RVSM Heightens Need for Precision in Altitude Measurement

Part 2 of a 2-part series

Last month, Avionics News explored the technological advances that have sharpened the accuracy of aircraft altimeters—although research still indicates false indications can occur at any altitude or flight level. This month we examine limitations of the altimeters themselves, most associated with the 'weak link' in altimetry—the human.

BY FLIGHT SAFETY FOUNDATION STAFF

Fatigue, Heavy Workloads Contribute to Mis-setting Errors

An ASRS report on international altimetry said that several factors appear to increase the possibility of altimeter-setting errors:

• Fatigue, which may result from lengthy international flights;

• Heavy workloads during approach, especially when transition altitudes are relatively low. "Obtaining altimeter settings and landing data closer to the approach segment complicates the task of preparing data for landing at the very time the flight crew may be most fatigued;"

• Language difficulties, including "rapid delivery of clearances ... , unfamiliar accents and contraction of hPa (hectopascals) or mb (millibars) ... Other flight crews communicating in their native [languages] contribute to a lack of awareness of what other traffic is doing,"

• Communication procedures in which one person receives approach and landing information and conveys the information to the rest of the flight crew. This procedure "means that a misconception or misunderstanding is less likely to be detected until too late;" and,

• Cockpit management, which "often [provides] inadequate crew briefing for approach and landing, with no mention of how the altimeter setting will be expressed—that is, [inches of mercury], [millibars] or [hectopascals]. Flight crews also may not adequately review approach charts for information. Some airlines do not provide the second officer with approach [charts]; unless he or she makes an extra effort to look at one of the pilot's charts, the altimeter-setting standard may be unknown." (In addition, some airlines provide only one set of approach charts for the captain and first officer to share.)[33]

The ASRS report contained several recommendations, including having each flight crewmember "pay particular attention" during the review of approach charts before the descent to whether altimeter settings will be given in inches, millibars or hectopascals; ensuring that the approach briefing includes mention of how the altimeter setting will be expressed; enabling more than one flight crewmember to hear ATC clearances and ATIS messages; and complying with proper crew coordination standards by cross-checking other crewmembers for accurate communication and procedures.

'Odd' Altimeter Settings Should Prompt Questions

Some of the most frequent errors involving incorrect altimeter settings occur because the barometric pressure is unusually high or unusually low—and because when pilots hear the unexpected altimeter settings, they inadvertently select the more familiar altimeter settings that they had expected. The result can be that an aircraft is hundreds of feet lower (or higher) than the indicated altitude.

For example, in a report submitted to ASRS, the first officer of an air carrier cargo flight described the following event, which occurred in December 1994, during approach to Anchorage, Alaska, after a flight from Hong Kong:

Destination weather [included an altimeter setting of] 28.83 [in. Hg]. Prior to initial descent, the second officer received and put the ATIS information on the landing bug card, except that the altimeter was written as 29.83 [in. Hg]. We were initially cleared to 13,000 feet. I repeated the descent clearance and gave the altimeter as 29.83 [in. Hg]. Center did not catch this in my readback. [On final approach], the second officer noticed the radio altimeter at 800 feet and the barometric altimeter at approximately 1,800 feet. ... The captain started a go-around at the same time the tower reported they had a low-altitude alert warning from us. ... As we taxied, we heard the tower tell another aircraft they had a low-altitude alert. ... Was this [due] to an improper altimeter setting, too?[34]

ASRS said that reports involving unexpected altimeter settings are filed "in bunches, as numerous flight crews experience the same problem on the same day in a particular area that is encountering unusual barometric pressures."[35]

Other errors occur when pilots misunderstand altimeter settings they receive from ATC or incorrectly copy an altimeter setting. The following ASRS reports are examples:

• "The 30.06 [in. Hg] altimeter setting we used was actually the wind speed and direction and was written [as] 3006," a Boeing 767 first officer said. "In my mind, this was a reasonable altimeter setting. The ATIS setting was actually 29.54 [in. Hg];"[36]

• "The altimeter [setting] was 28.84 [in. Hg]," the second officer on a cargo flight said. "I remember enlarging the 8s with two circles on top of each other, thinking this would be sufficient in drawing attention to the low altimeter setting. The next crew after our flight found the altimeter to be set at 29.84 [in. Hg] instead of the actual 28.84 [in. Hg] setting;"[37] and,

• "The pilot not flying understood [the] ATIS recording to state altimeter setting to be 29.99 [in. Hg] when actually the setting was 29.29 [in. Hg]," the captain of an MD-83 passenger flight said. He suggested that "slower, more pronounced ATIS recordings" might help avoid similar problems.[38]

Some controllers emphasize the altimeter setting when the barometric pressure is unusually low, but typically this is not a requirement.

