The Air

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Gleim sections 2.2, 2.4-7, 5.1, 5.2

Structure of the Atmosphere

The atmosphere consists of several layers:

- Troposphere (starts at ground, 8-18 km high)
  - General decrease in temperature with altitude
  - All weather occurs here
  - Contains 99% of all water in the atmosphere
  - Height varies with latitude (higher near equator) and season (higher in summer)
  - Most flying is confined to the troposphere
- Tropopause
  - Narrow region between troposphere and stratosphere
  - Temperature remains constant with altitude
- Stratosphere (from top of tropopause to 50 km)
  - Temperature remains constant until about 25 km
  - Temperature *rises* above 25 km to 50 km
  - Contains ozone layer
- Stratopause transition layer
- Mesosphere (from top of stratopause to 80 km)
  - Temperature decreases with altitude
- Mesopause transition layer
- Thermosphere (from top of mesopause to 300 km)
- Exosphere (from top of thermosphere to 1000 km)

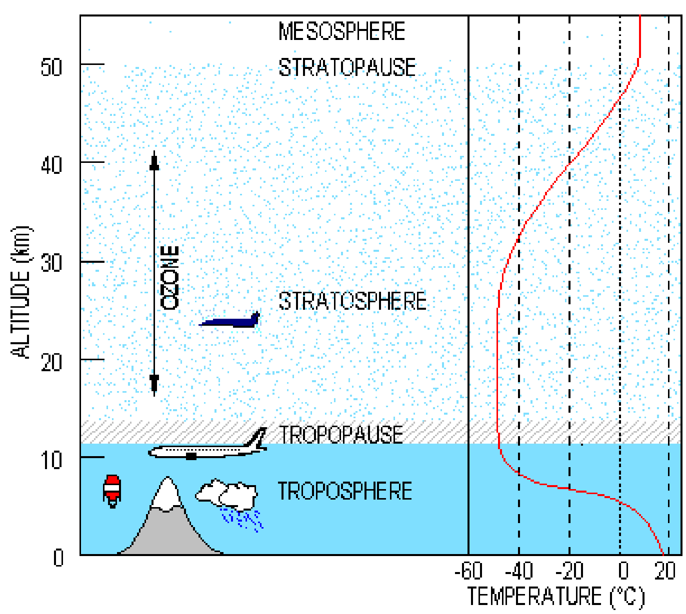


Figure 1: Structure of the atmosphere

Gas Properties

Concepts: pressure, density, temperature, humidity

- Assume a perfect gas!
  - This means intermolecular forces are negligible
- *Pressure* is the force exerted on an area by molecular motion (e.g. pounds per square inch)
  - You can feel this holding your hand outside a car window
  - Pressure will increase if temperature increases (more motion)
  - Pressure will increase if density increases (more molecules to impact)
- *Density* is the amount of mass per unit volume (e.g. slugs per cubic foot)
  - **Density will increase if pressure increases** (pushing the molecules together)
  - **Density will decrease if temperature increases** (more activity pushing the molecules apart)
  - Pressure and temperature "fight" to cause density – pressure pushes molecules together, temperature pushes them apart
- *Temperature* is the average energy of the molecules (e.g. degrees Celsius or Fahrenheit)
  - Temperature will change only with the addition of external heat (not really true, but practical for our purposes here – this will change when we talk about weather concepts later)
- The *equation of state* is: Pressure = Density * Temperature * gas-constant
- The *gas-constant* isn't really constant in real life! The water content of the air will change it. **Humid air is less dense than dry air**. The difference is fairly minor, though.

The Standard Atmosphere

- Pressure, density, and temperature vary widely from day to day based on latitude, local weather conditions, season, etc.
- To provide a way to talk about the atmosphere, a *standard atmosphere* has been defined
- **Sea level conditions are: 59 F (15 C) and 29.92 in Hg (1013 mb)**
- The standard atmosphere is used to talk about aircraft performance

