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Rapid High-altitude Icing Linked to Series of Fatal Accidents

Australian accident investigations, pilot surveys and computer models suggest that the Mitsubishi MU-2 can be unforgiving in high-altitude icing conditions. An exhaustive study, completed by the Australian Bureau of Air Safety Investigation (BASI), details a series of MU-2 crashes where icing was a factor. The report also suggests that the high performance aircraft demands special pilot recovery skills in emergency situations.

Editorial Staff Report

The Mitsubishi MU-2B-60 Marquis was cruising at 21,000 feet on a night charter flight in visual meteorological conditions between Perth and Port Hedland, Australia, when it rolled suddenly to the left and entered a violent spin.

The pilot radioed that the aircraft was out of control and descending. Thirty seconds later, the pilot radioed that the aircraft was "in ice and...spinning down through 8,000 feet." A few moments later, at about 0105 hours local time, another pilot in the vicinity reported witnessing the twin-engine turboprop crash and burn. The pilot and a passenger were killed.

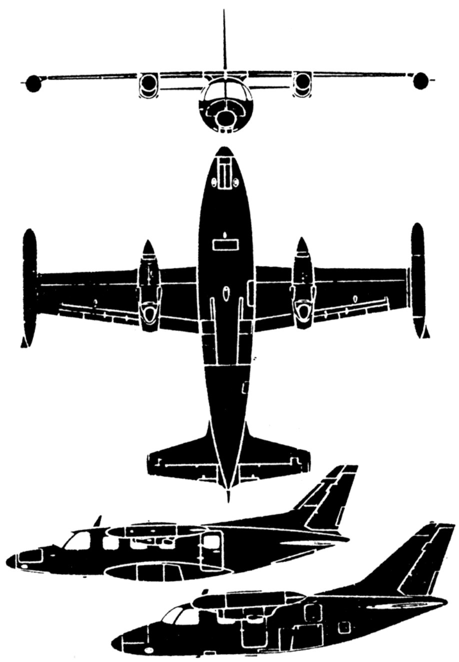
The January 1990 accident, along with a strikingly similar MU-2 accident in Australia in 1988, spawned a major two-year inquiry by BASI to investigate possible causal factor links between the two crashes and other MU-2 accidents. The recently released BASI report examined both accidents in detail along with data from 10 other MU-2 crashes in the United States and France between 1981 and 1990 where icing was suspected as a major causal factor.

"Analysis showed that a number of incidents had occurred in Australia and overseas involving encounters with ice while climbing to altitude or while cruising at altitudes mainly above FL 150 [15,000 feet]," the BASI report said. "Patterns emerging from the analysis indicated that many of these encounters resulted in a rapid loss of airspeed, sometimes to the point of stall and loss of control."

BASI noted that the 1988 MU-2 accident also occurred in meteorological conditions conducive to the formation of rime or clear ice. In that accident, the pilot and nine passengers were killed.

In addition, BASI said there were several other factors common to both Australian crashes. Analysis of the data suggested that:

- The aircraft probably accrued airframe icing which may not have been visible to the pilot;
- The airspeed decreased and the autopilot attempted to maintain aircraft attitude, rate of climb or altitude by applying nose-up trim;



The Mitsubishi MU-2, a twin turboprop, multi-purpose utility transport aircraft, was first flown in 1963. The aircraft can seat up to 11 passengers and has been produced in various versions of differing power, weight and performance. Later versions were assembled in the United States at a plant in Texas. The Marquis (manufacturer's designation MU-2B-60) was first flown in 1977 and certified in 1978. The Marquis models were powered by Garrett TPE331-10-501M engines. The MU-2 has a maximum cruising speed of 308 knots, a range of 1,395 nautical miles (with maximum fuel at maximum altitude and 45 minutes reserve)and a service ceiling of 29,750 feet. Production ceased in 1986 after 755 MU-2s had been built.

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

- The airspeed continued to decrease to the point of stall, which probably was considerably higher than the normal clean stall speed for the aircraft;
- The aircraft probably entered a spin from which the pilot failed to recover; and,
- Both pilots had inadequate training on the aircraft.