Altimeter Design Can Cause Mis-reading of Indicator

Sometimes, even though the altimeter setting has been selected correctly, errors occur in reading an altimeter. In 1994, the Foundation included among its recommendations to reduce the worldwide CFIT accident rate a request that ICAO issue a warning against the use of three-pointer altimeters and drum-pointer altimeters.

"The misreading of these types of altimeters is well documented," the Foundation said.[39]

In 1998, ICAO adopted amendments to its standards and recommended practices to prohibit the use of these altimeters in commercial aircraft operated under instrument flight rules (IFR), citing a "long history of misreadings."[40]

Before the adoption of those amendments, a Nov. 14, 1990, accident occurred in which an Alitalia McDonnell Douglas DC-9-32 struck a mountain during a night instrument landing system (ILS) approach to Kloten Airport in Zurich, Switzerland. The accident report said that, among other problems, the flight crew "probably misread the [drum-pointer] altimeter during the approach and hence did not realize that the aircraft was considerably below the glide path." The airplane was destroyed, and all 46 people in the airplane were killed.[41]

The report said that drum-pointer altimeters are "less easy to read correctly, especially during periods of high workload" than other altimeters. "A quick look after being distracted can usually induce a reading 1,000 feet off, if the barrel drum is halfway between thousands," the report said.

In a report submitted to ASRS, the single pilot of a small corporate airplane described a similar altimeter-reading problem:

I was assigned 5,000 feet [by ATC]. I thought I was getting ready to level off at 5,000 feet, and departure [control] asked what altitude I was climbing to. I realized I was at 5,700 feet instead of 4,700 feet. This altimeter [makes it] difficult to tell sometimes what the altitude is because the 1,000-foot indicators are in a window to the left. No excuse. I simply looked at it wrong. I know it is difficult to read, so I should have been more alert.[42]

In some incidents, especially when barometric pressure is fluctuating, flight crews operate without the most current altimeter settings.

For example, the crew of an American Airlines McDonnell Douglas MD-83 was conducting a very-high-frequency omnidirectional radio (VOR) approach to Bradley International Airport in Windsor Locks, Conn., in night instrument meteorological conditions (IMC) on Nov. 12, 1995, when the first officer glanced at the altimeter and observed that the airplane was below the minimum descent altitude. He told the captain, who was the pilot flying. Moments later, the airplane struck trees on a ridge about 2.5 nautical miles (4.6 kilometers) northwest of the approach end of the runway. The captain began a go-around, applying all available power; the airplane struck the localizer antenna array at the end of a safety overrun area, landed on a stopway and rolled down the runway.[43]

The airplane received minor damage. One passenger received minor injuries; the 77 other people in the airplane were not injured.

When the accident occurred, the indicated altitude on the altimeter, using the QFE method, was "about 76 feet too high ... resulting in the airplane being 76 feet lower than indicated on the primary altimeters," the U.S. National Transportation Safety Board said in the final report on the accident. The report said that the probable cause of the accident was "the flight crew's failure to maintain the required minimum descent altitude until the required visual references identifiable with the runway were in sight." Contributing factors were "the failure of the ... approach controller to furnish the flight crew with a current altimeter setting, and the flight crew's failure to ask for a more current setting."

Occasionally, in remote areas, flights are conducted far from weather-reporting stations. Rarely, the altimeter setting provided by ATC is inaccurate.