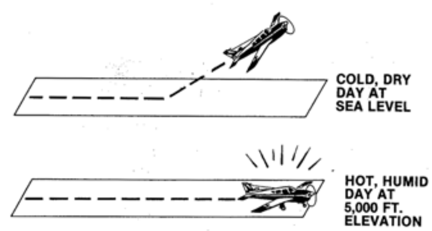
Alt (ft)	Temp (C)	Temp (F)	Pres (psi)	Pres (in Hg)	Pres (mb)	Pres ratio	Dens (slg/ft^3)	Dens ratio
0	**15.2**	**59.4**	**14.7**	**29.9**	**1013**	**1.000729**	**0.002378**	**1.000591**
1,000	13.2	55.8	14.2	28.9	977	0.964958	0.002309	0.971533
2,000	11.2	52.2	13.7	27.8	942	0.930230	0.002242	0.943125
3,000	9.2	48.6	13.2	26.8	908	0.896520	0.002176	0.915357
4,000	7.2	45.0	12.7	25.8	875	0.863807	0.002111	0.888219
5,000	5.3	41.5	12.2	24.9	843	0.832066	0.002048	0.861701
6,000	3.3	37.9	11.8	24.0	811	0.801277	0.001987	0.835792
7,000	1.3	34.3	11.3	23.1	781	0.771416	0.001927	0.810483
8,000	-0.7	30.7	10.9	22.2	752	0.742463	0.001868	0.785765
9,000	-2.7	27.1	10.5	21.4	723	0.714396	0.001810	0.761628
10,000	-4.7	23.5	10.1	20.6	696	0.687195	0.001754	0.738062
11,000	-6.7	20.0	9.7	19.8	669	0.660838	0.001700	0.715058
12,000	-8.7	16.4	9.3	19.0	643	0.635305	0.001646	0.692606
13,000	-10.7	12.8	9.0	18.3	618	0.610578	0.001594	0.670698
14,000	-12.7	9.2	8.6	17.5	594	0.586635	0.001543	0.649323
15,000	-14.7	5.6	8.3	16.9	571	0.563458	0.001494	0.628474
16,000	-16.6	2.0	8.0	16.2	548	0.541029	0.001446	0.608140
17,000	-18.6	-1.5	7.6	15.5	526	0.519327	0.001398	0.588314
18,000	**-20.6**	**-5.1**	**7.3**	**14.9**	**505**	**0.498336**	**0.001352**	**0.568986**
19,000	-22.6	-8.7	7.0	14.3	484	0.478037	0.001308	0.550147
20,000	-24.6	-12.3	6.7	13.7	464	0.458413	0.001264	0.531789
21,000	-26.6	-15.9	6.5	13.1	445	0.439447	0.001222	0.513903
22,000	-28.6	-19.4	6.2	12.6	426	0.421120	0.001180	0.496482
23,000	-30.6	-23.0	5.9	12.1	409	0.403418	0.001140	0.479515
24,000	-32.6	-26.6	5.7	11.6	391	0.386323	0.001101	0.462996
25,000	-34.6	-30.2	5.4	11.1	375	0.369819	0.001062	0.446916
26,000	-36.5	-33.8	5.2	10.6	358	0.353891	0.001025	0.431266
27,000	-38.5	-37.4	5.0	10.1	343	0.338522	0.000989	0.416039
28,000	-40.5	-40.9	4.8	9.7	328	0.323699	0.000954	0.401226
29,000	-42.5	-44.5	4.5	9.3	313	0.309406	0.000919	0.386821
30,000	-44.5	-48.1	4.3	8.8	299	0.295628	0.000886	0.372814

Figure 2: The standard atmosphere

Types of Altitude

Concepts: true altitude, absolute altitude, pressure altitude, density altitude, indicated altitude

- *True altitude* is the actual height above *mean sea level* (MSL)
- *Absolute altitude* is the actual height above the surface (AGL = above ground level)
- In practice, it is not possible to measure true altitude or absolute altitude. Instead, local atmospheric conditions (pressure, density, and temperature) at altitude are used to determine various measurements.
- *Pressure altitude* is the altitude in the standard atmosphere that has the local pressure
  - Determine the local pressure (e.g. 12.6 in Hg)
  - Look up the pressure in the standard atmosphere table
  - Read the pressure altitude (22,000 feet)
  - **Pressure altitude and true altitude will be the same with a standard atmosphere**
  - **The FAA says that "pressure altitude is true altitude corrected for non-standard atmospheric pressure"**
  - **Pressure altitude is read by the airplane's altimeter when the altimeter is set to 29.92**
- *Density altitude* is the altitude in the standard atmosphere that has the local density
  - Determine the local density (this isn't easy)
  - Look up the density in the standard atmosphere table
  - Read the density altitude
  - Density altitude and true altitude will be the same with a standard atmosphere
  - **Density altitude and pressure altitude will be the same with standard temperature**
  - **When the density is *less*, the density altitude is *higher* – the air is "thinner" when you go up in altitude**
  - **Density altitude is higher when at a high altitude, on a hot day, and in humid conditions**
  - **Density altitude is a major determining factor in airplane performance. Higher density altitudes result in less performance across the board: take off and landing distance are longer, climb performance is worse, and propeller efficiency is worse.**
  - **The FAA says that "density altitude is pressure altitude corrected for non-standard temperature"**
- *Indicated altitude* is defined below



