AIRCRAFT METEOROLOGICAL OBSERVATIONS

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Air traffic is influenced by meteorological conditions influence significantly. Therefore, knowledge of the meteorological situation is very important, however, ground d measurements or satellite observations aren't sufficient. Consequently, a series of meteorological measurements and observations is performed directly on an aircraft. The article deals with measurement of pressure, temperature and wind shear during a flight. The next part is dedicated to the observation of weather phenomena, such as icing, turbulence, storms or volcanic activity and their influence on aircraft. The last part deals with UAVs and their utilization possibilities for meteorological purposes.

K e y w o r d s: meteorology, sensors, unmanned aerial vehicle (UAV)

1 INTRODUCTION

Meteorology is an autonomous science that affects us in different ways, and which we can also observe and measure a variety ways.

The aim of this article is to point to various changes which are taking place in the atmosphere and which can be observed by an aircraft. Various phenomena such as temperature, pressure and wind, whose with its activities affect on aircraft or on different aerial vehicles, can be observed and measured in various ways that year after year improve and innovate in order to ensure the safety not only the aircraft and crew, but also the drones, which are very useful in obtaining information about weather conditions in different locations around the world. Getting information about this phenomena that affect aircrafts is acquired through the latest technologies available on the market. Technology, which is located in an aircraft or other aerial vehicle, is intended for observation of meteorological phenomena. Through various sensors that are located on the aircraft we can collect information about air pressure and temperature. For getting more information, such as the presence of clouds, which can cause a storm we can use the radar.

2 METEOROLOGY

Meteorology is the interdisciplinary scientific study of the atmosphere. Studies in the field stretch back millennia, though significant progress in meteorology did not occur until the 18th century. The 19th century saw breakthroughs occur after observing networks developed across several countries. After the development of the computer in the latter half of the 20th century, breakthroughs in weather forecasting were achieved.

Meteorological phenomena are observable weather events which illuminate, and are explained by the science of meteorology. Those events are bound by the variables that exist in Earth's atmosphere; temperature, air pressure, water vapor, and the gradients and interactions of each variable, and how they change in time. Different spatial scales are studied to determine how systems on local, regional, and global levels impact weather and climatology.

Meteorology, climatology, atmospheric physics, and atmospheric chemistry are sub-disciplines of the atmospheric sciences. Meteorology and hydrology compose the interdisciplinary field of hydrometeorology. Interactions between Earth's atmosphere and the oceans are part of coupled ocean-atmosphere studies. Meteorology has application in many diverse fields such as the military, energy production, transport, agriculture and construction. [1]

Meteorological (and related environmental and geophysical) observations are made for a variety of reasons. They are used for the real-time preparation of weather analyses, forecasts and severe weather warnings, for the study of climate, for local weather-dependent operations (for example, local aerodrome flying operations, construction work on land and at sea), for hydrology and agricultural meteorology, and for research in meteorology and climatology. The purpose of the *Guide to Meteorological Instruments and Methods of Observation* is to support these activities by giving advice on good practices for meteorological measurements and observations. [2]

Aircraft have been used in meteorological research for several decades. Indeed, historically, the study of meteorology has closely paralleled the development of aircraft since aircraft flight plans depend crucially on weather conditions and conversely aircraft provide an excellent platform for meteorological data obtaining. Developments in aviation have resulted in much improved instrumentation and techniques for measuring of the meteorological parameters in the atmosphere. [3]

Air data is a measurement of the physical characteristics of the air mass that surrounds an aircraft. The two main measured physical characteristics are temperature and pressure. Using these basic measurements individually and in combination allows many other flight parameters to be calculated.

Air data are measured using a variety of sensing devices. The output of these devices provides air data information necessary for safe, effective operation of the aircraft. Basic air data measurements include:

- speed (Mach, as well as indicated, true, calibrated, and equivalent airspeeds),
- altitude,
- rates of climb or descent (altitude rate),
- angle-of-attack, angle-of-sideslip. [2]