The BASI report suggested that lack of pilot training in the MU-2, coupled with aircraft handling characteristics under certain flight conditions, were the likely causes of many of the crashes.

"Experience with the aircraft as documented in this report suggests that there are serious limitations to safe flight in icing conditions, particularly at high altitudes and [heavy] weights," the BASI report said.

The report added that computer simulation of the MU-2's performance under such conditions supports "observations made by pilots that performance degradation can be rapid, sometimes leading to loss of control."

The pilot in command (PIC) of the charter flight to Port Hedland held a commercial pilot certificate and had logged 11,030 hours total flight time, of which 51.7 hours were in the MU-2. According to the report, the pilot, age 51, had returned to commercial flying in 1989 after a 15-year hiatus. The accident flight was the pilot's first flight as PIC of an MU-2 on a commercial operation.

The PIC was a former accident investigator and was "aware of the MU-2's icing potential and the dangers of such conditions," BASI said.

Despite the pilot's extensive aviation experience, the BASI report said that an investigation revealed that "contrary to the prevalent impression that he was meticulous and [flew] 'by the book,' the pilot tended to be less rule-bound and sometimes casual in attitude."

The report said that the pilot had experienced difficulty achieving proficiency after returning to full-time commercial aviation (including a delay in his endorsement for the MU-2 due to unsatisfactory performance) and did not have recent experience in high-altitude operations in pressurized aircraft.

The BASI report said that the company pilot flew with the pilot and "concluded that the pilot needed further flight supervision before he could command flights in the company aircraft." BASI said the pilot "disagreed with this assessment," but agreed to fly under supervision for a further period of training.

In addition, the report said the accident flight was flown at altitudes that were considered to have been too high for optimum performance, also suggesting gaps in the pilot's abilities.

Prior to the accident, the pilot had not flown the MU-2 for six days, but had flown 11 hours in a Beech Queen

Air, a twin-engine, piston-powered aircraft with lesser performance characteristics than the MU-2.

Before the accident flight, the pilot had complained to coworkers that his sleeping pattern had been disrupted by the night flights that he had been assigned. On the day of the accident, the pilot reportedly had rested or slept only nine hours in the previous 42 hours. Prior to his MU-2 endorsement, during a night familiarization flight, the pilot reportedly removed his headset at about 0100 hours and slept for an hour, stating to the aircraft captain that this was his low time.

The passenger on the flight was a certified flight instructor who held a commercial pilot certificate and a multi-engine command instrument rating. He had logged a total of 1,525 flying hours, but was not endorsed to fly the MU-2.

There was no indication before the crash that the pilot was aware of any looming disaster. A transcript of air-to-ground communications suggests the pilot believed that he was involved in normal cruise operations until the loss of control.

The pilot gave Perth air traffic control a routine position report one minute before radioing: "Perth Mike Uniform Alpha's out of control, going down."

Thirty seconds later, apparently under high physical stress, the pilot reported: "We are in ice and we are spinning down through 8,000." It was the pilot's last transmission.

The aircraft impacted the ground in a near-vertical attitude, and much of the forward section penetrated the ground to a depth of nearly 1 meter. The fuselage was totally destroyed, and the wreckage was confined to a relatively small area of 200 meters by 140 meters.

Marks on the edge of the crater indicated that the leading edge of the left wing had hit the ground in a left rotation. "A spin was suggested by the vertical attitude and the airspeed at impact, which was later determined as being 175 knots," the report said. Both engines appeared to be operational at impact, it said.

The BASI investigation concluded that the following factors contributed to the crash of the Port Hedland-bound flight:

- The pilot did not have recent experience in high-performance, high-altitude aircraft except for the 51.7 hours in the MU-2.
- Certain aspects of the pilot's planning and attitude toward the operation of the MU-2 indicated that the pilot did not take sufficient account of the operational characteristics of the aircraft type.
- The pilot's situational awareness was probably impaired during the flight due to cumulative fatigue and insufficient sleep in the previous 42 hours.
- Meteorological conditions were conducive to the formation of airframe icing.
- The pilot was unable to recover from the spin before the aircraft hit the ground.

The pilot of the MU-2 in the 1988 crash also lacked experience in the aircraft, the report said.