COMBINED EFFECT OF ALTITUDE, TEMPERATURE, AND MOISTURE ON THE TAKEOFF AND RATE OF CLIMB

The Static System

Concepts: total pressure, static pressure, dynamic pressure, static pressure source

- *Total pressure* is the amount of pressure measured by the object we care about (the airplane, or the hand out the window). Total pressure consists of two parts: static pressure and dynamic pressure.
- Static pressure is the amount of pressure ignoring the overall movement of the air. For example, a barometer inside of a moving car measures the static pressure because the air is not moving *en masse* in relation to the barometer – they are both moving together.
- Dynamic pressure is the amount of pressure caused solely by the motion of an air mass. This is the difference felt by having your hand out the window instead of inside the car.
- In an airplane, static pressure comes from a *static pressure source*
  - The static pressure source is usually a very small hole mounted out of the airflow – e.g. on the fuselage
  - **The static source provides information to three instruments: altimeter, airspeed indicator, and vertical speed indicator**
  - A static pressure source can get clogged by dirt or covered by ice
  - This can be very dangerous because you can no longer tell altitude or airspeed
  - Most airplanes have an *alternate static source* located inside the cabin with a selection knob

The Altimeter

Concepts: altimeter operation, altimeter display, Kollsman window, effects of non-standard atmosphere

Figure 3: Altimeter

- An altimeter operates by comparing the static pressure acquired from a static source with a known reference pressure, and assuming a *standard change in pressure with altitude*

- *Indicated altitude* is simply the altitude indicated by reading the altimeter. It may be different than true, pressure, or density altitude depending on conditions.
- **Indicated altitude and true altitude will be the same on a standard day with the altimeter properly set**

- An altimeter generally has three hands
  - The long hand with the triangle at the end measures ten-thousands (on some altimeters this is a short, skinny hand)
  - The short, fat hand measures thousands
  - The long, skinny hand measures hundreds
  - The altimeter shown above is displaying 820 feet
  - The striped area at the bottom serves as a warning that the altimeter is showing less than 10,000 feet. Above 10,000 feet the area will be covered up. (This is only available on some altimeters)

- Because the altimeter reads pressure, corrections need to be made for non-standard pressure. This is done by using a dial to enter a value into the *Kollsman window*. The value is received from a nearby airport. **If 29.92" is entered in this window, the altimeter will display the pressure altitude.**
- The way the number is determined is very simple: a person with an altimeter on the ground turns the knob until the altimeter reads the known ground elevation. This can also be done by the pilot on the ground if a local altimeter setting is not available.

- When flying from one region to a region with a different pressure correction (such as flying from a "high" to a "low" or vice versa), and the same indicated altitude is maintained, the airplane's true altitude will be either higher or lower than expected unless the Kollsman value is reset.
- **When flying from a "high" to a "low" the airplane will be lower than expected** (the altimeter will indicate higher than expected). At point (1) the altimeter is set to 29.92 and the airplane is cruising at 2000 feet. The airplane flies to a region of low pressure where the proper setting is 28.85, but the altimeter setting is not changed. While maintaining a constant *indicated* altitude, the airplane's *true* altitude at point (2) has decreased by 1000 feet. At point (3) the altimeter is set to 28.85, giving a correct altitude reading of 1000 feet, and the airplane is climbed back to 2000 feet at point (4).

- **Notice that decreasing the altimeter setting also decreases the indicated altitude by about 1000 feet per in Hg.**

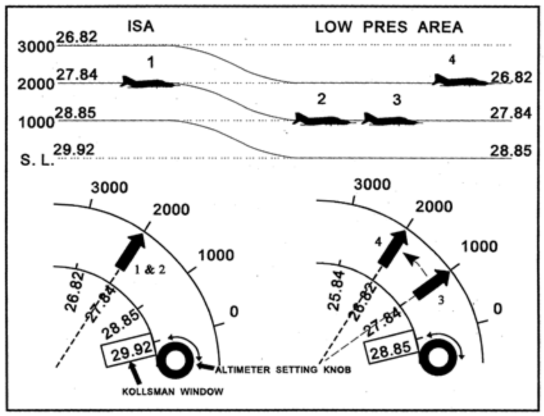


Figure 4: Effect of changing pressure on altitude

- When flying in a region where the temperature does not change in the "standard" way with altitude, the pressure levels will be closer together or farther apart than expected by the altimeter. Notice in the figure that in the "hot" region the pressure levels are farther apart. The altimeter setting (29.92 vs. 31.02) is used capture this difference. As noted above, the altimeter setting is determined on the ground at a given airport. This leads to an important observation…

