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A STUDY OF BAROMETRIC ALTIMETER ERRORS IN HIGH LATITUDE REGIONS

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ABSTRACT

Present day barometric altimeters calculate atmospheric heights by assuming the ICAO (International Civil Aviation Organization) Standard Atmosphere, which is an average, piece-wise continuous, mid-latitude temperature profile of the earth's atmosphere. The ICAO temperature profile has been used in the aviation field for over 30 years. Nevertheless, seasonal changes in conjunction with latitudinal variations can produce temperature profiles that can significantly differ from the ICAO standard atmosphere, especially for geographical regions located at high latitudes during winter seasons. This study investigates altimeter errors that occur due to cold temperatures at high latitude locations. If the temperature profile is colder than the standard atmosphere, the altimeter will read an altitude that is higher than the true altitude of the aircraft. These errors are very critical in mountainous terrain areas. Climatological temperature profiles from a high latitude region will be used to conduct an altimeter error analysis. The case study will highlight key issues in using barometric altimeters in these situations and help identify problem areas. Recommendations on improving or enhancing current barometric altimeter operations will be discussed and future studies will be outlined.

1. INTRODUCTION

1.1 The standard aircraft altimeter (figure 1) is a barometric device that measures pressure and not altitude directly. The pressure altimeter is a barometer that measures changes in atmospheric pressure and through a series of assumptions and computer algorithms, converts these changes, and displays an altitude. This conversion process assumes standard atmospheric conditions. Therefore, when the atmospheric conditions deviate from the standard atmospheric conditions, errors in determining the correct altitude will result.

Figure 1. Typical Barometric Altimeter Gauge.

1.2 Present day barometric altimeters calculate atmospheric heights by assuming the International Civil Aviation Organization Standard Temperature Atmosphere (U.S. ICAO Standard Atmosphere, 1958, 1962, 1966, 1976), which is an average, piece-wise continuous, mid-latitude temperature profile of the earth's atmosphere. The ICAO temperature profile has been used in the aviation field for over 30 years (figure 2). Nevertheless, seasonal changes in conjunction with latitudinal variations can produce temperature profiles that can significantly differ from the ICAO standard atmosphere, especially for geographical regions located at high latitudes during winter seasons. This study investigates altimeter errors that occur due to cold

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temperatures at high latitude locations. If the temperature profile is colder than the standard atmosphere, the altimeter will read an altitude that is higher than the true altitude of the aircraft. These errors are very critical in mountainous terrain areas. Climatological temperature profiles from a high latitude region will be used to conduct an altimeter error analysis. The case study will highlight key issues in using barometric altimeters in these situations and help identify problem areas. Recommendations on improving or enhancing current barometric altimeter operations will be discussed and future studies will be outlined.

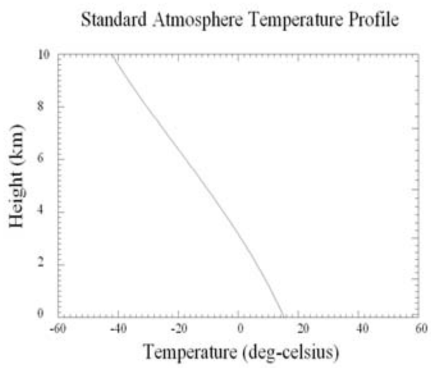

Figure 2. Standard Atmospheric Temperature Profile.

1.3 The motivation for this study came from an article about flight accidents in Alaska in which James LaBelle was quoted as saying “Between 1990 and 1998, there were 1,510 aviation accidents, an average of one accident every 2 days, that took the lives of 355 people. The commercial aviation accident rate in Alaska is three to four times greater than that of the other 49 States. Indeed, we were saddened to learn of the most recent commuter airline accident that occurred just last Tuesday 50 miles from Bethel, Alaska. That accident took the lives of 6 people. It is also significant to note that aircraft accidents are the leading cause of occupational fatalities in Alaska.Flight operations in Alaska are diverse, with a challenging environment, such as rough terrain, adverse weather, and unique air transportation requirements. Due to the large geographic area and lack of other forms of transportation, aviation is often the only way to traverse much of the State. These challenges increase the risks to safe flight operations” (LaBelle, 1999).

1.4 Alaskan cities are located at latitudes from 51.88 degrees N (Adak, AK) to 71.8 degrees N (Barrow, AK). Global climatological temperature profiles show dependence on latitude and season which may result in significant errors in altimeter readings that can further mislead pilots when flying under severe weather conditions.

2. SOURCES OF ERRORS

Because the standard aircraft altimeter calculates altitude from specific meteorological measurements, it is subjected to several sources of errors.

2.1 For these studies, the most relevant meteorological data types are the temperature and the pressure versus height. The next section reviews the meteorological instrumentations that will either measure or infer these parameters.

2.2 The accuracy of aircraft altimeters is subject to the following factors:

1. Nonstandard temperatures of the atmosphere (addressed in this study).
2. Nonstandard atmospheric pressure.
3. Instrument error.

