RVSM Heightens Need for Precision in Altitude Measurement

Part 1 of a 2-part series

Technological advances have honed the accuracy of aircraft altimeters, but as we'll explore in part 1 of this 2-part series, false indications still can occur at any altitude or flight level. Next month's issue will examine limitations of the altimeters themselves, most associated with the 'weak link' in altimetry—the human.

BY FLIGHT SAFETY FOUNDATION STAFF

With the expanding use of reduced vertical separation minimum (RVSM) airspace, precise aircraft altitude information has become increasingly important. The reduction of standard vertical separation of aircraft to 1,000 feet/300 meters between Flight Level (FL) 290 (approximately 29,000 feet) and FL 410 means that deviation from an assigned flight level presents greater risks than existed with vertical separation of 2,000 feet/600 meters.

RVSM standards and advanced flight deck technology on transport category aircraft are designed to help minimize those risks. Nevertheless, hazards—involving malfunctioning instrument systems as well as human error—remain.

RVSM implementation has become possible in part because of improvements in the accuracy of modern altimeter systems, compared with the barometric (pressure) altimeters that were used in jet transports in the late 1950s (see "The Evolution of Altimetry Systems," page 72).[1] Because the accuracy of conventional pressure altimeters is reduced at higher altitudes, the international standard established in 1960 was for vertical separation of 2,000 feet between aircraft operated above FL 290.

As technological advances in altimeters, autopilots and altitude-alerting systems led to more precision in measuring and maintaining altitude, the International Civil Aviation Organization (ICAO) determined, after a series of studies in the 1980s, that RVSM was technically feasible and developed a manual for RVSM implementation.[2] Further guidance for aircraft operators is contained in two ICAO-approved documents: European Joint Aviation Authorities Leaflet No. 6[3] and U.S. Federal Aviation Administration Document 91-RVSM.[4]

Included in these documents are minimum equipment requirements for RVSM operations:

- Two independent altitude-measurement systems;
- One secondary surveillance radar transponder with an altitude-reporting system that can be connected to the altitude-measurement system in use for altitude-keeping;
- An altitude-alerting system; and,
- An automatic altitude-control system.

In addition, an ICAO minimum aircraft system performance specification (MASPS) requires that the altimetry systems in RVSM-approved aircraft have a maximum altimeter system error (ASE) of 80 feet/25 meters and that the automatic altitude-control systems must be able to hold altitude within 65 feet/20 meters. (ICAO defines ASE as "the difference between the altitude indicated by the altimeter display, assuming a correct altimeter barometric setting, and the pressure altitude corresponding to the undisturbed ambient pressure.")

The ICAO manual for RVSM implementation says that before flight in RVSM airspace, a flight crew should conduct a ground check to ensure that the required two main altimeter systems are within the prescribed tolerances.

During flight, "generally flight crew operating procedures in RVSM airspace are no different than those in any other airspace," the ICAO manual says.

Nevertheless, the manual says, "It is essential that the aircraft be flown at the cleared flight level (CFL). This requires that particular care be taken to ensure that air traffic control (ATC) clearances are fully understood and complied with ... During cleared transition between [flight] levels, the aircraft should not be allowed to overshoot or undershoot the new flight level by more than [150 feet/45 meters]."

In addition, flight crews should conduct regular hourly cross-checks between the altimeters, and "a minimum of two RVSM MASPS-compliant systems must agree within 60 meters (200 feet). Failure to meet this condition will require that the system be reported as defective and notified to ATC," the ICAO manual says.

Height-monitoring is another RVSM requirement, and the U.K. Civil Aviation Authority (CAA) said in mid-2004 that height-monitoring had revealed the problem of "ASE drift," a phenomenon in which, over time, most aircraft

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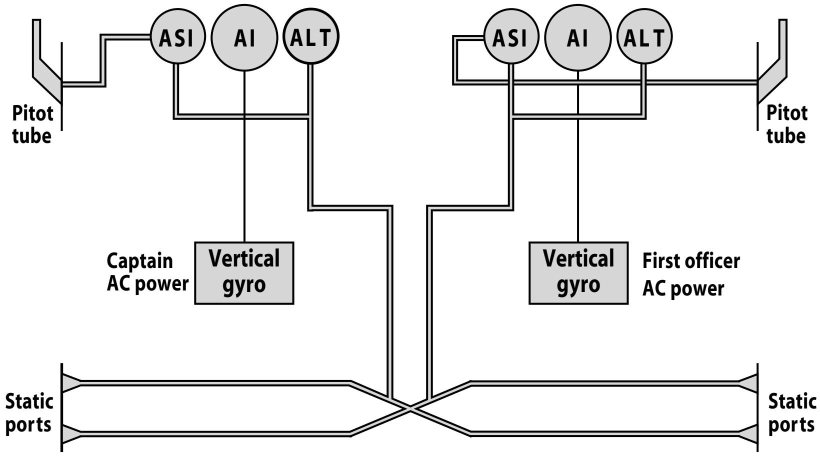
The Evolution of Altimetry Systems