"There is evidence that the pilot's endorsement training was inadequate and that certain deficiencies identified during training had not been rectified. It is therefore probable that the pilot had not been exposed to all of the aircraft's operational characteristics [performance at high altitude] before operating [it] on his own. It is therefore unlikely that the pilot had achieved a skill and knowledge level needed to operate an aircraft such as the MU-2 in an emergency situation."

The pilot reported: "We are in ice and we are spinning down through 8,000."

The report noted that flying was a secondary responsibility for this pilot, who was also the company's marketing manager.

According to BASI, a computer-generated model demonstrated than an MU-2 aircraft operating at altitudes above 15,000 feet and encountering light to moderate ice "could rapidly lose a significant amount of airspeed."

This loss could suddenly reduce airspeed to below 150 knots, which was shown to be the average speed at which pilots had experienced a stall and loss of control," the report said.

The BASI report said that research indicated that ice can form quickly on the MU-2's airframe and that stall speeds can be "far in excess of uncontaminated [clean, no flaps, no gear] aircraft stall speeds."

After receiving several additional unsolicited reports on MU-2 control-loss incidents, BASI launched a nationwide survey of MU-2 pilots and operators and requested data about the aircraft's handling characteristics, especially at flight levels above 15,000 feet. BASI also collected accident and incident reports from worldwide safety organizations. With information supplied by pilots and operators who responded to the survey, BASI compiled a database containing reports of 15 accidents and 46 incidents.

The results indicated that:

- Most flights were charter operations, reflecting the typical use of the MU-2, at least in Australia.
- Most of the incidents occurred during cruise.
- Two-thirds of the cases involved single-pilot operations.
- Pilots generally held commercial or senior commercial certificates, and a significant number also held air transport certificates.
- More than half of the accidents and incidents occurred at night, and most took place in instrument meteorological conditions.
- Autopilots were engaged in most of the aircraft at the time of the accidents or incidents.
- One-third of the aircraft were in a high, nose-up trim condition at the time of the occurrence.
- Aircraft icing was reported in a significant number of the cases.
- Control of the aircraft was lost in 34 cases, resulting in 15 accidents.

The report said that the events leading up to control loss … could occur quickly while the pilot was distracted with other cockpit duties.

The most frequent type of incident involved rapid speed loss caused by ice, according to the BASI survey. In some of the reported incidents, pilots were able to take appropriate action, generally by immediately lowering the aircraft nose and descending, and did not lose control of the aircraft.

However, many of the incidents and all of the accidents in the database involved a loss of control. About half of the incidents reported involved a loss of control from which the pilot was able to recover.

Several pilots in the BASI survey reported icing on the aircraft body in areas that are not de-iced and that there was evidence that this could be related to a high, nose-up attitude.

"The MU-2 cruises in a nose-up attitude that is dependent on aircraft weight, altitude and center of gravity," the BASI accident report said. "If a heavy aircraft is cruising in its higher flight regime, it is reasonable that the aircraft could have an attitude relative to the airflow high enough to allow ice to form on the undersurfaces of the fuselage. It is also conceivable that this could occur without the pilot's knowledge."

The report said that the events leading up to control loss (icing conditions, altitudes above 15,000 feet, nose-up trim inputs) could occur quickly while the pilot was distracted with other cockpit duties.

"In particular, speed loss due to ice, autopilot selection of higher nose-up settings and possible entry into an incipient stall condition are reported to have occurred without the pilot being aware of them. In addition, in cases where the pilot reported airframe icing, this was not generally recognized until after the event." The report noted that the MU-2's aerodynamic soundproofing also increases the possibility that aerodynamic noises associated with airspeed loss can go unnoticed by the pilot.

The MU-2 is equipped with a pneumatic de-icing system, with de-icing boots on the propellers, wings and vertical and horizontal stabilizers.

According to the BASI report, the MU-2 is not equipped with an ice warning device. It said neither the flight manual, approved by the U.S. Federal Aviation Administration (FAA) and the Australian Civil Aviation Authority (CAA), nor the pilot's operating manual advises pilots on how to detect ice formation.