The pilot of a small business airplane said that, as he was flying his airplane near Lake Michigan, at an indicated altitude of 17,000 feet, ATC "reported my altitude encoder indicated 16,000 feet on the readout. I had departed [under visual flight rules] and picked up my IFR clearance at about 4,000 feet. ... I had set the [altimeter setting] as provided by [ATC] when clearance

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was provided. I was approaching a cold front, which was lying north to south over Lake Michigan. I asked for an altimeter setting. The setting provided was one inch lower than the previously provided setting (about 100 nautical miles [185 kilometers] earlier). I reset my altimeter. ... After the reset, my altimeter now indicated 16,000 feet ... The problem was evidently a very steep pressure gradient behind the cold front."[44]

In 1997, ASRS reviewed its database, as well as accident reports and incident reports of the Canadian Aviation Safety Board (predecessor of the Transportation Safety Board of Canada), and found that most altimeter mis-setting incidents that occurred during periods of extremely low barometric pressure occurred in very cold locations or in areas known for severe weather and unusual frontal systems. A number of reports were filed from northern Europe, including Brussels, Belgium; Copenhagen, Denmark; Frankfurt, Germany; Keflavik, Iceland; and Moscow, Russia.[45]

Temperature Errors Sometimes Are Overlooked

Just as pilots adjust the altimeter settings for nonstandard air pressure, a correction also is required—in some situations—for nonstandard air temperature. When the air temperature is warmer than the standard temperature for a specific height in the atmosphere, the true altitude is higher than the altitude indicated on the altimeter. When the air temperature is colder than the standard temperature, the true altitude is lower than the indicated altitude. Moreover, in extremely cold temperatures, the true altitude may be several hundred feet lower. (See Figure 6)

ICAO says that when the ambient temperature on the surface is "much lower than that predicted by the standard atmosphere," a correction must be made, and the calculated minimum safe altitudes must be increased accordingly.

"In such conditions, an approximate correction is 4 percent height increase for every 10 degrees Celsius (C) below the standard temperature, as measured at the altimeter-setting source," ICAO says. "This is safe for all altimeter-setting source altitudes for temperatures above minus 15 degrees C [five degrees Fahrenheit (F)]."[46]

ICAO says that for colder temperatures, temperature-correction tables should be used.

ICAO's temperature-correction table shows, for example, that if the ambient temperature on the surface is minus 20 degrees C (minus 4 degrees F), and the airplane is being flown 1,000 feet above the altimeter-setting source, the pilot should add 140 feet to published procedure altitudes; at 5,000 feet, the pilot should add 710 feet (Table 1, page 57).

Typically, operators should coordinate the handling of cold-temperature altitude corrections with ATC facilities for each cold-weather airport or cold-weather route in their system. The operators should confirm that minimum assigned flight altitudes/flight levels and radar vectoring provide adequate terrain clearance in the event of the coldest expected temperatures; should develop cold-weather altitude-correction procedures, including an altitude-correction table; and should determine which procedures or routes have been designed for cold temperatures and can be flown without altitude corrections.[47]

The fight crew training manual for Boeing 737-300/400/500 airplanes says that operators "should consider altitude corrections when altimeter errors become appreciable, especially where high terrain and/or obstacles exist near airports in combination with very cold temperatures (minus 30 degrees C/minus 22 degrees F, or colder). Further, operators should also consider correcting en route minimum altitudes and/or flight levels where terrain clearance is a factor. ... For very cold