2.1 Temperature

WMO defines temperature as a physical quantity characterizing the mean random motion of molecules in a physical body. Temperature is characterized by the behavour whereby two bodies in thermal contact tend to an equal temperature. Thus, temperature represents the thermodynamic state of a body, and its value is determined by the direction of the net flow of heat between two bodies. In such a system, the body which overall loses heat to the other is said to be at the higher temperature. Defining the physical quantity temperature in relation to the “state of a body” however is difficult. A solution is found by defining an internationally approved temperature scale based on universal freezing and triple points. Currently, such scale is the International Temperature Scale of 1990 (ITS-90) and its temperature is indicated by T90. For the meteorological range (–80 to +60°C) this scale is based on a linear relationship with the electrical resistance of platinum and the triple point of water, defined as 273.16 Kelvin (BIPM, 1990). For meteorological purposes, temperatures are measured for a number of media. The most common variable measured is air temperature (at various heights). Other variables are ground, soil, grass minimum and seawater temperature. WMO (1992) defines air temperature as “the temperature indicated by a thermometer exposed to the air in a place sheltered from direct solar radiation”. Although this definition cannot be used as the definition of the thermodynamic quantity itself, it is suitable for many applications.

Temperature measurement

Air temperature information is generated by measurements of static air temperature (SAT), total air temperature (TAT), or outside air temperature (OAT). Static air temperature is the temperature of the undisturbed air through which the aircraft is about to fly. It is required for calculating true airspeed (the actual aircraft speed moving through the air). The total temperature measurement, on the other hand, is a component of the airstream so it reflects the effects of bringing airflow to rest. It is the only way to accurately measure OAT above 200 KIAS. Typically, total temperature measurements are higher (warmer) than static temperature measurements. Outside air temperature data also helps regulate engine performance at take-off or at cruising altitude to maximize fuel efficiency. Air temperature measurement devices are usually probes incorporating an element which changes its electrical resistance with any air temperature changes. Because moisture and icing can affect the measured temperature, heating elements are included, which must be isolated from the sensing element to ensure an accurate temperature measurement. The measured resistance from the temperature sensor is sent to a signal conditioner for conversion into analog or digital signals. Depending on the application, temperature data may be combined with pressure data in the same transducer. [2]

2.2 Pressure

The atmospheric pressure on a given surface is the force per unit area exerted by virtue of the weight of the atmosphere above. The pressure is thus equal to the weight of a vertical column of air above a horizontal projection of the surface, extending to the outer limit of the atmosphere.

Apart from the actual pressure, pressure trend or tendency has to be determined as well. Pressure tendency is the character and amount of atmospheric pressure change for a 3 hours or other specified period ending at the time of observation. Pressure tendency is composed of two parts:

- the pressure change,
- the pressure characteristic.

The pressure change is the net difference between pressure readings at the beginning and end of a specified interval of time. The pressure characteristic is an indication of how the pressure has changed during that period of time, for example, decreasing then increasing, or increasing and then increasing more rapidly.

Pressure measurement

Static pressure is the atmosphere weight over a particular area in a given location. The higher the altitude is, the less is atmosphere above it, and therefore the lower is the measured pressure. At sea level, the static air pressure is sufficient to raise the mercury in a barometer 29.92 inches (or 1013 Millibars). But at 18,000 feet above sea level the pressure is only half as great — raising the mercury only 15 inches. In this way, static pressure measurements can give an indication of altitude.

Measuring true static pressures from a fixed location on the ground is one thing. Measuring it on an aircraft in flight is quite another. That’s because the aircraft influences and disturbs the atmosphere through which it flies. The altered atmosphere in turn affects the ability to provide an accurate static pressure measurement. A common technique to measure static pressure is to mount pressure inlet ports flush with the aircraft fuselage, but this solution requires finding locations on the aircraft fuselage with clean airflow. In addition, the area around these flush ports must be smooth and uniform to ensure accurate movement. This means accurate static pressure measurement must consider a number of factors including:

- airspeeds,
- Mach number (M),
- angle-of-attack (AOA),
- angle-of-sideslip (AOS),
- aircraft design (location of flaps, landing gear, rotor blades, etc.).

Another way to measure the static pressure is to place a static port on the body of a Pitot probe. This approach gives better measurements than flush-mounted static ports because the static port is now located away from the aircraft fuselage and away of the influences of the variations in the aircraft skin. The port is not part of the fuselage; it can be manufactured with greater precision to provide a smoother airflow surface. Placing the static port on the Pitot probe, therefore, greatly improves accuracy and repeatability of static pressure measurements.

