually override the autopilot were that he was distracted by the conversation with the flight attendant or that he was using a technique appropriate for the B-737-400 but not appropriate for the Falcon.

"When the [B-737-400] autopilot is engaged in command mode (CMD), longitudinal [pressure] and/or lateral pressure applied on the control wheel will revert the autopilot mode into CWS [control-wheel steering] pitch [mode] and/or roll mode, provided that the pressure exceeds a certain threshold," the report said. "Manual override of the … autopilot will not disengage it. The autopilot will maneuver the aircraft in response to any control pressures applied by either pilot."

The report said that the Falcon autopilot response to manual control-wheel input is significantly different; the autopilot counters manual movement of the elevators or ailerons.

The PF's movement of the control column caused the elevator to move from a three-degrees nose-down position to a 14-degrees nose-up position. The report said that, if the Arthur unit had been operating normally in the high-speed position, the PF would have been able to move the elevator only to four degrees nose-up.

The autopilot began to counter the PF's nose-up elevator input by moving the horizontal stabilizer to trim the aircraft nose-down.

"During this phase, the [PF] felt a progressive increase in effort on the control column," the report said. "[He] continued to pull back on the control column to maintain a nose-up movement, and he applied more and more force."

Elevator-servomotor torque reached the maximum value, and the autopilot disengaged. During the next 24 seconds, the aircraft entered 10 pilot-induced pitch oscillations with average periods of 2.4 seconds and with peak vertical accelerations of +4.7 g [i.e., 4.7 times standard gravitational acceleration] and –3.26 g. The Falcon 900B flight-load-factor limits are +2.6 g and –1.0 g.

The pilots described the upset as violent. The flight attendant said that the aircraft behaved like "an afraid horse."

"She hit with her entire body the upper part of the cabin, then the jump seat," the report said. "She remembers these movements were repeated four times [before she was able to brace herself]."

The report said that the aircraft was within weight-and-balance limits at the time and that the movement of the passengers in the cabin did not significantly affect the aircraft's center of gravity during the upset.

The PF reduced power and regained control when airspeed decreased below 240 knots at about FL 130. The PNF declared an emergency to ATC.

"We are in emergency, sir, request vector to final approach," the PNF said. "We have problems with the controls."

ATC provided radar vectors to Bucharest-Otopeni International Airport. At 1933, the crew landed the aircraft on Runway 8R. Six passengers were dead; the four injured passengers and the injured flight attendant were transported by ambulances to an emergency hospital. One of the injured passengers died three days after the accident.

The report said that the fatal injuries, serious injuries and minor injuries received by the cabin occupants were caused by impact with the cabin ceiling and cabin furniture.

The report said that the fatal injuries, serious injuries and minor injuries received by the cabin occupants were caused by impact with the cabin ceiling and cabin furniture.

"Interior furnishings, tables and armchairs were severely damaged," the report said. "[The] luggage compartment and aft lavatory were in great disarray, with glass particles, grease, toilet paper and waste found on the inner surface assembly."

The report said that several cabin-floor panels were distorted, but visual examination of the flight-control cables showed no distortion or interference.

The flight deck received minor damage during the upset.

"The copilot's left armrest was found collapsed," the report said. "Several circuit breakers were found broken. Pushbuttons on the upper panel were covered with traces of blood."

An inspection showed no structural damage, except for a crack in the upper-fuselage skin that was caused by penetration of a metal catering container. The crack measured 127 millimeters by 25 millimeters (five inches by one inch).

The report said that the accident aircraft's cockpit voice recorder (CVR) was not functional. The recording tape was broken, and components were excessively worn and contaminated with "sticky deposits."

The report said that the DFDR, which was designed to record 58 parameters, did not properly record three parameters: coordinated universal time, flight number and angle-of-attack.

Based on the findings of the accident investigation, the CAI made the following recommendations:

- "The HCAA and Olympic Airways should reconsider the policy regarding operation and maintenance of a single-airplane fleet;

- "Olympic Airways should use only an approved checklist;

- "The HCAA and Olympic Airways should reconsider the policy regarding the passengers' seat belts;

- "The HCAA and Olympic Airways should reconsider the policy regarding the number of pilot ratings that can be exerted at the same time, observing the provisions of JAR-OPS [Joint Aviation Requirements–Operations] 1.980 regarding 'Operation on more than one type or variant';[1]

- "The DGAC [French Direction Générale de l'Aviation Civile] and Dassault Aviation should modify the Arthur-unit-inoperative abnormal procedure from the AFM in order to reduce the possibility of human perception error;

- "The DGAC should, in parallel, reassess existing crew training procedures with regard to the Arthur-unit-inoperative abnormal procedure;

- "Dassault Aviation should re-evaluate maintenance related to pitch-feel malfunction causes and ensure that appropriate training and documentation be offered to maintenance personnel during troubleshooting;

- "The JAA [European Joint Aviation Authorities] and the FAA [U.S. Federal Aviation Administration] should promote evolutions of regulatory requirements for flight-control [systems] and guidance systems that would require:

  – "Risk reduction of aircraft-pilot coupling through new designs which would take into account recent knowledge acquired on pilot behavior and interaction with automation; [and,]

  – "Safe and transient-free disengagement of automatic flight control and guidance systems to prevent hazardous crew-automation interactions;

- "The JAA and the FAA should make sure that training programs and documentation of all operating airplanes provide sufficient information and illustrative examples of aircraft-pilot coupling and of possible unsafe crew-automation interactions; [and,]

- "The HCAA and, by extension, all authorities in charge of civil aviation should ensure that annual inspections of flight recorders and flight-data-acquisition units be carried out in the spirit of existing provisions of ICAO [International Civil Aviation Organization] Annex 6, Seventh Edition, Attachment D."[2]

The report said that DGAC, on Nov. 17, 1999, issued an airworthiness directive (1999-464-029[B]) that restricts indicated airspeed to 260 knots or 0.76 Mach when the "PITCH FEEL" light illuminates in the Falcon 50, 900B or 900EX.♦

[Editorial note: This article, except where specifically noted, is based on the Romanian Civil Aviation Inspectorate's *Final Report on the Accident: Falcon 900B, SX-ECH, 14 September 1999, in Bucharest FIR Area, Romania.* The 92-page report contains photographs, diagrams and appendixes.]

Notes

1. Joint Aviation Requirements–Operations 1.980 states: "An operator shall ensure that a flight crewmember does not operate on more than one [aircraft] type or variant unless the flight crewmember is competent to do so. When considering operations of more than one type or variant, an operator shall ensure that the differences and/or similarities of the airplanes concerned justify such operations."

2. International Civil Aviation Organization *International Standards and Recommended Practices, Annex 6 to the Convention of International Civil Aviation, Operation of Aircraft,* Part 1, *International Commercial Air Transport–Aeroplanes,* Attachment D, "Flight Recorders," contains information on general requirements, performance requirements and inspection of flight data recorders and cockpit voice recorders installed in airplanes engaged in international air navigation.

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