Cloud and Weather Phenomena based on the Temperature Gradient

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1 Introduction

Most of cloud and weather phenomena occur in the troposphere. With ISA atmosphere model by US Standard Atmosphere 1976 [1], we can obtain the temperature gradient in the atmosphere, which is an important cause of those phenomena. And combined with basic thermodynamics and meteorology knowledge, we can further know about the details of how clouds and weather phenomena occur and the influences to flight.

2 Theory

2.1 Air Properties in the Atmosphere

There are several layers in the atmosphere, and most of weather phenomena occur in the troposphere. They are related to air properties and water vapor behavior directly. Applied with ISA atomsphere model in US Standard Atmosphere 1976 [1], the air properties in troposphere is shown in *eq.*1 and Figure 1.

$$T = T_0 - 6.5 \cdot H \qquad (1)$$

Designation	Denotation	Value	Unit
T	Temperature		K
T_0	Sea Level Temperature	288.15	K
H	Geopotential Height		m

While the air going up, with less atmospheric pressure, the air will start an *adiabatic cooling* process and then expand.[2] In order to increase the volume, the air have to do $P-V$ work to the surroundings. With the first law of thermodynamics, the internal energy will decrease because of doing $P-V$ work at the surroundings. The temperature, which represents internal energy, therefore decrease.

2.2 Thermodynamics for Gas-Vapor Mixtures

Air and water vapor mixture plays important roles in most of weather phenomena. When the temperature

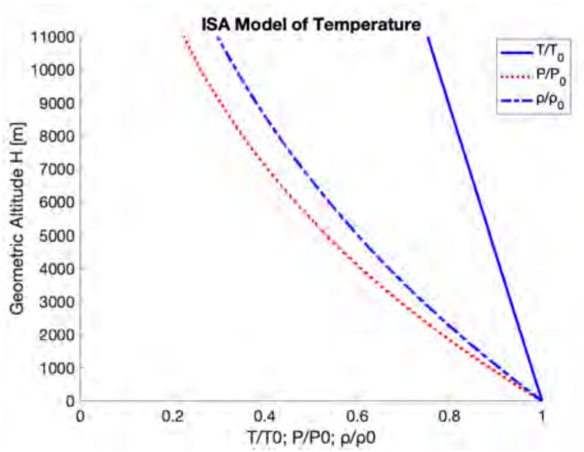

Fig. 1 Temperature Variation in Troposphere by ISA Model.

comes to the saturated temperature at certain pressure, it is called *Dew Point Temperature,* T_{dp}. We can check the dew point temperature on *psychrometric chart*, which elaborated by the relations between properties of gas-vapor mixture in the air.[3] The higher geometric altitude is, the less saturated pressure of gas-vapor mixture is. Moreover, with the same content of water, the specific humidity of gas-vapor mixture would increase. At the same time, the dew point becomes lower with the increasing of altitude. Therefore, at different pressure and dew point temperature, clouds develop in various type, which will be discussed later.

2.3 Temperature Inversions

It is known that the temperature lapse rate is $2^o/1000ft$ according to the international standard atmosphere (ISA). However, the temperature can increase in an short range of altitudes which is called temperature inversion. This is a special phenomena that occurs near the ground. Due to the specific heat difference of solid ground and air, the huge temperature gradient variation causes the convection and condensation of air and water vapor. There are several types of inversion which are surface inversion, subsidence inversion and frontal inversion.

Inside the inversion layers, the visibility is poor. Also, vertical windshear and turbulence will appear. These will diminish the climb performance of aircraft. But the thickness of an inversion layer is about $500ft$, so that it does not affect the safety of aircraft [4].

Fig. 2 Surface inversion [4]

2.4 Types of Cloud

There are several ways to form clouds. These are convection, orographic lifting, mixing and converge.[5] The concept of convection and orgraphic lifting are the same. When the moisture air moving upward in the atmosphere, it will be condensed as cloud according to temperature gradient and dew point temperature. There are three major type of cloud which are low-level cloud, middle-level cloud and high-level cloud.