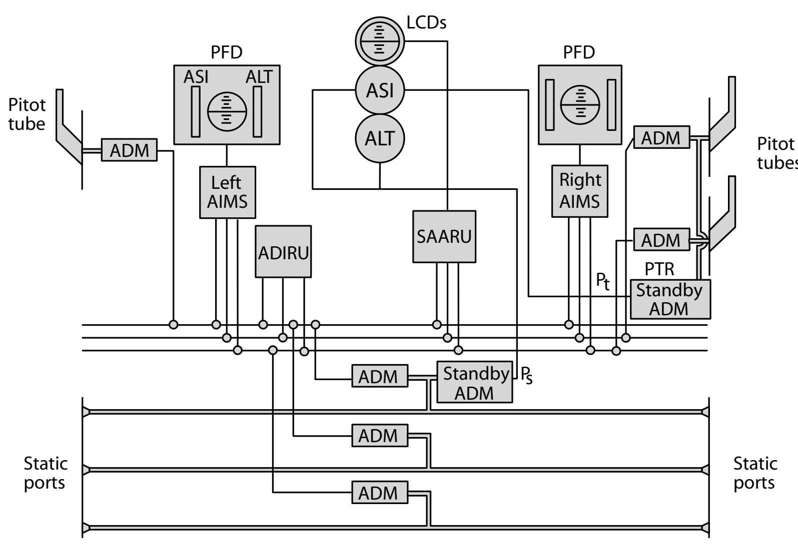
Figure I
Typical Flight Instrumentation on Early Jet Transports



AC=Alternating current AI=Attitude indicator ALT=Altimeter
ASI=Airspeed indicator

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.

Figure 2
Typical Flight Instrumentation on Modern, Fly-by-wire Airplanes



ADIRU=Air data inertial refercen unit ADM=Air data module
AIMS= Airplane information managemetn system ALT=Altimeter
ASI=Airspeed indicator LCD=Liquid crystal display PFD= Primary flight display Ps= Static pressure Pt= Total pressure SAARU= Secondary attitude air data reference unit

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.

Altimeters have provided pilots with essential flight information since the development in 1928 of an accurate barometric (pressure) altimeter.

Altimeters indirectly measure the height of an aircraft above mean sea level or above a ground reference datum by sensing the changes in ambient air pressure that accompany changes in altitude and provide a corresponding altitude reading in feet or meters.

Static air pressure typically is derived from static sources mounted on the sides of the fuselage.

Figure 1 shows how the system typically works in early jet transports. A static line connects the static ports to the altimeter, mounted in an airtight case in which a sealed aneroid barometer reacts to changes in static air pressure. When static air pressure increases, the barometer contracts; when static air pressure decreases, the barometer expands. The movement of the barometer causes movement of height-indicating pointers, which present an altitude indication on the face of the altimeter.[1]

Also on the face of a conventional barometric altimeter is a barometric scale, calibrated in hectopascals (hPa; millibars) or inches of mercury (inches Hg). The scale can be adjusted by a pilot to the local barometric pressure (e.g., within 100 nautical miles [185 kilometers]) or to standard barometric pressure—1013.2 hPa or 29.92 inches Hg—as required by applicable regulations.

The system changed as new airplane models were introduced with air data computers and other advanced electronics and digital displays.

Figure 2 shows how the system typically works in modern transport category aircraft, in which an air data inertial reference unit (ADIRU) is the primary source for altitude (as well as airspeed and attitude), and the information is displayed on the pilots' primary flight displays. Pitot and static pressures are measured by air data modules (ADMs) connected to three independent air pressure sources; ADM information is transmitted through data buses to the ADIRU. The ADIRU calculates altitude and airspeed by comparing information from the three sources, and provides a single set of data for both the captain and the first officer. If an ADIRU fails, an electronic standby altimeter and an electronic standby airspeed indicator receive pitot-static data from standby ADMs.[2]

The newest systems are "far more accurate" than the altimeters that were installed in early jet transports, said Jim Zachary, president of ZTI, an avionics consulting firm.[3]

"The old-type altimeters were not corrected for static source error, which is a function of airspeed," Zachary said. "The pilot would look at the altitude and look at the airspeed and go to some chart and say, 'OK, I've got to do this correction, change my altitude, add 100 feet or 200 feet.'

"That's all done automatically now ... The new electronic altimeters have an integrated ADM and are connected to pitot (for airspeed) and static pneumatics. All errors are corrected internally. This is extremely important for the new, demanding requirements for reduced separation of aircraft. ... It means that you have an altimeter that's absolutely correct."

— FSF Editorial Staff

Notes

1. Harris, David. Flight Instruments and Automatic Flight Control Systems. Oxford, England: Blackwell Science, 2004.

2. Carbaugh, Dave; Forsythe, Doug; McIntyre, Melville. "Erroneous Flight Instrument Information." Boeing Aero No. 8 (October 1999).

3. Zachary, Jim. Telephone interview by Werfelman, Linda. Alexandria, Virginia, U.S. Nov. 12, 2004. Flight Safety Foundation, Alexandria, Virginia, U.S.

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begin to fly lower than their displayed altitude."[5]

U.K. CAA's continuing investigation[6] of ASE drift has found that likely causes include changes over time in the performance of air data computers and erosion of pitot-static probes.

The investigation also has found that ASE can be exacerbated by inadequate operational practices by flight crews, especially noncompliance with aircraft operating restrictions contained in the RVSM airworthiness approval.

"In particular, if the approval was based on adherence to speed limits, the flight crew must be aware of those limits and ensure that the aircraft is operated within the cleared speed envelope," U.K. CAA said.