Increasingly, pressure sensors are incorporating advanced silicon technology that provides superior accuracy and reliability compared to non-silicon based sensors. The superior consistency of the solid state pressure sensor combined with its unequaled long-term stability performance ensures highly accurate measurements year after year. Solid state pressure sensors use batch fabrication and micromachining processes to provide consistent, high accuracy performance at affordable prices. The sensor's mechanical design assures uniform thermal expansion of all sensor structures to minimize stresses, which reduces the temperature sensitivity of the sensor device. Silicon, a crystalline material, is used as a diaphragm structure because it is totally elastic to applied stresses. This elasticity enhances the stability and repeatability of the sensor. [2]

2.3 Wind

The ultimate goal of atmospheric sampling is to extract a sample, representative of a constituent of interest (pollutant) present in the environment, to determine its concentration. In order to determine a pollutant concentration, the mass of the pollutant and the volume of air sampled must be known. Air measuring devices provide an accurate measure of the rate of gas flow (e.g., liters per minute, cubic feet per hour) or volume (e.g., liters, cubic feet) over a measured time period (e.g., minutes, hours) through the sampling train. [16]

Observations of upper winds are essential for operational weather forecasting on all scales and at all latitudes, and are usually used in conjunction with measurements of mass field (temperature and relative humidity). They are vital to the safety and economy of aircraft operations. Uncertainties in upper winds are the limiting factor in the accuracy of modern artillery and are, therefore, important for safety in military operations. Accurate upper wind and vertical wind shear measurements are critical for the launching of space vehicles and other types of rocket. In the boundary layer, upper winds with reliable measurements of vertical wind shear are essential for environmental pollution forecasting. Upper winds are normally input into numerical weather.

The upper-wind reports should contain enough information to define the vertical wind shear across the boundaries between the various layers in the mass fields. For instance, wind shear across temperature inversions or significant wind shear associated with large changes in relative humidity in the vertical should be reported whenever possible. [2]

Sensors

New sensors for wind measurement have been developed to warn pilots of wind shear. The sensors will be able to alert pilots of approaching wind shear, offering time to climb above dangerous weather. A new breed of cockpit radars could help prevent airplane accidents caused by wind shear – a phenomenon that is associated with thunderstorms and can produce sudden, fierce downdrafts. The new "predictive" sensors will alert pilots 15 to 60 seconds before their aircraft encounters wind shear, giving them enough time to climb above the dangerous weather. The sensors rely on Doppler radar, developed at NASA's Langley Research Center, to search the airspace ahead of the plane for regions where the airspeed varies greatly across a short distance. When the radar finds such a region, an onboard computer checks for "false alarms" caused by moving objects on the ground or momentary turbulence. If the wind shear readings persist, and the jet is within 1.5 nautical miles of the bad weather, the computer issues an audible warning. [5]

3 METEOROLOGICAL OBSERVATIONS

3.1 Methods and devices used for weather phenomena monitoring

Aircraft icing

Aircraft icing is the accretion of super-cooled liquid onto an airplane during flight. Accreted ice adversely affects flight; thus, it is an important component of an aviation weather forecast. Meteorology associated with in-flight icing begins with the micro-scale, addressing growth of super-cooled droplets and their collision with and adhesion to airframes. Cloud-scale and meso-scale processes control the amount and distribution of super-cooled liquid water. Synoptic weather patterns govern the movement and overall location of icing environments. Any discussion of aircraft icing must also include the development and use of numerical weather prediction models as well as in situ and remote sensors for icing detection, diagnosis, and forecasting. There are isolated cases of snow and frost adhesion during flight, but since these rarely occur they will not be discussed here. Similarly, precipitation or frost adhering to the wings of an airplane prior to takeoff, and carburetor icing, will not be covered.

Effects on an aircraft

Although the basic concept of in-flight icing is a simple one, the processes contributing to icing, and the results of icing, are at once quite complex and fascinating. Meteorologists, aerospace engineers, and pilots need and want information about icing because it can adversely affect the flight characteristics of an aircraft. Icing can increase drag, decrease lift, and cause control problems. The added weight of the accreted ice is generally a factor only for light aircraft. Aircraft can fly in icing conditions, and to do so legally they must first be certified. For certification of a particular type of airplane, it must be flown in a range of natural icing conditions and demonstrate that these conditions result in no significant effect on the airplane's performance.