Figure 6
Effects of Temperature on True Altitude

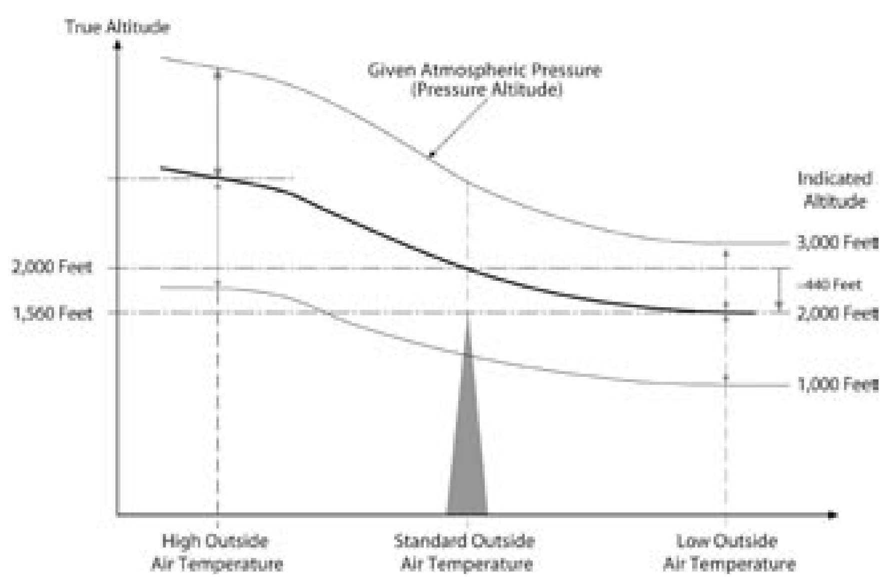

Table 1
Cold-temperature Altitude Correction Chart

Airport temperature (degrees Celsius/Fahrenheit)	Height above the elevation of the altimeter setting source (feet)													
	200	300	400	500	600	700	800	900	1,000	1,500	2,000	3,000	4,000	5,000
0/32	20	20	30	30	40	40	50	50	60	90	120	170	230	280
-10/14	20	30	40	50	60	70	80	90	100	150	200	290	390	490
-20/-4	30	50	60	70	90	100	120	130	140	210	280	420	570	710
-30/-22	40	60	80	100	120	140	150	170	190	280	380	570	760	950
-40/-40	50	80	100	120	150	170	190	220	240	360	480	720	970	1,210
-50/-58	60	90	120	150	180	210	240	270	300	450	590	890	1,190	1,500

Source: International Civil Aviation Organization

temperatures, when flying published minimum altitudes significantly above the airport, altimeter errors can exceed 1,000 feet, resulting in potentially unsafe terrain clearance if no corrections are made."

In one reported occurrence, a McDonnell Douglas MD-80 was flown to Kelowna, British Columbia, Canada, when the surface temperature in Kelowna was minus 27 degrees C (minus 17 degrees F). The crew received clearance for a nonprecision approach; soon afterward, the crew abandoned the approach and asked ATC for radar vectors for another nonprecision approach, flew the approach and landed the airplane. Later, flight crewmembers told other pilots that they had abandoned the first approach after they realized that they had not applied the necessary 800-foot cold-temperature correction to the published procedure-turn altitude of 4,900 feet above field elevation. A ground-proximity warning system (GPWS) terrain warning occurred near a mountain east of the localizer; the airplane flew over the mountaintop with a clearance of 150 feet.[48]

Despite the technological advances in aircraft altimetry and airspeed systems, static ports and pitot probes still are required. Blockages in the pitot-static system still occur, and accidents can result (see "Technological Advances Haven't Eliminated Pitot-static System Problems," page 58).

These blockages most frequently occur while an airplane is on the ground, sometimes because of tape that is placed over static ports during maintenance and not removed afterward, or because of water that enters and becomes trapped in static lines and then freezes when the airplane is flown into colder temperatures at higher altitudes. Typically, the problem does not become apparent to the flight crew until after takeoff; even then, they may experience considerable confusion about conflicting information available from their flight instruments.

Altitude Information Comes From Other Sources

Other systems, including radio altimeters and the geometric altitude component of terrain awareness and warning systems (TAWS)[49] and navigation systems based on the global positioning system (GPS), also provide altitude information.

Radio altimeters, which typically are used below 2,500 feet above ground level during approaches and landings, measure the vertical distance between an aircraft and the ground directly beneath it. They function this way: The radio altimeter's transmitter beams a radio signal downward; the signal is reflected by the ground to the radio altimeter's receiver. The received frequency differs from the transmitted frequency, and that difference varies according to aircraft height and the time required for the signal to travel from the airplane to the ground and back. The frequency difference is used in calculating the height of the aircraft above the ground.[50]

The radio altimeter is designed to be accurate, plus or minus one foot, or plus or minus 3 percent of the indicated height above the ground, whichever is larger. Errors can be introduced by reflections from the landing gear or other parts of the aircraft, uneven terrain and large buildings or trees.

The geometric altitude component of TAWS measures the aircraft's true altitude and is computed by blending "component altitudes," such as GPS altitude, radio altitude and QNH-corrected barometric altitude; the computation also compensates for errors caused by nonstandard air temperatures.

