Atmospheric Conditions Affecting Aircraft Performance

To fully understand the varying performance characteristics of aircraft, it is necessary to understand certain elements of the environment in which they operate.

The performance of all aircraft is affected significantly by the atmospheric conditions in which they operate. These conditions are constantly varying, based simply on the daily heating and cooling of the earth by the sun, and the associated winds and precipitation that occur.
Airfield

"OVERALL AIRFIELD LAYOUT CONCEPT"

- PROVIDE DUAL PARALLEL TAXWAYS FOR DEPARTURE CUEING
- PROVIDE HOLDING BAY APRONS FOR DEPARTURE CUEING
- PROVIDE STANDARD WIDTH ENTRANCE TAXWAY

TERMINAL RAMP

- PROVIDE FULL PARALLEL TAXWAY
- TERMINATE TAXWAY CONNECTOR FROM TERMINAL APRON AT PARALLEL TAXWAY
- PROVIDE SEPARATE BY-PASS TAXWAY FOR DEPARTURE CUEING IN LIEU OF WIDE PAVEMENT AREA

- PRIMARY DEPARTURE RUNWAY
  - PROVIDE CROSSING TAXWAY IN LAST THIRD OF RUNWAY
    - TO BE USED DURING RUNWAY 22R OPERATION
  - PROVIDE DISCONTINUITY BETWEEN ACUTE-ANGLED EXIT TAXIWAY AND CROSSING TAXIWAY

- PRIMARY ARRIVAL RUNWAY

- PROVIDE PROPERLY SITED END-AROUND TAXIWAY (USE THIS END TO CROSS RUNWAY 4R ARRIVALS WHILE DEPARTING RUNWAY 4L)
Nomenclatures

- Nautical Mile = Knot = 6080 ft
- 6080 ft/nm divided by 5280 = 1.15 sm/nm
- Ground Speed \( V_G = \frac{(\text{Distance between Points A & B})}{T} \)
- Air Speed = The speed the winds feel
  - True Air Speed \( V_{TAS} = V_G \pm \text{Head wind} \)
  - Indicated Air Speed \( V_{TAS} = V_{IAS} [1 + (0.02 \text{ Alt}/1000)] \)
- Mack Number \( (N) = \frac{V_{TAS}}{V_s} \)
Air Pressure and Temperature

- In the standard atmosphere it is assumed that from sea level to an altitude of about 36,000 ft, known as the *troposphere*, the temperature decreases linearly.
- Above 36,000 to about 65,000 ft, known as the *stratosphere*, the temperature remains constant; and
- Above 65,000 ft, the temperature rises.
- Many conventional jet aircraft fly as high as 41,000 ft.
- The supersonic transports flew at altitudes on the order of 60,000 ft or more.
In the troposphere the standard atmosphere is defined as follows:

1. The temperature at sea level is 59°F or 15°C. This is known as the *standard temperature* at sea level.

2. The pressure at sea level is 29.92126 in Hg or 1015 mb. This is known as the *standard pressure* at sea level.

3. The temperature gradient from sea level to the altitude at which the temperature becomes −69.7°F is 3.566°F per thousand feet. That is, for every increase in altitude of 1000 ft, the temperature decreases by approximately 3.5°F or 2°C.
Both standard pressure and standard temperature decrease with increasing altitude above sea level. The following relation establishes the standard pressure in the troposphere up to a temperature of −69.7°F.

\[ \frac{P_0}{P} = \frac{T_0^{5.2561}}{T} \]

where
- \( P_0 \) = standard pressure at sea level (29.92 inHg)
- \( P \) = standard pressure at a specified altitude
- \( T_0 \) = standard temperature at sea level (59°F) in Absolute or Rankine units
- \( T \) = standard temperature at a specified altitude

Absolute zero is equal to −459.7°F, 0°F is equal to 459.7°R, and 59°F is equal to 518.7°R.
Wind Speed and Direction

- Since aircraft depend on the velocity of air flowing over their wings to achieve lift, and fly through streams of moving air, similar to ships moving along water with currents, the direction and speed of wind, both near the surface of airports and at altitudes have great effect on aircraft performance.
The angle between the desired track and the calculated heading is known as the \textit{crab angle}. The magnitude of this angle can be obtained from the following relation:

\[ \sin x = \frac{V_c}{V_h} \]
Speed of Sound

The speed of sound may be computed from the formula

- \( V_{sm} = 33.4 T^{0.5} \)
- \( V_{sf} = 49.04 T^{0.5} \)

**Where:**

- \( V_{sm} \) = speed of sound in miles per hour at some temperature
- \( V_{sf} \) = speed of sound in feet per second at some temperature
- \( T \) = temperature in degrees Rankine
Important Speed Terms

- $V_{ne}$: Do-Not-Exceed Speed, the fastest an aircraft may cruise in smooth air to maintain safe structural integrity.