"While notes for a ground school course [conducted by FlightSafety International in the United States] say that wing de-ice boots should be activated when about 1/4-inch (6mm) of ice is seen to have formed on the wing leading edge, no advice is provided about how this thickness should be gauged [overall]. Thus, those pilots who have [FSI] documentation will know that when they see 1/4-inch of ice on the wings they should activate the wing de-icing equipment; but they are still not advised on how to estimate how much ice, if any, has formed on other parts of the airframe."

Allen Johnson, center manager for FlightSafety International's training facility in Houston, Texas, said FlightSafety has worked closely with Mitsubishi on training and icing issues. He said advanced training helps MU-2 pilots avoid potentially dangerous icing situations.

"In my experience, it's a solid airplane with few surprises. But you must pay attention to the airspeed. With training, the airplane's record has been very good."

Jerry Drennan, program manager of FlightSafety International's Mitsubishi training program, said he thought several of the BASI report's findings were flawed.

"I've known this aircraft for more than 13 years. This is a very safe airplane. It just has to be flown properly," he said.

Drennan said that lack of training could have contributed to many of the reported MU-2 accidents. "The airplane is extremely stable. But if you don't fly it right, it will eat you up in a heartbeat," Drennan said.

The BASI report added: "Interviewed pilots spoke of the difficulty of determining ice formation, even in areas normally visible to the pilot. When glaze ice forms, it is virtually transparent during the daytime and almost impossible to detect on the wing leading edges at night. They [the pilots] advised that determining ice thickness on the wings was reduced to guesswork, especially at night. Some pilots use the formation of ice on the windscreen wiper as an indication that ice is forming on the wings and that the de-icing system should be activated."

More unsettling, the BASI report said, were several pilot reports that described events attributed to unseen ice forming along the lower part of the fuselage. "Performance degradation experienced was attributed to ice accretion on the airframe, with little or no ice on the wing leading edges or windscreen wipers providing advance warning of the ice formation."

Said one surveyed pilot: "The aircraft was cruising at FL 150 [15,000 feet] at night. It entered a line of cumulus-type cloud and immediately started to accumulate ice. I watched the leading edges for a suitable amount of ice to form before activating the de-ice boots, but noticed that the autopilot was slowly trimming the nose up. I noticed that the airspeed had decreased to 120 knots and activated the boots immediately and descended. As the aircraft passed FL 130 [13,000 feet] I felt a great sheet of ice slide off the airframe from underneath and the airspeed increased to normal."

BASI recommended that the CAA work with the aircraft's manufacturer to develop a device that can be fitted on the MU-2 to help warn pilots that ice is forming or has formed on the airframe.

BASI concluded that there was an identifiable event sequence leading to the two Australian MU-2 accidents and in several other incidents and accidents in Australia and elsewhere.

There was also evidence indicating that the elevator trim tab can be driven beyond the normal operating range of nose-up elevator trim by the autopilot as airspeed decreases in an icing encounter, the report said.

"If the pilot fails to see the airspeed loss or the high trim input (a possibility according to survey responses), the pilot may lose control of the aircraft as it stalls. If there is a large amount of nose-up elevator trim, the pilot probably will be unable to overcome the high stick forces on the control column to effect recovery until the trim is moved towards neutral and the high nose-up forces are removed from the elevator."

BASI suggested that the CAA work with the aircraft manufacturer to develop an aural and visual system to warn pilots when the elevator trim has exceeded the normal operating range.

Elevator trim neutralization is also an important factor in MU-2 spin recovery, the BASI report said. It said the MU-2 flight manual should include a recommendation that the pilot neutralize elevator trim as part of the spin recovery procedure. [There was no evidence that the pilots involved in the two MU-2 accidents, studied in depth by the BASI report, had received spin training since their student pilot days.]