In addition, during RVSM operations, both the active autopilot and the operating transponder should be selected to the same altimetry system, "unless there is a systems limitation or functionality which makes the requirement unnecessary and is detailed in the AFM [aircraft flight manual]."

Air Data Computers, Glass Cockpit Displays Improve Accuracy

Despite the findings about ASE drift, the precision of altitude information available on the flight deck has increased in recent years because of the development of the air data computer (ADC), air data inertial reference unit (ADIRU) and digital displays. Modern systems may include an ADIRU that receives information from air data modules (ADMs) connected to the airplane's pitot probes and static pressure sources; the unit incorporates the best of that information (rejecting data that are incompatible with data produced by the other sources) to provide a single set of data to both pilots. Other standby ADMs provide information for standby flight instruments.[7,8]

Improvements in the accuracy of modern altimeter systems, however, have not eliminated the possibility of critical altimeter-setting problems, which often result from human error.

Several factors related to barometric altimeters often have been associated with a flight crew's loss of vertical situational awareness, which in turn has been associated with many controlled-flight-into-terrain (CFIT) accidents.[9,10] These factors include confusion resulting from the use of different altitude and height reference systems and different altimeter-setting units of measurement.

In 1994, the Flight Safety Foundation (FSF) CFIT Task Force said, "Flight crew training is now used as a means of solving this problem, but consideration should be given to discontinuing the use of some altimeter designs and standardizing the use of altitude and height reference systems and altimeter-setting units of measurement." Many of the Foundation's recommendations have since been endorsed by ICAO, civil aviation authorities and aircraft operators in many countries.

ICAO has recommended procedures for providing adequate vertical separation between aircraft and adequate terrain clearance, including what units should be used to measure air pressure, what settings should be used to display the measurement and when during a flight the settings should be changed; nevertheless, many variations are used by civil aviation authorities in different countries (see "ICAO Prescribes Basic Principles for Vertical Separation, Terrain Clearance," page 74).[11]

Capt. David C. Carbaugh, chief pilot, flight operations safety, Boeing Commercial Airplanes, said that, despite technological advances, "a human still has to set the altimeter, and it'll display what it's asked to display; if you ask it to display the wrong thing,

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ICAO Prescribes Basic Principles for Vertical Separation, Terrain Clearance

The International Civil Aviation Organization (ICAO) recommends a method of providing adequate vertical separation between aircraft and adequate terrain clearance, according to the following principles:[1]

• During flight, when at or below a fixed altitude called the transition altitude, an aircraft is flown at altitudes determined from an altimeter set to sea level pressure (QNH)[2] and its vertical position is expressed in terms of altitude;

• During flight, above the transition altitude, an aircraft is flown along surfaces of constant atmospheric pressure, based on an altimeter setting of 1013.2 hectopascals [29.92 inches of mercury], and throughout this phase of a flight, the vertical position of an aircraft is expressed in terms of flight levels. Where no transition altitude has been established for the area, aircraft in the en route phase shall be flown at a flight level;

• The change in reference from altitude to flight levels, and vice versa, is made, when climbing, at the transition altitude and, when descending, at the transition level;

• "The adequacy of terrain clearance during any phase of a flight may be maintained in any of several ways, depending upon the facilities available in a particular area, the recommended methods in the order of preference being:

– The use of current QNH reports from an adequate network of QNH reporting stations;

– The use of such QNH reports as are available, combined with other meteorological information such as forecast lowest mean sea level pressure for the route or portions thereof; and,

– Where relevant current information is not available, the use of values of the lowest altitudes of flight levels, derived from climatological data; and,

• During the approach to land, terrain clearance may be determined by using the QNH altimeter setting (giving altitude) or, under specified circumstances ... a QFE3 setting (giving height above the QFE datum).

ICAO says that these procedures provide "sufficient flexibility to permit variation in detail[ed] procedures which may be required to account for local conditions without deviating from the basic procedures."

— FSF Editorial Staff

Notes

1. International Civil Aviation Organization. Procedures for Air Navigation Services. Aircraft Operations, Volume 1: Flight Procedures. Part VI, Altimeter Setting Procedures.

2. QNH is the altimeter setting provided by air traffic control or reported by a specific station and takes into account height above sea level with corrections for local atmospheric pressure. On the ground, the QNH altimeter setting results in an indication of actual elevation above sea level; in the air, the QNH altimeter setting results in an indication of the true height above sea level, without adjustment for nonstandard temperature.

3. QFE is an altimeter setting corrected for actual height above sea level and local pressure variations; a QFE altimeter setting applies to a specific ground-reference datum. On the ground, a correct QFE altimeter setting results in an indication of zero elevation; in the air, the QFE setting results in an indication of height above the ground reference datum.

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that's what it will display. It's well-documented that the human is the weak link in altimetry."[12]

Altimeter mis-setting has been identified as one of the top six causal factors associated with level busts,[13] which are defined by the European Organisation for Safety of Air Navigation (Eurocontrol) as unauthorized vertical deviations from an ATC flight clearance of more than 300 feet outside RVSM airspace and more than 200 feet within RVSM airspace.[14]

"Level busts, or altitude deviations, are a potentially serious aviation hazard and occur when an aircraft fails to fly at the level required for safe separation," Eurocontrol said in the "Level Bust Briefing Notes," a set of discussion papers included in the European Air Traffic Management Level Bust Toolkit. (The tool kit is designed to raise awareness of the level bust issue among aircraft operators and air navigation service providers and to help them develop strategies to reduce level busts. Fourteen briefing notes are a fundamental part of the tool kit.)