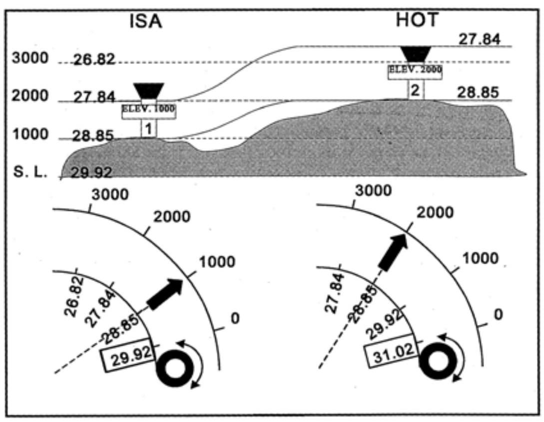


Figure 5: Effect of non-standard temperature on altitude

IMPORTANT: The altimeter is **only accurate on the ground at the airport where the altimeter setting was received**. At any other altitude, the *indicated altitude* (the altitude indicated by the altimeter) may be higher or lower than the true altitude! **On a cold day, the true altitude will be lower, and on a hot day, the true altitude will be higher. If you don't reset your altimeter setting, it can be dangerous to fly from a high pressure area to a low pressure area, or from a hot area to a cold area.**

- However, this is not as bad as it may seem, because:
  - Being near the ground at an airport is generally the most dangerous place for an airplane, and that's where the altimeter is most accurate
  - FAA regulations are designed to provide a sufficient margin of error. For example, airplanes without visual reference are required to clear mountain ranges by 2,000 feet, more than enough to guarantee that any non-standard temperature rate will not cause a large enough altimeter error be dangerous.

- FAR 91.121 - Altimeter settings
  (a) Each person operating an aircraft shall maintain the cruising altitude or flight level of that aircraft, as the case may be, by reference to an altimeter that is set, when operating --
  (1) Below 18,000 feet MSL, to --
  (i) The current reported altimeter setting of a station along the route and within 100 nautical miles of the aircraft;
  (ii) If there is no station within the area prescribed in paragraph (a)(1)(i) of this section, the current reported altimeter setting of an appropriate available station; or
  (iii) In the case of an aircraft not equipped with a radio, the elevation of the departure airport or an appropriate altimeter setting available before departure; or
  (2) At or above 18,000 feet MSL, to 29.92” Hg.

The Vertical Speed Indicator

Figure 6: Vertical speed indicator

- The vertical speed indicator (VSI) indicates the *rate of change of altitude*, usually in feet per minute
- It does this by using a chamber with a calibrated leak
- The VSI generally uses the same static source as the altimeter

The Pitot System and the Airspeed Indicator

Concepts: total pressure, static pressure, dynamic pressure, true airspeed, indicated airspeed, calibrated airspeed

Figure 7: Airspeed indicator and pitot tube

- A *pitot tube* (named after Henri Pitot who invented it in 1732) measures the total air pressure. It consists of a narrow opening with a closed tube behind it. **The pitot tube supplies information only to the airspeed indicator.**
- The airspeed indicator uses the total air pressure and the static air pressure from the static source to determine the dynamic air pressure, and from that determine the speed of the airplane through the air (sort of like a car speedometer)
- The dynamic pressure depends on both the velocity of the air and the density. Thus as the air becomes less dense with increasing altitude, the measured dynamic pressure decreases, and thus the *indicated airspeed* becomes less than the *true airspeed*.
- It is possible to correct the indicated airspeed for pressure altitude and temperature (which determine density). Some airspeed indicators have a dial that can be used for this purpose (see figure). A good rule of thumb is to increase the indicated airspeed by 2% for each 1000 feet of altitude. Thus at 10,000 feet, multiply the indicated airspeed by 1.2 (20%).
- **Because the pitot tube and the static source may not measure the precise conditions of the atmosphere because of the interference of the airplane body or other reasons ("position and installation errors"), the airspeed indicator may not be perfectly accurate. The *calibrated airspeed* is the airspeed that would be indicated if the system was perfect.** Usually the airplane manufacturer will provide a table to convert between indicated airspeed and calibrated airspeed. The difference is usually negligible, especially at higher speeds, and can be ignored to a first approximation. But you should check the tables for your airplane to see how big the difference is just in case! And at low speeds, the difference may become larger.
- The airspeed indicator has various markings on it (colored arcs) indicating aircraft limitations which will be dealt with in a future lesson