Table 1 Cloud Type

Altitude	Name
Low	Nimbostratus, stratocumulus, stratus, cumulus, cumulonimbus
Middle	Altrostratus, Alrocumulus
High	Circus, cirrostratus, cirrocumulus

Fig. 3 Cumulonimbus could in early forming stage [4]

Fig. 4 Altrostratus [4]

Fig. 5 Hair shaped circus [4]

Thunderstorm are developed from many well-developed and active cumulonimbus. Strong convection occurs because of temperature difference in a wide range altitude distribution of cloud. The signature of thunderstorm are lighting, strong wind and heavy rain. There are three major state during the the life cycle of thunderstorm which are building stage, mature stage and dissipating state. In building state, the weather will become very windy and dark. During the mature stage, there will be lighting and heavy raining. Finally in the dissipating stage, it will keep raining for a period of time and the sky will become clear [6].

Fig. 6 Thunderstorm in mature stage [4]

2.5 Weather Phenomena

2.5.1 Icing

Icing is an serious hazard in flying activity. When icing occurs on the wing surface, it will change the shape of airfoil, and the weight of aircraft. It may affect the generation of lift and decrease the controllability of aircraft. Due to temperature gradient in troposphere, the surface temperature of aircraft varies with respect to altitude. When air moisture is attached on objects whose temperature are less than 0^oC, icing will occur. There are many types of airframe icing, such as rime ice, clear rice and mixed rice. Clear ice is the most dangerous icing behaviour. It is because the ice is not easy to be removed and discovered. When the super cool water droplet attach the airfoil, the freezing process will be happened. Rime ice will be formed when the supper cool water droplet is frozen with some air. Since some air bubbles are inside the ice, it is in white color. Therefore, it can be removed and discovered easily.

2.5.2 Fog

Fog is an important phenomena in ground-level aviation. It will affect the visibility while landing or taking off. According to temperature difference between ground-level air and the ground, when the temperature of moisture air drop to the dew point in heat equilibrium process, it will transform into fog. There are several kinds of frog, which are radiation, advection, upslope and frontal fog.

3 Discussion

The air stability and humidity are the most important factors to cloud formation, which are based on temperature gradient.

3.1 Environmental Lapse Rate

The environmental lapse rate helps us to determine the stability of a certain parcel of air. An unstable air means that a parcel of air remains warmer than surrounding after some vertical convection. It will keep rising which can produce the cloud in column shape in different altitude. On the other hand, stable air means that the air have the same temperature after having small vertical movement. It will produce the cloud in layer - shaped. From the ISA model temperature gradient, it is found that the dry adiabatic lapse rate and saturated adiabatic lapse rate are $3^oC/1000ft$ and $1.5^oC/1000ft$ respectively. There are 3 kinds of lapse rate: environmental lapse rate (ELR), dry adiabatic lapse rate (DALR) and saturated adiabatic lapse rate (SALR). These different temperature gradient determine the stability of air, which provide reasonable reference to determine the air stability. 7 shows the air stability condition.

Lapse Rates	Stability Condition
1. ELR > DALR	Unstable in all circumstances.
2. ELR = DALR	Neutral if unsaturated; unstable if saturated.
3. ELR < DALR but > SALR	Stable if unsaturated; unstable if saturated.
4. ELR = SALR	Stable if unsaturated; neutral if saturated.
5. ELR < SALR	Stable in all circumstances.
6. ELR is negative	Stable in all circumstances.

Fig. 7 The table shown the stability of different kind of air under different environmental lapse rate [4].

3.2 Temperature Gradient and Cloud Formation

The dew point temperature indicates the humidity of air. With air temperature and dew point temperature, we can determine where the cloud would start forming by the following equation. [4]

$$h = \frac{T - T_{dp}}{2.5} \quad (2)$$

Designation	Denotation	Unit
h	Cloud base height	*1000ft
T	Air Temperature	$^\circ$ C
T_{dp}	Dew Point Temperature	$^\circ$ C

According to ISA model and observation data, temperature gradient in the troposphere is predictable. Compared with the dew point temperature, we can make a prediction about the type of cloud and decide the flying path to avoid these kinds of cloud to ensure the safety of flying.

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