- $V_{a}$: Design Maneuvering Speed, the recommended speed for an aircraft performing maneuvers (such as turns) or operating in turbulent air.

- $V_{lo}$: Liftoff Speed, the recommended speed at which the aircraft can safely liftoff.
Important Speed Terms

- **Vr**: Rotate Speed, the recommended speed at which the nose wheel may be lifted off the runway during takeoff.

- **V1**: Decision Speed, the speed at which, during a takeoff run, the pilot decides to continue with the takeoff, even if there might be an engine failure from this point before takeoff. If an aircraft develops an engine issue prior to reaching **V1**, the pilot will abort the takeoff.
Important Speed Terms

- $V_{so}$: Stall Speed (landing configuration), the minimum possible speed for an aircraft in landing configuration (landing gear down, flaps extended) to maintain lift. If the aircraft’s airspeed goes below $V_{so}$, the airplane loses all lift and is said to **stall**. This speed is also typically the speed at which an aircraft will touch down on a runway during landing.

- $V_{ref}$: Reference Landing Approach Speed, the speed at which an aircraft travels when on approach to landing. $V_{ref}$ is typically calculated as $1.3 \times V_{so}$. 
Calculation, 4 Cases
Normal takeoff case:

- $FL_1 = FS_1 + CL_{1\text{max}}$

where

$$TOD_1 = 1.15(D35_1)$$

$$CL_{1\text{max}} = 0.50[TOD_1 - 1.15(LOD_1)]$$

$$TOR_1 = TOD_1 - CL_{1\text{max}}$$

$$FS_1 = TOR_1$$
Engine-failure takeoff case:

\[ FL_2 = FS_2 + CL_{2\text{max}} \]

Where:

\[ TOD_2 = D35_2 \]
\[ CL_{2\text{max}} = 0.50(TOD_2 - LOD_2) \]
\[ TOR_2 = TOD_2 - CL_{2\text{max}} \]
\[ FS_2 = TOR_2 \]
Engine-failure aborted takeoff:

- $F L_3 = F S + S W$

Where:

$F L_3 = D A S$
Landing case:

- $FL_4 = LD$

Where:

- $LD = SD/0.60$
- $FS_4 = LD$
To determine the required field length and the various components of length which are made up of full-strength pavement, stopway, and clearway, the above equations must each be solved for the critical design aircraft at the airport. This will result in finding each of the following values:

- \( FL = \max\left[ (TOD_1), (TOD_2), (DAS), (LD) \right] \)
- \( FS = \max\left[ (TOR_1), (TOR_2), (LD) \right] \)
- \( SW = [(DAS) - \max (TOR_1, TOR_2, LD)] \)
Determining the Required R/W Length

where

- \( SW_{\text{min}} \) is zero.

- \( CL = \min [(FL - DAS), (CL_{1\text{max}}), (CL_{2\text{max}})] \)

where

- \( CL_{\text{min}} \) is zero and \( CL_{\text{max}} \) is 1000 ft.

If operations are to take place on the runway in both directions, as is the usual case, the field length components must exist in each direction.
Example

Example Problem 2-1

Determine the runway length requirements according to the specifications of FAR 25 and FAR 121 for a turbine-powered aircraft with the following performance characteristics:
Normal takeoff:
- Liftoff distance = 7000 ft
- Distance to height of 35 ft = 8000 ft

Engine failure:
- Liftoff distance = 8200 ft
- Distance to height of 35 ft = 9100 ft

Engine-failure aborted takeoff:
- Accelerate-stop distance = 9500 ft
Normal landing:
- Stop distance = 5000 ft
From Eq. (2-4) for a **normal takeoff**

- TOD1 = 1.15 D351 = (1.15)(8000) = 9200 ft
- CL1max = 0.50[TOD1 − 1.15(LOD1)] = (0.50)[9200 − 1.15(7000)] = 575 ft
- TOR1 = TOD1 − CL1max = 9200 − 575 = 8625 ft
From Eq. (2-5) for an engine-failure takeoff