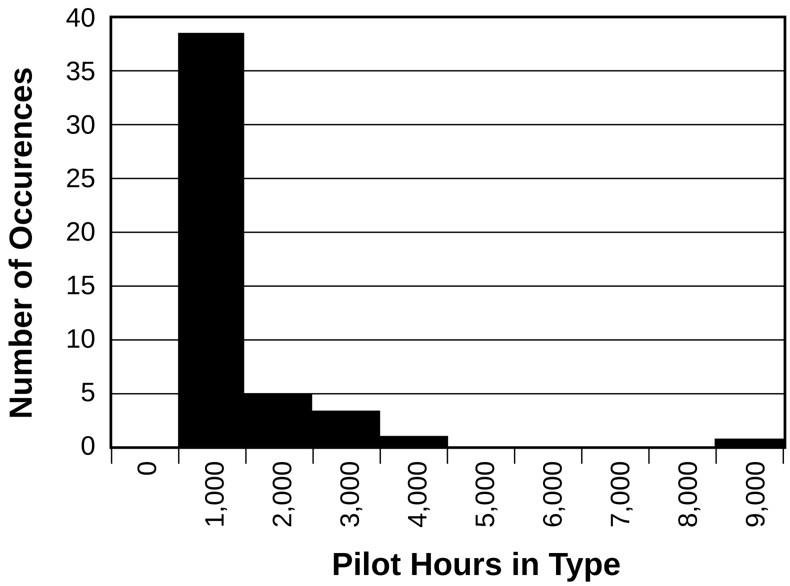
"The MU-2 has largely unknown spin characteristics, but it is at least known that a high rate of descent is experienced along with possible violent (and unstable) oscillations. It has been estimated that the stick forces needed to recover from a spin, if there is a high nose-up trim input, could well be beyond the pilot's [physical] capability unless the trim input is first reduced."

The aircraft is not certified for intentional spins. Although the BASI report said spin recovery follows procedures relatively standard for most aircraft (power to idle, full opposite rudder, brisk forward control wheel movement), there is evidence that the MU-2 can experience "nose oscillations of between 30 degrees below the horizon to 90 degrees below the horizon and an extremely high descent rate."

The BASI report also suggested that the adequacy of the MU-2's stall warning system be studied in icing conditions.

"If airspeed is lost due to ice-contaminated wings and the autopilot attempts to maintain altitude by increasing the angle of attack, it is possible that the aircraft will reach a

Table 1
Total MU-2 Pilot Experience in MU-2 Occurrences



In general, pilots involved in these MU-2 occurrences (accidents/incidents) had recorded less than 1,000 hours on the MU-2.

Source: Australian Bureau of Air Safety Investigation

stall angle of attack before the stall warning activates," the report said.

FlightSafety International's Drennan said proper situational awareness (monitoring of airspeed, pitch and trim) could prevent such emergencies from developing.

Table 2
Average MU-2 Pilot Experience in MU-2 Occurrences

Pilots who:	**Average MU-2 hours**
Maintained control	959 (21)
Lost control	785 (24)
—Regained control	1,237 (14)
—Failed to regain control	151 (11*)

(Figures in parentheses are the base numbers for averages)

* One pilot apparently recovered from the initial spin, but aircraft reentered spin that resulted in fatal crash.

Source: Australian Bureau of Air Safety Investigation

The MU-2 is fitted with a stall warning system which activates stick shakers as the aircraft approaches the stall. Information collected in the BASI report, however, suggested that significant speed loss and stalling can occur in icing conditions without the stick shaker activating.

BASI concluded that there was an identifiable event sequence leading to the two Australian MU-2 accidents and to several other incidents and accidents in Australia and elsewhere.

"It is believed that if one or more of these factors could be eliminated from the typical sequence of events leading to loss of control of the aircraft, the sequence would be broken and the pilot enabled to take action sufficiently early to prevent the situation from developing to the point of loss of control," the report said.

BASI recommended that the CAA withdraw unlimited approval for the MU-2 aircraft to be flown in known icing conditions until it is possible to determine the operational limits of safe flight in such conditions.

Evidence also indicated that pilot experience was clearly linked to the outcome of the reported occurrences. (Tables 1, 2 and 3)

Since the two accidents, regulations requiring increased training and performance standards for MU-2 pilots have been approved by the CAA and implemented, the BASI report said. These changes include training requirements that acknowledge that the MU-2 is a unique and complex, high-performance aircraft and increase the operational training hours required for endorsements.