"When RVSM applies, the potential for a dangerous situation to arise is increased. This operational hazard may result in serious harm, either from a midair collision or from collision with the ground (CFIT)," the briefing notes said.

Studies have shown that an average of one level bust per commercial aircraft occurs each year, that one European country reports more than 500 level busts a year and that one major European airline reported 498 level busts from July 2000 to June 2002.[15]

Tzvetomir Blajev, coordinator of safety improvement initiatives, Safety Enhancement Business Division, Directorate of Air Traffic Management Programmes, Eurocontrol, said that data is not sufficient to evaluate incorrect altimeter settings in European RVSM airspace.[16]

Nevertheless, Blajev said, “An incorrect altimeter setting is of concern to us. ... Some of the 21 recommendations in the Level Bust Toolkit are designed to fight the risk of errors in altimeter settings. One specifically is targeted at this: ‘Ensure clear procedures for altimeter cross-checking and approaching level calls.’ To support the implementation of this recommendation, we have developed a briefing note.”

Different Standards Lead to Confusion

Some altimeter-setting errors that occur during international flights have been attributed to the fact that not all civil aviation authorities have the same altimeter-setting rules and requirements.

C. Donald Bateman, chief engineer, flight safety systems, Honeywell, said, “We have so many different altimeter-setting standards. Obviously, there’s a good chance we’re going to have errors, and we’ve had them.”[17]

For example, different altimeter-setting practices involving QFE and QNH can cause confusion.

QFE is an altimeter setting corrected for actual height above sea level and local pressure variations; a QFE altimeter setting applies to a specific ground-reference datum. On the ground, a correct QFE setting results in an indication of zero elevation; in the air, the QFE setting results in an indication of height above the ground-reference datum.

QNH is the altimeter setting provided by ATC or reported by a specific station and takes into account height above sea level with corrections for local atmospheric pressure. On the ground, the QNH altimeter setting results in an indication of actual elevation above sea level; in the air, the QNH altimeter setting results in an indication of the true height above sea level, without adjustment for nonstandard temperature.

(Another “Q code” is QNE, which refers to the standard pressure altimeter setting of 1013.2 hectopascals [hPa], or 29.92 inches of mercury [in. Hg].)

Some operators require flight crews to set the altimeter to QFE in areas where QNH is used by ATC and by most other operators.

The FSF Approach-and-Landing Accident Reduction (ALAR) Task Force said that using QNH has two

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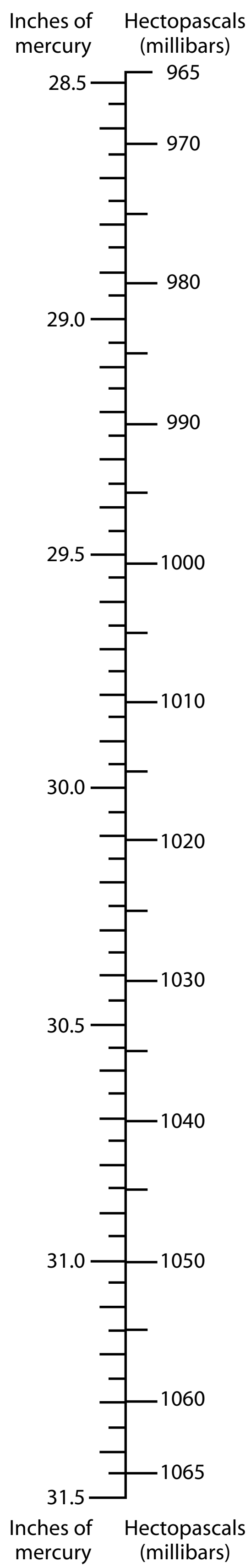
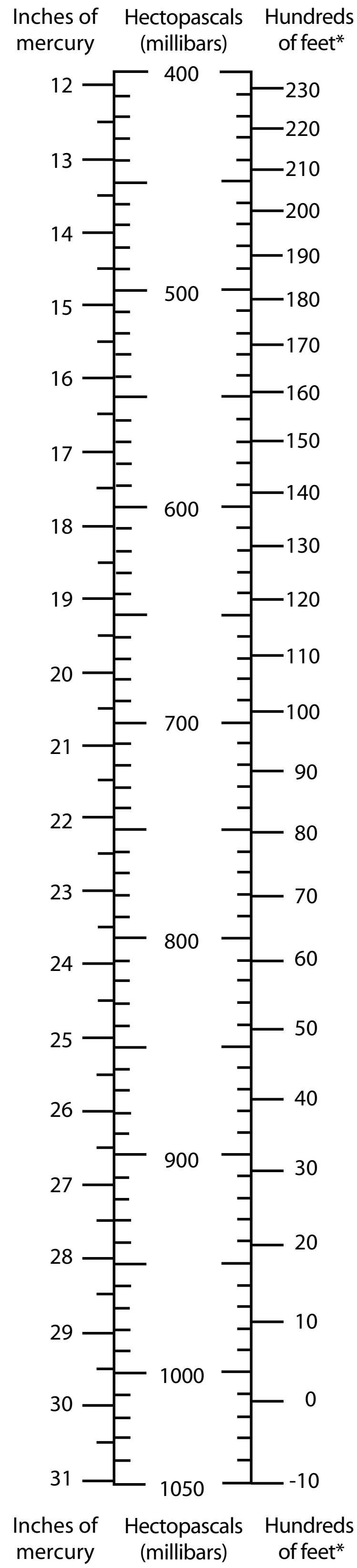
Figure I
Altimeter-setting
Conversion Table