Geometric altitude is included on the TAWS terrain-awareness display to provide the flight crew with a reference altitude for the display and for terrain-avoidance alerts — not for vertical navigation.

A study by Honeywell of the effects of including a digital readout of geometric altitude on the terrain awareness display resulted in findings that

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Technological Advances Haven't Eliminated Pitot-static System Problems

Despite many technological advances that have led to the development of aircraft systems capable of precise altitude and airspeed measurements, conventional pressure altimeters and airspeed indicators depend on simple static ports and pitot probes to function correctly. Pitot-static system problems continue to occur and — rarely — become factors in accidents.

"The fact that these accidents occur infrequently can contribute to the 'startle' factor [that] flight crews experience, leaving them uncertain about how to respond to the anomaly," said Capt. David C. Carbaugh, chief pilot, flight operations safety, Boeing Commercial Airplanes.[1]

One such accident involved an Aeroperu Boeing 757-200 that struck the Pacific Ocean off the coast of Lima, Peru, on Oct. 2, 1996, about 30 minutes after takeoff from Jorge Chavez International Airport in Lima on a night flight to Santiago, Chile. The airplane was destroyed, and all 70 people in the airplane were killed.[2] The flight crew had realized immediately after liftoff that their altimeters and airspeed indicators were not providing correct information and had declared an emergency, but they were unable to diagnose the problem and to safely land the airplane.

The final report by the Peruvian General Director of Air Transport Commission of Accident Investigations said that the probable cause of the accident was adhesive tape that was not removed from the static ports after maintenance; the captain did not observe the tape during his walk-around preflight inspection.

The report said that during the takeoff roll, airspeed indications and altitude indications were normal; afterward, however, altimeter indications increased too slowly, and the indicated airspeed (IAS) was too slow. A wind shear warning was activated three times, although wind was relatively calm and there was no significant weather. The ground-proximity warning system repeatedly sounded warnings of "TOO LOW TERRAIN" and "SINK RATE."

About one minute before the airplane struck the water, as the "TOO LOW TERRAIN" warning sounded, there was no reaction from the crew, who believed an altimeter indication that the airplane was at 9,700 feet.

The report said that the cockpit voice recorder showed that the captain was "confused in his reactions ... and [hesitant] with his commands," while the first officer displayed "equivalent confusion." Neither pilot identified the cause of the problem.

Erroneous airspeed indications have been cited in several accidents, including a Feb. 6, 1996, accident in which a B-757-200 struck the Caribbean Sea off the northern coast of the Dominican Republic about five minutes after takeoff from Gregorio Luperon International Airport in Puerto Plata for a flight to Frankfurt, Germany. The airplane — which was operated by Birgenair, a charter company in Istanbul, Turkey, for Alas Nacionales, a Dominican airline — was destroyed, and all 189 occupants were killed.[3]

In the final report, the Dominican Junta Investigadora de Accidentes Aéreos said that the probable cause of the accident was "the failure on the part of the flight crew to recognize the activation of the stick shaker as an imminent warning of [an] aerodynamic stall and their failure to execute proper procedures for recovery [from] the control loss."

The report said, "Before activation of the stick shaker, confusion of the flight crew occurred due to the erroneous indication of an increase in airspeed [on the captain's airspeed indicator] and a subsequent overspeed warning."

The erroneous airspeed indication and the erroneous overspeed warning resulted from an obstruction of the airplane's upper-left pitot tube.

The report said that the airplane had not been flown for 20 days before the accident and that, during that time, routine maintenance had been performed, including an inspection and ground test of the engines. Investigators believed that engine covers and pitot covers were not installed before or after the ground test.

During the takeoff roll, the captain determined that his airspeed indicator was not working; four other sources of airspeed information were available, and he continued the takeoff "contrary to the established procedures," the report said.

During climbout, the crew decided that the captain's airspeed indicator and the first officer's airspeed indicator were providing incorrect indications and that the alternate airspeed indicator was providing correct information. Nevertheless, none of the three flight crewmembers (the captain, the first officer and a relief captain) suggested "the appropriate course of action to compare the indications or to switch the instrument selector [to the alternate source] to derive airspeed information from the [first officer's air data computer] and its pitot system," the report said.