2.3 The type of altimeter errors due to nonstandard temperatures is dependent on the temperature profile rather than the surface temperature only. Even though the altimeter may be set for current surface conditions, it may be incorrect at higher levels. If the air is warmer than the standard for the flight altitude, the aircraft will be higher than the altimeter indicates; if the air is colder than standard for flight altitude, the aircraft will be lower than the altimeter indicates. Thus, "If it's cold, look out below" or to quote an old saying: "*GOING FROM A HIGH TO A LOW, LOOK OUT BELOW*."

3. TEMPERATURE PROFILING METHODS

Temperature profiling of the atmosphere can be measurements either indirectly by remote sensing techniques or by point measurements such as balloon borne instrumentations. Ground based temperature measurements can be obtained by microwave, acoustic, or infrared sensors. Temperature profiles can also be obtained through satellite based sounders such as the TIROS Operational Vertical Sounder (TOVS) system and the GOES satellite. A brief description of these instruments is given. Table 1 is a tabulation of various meteorological sensors and their associated characteristics.

MET SENSOR	MEASUREMENT	METHOD	RANGE
Microwave Radiometer	Temperature	Ground-based, Remote Sensing, Continuous sampling (minutes)	near surface to 10 km, vertical
Surface Met Sensors	Temperature, Pressure, Relative Humidity, Winds	Ground-based, Point measurement, Continuous sampling (minutes, seconds)	limited to extrapolation algorithms near the surface
Sounders on GOES Satellite	Inferred temperature and winds from Infrared/Microw ave Radiances	Satellite-based, Remote Sensing, Geostationary , Hemispheric sampling (hourly)	Top of Atmosphere to Surface depending on the spectral channel
Sounders on NOAA Satellite	Inferred temperature and winds from Infrared/Microw ave Radiances	Satellite-based, Remote Sensing, Polar Orbiting, 1-2 passes/day	Top of Atmosphere to Surface depending on the spectral channel
Radiosonde	Temperature, Pressure, Relative Humidity, Winds	Balloon-based, Point measurement, 2 Launches/day operationally	Ascension from surface to stratosphere depending on wind drift

Table 1. Table of meteorological sensors for atmospheric temperature measurements.

3.1 MICROWAVE RADIOMETER

The ground based microwave radiometer is capable of measuring temperature profiles from the surface up to 10 km height (Radiometrics, 1997; Measure and Yee, 1992; Yee and Measure, 1992). The microwave radiometer incorporates a frequency agile local oscillator permitting frequency tuning in the 22-30 GHz and 51-59 GHz regions. The tunable frequencies cover the oxygen band, water line, and window region thereby allowing measurements of temperature, water vapor, and liquid water. Past field experiments have shown the instrument to be reasonably reliable and portable.

3.2 SURFACE METEOROLOGICAL SENSORS.

The surface meteorological sensors measure pressure, relative humidity, temperature, wind speed and wind direction, and radiation. From these surface parameters, there are computer models that can estimate atmospheric temperature profiles in the lower boundary layers.

3.3 GOES SATELLITE

The GOES I-M Sounder is a 19-channel radiometer that senses specific data parameters for atmospheric temperature and moisture profiles, surface and cloud top temperature, and ozone distribution (Menzel, 1995; Hayden and Schmit, 1994). The satellite Sounder system is able to measure profiles over remote locations where ground-based balloon systems are absent. The Sounder has 4 sets of detectors:
visible (.7 micrometer)
long wave IR (12-14.7 micrometers)
medium wave IR (6.5-11 micrometers)
short wave IR (3.7-4.5 micrometers).

3.4 NOAA SATELLITE

The TIROS Operational Vertical Sounder (TOVS) system is used to infer temperature and winds. The system consists of three separate instruments: High Resolution Infrared Radiation Sounder (HIRS), Microwave Sounding Unit (MSU) and Stratospheric Sounding Unit (SSU). The HIRS instrument is a step-scanned multi-channel spectrometer with 20 channels primarily in the infrared region of the spectrum. These 20 spectral bands permit the calculation of the vertical temperature profile from Earth's surface to about 40 km.

Multispectral data from one visible channel (0.69 micrometers), seven shortwave channels (3.7 to 4.6 micrometers) and twelve longwave channels (6.5 to 15 micrometers) are obtained from a single telescope and a rotating filter wheel containing twenty individual filters. The instantaneous FOV (Field Of View) is 1.3 to 1.4 degrees from an altitude of 833 kilometers, encompassing an area of approximately 19-20 kilometers at nadir on the Earth. The swath width is about 2300 km. (Kidder & Vonder Haar, 1995)

3.5 RADIOSONDE

The radiosonde is a balloon-borne instrument for the simultaneous measurement and transmission of meteorological data producing vertical profiles of atmospheric pressure, temperature, humidity, and wind speed and direction. Newer radiosondes employ GPS (Global Positioning Satellites) to derive the winds as the balloon ascends. The balloon ascends from the surface up to 20-30 km height over approximately 1-2 hour period.