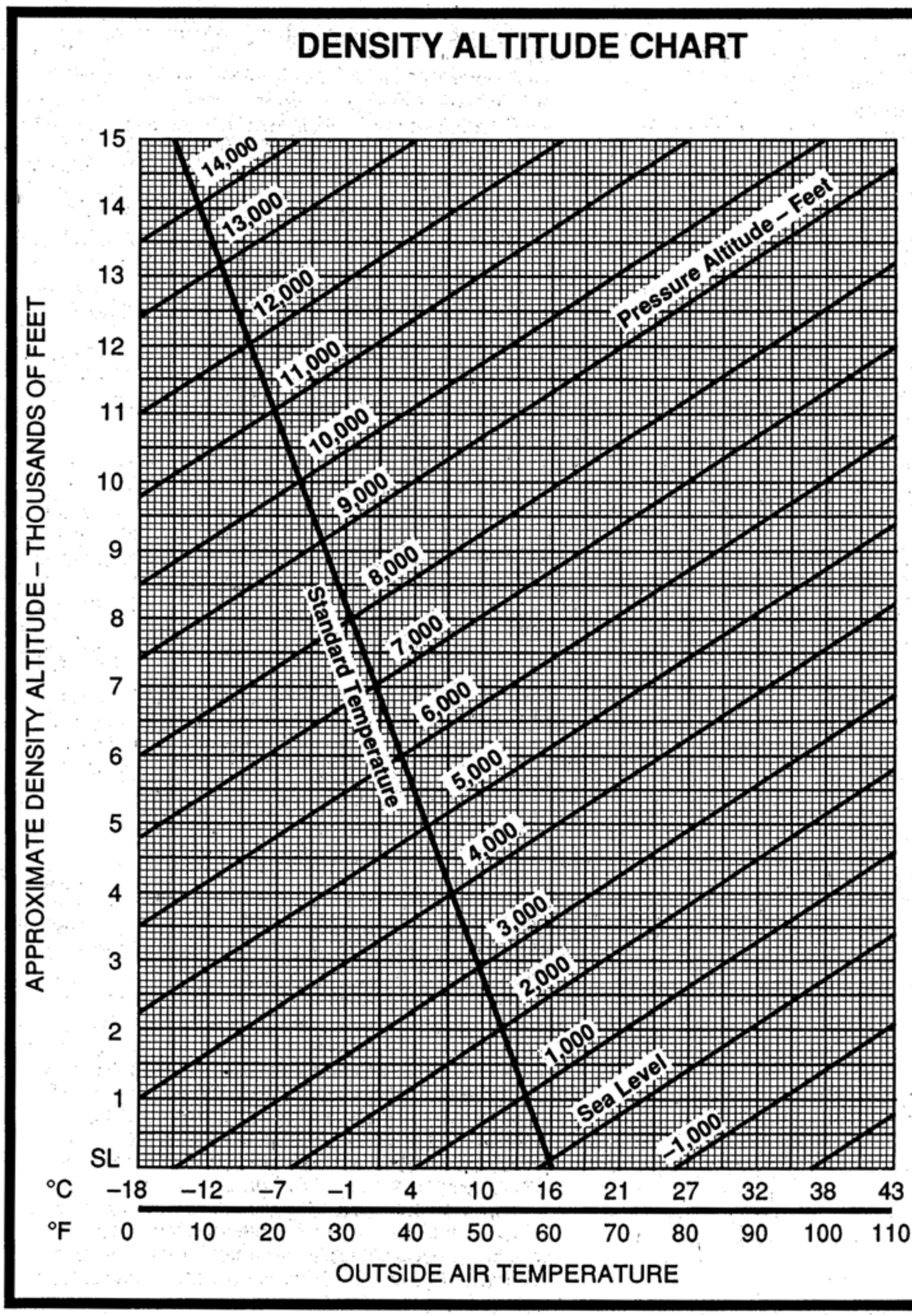
Static and Pitot System Failures

- There are three basic failures that can happen:
  - Static source can be blocked (ice or dirt)
  - Pitot tube can be blocked (usually ice)
  - Pitot tube and drain hole can be blocked (usually ice)