Source: U.S. Government Printing Office

Figure 2
Pressure/Altitude
Conversion Table



*Standard Atmosphere

Source: U.S. Government Printing Office

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advantages: "eliminating the need to change the altimeter setting during operations below the transition altitude/flight level" and eliminating "the need to change the altimeter setting during a missed approach." (Such a change usually is required when QFE is used.)[18]

Many civil aviation authorities use hectopascals (millibars), to measure barometric pressure; others use inches of mercury (Figure 1); if a pilot confuses the two and mis-sets the altimeter, the result can mean that the aircraft is hundreds of feet lower (or higher) than the indicated altitude (Figure 2; Figure 3, page 77).[19]

The ICAO standard is for altimeter settings to be given in hectopascals, and in 1994, the Foundation recommended that all civil aviation authorities adopt hectopascals for altimeter settings to eliminate the "avoidable hazard of mis-setting the altimeter."[20]

In 2000, the Foundation repeated the recommendation in its "ALAR Briefing Notes:"

When inches Hg is used for the altimeter setting, unusual barometric pressures, such as a 28.XX inches Hg (low pressure) or a 30.XX inches Hg (high pressure), may go undetected when listening to the ... ATIS [automatic terminal information service] or ATC, resulting in a more usual 29.XX altimeter setting being set.

Figure 4, page 77 and Figure 5, page 78 show that a 1.00 in. Hg discrepancy in the altimeter setting results in a 1,000-foot error in the indicated altitude.

In Figure 4, QNH is an unusually low 28.XX inches Hg, but the altimeter was set mistakenly to a more usual 29.XX inches Hg, resulting in the true altitude (i.e., the aircraft's actual height above mean sea level) being 1,000 feet lower than indicated.

In Figure 5, QNH is an unusually high 30.XX inches Hg, but the altimeter was set mistakenly to a more usual 29.XX inches Hg, resulting in the true altitude being 1,000 feet higher than indicated.[21]

Numerous reports about these problems have been submitted to the U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS),[22] including the following:

• The captain of an air carrier passenger flight said that during descent to Frankfurt, Germany, "the altimeters were incorrectly set at 29.99 inches Hg instead of 999 hPa, resulting in Frankfurt approach control issuing an altitude alert. The reason I believe this happened is that the ATIS was copied by the relief pilot using three digits with a decimal point. Since Frankfurt normally issues both hectopascals and inches of mercury on the ATIS, I incorrectly assumed that the decimal denoted the inches of mercury scale and announced '2999' and set my altimeter. The first officer did the same. ... In the

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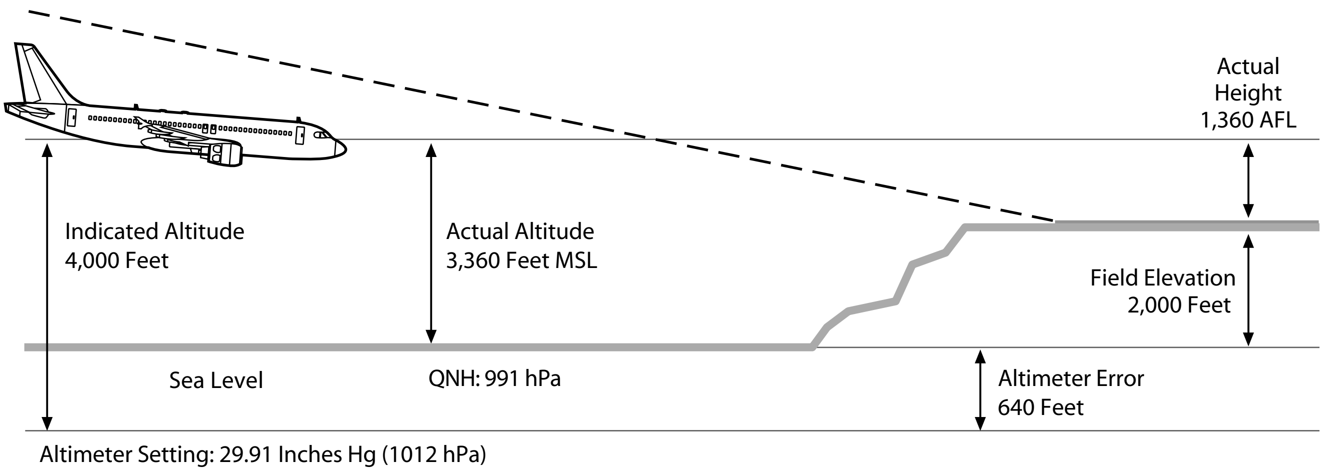
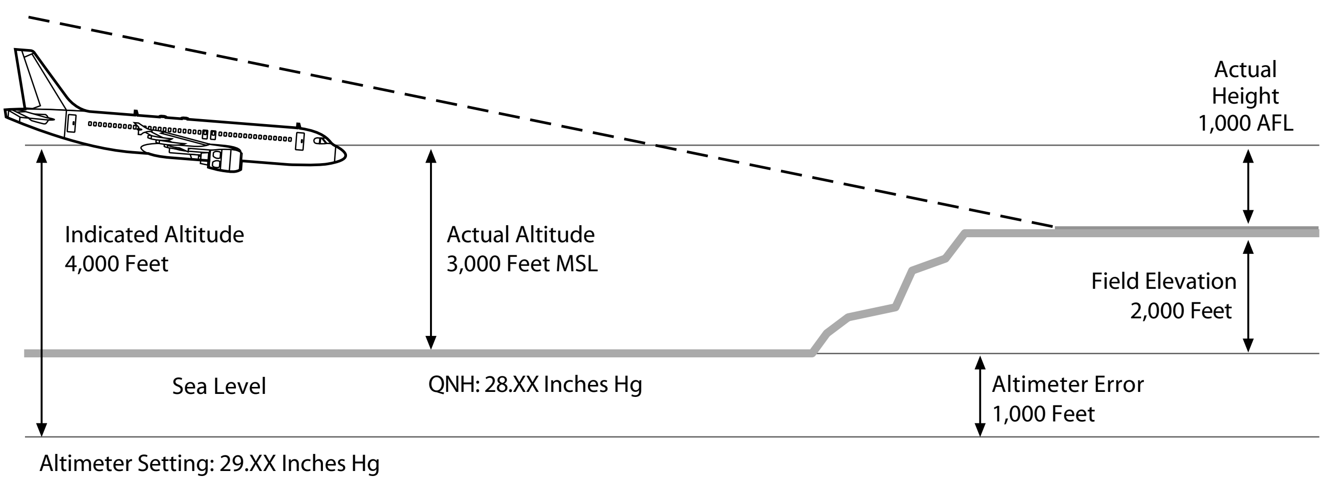
Figure 3
Effect of an Altimeter Mis-set to inches, Rather Than Hectopascals