The wreckage of the airplane was not recovered, and the cause of the pitot-system obstruction was not determined, but the report said that the obstruction likely resulted from "mud and/or debris from a small insect that was introduced in the pitot tube during the time the aircraft was on the ground in Puerto Plata."

Pitot-static System Problems Have Many Causes

Other aircraft accident reports and incident reports have identified numerous causes of malfunctions in static ports and pitot probes, including disconnected or leaking static lines or pitot lines, trapped water in static lines or pitot lines, icing of static ports or pitot probes, blockage of static ports or pitot probes by insects, static-port covers or pitot-probe covers that were not removed before flight, and static-port drain caps that were not replaced following maintenance.[4,5]

"Even the fancy new pitot-static systems still have a probe that sticks out into the airflow, and they still require information from the probe," Carbaugh said.

The incorrect information also affects other aircraft systems or indicators. For example, terrain awareness and warning system (TAWS)[6] information may be unavailable, overspeed warnings and wind shear warnings may be unreliable, and engine indication and crew alerting system messages may not identify the basic source of the problem (Table 1). Other aircraft systems and indicators are unaffected, including pitch and roll indicators, radio altimeters (within the normal activation limits) and radio navigation aid signals (Table 2, page 60).

If a blockage occurs in the static system, erroneous altitude indications and airspeed indications can result. The altitude indicator operates correctly during the takeoff roll. After liftoff, however, the altitude indicator remains at the field elevation (assuming that the initial altimeter setting indicated the field elevation). The static-port blockage causes erroneous airspeed indications following liftoff, when the airspeed indicator lags behind the actual airspeed during climb. The vertical speed indicator (VSI) stops indicating a rate of climb or descent.

If a blockage occurs that traps pressure in a pitot probe, the airspeed indicator does not move from its lower stop during the takeoff roll. After liftoff, the airspeed indication begins to increase, and continues increasing as altitude increases; the airspeed indication may appear to exceed the maximum operating limit speed (VMO) and may result in an overspeed warning. During climb, the altimeter and the VSI function correctly, for practical purposes. If a blockage occurs in the pitot probe's ram inlet while the water drain hole is unobstructed, pressure in the pitot tube may escape; in this event, the airspeed indication decreases to zero.

In incidents involving erroneous altitude indications and erroneous airspeed indications, the problem must be diagnosed promptly by flight crews, and recovery techniques must be initiated immediately.

"The longer erroneous flight instruments are allowed to cause a deviation from the intended flight path, the more difficult the recovery will be," Carbaugh said. "Some basic actions are key to survival.[7]

"Regardless of the situation, good communication between crewmembers is essential, and several basic actions are paramount:

- "Recognizing an unusual or suspect indication;
- "Keeping control of the airplane with basic pitch and power skills;
- "Taking inventory of reliable information;
- "Finding or maintaining favorable flying conditions;
- "Getting assistance from others; [and,]
- "Using checklists."

The most important action is maintaining "reasonable airplane control" with normal pitch and power settings, he said. "Troubleshooting should be done later."

In addition, he said, "Do not trust previously suspected instruments, even if they appear to be operating correctly again."

Michel Trémaud, senior director, safety and security, Airbus

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Table 1
Reliable Information/Systems With Pitot-static System Malfunction

System/Indicator	Notes
Pitch and roll	
Engine thrust	No engine pressure ratio, use engine low-pressure rotor (fan) speed
Radio altitude	When within normal activation limits
Basic ground-proximity warning system	(Initial versions of terrain awareness and warning system may not be reliable)*
Terrain awareness and warning system with geometric altitude	(Initial versions of terrain awareness and warning system may not be reliable)
Stick shaker	May not always be available, but reliable if activated
Groundspeed	Uses inertial information
Airplane position	Uses inertial information
Track and heading	
Radio navigation aid signals	

* Terrain awareness and warning system (TAWS) is the term used by the European Joint Aviation Authorities and the U.S. Federal Aviation Administration to describe equipment meeting International Civil Aviation Organization standards and recommendations for ground-proximity warning system (GPWS) equipment that provides predictive terrain-hazard warnings. "Enhanced GPWS (EGPWS)" and "ground collision avoidance system" are other terms used to describe TAWS equipment.