	Altimeter	VSI	Airspeed Indicator
Static blocked	Stuck on last alt	Reads zero	Holds current value until altitude or airspeed changes Increases with decreasing altitude Decreases with increasing altitude
Pitot tube only blocked	No effect	No effect	Reads zero
Pitot tubs and drain blocked	No effect	No effect	Holds current value until altitude changes Increases with increasing altitude Decreases with decreasing altitude

Determining Density and Pressure Altitude

- If you know the *pressure altitude* and the outside air temperature, it is possible to compute the density altitude using the chart below. Simply find the place where the pressure altitude line (diagonally in the middle of the graph) and the temperature line (at the bottom of the graph) intersect, and read the density altitude on the left side of the graph.
- If you know the indicated altitude and altimeter setting, you can find the pressure altitude for use above by using the conversion factor on the right. For example, if the altimeter setting is 28.0” Hg, add 1,824 to the indicated altitude to get the pressure altitude, and then use the chart to find the density altitude as described above. In an airplane you could also momentarily set the Kollsman window to 29.92, read the pressure altitude, and then set it back to what it was. These methods should give identical results.
- The chart can be confusing – the two columns of numbers on the right are *unrelated* to the graph on the left. **Do not try to use the altimeter setting column of numbers to read anything from the graph!**



Altimeter Setting (" Hg)	Pressure Altitude Conversion Factor
28.0	1,824
28.1	1,727
28.2	1,630
28.3	1,533
28.4	1,436
28.5	1,340
28.6	1,244
28.7	1,148
28.8	1,053
28.9	957
29.0	863
29.1	768
29.2	673
29.3	579
29.4	485
29.5	392
29.6	298
29.7	205
29.8	112
29.9	20
29.92	0
30.0	–73
30.1	–165
30.2	–257
30.3	–348
30.4	–440
30.5	–531
30.6	–622
30.7	–712
30.8	–803
30.9	–893
31.0	–983

Figure 8: Density altitude conversion chart

Case Study – Importance of Kollsman Window

(From the AOPA Air Safety Foundation web page)

NTSB ***IAD01LA028*** **—** On January 19, 2001, a commercial pilot learned a hard lesson about changes in barometric pressure when the PA-34 he was flying sustained substantial damage after impacting the ground during an ILS approach to Bluefield, WV (BLF). Fortunately, the pilot was not hurt during the accident.

The pilot received a preflight briefing that indicated IFR conditions prevailed for the entire area. He was also given a NOTAM, which reported that the Runway End Identifier Lights were out at BLF. Bluefield ASOS reported 100-foot ceilings and an altimeter setting of 29.78. An FBO employee reported that the visibility was ¼ mile with "a lot of fog", which extended to the ground.

The pilot attempted three ILS approaches. Upon reaching the decision height on the first two, the pilot indicated that all he saw was clouds. During the second missed approach, the pilot was considering diverting to Beckley, WV, when the FBO employee contacted him on the radio. The employee indicated that the runway lights were on the low setting, and asked the pilot if he would like the intensity increased. The pilot agreed, and began the third approach.

Upon reaching the decision height on the third approach, the pilot indicated he might have been looking for the lights, and not monitoring his altitude. He then felt trees "slapping" the airplane. Several seconds later, the aircraft impacted the ground.

During the investigation, it was noted that 29.97 was set into the Kollsman window on the aircraft's altimeter. The pilot obtained altimeter settings from both Indianapolis Center and the Bluefield ASOS, but could not remember what the setting was. About 1,200 feet from the wreckage tops of trees approximately 60-70 feet tall were found sheared off.

The NTSB determined the cause of this accident to be the pilot's failure to enter the correct altimeter setting, which resulted in flight below the decision height.

According to the AIM, Section 7-2-3 (b):

> Once in flight, it is very important to frequently obtain current altimeter settings en route. If you do not reset your altimeter when flying *from* an area of high pressure into an area of low pressure, *your aircraft will be closer to the surface than your altimeter indicates*. An inch error in the altimeter setting equals 1,000 feet of altitude. To quote an old saying: **"GOING FROM A HIGH TO A LOW, LOOK OUT BELOW."**

In this instance, the altimeter was off .19 inches, or about 190 feet. The decision height for the approach was 300 AGL. The pilot was flying 190 feet LOWER than his altimeter indicated, so when he reached the decision height he was approximately 100 feet AGL. Pilots operating IFR below 18,000 feet must ensure the proper altimeter setting is set in the Kollsman window.