AFL= Above Field level MSL=Mean seal level Hg=Mercury
QNH= Altimeter setting that causes altimeter to indicate height avove mean seal level (thus, field elevation at touchdown)

Source: Flight Safety Foundation Approach-and-landing Accident Reducation (ALAR) Task Force

Figure 4
Effect of a One-inch-high Altimeter Setting



AFL= Above Field level MSL=Mean seal level Hg=Mercury
QNH= Altimeter setting that causes altimeter to indicate height avove mean seal level (thus, field elevation at touchdown)

Source: Flight Safety Foundation Approach-and-landing Accident Reducation (ALAR) Task Force

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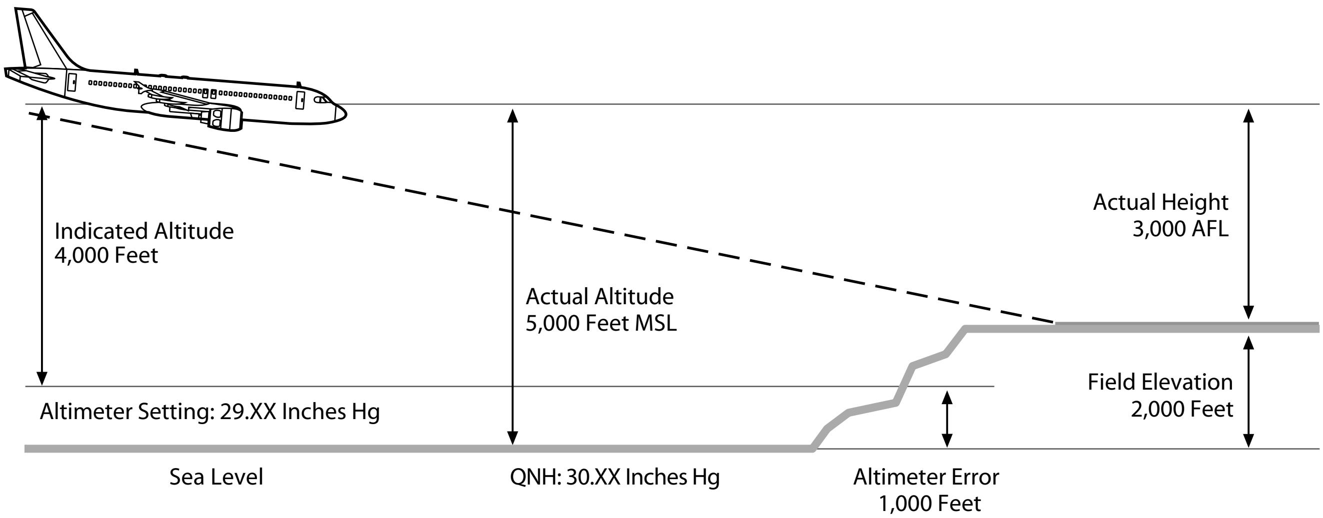
Figure 5
Effect of a One-inch-low Altimeter Setting



AFL= Above Field level MSL=Mean seal level Hg=Mercury
QNH= Altimeter setting that causes altimeter to indicate height avove mean seal level (thus, field elevation at touchdown)

Source: Flight Safety Foundation Approach-and-landing Accident Reducation (ALAR) Task Force

future, I will insist that all ATIS information is to be copied, and particularly both altimeter settings.