4. CASE STUDY

For this case study, a representative Alaskan latitudinal belt was selected i.e. 60N latitude for a winter season. A collection of climatological temperature profiles for the region during the winter month of January was assembled and an averaged temperature profile was calculated (Figure 3). From the 60N latitude temperature profile, altitudes based on atmospheric pressure were calculated. For comparison, the altitudes that a standard pressure altimeter would indicate assuming a standard atmospheric temperature profile were calculated. Altimeter errors as a function of pressure readings were determined.

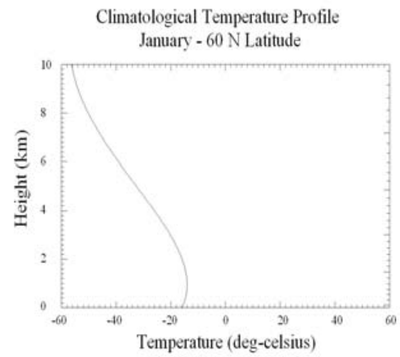

Figure 3. Climatological Temperature Profile for January, 60 degrees N Latitude.

5. CASE STUDY RESULTS

A depiction of the temperature effects on altimeter readings is illustrated in figure 4. If the atmospheric temperatures were warmer than the standard atmosphere, the indicated altimeter readings would be lower than the actual height. On the other hand, if the atmospheric temperatures were colder than the standard atmosphere, the indicated altimeter readings would be higher than the actual height. In the example shown in the figure 4, the airplane is flying on the 800mb pressure level. If the standard atmosphere is assumed, the pilot's altimeter would read 1843 meters but if the temperature profile follows the more realistic January 60N latitude temperature profile, the pilot would be flying at 1689 meters.

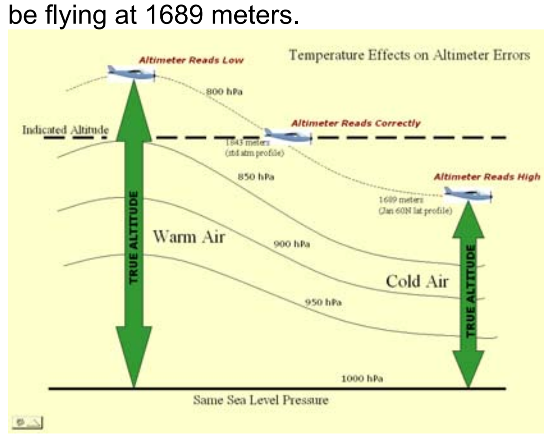

Figure 4. Depiction of Temperature Effects on Altimeter Errors.

For this case study, an altimeter correction graph was calculated as shown in figure 5. These results indicate that altimeter errors can be as high as 340 meters when the pressure altimeter reads 280 mb. Because of the non-linear characteristics of the January 60N latitude temperature profile, the altimeter corrections do not exhibit a linear relationship.

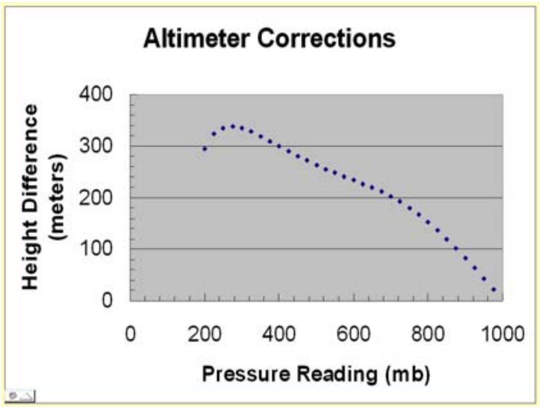

Figure 5. Altimeter Corrections for January, 60 degrees N Latitude, temperature profile.

6. CONCLUSION

Previous research in using ground based microwave radiometers to retrieve temperature profiles from varied locations indicated significant deviation of the high latitude temperature profiles from the standard atmosphere temperature profile. Deriving a climatological temperature profile for a high latitude case (month of January, 60 degree latitude), we investigated the altimeter errors that would occur due to a non-standard temperature profile. Preliminary results indicate altimeter errors can be as high as 340 meters when the pressure altimeter reads 280 mb.

The Flight Information Handbook's "Temperature Correction Chart" gives temperature corrections that apply to instrument approaches. These estimated corrections should be adhered to, when applicable, but recognize that the chart only applies under the conditions set out. Simply applying those numbers to any situation can be misleading. Among other things, the FIH Temperature Correction Table does not necessarily account for the behavior of the actual atmosphere on any given day.

Extreme caution should be exercised when flying in proximity to obstructions or terrain in low temperatures and pressures. This is especially true in extremely cold temperatures that cause a large differential between the Standard Atmospheric Day temperature and actual temperature. This circumstance can cause serious errors that result in the aircraft being significantly lower than the indicated altitude. Future studies will be to investigate other latitudinal regions for different seasons.

7. RECOMMENDATIONS

- Collect and assemble climatological temperature profiles for other latitudinal belts for the different seasons to compile more detailed pressure altimeter errors due to non-standard atmosphere conditions.
- Perform test and evaluation at a specific geographical location
- Investigate the use of ground based microwave radiometers to correct for temperature profiles in high latitude regions

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