Source: Adapted from Carbaugh, David C. "Erroneous Flight Instrument Information." In Enhancing Safety in the 21st Century: Proceedings of the 52nd Annual International Air Safety Seminar. Alexandria, Virginia, U.S.: Flight Safety Foundation, 1999.

Table 2 Unreliable Information/Systems With Pitot-static System Malfunction	
System/Indicator	**Notes**
Autopilot	
Autothrottles	
Airspeed	
Altimeter	Blocked static system or blocked pitot-static system
Vertical speed	
Wind information	
Vertical navigation	
Terrain awareness and warning system*	Initial versions of terrain awareness and warning systems
Overspeed warning	
Wind shear warning	
Elevator feel	
Engine indication and crew alerting system messages	May not identify the basic problem

* Terrain awareness and warning system (TAWS) is the term used by the European Joint Aviation Authorities and the U.S. Federal Aviation Administration to describe equipment meeting International Civil Aviation Organization standards and recommendations for ground-proximity warning system (GPWS) equipment that provides predictive terrain-hazard warnings. "Enhanced GPWS (EGPWS)" and "ground collision avoidance system" are other terms used to describe TAWS equipment.

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Customer Services, said, "Detecting an unreliable airspeed indication presents some traps: All indications may be consistent but equally unreliable, [and] indications may differ, but attempting to assess the correct indication may be hazardous.[8]

"Abnormally large indicated-airspeed fluctuations are an obvious attention-getter [and] unusual differences between the captain's and first officer's instruments or between IAS and target airspeed may suggest an unreliable airspeed condition. ... Flight crew awareness of IAS/pitch/thrust/climb rate characteristics is the most effective clue; that is, IAS increasing with typical climb pitch attitude or IAS decreasing with typical descent pitch attitude would indicate a problem."

Other signs of unreliable airspeed indications include an unexpected stall warning, unexpected overspeed warning or simultaneous stall warning and overspeed warning; and an unanticipated IAS-aerodynamic noise relationship, Trémaud said.

If a flight crew detects an unreliable airspeed indication, typical procedures call for achieving short-term flight path control with pitch and power and then conducting procedures discussed in the quick reference handbook for flight control through landing.

"The art and heart of this procedure is to achieve the desired speed by applying a given pitch attitude and a given power/thrust," Trémaud said. "This procedure is amazingly accurate in reaching the desired speed with a difference of less than five knots. However, applying this procedure with accuracy requires prior training in the simulator." (This type of simulator training is not included in type-qualification courses but may be included by operators in their recurrent training programs.)

— FSF Editorial Staff

Notes

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2. Commission of Accident Investigations, General Director of Air Transport, Peru. Final Report: Accident of Boeing 757-200, Operated by an Airliner of Transport of Peru, South America, Aeroperu, Occurred on the Day of October 12, 1996, [actual date was Oct. 2, 1996] Location: Lima, Peru. The original report was written in Spanish; an English translation was distributed by the Air Line Pilots Association, International.
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4. Carbaugh, David C. Interviews by Lacagnina, Mark, and Werfelman, Linda. Alexandria, Virginia, U.S., Oct. 24, 2004; Oct. 28, 2004. Flight Safety Foundation, Alexandria, Virginia, U.S. Additional information from Carbaugh, "Erroneous Flight Instrument Information."
5. Trémaud, Michel. E-mail communication with Werfelman, Linda. Alexandria, Virginia, U.S., Oct. 22–28, 2004. Flight Safety Foundation, Alexandria, Virginia, U.S.
6. Terrain-awareness and warning system (TAWS) is the term used by the European Joint Aviation Authorities and the U.S. Federal Aviation Administration to describe equipment meeting International Civil Aviation Organization standards and recommendations for ground-proximity warning system (GPWS) equipment that provides predictive terrain-hazard warnings; enhanced GPWS and ground collision avoidance system are other terms used to describe TAWS equipment.
7. Carbaugh. "Erroneous Flight Instrument Information."
8. Trémaud.