" ... Safety would also be greatly enhanced if ICAO standards were complied with by the controllers (i.e., stating the units when giving the altimeter setting) ... I believe this could happen to almost any pilot, given similar circumstances. I feel that stating units by all concerned would eliminate most of the problem,"[23]

• Another pilot said that at the end of a long overwater flight, "approach control gave the altimeter as 998 hPa. I read back 29.98 [inches Hg]. [The] approach controller repeated his original statement. Forgetting that our altimeters have settings for millibars and hectopascals (which I had only used once in my career, and that was six months ago), I asked where the conversion chart was. 'Old hand' captain told me that approach [control] meant 29.98 [inches Hg]. Assuming that he knew what he was doing, I believed him. We were a bit low on a ragged approach, and I knew we were awfully close to some of the hills that dot the area ... but it was not until we landed and our altimeters read 500 feet low that I realized what had happened."[24]

Transition Altitudes Vary

Civil aviation authorities worldwide have established transition altitudes at which flight crews switch their altimeter settings between the standard altimeter setting for flights at or above the transition altitude and the altimeter setting being reported by the nearest reporting station for flights below the transition altitude. The designated transition altitude varies from 3,000 feet in Buenos Aires, Argentina, to 18,000 feet in North America.[25] Transition altitudes can be specified for entire countries or for smaller areas, such as individual airports; in some jurisdictions, the transition altitude varies, depending on QNH.

NASA said that numerous ASRS reports have been submitted involving altimeter mis-setting events at transition altitudes. The reports included the following:

• A flight crew on an air carrier cargo flight in Europe said that they forgot to reset their altimeters at the unfamiliar transition altitude of 4,500 feet. "Climbing to FL 60 ... we were task-saturated flying the standard instrument departure, reconfiguring flaps and slats, resetting navigation receivers and course settings, resetting engine anti-ice, etc. The crew missed resetting the Kollsman [barometric altimeter] window to 29.92 [inches Hg] at 4,500 feet MSL [above mean sea level] and leveled off at FL 60 indicated altitude with a Kollsman setting of 28.88 [inches Hg]. Departure [control] informed us of our error,"[26]

• A first officer on an air carrier passenger flight said, "Due to a distraction from a flight attendant, we neglected to reset altimeters passing through FL 180 from 29.92 [inches Hg] to 29.20 [inches Hg]. Extremely low pressure caused us to be at 12,200 feet when we thought we were at 13,000 feet.

The controller queried us; we realized our error and climbed to 13,000 feet after resetting the altimeter. We didn't accomplish the approach checklist on descent, which would have prevented this,"[27]

• A first officer on an air carrier cargo flight said, "Received low-altitude warning, pulled up and discovered altimeter ... was mis-set. Altimeter was set at 29.84 [inches Hg] and should have been set at 28.84 [inches Hg]. Crew distracted with a [mechanical problem] about the time of altimeter transition [through FL 180];"[28] and,

• A first officer on an air carrier passenger flight said, "Just before we began descent, the flight attendant brought up dinner for both of us at the same time. Started descent as [we] started eating. Because of distraction, we failed to reset altimeters at 18,000 feet. Descended to 17,000 feet with wrong altimeter setting. Resulted in level-off 300 feet below assigned altitude. Received [traffic advisory] of traffic at 16,000 feet. Controller suggested that we reset altimeters."[29]

ASRS said, "The cure is strict adherence to checklists and procedures (sterile cockpit,[30] readback of ATC clearances, etc.) and good CRM [crew resource management] techniques for cross-checking with the other crewmember(s)."

Another element that sometimes introduces confusion is the use of metric altitudes in some countries (for example, in Russia and China). The FSF "ALAR Briefing Notes" said that this requires standard operating procedures (SOPs) for the use of metric altimeters or conversion tables.[31]

The "ALAR Briefing Notes" said that, in general, to prevent many altimeter-setting errors associated with different units of measurement or extremes in barometric pressure, the following SOPs should be used "when broadcasting (ATIS or controllers) or reading back (pilots) an altimeter setting:

• "All digits, as well as the unit of measurement (e.g., inches or hectopascals) should be announced.

"A transmission such as 'altimeter setting six seven' can be interpreted as 28.67 inches Hg, 29.67 inches Hg, 30.67 inches Hg or 967 hPa.

"Stating the complete altimeter setting prevents confusion and allows detection and correction of a previous error; [and,]

• "When using inches Hg, 'low' should precede an altimeter setting of 28.XX inches Hg, and 'high' should precede an altimeter setting of 30.XX inches Hg."[32]