MU-2 pilots surveyed by BASI said the aircraft required special handling techniques because several of its flying features gave it a "jet-like feel." Some of the features noted were roll control by spoilers rather than by ailerons, low aspect ratio, high wing loading, special handling skills at speeds lower than 150 knots (especially in engine failure after takeoff scenarios) and the use of propeller slipstream lift generation and full-span, double-slotted fowler flaps.

"Australian MU-2 pilots now have better training and higher overall flight experience than previously," the report said. "Higher levels of training have also reduced MU-2 accident rates in the United States."

But the BASI report said that higher training standards will not remedy the problem completely.

Just a few months after introduction of the tougher training standards, an MU-2 pilot, who met the new experience requirements and who was confident that he was aware of icing problems relating to the aircraft, reported the following incident while cruising at 18,000 feet:

Table 3
Average Overall Pilot Experience in MU-2 Occurrences

	Total hours	Turbine hours	MU-2 hours
Accident pilots	4,912 (11)	961 (5)	151 (11)
Incident pilots	7,869 (36)	2,220 (30)	1,026 (37)

(Figures in parentheses are the base numbers for averages)

Source: Australian Bureau of Air Safety Investigation

"With little or no turbulence and no more than one to two minutes since inspecting the wing, airframe vibrations began (autopilot engaged). I was doing the flight log at the time. I looked up to see the indicated airspeed (IAS) at 125 knots, 60 degree bank to left [with] IAS decreasing at about 2 knots a second. I disconnected the autopilot and had the feeling that the tail was trying to overtake me. Wings were leveled and I pushed forward until 160 knots (KIAS). I eased back gently and stalled. All anti-ice, de-ice and igniters were selected as per the flight manual. I unstalled at 170 KIAS and 1,000 feet low. Total reaction time available to me was about 5 seconds. Beyond 5 seconds I would have been inverted, and stalled, judging by the roll and IAS reduction rates."

The BASI report noted that evidence produced at the time "was considered adequate for certification."

The report said that documentation regarding general flight testing in icing conditions is based on pilot reports. "There is no evidence of systematic flight testing of the aircraft in icing conditions. In particular, performance in icing conditions at high altitudes (above 15,000 feet), and at high weights, was apparently not the subject of rigorous flight testing. This is not necessarily to imply that such testing was required for certification at that time, simply to point out that this aspect of the aircraft's performance was not so tested.

"Subsequent tests included some icing conditions, but these tests were limited to below 11,000 feet and in aircraft at well below maximum take-off weight. In addition, the tests were conducted only on the short-fuselage version of the MU-2."

The manufacturer, in an engineering report, listed 46 accounts of Mitsubishi flight tests in icing conditions ranging from light to severe at temperatures from -54° F to +32° F.

BASI said: "Assessment of the data disclosed that 21 accounts took the form of 'icing encounter reports' compiled in a survey conducted between 29 January and 16 February 1976. Pilots answered a series of pro-forma questions about their experiences in icing. Some of the accounts related to events up to seven years prior to the survey. The other 25 accounts are pilot reports of ice encounters covering the period 1966 to 1976. All these reports would more properly be labeled 'pilot testimonials' rather than flight tests."

In order for such evidence to be considered in a certification context, the report said it would have to be:

- Approved by the manufacturer or certification authority;
- Carried out to a schedule that addresses the certification requirement;
- Supported by a flight test plan that stipulates the conditions surrounding each test (weight and balance, flight parameters, etc.); and,
- Supported by a detailed report recording all facets of the flight.

The BASI report said that for a flight test to meet such requirements, it would be expected to include operations:

- At maximum cruising altitudes;
- With weights up to maximum gross at takeoff;
- Throughout a range of icing conditions; and,
- With exploration of controllability and stall margins.

The BASI report noted that evidence produced at the time "was considered adequate for certification." It added: "This is not to suggest that the certification for flight in icing conditions of other aircraft certified in the same manner as the MU-2 is necessarily inadequate. Simply that, with its accident and incident history, the true performance limitations of the MU-2 in particular are not known."

The BASI report said that until flight tests establish safe limits of flight for the MU-2 in icing conditions, the "potential for pilots to encounter similar problems will continue."

"The MU-2's safety performance in high-level icing situations is considered to have serious limitations. Beyond these limits, performance degradation can be swift and catastrophic." ♦

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