Certified aircraft are commonly equipped with devices that either serve to prevent ice from adhering to the airframe or remove it once it has adhered. Such anti-icing or de-icing equipment may be deployed manually or through an automatic system triggered by an icing detection probe. Equipment includes pneumatic 'boots', heat, and liquid. All three can be applied to the leading edges of the wings and tail, and occasionally to propellers. Tailplane icing is a subset of icing and refers to icing that accretes on the vertical and horizontal stabilizers. It is not necessarily caused by unique atmospheric conditions but is usually considered separately because it results in vastly different response of the airplane from that produced by icing on the wings. [6]

Turbulence

There are many existing types of turbulence. In general turbulence areas can be predicted using sensors for wind measurement or airborne radar. But problems may occur with a specific type of turbulence called clear-air turbulence (CAT), which can be defined as the turbulent movement of air masses in the absence of any visual cues such as clouds, and is caused when bodies of air moving at widely different speeds meet. The atmospheric region most susceptible to CAT is the high troposphere at altitudes of around 7,000–12,000 metres (23,000–39,000 ft) as it meets the tropopause. At lower altitudes it may also occur near mountain ranges. Thin cirrus cloud can also indicate high probability of CAT. CAT can be hazardous to the comfort, and even safety, of air travel.

Effects on aircraft

In the context of air flight, CAT is sometimes colloquially referred to as "air pockets". Standard airplane radars cannot detect CAT, as CAT is not associated with clouds that show unpredictable movement of the air. Airlines and pilots should be aware of factors that cause or indicate CAT to reduce the probability of meeting turbulence, as it can injure crew and passengers and even affect flight safety. Aircraft in level flight rely on a constant air density to retain stability. Where air density is significantly different, for instance because of temperature gradient, especially at the tropopause, CAT can occur. Where an aircraft changes its position horizontally from within the jet stream to outside the jet stream, or vice versa, a horizontal temperature gradient may be experienced. Because jet streams meander, such a change of position need not be the result of a change of course by the aircraft. Because the altitude of the tropopause is not constant, an airplane that flies at a constant altitude would traverse it and encounter any associated CAT. [7]

Thunderstorms

Thunderstorms are one of the most beautiful atmospheric phenomenon. As a pilot, however, thunderstorms are one of the most hazardous conditions you can encounter. All thunderstorms can produce severe turbulence, low level wind shear, low ceilings and visibilities, hail and lightning. Each of these hazards can be difficult to cope with; if all these conditions arrive at once, it can be disastrous. Understanding basic thunderstorm formation and structure can help you make safe decisions. Thunderstorms are formed by a process called convection, defined as the transport of heat energy. Because the atmosphere is heated unevenly, an imbalance can occur which thunderstorms attempt to correct. Three things are needed for convection to be a significant hazard to flight safety: moisture, lift and instability. [8]

Volcanic activity

Plumes of volcanic ash near active volcanoes are an aviation safety hazard, especially for night flights. The ash is hard and abrasive and can quickly cause significant wear on propellers and turbo-compressor blades, and scratch the cockpit windows, impairing visibility. It contaminates fuel and water systems, can jam gears, and can cause a flameout of the engines. Its particles have low melting point, so they melt in the combustion chamber and the ceramic mass then sticks on the turbine blades, fuel nozzles, and the combustors, which can lead to a total engine failure. It can also contaminate the cabin and damage avionics. [9]

Danger of volcanic ash to aviation

Volcanic ash consists of small tephra, which are bits of pulverized rock and glass less than 2 millimetres (0.079 in) in diameter created by volcanic eruptions. The ash enters the atmosphere from the force of the eruption and convection currents from the heated air, and is then carried away from the volcano by winds. The ash with the smallest size can remain in the atmosphere for a considerable period of time and be carried well away from the eruption point. The ash cloud can be dangerous to aviation if it reaches the heights and enters the paths used by aircraft.

Volcanic ash has a melting point of approximately 1,100 °C (2,010 °F), which is below the operating temperature of modern commercial jet engines, about 1,400 °C (2,550 °F). If ash is ingested into the engines by an aircraft flying though the ash cloud, then the ash melts in the engine on fuel nozzles and turbine blades rather than passing through the engine. Sulfur dioxide, another product of volcanoes which is also carried within the ash clouds following an eruption, is corrosive to aircraft that fly through it.