Notes

1. International Civil Aviation Organization (ICAO). Manual on Implementation of a 300 m (1,000 ft) Vertical Separation Minimum Between FL290 and FL410 Inclusive. Document 9574. Second edition—2002.
2. Ibid.
3. Joint Aviation Authorities (JAA). Guidance Material on the Approval of Aircraft and Operators for Flight in Airspace Above Flight Level 290 Where a 300-meter (1,000-foot) Vertical Separation Minimum Is Applied. Leaflet no. 6, Revision 1. Jan. 10, 1999.
4. U.S. Federal Aviation Administration (FAA). Guidance Material on the Approval of Operations/Aircraft for RVSM Operations. Document No. 91-RVSM. Feb. 20, 2004.
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6. Sanders, David. E-mail communication with Werfelman, Linda. Alexandria, Virginia, U.S., Nov. 1, 2004; Nov. 5, 2004. Flight Safety Foundation, Alexandria, Virginia, U.S. Sanders, a U.K. CAA press officer, said that the investigation is likely to continue for an "extended period."
7. Honeywell. Air Transport Avionics. www.cas.Honeywell.com/ats/products/nav.cfm. Nov. 5, 2004.
8. Carbaugh, David C. "Erroneous Flight Instrument Information." Boeing Aero No. 23 (July 2003).
9. Flight Safety Foundation (FSF) Controlled-flight-into-terrain (CFIT) Task Force. CFIT Education and Training Aid. 1996.
10. CFIT, as defined by the FSF CFIT Task Force, occurs when an airworthy aircraft under the control of the flight crew is flown unintentionally into terrain, obstacles or water, usually with no prior awareness by the crew. This type of accident can occur during most phases of flight, but CFIT is more common during the approach-and-landing phase, which begins when an airworthy aircraft under the control of the flight crew descends below 5,000 feet above ground level (AGL) with the intention to conduct an approach and ends when the landing is complete or the flight crew flies the aircraft above 5,000 feet AGL en route to another airport.
11. ICAO. Procedures for Air Navigation Services (PANS). Aircraft Operations, Volume 1: Flight Procedures. Part VI, Altimeter Setting Procedures.
12. Carbaugh, David C. Interview with Lacagnina, Mark, and Werfelman, Linda. Alexandria, Virginia, U.S., Oct. 28, 2004. Flight Safety Foundation, Alexandria, Virginia, U.S.
13. U.K. CAA Level Bust Working Group. On the Level Project Final Report, Civil Aviation Publication 710. London, England. December 2000.
14. European Organisation for Safety of Air Navigation (Eurocontrol). "Level Bust Briefing Notes: General." June 2004. This is one of 14 briefing notes—related papers about level-bust issues—that are part of the European Air Traffic Management Level Bust Toolkit, a package of informational materials produced by Eurocontrol and designed to raise awareness of the level bust issue among aircraft operators and air navigation service providers and to help them develop strategies to reduce level busts.
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ber 2000).

The "ALAR Briefing Notes" are part of the ALAR Tool Kit, which provides on compact disc (CD) a unique set of pilot briefing notes, videos, presentations, risk-awareness checklists and other tools designed to help prevent approach-and-landing accidents (ALAs) and CFIT. The tool kit is the culmination of the Foundation-led efforts of more than 300 safety specialists worldwide to identify the causes of ALAs and CFIT, and to develop practical recommendations for prevention of these accidents. The tool kit is a compilation of work that was begun in 1996 by an international group of aviation industry volunteers who comprised the FSF ALAR Task Force, which launched the second phase of work begun in 1992 by the FSF CFIT Task Force.

19. Hectopascal is the air-pressure measurement recommended by ICAO. The term is derived from the name of 17th-century French mathematician Blaise Pascal, who developed a method of measuring barometric pressure, and the Greek word for 100. One hectopascal is the equivalent of 100 pascals, or one millibar. One inch of mercury is equivalent to 33.86 hectopascals.

20. FSF. News Release: "Flight Safety Foundation Campaign to Reduce Controlled-flight-into-terrain Accidents Produces Safety Checklist, Specific Prevention Recommendations." Nov. 2, 1994.

21. FSF. "ALAR Briefing Notes."

22. The U.S. National Aeronautics and Space Administration (NASA) Aviation Safety Reporting System (ASRS) is a confidential incident-reporting system. The ASRS Program Overview said, "Pilots, air traffic controllers, flight attendants, mechanics, ground personnel and others involved in aviation operations submit reports to the ASRS when they are involved in, or observe, an incident or situation in which aviation safety was compromised." ASRS acknowledges that its data have certain limitations. ASRS Directline (December 1998) said, "Reporters to ASRS may introduce biases that result from a greater tendency to report serious events than minor ones; from organizational and geographic influences; and from many other factors. All of these potential influences reduce the confidence that can be attached to statistical findings based on ASRS data. However, the proportions of consistently reported incidents to ASRS, such as altitude deviations, have been remarkably stable over many years. Therefore, users of ASRS may presume that incident reports drawn from a time interval of several or more years will reflect patterns that are broadly representative of the total universe of aviation safety incidents of that type."

23. NASA ASRS. Report no. 295007. January 1995.

24. Thomas, Perry. "International Altimetry." ASRS Directline No. 2 (October 1991).

25. Patten, Marcia; Arri, Ed. "The Low-Down on Altimeter Settings." ASRS Directline No. 9 (March 1997).

26. NASA ASRS. Report no. 206218. March 1992.

27. NASA ASRS. Report no. 289818. November 1994.

28. NASA ASRS. Report no. 290122. December 1994.

29. NASA ASRS. Report no. 295619. February 1995.

30. The "sterile cockpit rule" refers to U.S. Federal Aviation Regulations Part 121.542, which states, "No flight crewmember may engage in, nor may any pilot-in-command permit, any activity during a critical phase of flight which could distract any flight crewmember from the performance of his or her duties or which could interfere with the proper conduct of those duties. Activities such as eating meals, engaging in nonessential conversations within the cockpit and nonessential communications between the cabin and cockpit crews, and reading publications not related to the proper conduct of the flight are not required for the safe operation of the aircraft. For the purposes of this section, critical phases of flight include all ground operations involving taxi, takeoff and landing, and all other flight operations below 10,000 feet, except cruise flight." [The FSF ALAR Task Force says that "10,000 feet" should be height above ground level during flight operations over high terrain.]

31. FSF. "ALAR Briefing Notes."

32. Ibid.

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