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included the following:[51]

• "An EGPWS [enhanced ground-proximity warning system] that employs geometric altitude as the reference altitude for the terrain display and predictive alerting functions leads to an earlier and improved detection rate of an altitude deviation resulting from altimetry-related anomalies;

• "The addition of a digital readout of geometric altitude on the terrain display leads to an earlier and improved detection rate of an altitude deviation resulting from altimetry-related anomalies; [and,]

• "Geometric altitude resulted in better and more consistent pilot decision making following the detection of an altitude anomaly—the display of geometric altitude does not negatively impact pilot decision making."

Ratan Khatwa, Ph.D., manager, flight safety human factors, Honeywell, said that minor differences are to be expected between the geometric-altitude display and the barometric altimeter indication. A significant difference during flight below transition altitude, however, could signal a problem. For example, the flight crew might have inadvertently mis-set the barometric altimeter; the QNH altimeter setting might be incorrect or the aircraft might be operating in an area of large differences from standard temperature or standard air pressure; or either the barometric altimeter or the static system might have failed.

Khatwa said that if a significant difference in the displays of geometric altitude and barometric altitude occurs in flight before the transition altitude, the flight crew should comply with the following procedures:

• "Check and confirm all altimeter settings;

• "Cross-check that any other barometric altimeters in the flight deck are in agreement;

• "Check that all altimeter settings are current and referenced to the landing airport;

• "Request assistance from ATC as necessary;

• "Monitor for significant temperature differences, especially in cold air. Updated weather information should be requested if in doubt; [and,]

• "Ensure that static ports are not iced over or are not partially blocked, and [that] heaters are switched on when below freezing."

The Honeywell study assigned the 30 participating pilots—all with about 8,000 flight hours to 9,000 flight hours and experience in using EGPWS—to one of three groups and presented them with several flight scenarios during a simulator session that was designed to evaluate their responses. Of the group of pilots who used a geometric-altitude display and a digital readout of geometric altitude, 97 percent positively detected altitude deviations. Of the group that used a display based on geometric altitude without a geometric-altitude readout, 78 percent detected altitude deviations. Of the group that used a display referenced only to barometric altitude, 49 percent detected the anomalies.

Evaluations of the pilots' responses to the flight scenarios found that 98 percent of those who used the geometric-altitude display and readout and 96 percent of those who used the geometric-altitude display responded correctly, compared with 78 percent of those who used only barometric altitude.

Pilots from all groups described their confidence level as "high, with respect to their ability to detect any altitude anomalies and their subsequent decision making," Khatwa said. Nevertheless, pilots using barometric altitude "often failed to detect altitude anomalies, and therefore, in those cases, [their] perceived terrain awareness did not match actual terrain awareness," he said.

Increased use of geometric altitude is likely, although geometric altitude is unlikely to replace barometric altitude in the near future.

"Use of EGPWS geometric altitude would eliminate the consequences of an incorrect altimeter setting or the consequences of not correcting the indicated altitude for extreme low outside air temperatures," said Michel Trémaud, senior director of safety and security for Airbus Customer Services.[52]

Carbaugh said that increased reliance on geometric altitude computed from satellite data might be a distant goal.

"Pitot tubes and static ports are pretty old technology, prone to insect nests and other things that can mess them up," he said. "But satellite-based data, geometric altitude, would be a whole different world."

Bateman said that increased use of geometric altitude technology could eliminate many of the problems connected with pressure altimeters. Nevertheless, he said, "I don't know how we could get by without pressure altimeters, as that is how the world of aviation flies today, with its QNE/QFE/QNH altimeter-setting references, ATC procedures and practices.

"If we could get rid of pressure altimetry and rely on [GPS-based geometric altitude], we could get rid of the possibility of false altimeter readings and common mode errors where the pressure altimeter can hurt the integrity of the flight. However, I believe we cannot guarantee the integrity of GPS everywhere in the world when we have inadvertent interference, or deliberate interference, nor could the United States probably ever get the rest of the world to switch over [to full reliance on GPS-based geometric altitude]."

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In recent years, aircraft altimeters and other altitude-measuring devices have become very precise. Nevertheless, false indications still occur. Continuing research into new methods of altitude-measurement and new uses of existing technologies—such as radio altimeters and GPS-based geometric altitude—may lead to continued improvements in the accuracy of altitude-measuring systems.

Notes

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