When flying at night ash clouds are not visible to pilots. In addition, they do not show up on radar — the ash particles are too small to return an echo to the onboard weather radars of commercial airliners. Even when flying in daylight, a visible ash cloud may be interpreted as a normal cloud formed by water vapour and not seen as a danger, especially if it has travelled well away from the eruption location. [10]

Weather Radar

Three common threats to aircrafts are turbulence, hail and windshear at low altitude. All three of these are by-products of thunderstorms. Weather radar is a popular method of alerting the flight crew to the presence and location of thunderstorms. An airborne weather radar is technically often called a Weather avoidance radar. The radar system will provide the pilot with the necessary weather information to avoid, not penetrate, severe and dangerous weather.

The radar transmits a beam of radiation which gets wider as it travels further from the source, similar to a flashlight beam which will illuminate a larger area at a distance than it will close up. The radar beam is a cone of radiation which will be tightly focused in the middle and less so towards the edges. This is often called the radar “beam width” or “beam diffusion”. The larger the parabolic dish or array the tighter the focus of the beam. More RF radiation is focused on the target with a tighter, focused radar beam. The more radiation that is focused on the target, the greater the return.

Design requirements that engineers must consider in system development are:

- size of target,
- distance (near/far) of target,
- relative speed of target.

These requirements will determine the system basics such as frequency, pulse width (PW) and the pulse repetition frequency (PRF).

Frequency is fixed by the choice of the magnetron, this is not variable. Pulse width and PRF are dynamically variable and will change depending upon range and mode.

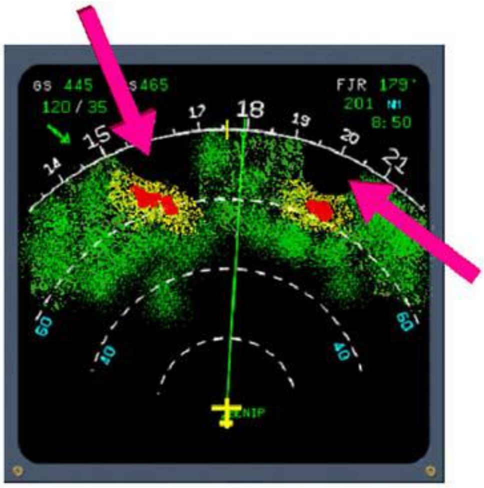

Fig. 1 Two active cells on airborne meteorological radar

A typical weather cell is approximately 3 miles in diameter. This is the size of the target that today’s weather radar systems are designed to detect. Example of a cell shown on airborne radar is on Fig. 1.

Most systems in use today have a ground map or search mode. In map mode variable gain will be enabled (operation of variable gain is discussed in detail in the Pilot’s Perspective section), PRF will be varied and the PW will be varied. It is not uncommon for PRF and PW to be varied with range in weather also, but not to the extent as in search or map modes.

Map/Search modes have different STC curves and are calibrated differently than weather modes and should never be used for weather detection.

A wide pulse width on a large target will generate a larger return, however wide pulse widths poorly illuminate the smaller targets. In search we are usually looking for a small target.

Very dangerous situation can occur due to the so called dead zone (Fig. 2) of many types of airborne radars. In case that aircraft has a temptation to fly fly through a narrow band between two areas of rough weather. But the large area with dangerous meteorological conditions behind them can be hidden. In many advenced radars in this area radar gives a recommendation to fly around such area because the narrow band is so intense that the radar pulses are unable to make it through to the severe storm behind. [11]

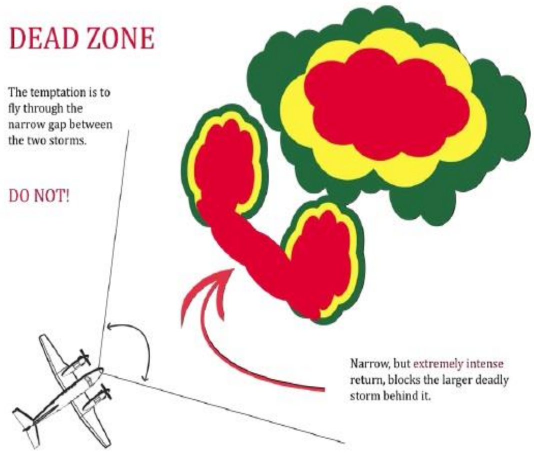

Fig. 2 Dead zone [11]

4 UAV METEOROLOGICAL MEASURMENTS AND OBSERVATIONS

Current trends in the area of onboard meteorological measurements involve except of new sensor development or increasing of sensor output precision and reliability also development of the whole meteorological systems placed on unmanned aerial vehicle (UAV) boards. Many of these UAVs are designed exclusively for the meteorological measurements.