- TOD2 = D352 = 9100 ft
- CL2max = 0.50(TOD2 − LOD2) = 0.50(9100 − 8200) = 450 ft
- TOR2 = TOD2 − CL2max = 9100 − 450 = 8650 ft
From Eq. (2-6) for an **engine-failure aborted takeoff**

\[ \text{DAS} = 9500 \text{ ft} \]

From Eq. (2-7) for a **normal landing**

\[ \text{LD} = \frac{\text{SD}}{0.6} = \frac{5000}{0.6} = 8333 \text{ ft} \]
Example Solution

Using the above quantities in Eqs. (2-8) through (2-11), the actual runway component requirements become

\[
FL = \max \left( (TOD1), (TOD2), (DAS), (LD) \right) \\
= \max \left( 9200, 9100, 9500, 8333 \right) = 9500 \text{ ft}
\]

\[
FS = \max \left( (TOR1), (TOR2), (LD) \right) \\
= \max \left( 8625, 8650, 8333 \right) = 8650 \text{ ft}
\]
Example Solution

- \( SW = [(DAS) - \max (TOR1, TOR2, LD)] \)
  \[
  = (9500) - \max [(8625), (8650), (8333)] = (9500 - 8650) = 850 \text{ ft}
  \]

- \( CL = \min [(FL - DAS), CL1_{\text{max}}, CL2_{\text{max}}] \)
  \[
  = \min [(9500 - 9500), 575, 450] = 0 \text{ ft}
  \]
Runway Performance

For any given operation, whether it be a takeoff or landing, an aircraft will require a certain amount of runway.
Runway Performance

Runway length requirements are often significantly affected by certain natural environmental conditions at the airport. The more important of these conditions are:

- Temperature,
- Surface wind,
- Runway gradient,
- Altitude of the airport, and
- Condition of the runway surface.
At higher altitudes the rate of increase is higher than at lower altitudes. For planning purposes, it can be estimated that between sea level and 5000 ft above sea level, runway lengths required for a given aircraft increases approximately 7 percent for every 1000 ft of increase in elevation, and greater under very hot temperatures those that experience very hot temperatures or are located at higher altitudes, the rate of increase can be as much as 10 percent.

Thus, while an aircraft may require 5000 ft of runway to takeoff at an airport at sea level, the same aircraft may require 7500 ft or more at an airport 5000 ft above sea level, especially during periods of high temperatures.
Surface Wind

It is often estimated that for every 5 kn of headwind, required runway length is reduced by approximately 3 percent and for every 7 kn of tailwind, runway length requirements increase by approximately 7 percent.

For airport planning purposes runway lengths are often designed assuming calm wind conditions.
Aircraft operating for takeoff on a runway with an uphill gradient requires more runway length than a level or downhill gradient, the specific amount depending on elevation of the airport and temperature. Conversely, landing aircraft require less runway length when landing on a runway with an uphill gradient, and more length for a downhill gradient.

For turbine-powered aircraft this amounts to **7 to 10 percent for each 1 percent of uniform gradient**.

Airport design criteria limit the gradient to a maximum of **1.5 percent**.

Any point on R/W Should be no more than 5 ft above or below the average line.
Jet operations are limited to no more than 0.5 inch of slush or water. Between, 0.25 and 0.5 inch depth, the takeoff weight of an aircraft must be reduced substantially to overcome the retarding force of water or slush. It is therefore important to provide adequate drainage on the surface of the runway for removal of water and means for rapidly removing slush. Both water and slush result in a very poor coefficient of braking friction.

When tires ride on the surface of the water or slush the phenomenon is known as hydroplaning. When the tires hydroplane, the coefficient of friction is on the order of wet ice and steering ability is completely lost. the approximate speed at which hydroplaning develops may be determined by the following formula:

$$V_p = 10 \rho^{0.5}$$
Determine the Runway Length for all-engine case, considering the aircraft has a rotation velocity of 118.6 knots and a horizontal acceleration rate of 5 ft/sec² on the ground and early flight. The vertical climb rate is 2 ft/sec. Provide a summary sketch showing R/W elements and their length. Consider the following R/W conditions:

- Elevation is = 2000 ft above sealevel
- R/W gradient = +1%