4.1 Unmanned aerial vehicle (UAV)

An unmanned aerial vehicle (UAV), commonly known as a drone is an aircraft without a human pilot on board. Its flight is controlled either autonomously by computers in the vehicle, or under the remote control of a pilot on the ground or in another vehicle. There are a wide variety of drone shapes, sizes, configurations, and characteristics. Historically, UAVs were simple remotely piloted aircraft, but autonomous control is increasingly being employed. They are deployed predominantly for military applications, but also used in a small but growing number of civil applications, such as policing, firefighting, and nonmilitary security work, such as surveillance of pipelines. UAVs are often preferred for missions that are too "dull, dirty, or dangerous" for manned aircraft. [12]

One crucial type of data for UAV flights is real-time weather information. This information is especially important during take-off and landing. Real-time weather data is typically gathered from a weather station to support operations [13]. But there are also special types of UAVs designed for utilization in meteorology. These UAVs equipped with different meteorological sensors including temperature, pressure, humidity sensors, but also electromagnetic spectrum sensors, gamma ray sensors, biological sensors, and chemical sensors. A UAV's electromagnetic sensors typically include visual spectrum, infrared, or near infrared cameras as well as radar systems. Other electromagnetic wave detectors such as microwave and ultraviolet spectrum sensors may also be used, but are uncommon. Biological sensors are sensors capable of detecting the airborne presence of various microorganisms and other biological factors. Chemical sensors use laser spectroscopy to analyze the concentrations of each element in the air.

4.2 Meteorological UAVs

Airborne measurements are in meteorological field experiments essential. Since aircraft travel over a large distance in a comparatively short time, airborne systems are able to take a 'snapshot' of the atmospheric flow. Length scales between convection and small scale turbulence are covered. For that reason airborne measurements are a good supplement to ground-based measurements and remote sensing. The airborne measurements of meteorological parameters within the atmospheric boundary layer may be used for investigating the water and energy balance between the surface and the atmosphere as well as for parametrisation and validation of numerical models. Furthermore, airborne data can be compared with ground-based measurements and remote sensing for reference or cross-validation.

The goal of meteorological UAV construction is in general to perform measurement flights with less costs compared to a research aircraft and to make measurements where manned research aircraft are not permitted to fly or where it is too risky, e.g., over volcano craters or at low level during night. Since remote control is only possible within the range of sight but airborne meteorological measurements should cover a large range, a fully autonomous carrier system for the meteorological payload was essential. For the meteorological sensors, the focus was set to boundary layer meteorology, so the system had to be capable of performing turbulence measurements. The determination of the three dimensional wind vector was the main challenge within the development process. For the determination of the wind vector, the air flow, the speed along the aircraft track and attitude of the aircraft need to be measured with high precision. The meteorological measurements should be highly resolved with a spatial resolution of two metres or less. Additionally, accurate temperature, humidity, barometric pressure and three dimensional wind vector measurements had to be achieved at low costs. [14]

The limitations of manned airborne measurements led to the idea of development of an autonomous unmanned airborne meteorological measurement platform. An example of research result in this area is the M^2AV. The main specifications of the M^2AV were a maximum take-off weight of 5.0 kg, payload of about 1 kg and a range of more than 50 km at a mean cruising speed of 20 m s^{-1}.

Fig. 3 The M^2AV system [14]

Other example of meteorological UAV is the Small Meteorological Observer (SUMO) [17], which was designed for atmospheric boundary layer research (Fig. 4). Its main advantages are cost effectiveness and user friendliness that enables operation after a short training.

Fig. 4 SUMO prototype [17]

The TornadoChaser [18] is a remotely-piloted uninhabited aerial vehicle designed to fly into a pre-tornadic, severe thunderstorm (Fig. 5). The project goal is to provide in situ meteorological measurements during tornado-genesis, the initial stage of tornado development. Past attempts to gather this information have put pilots, and their aircraft, into dangerous situations. A remotely-piloted vehicle removes the pilot from the storm while keeping a human in the loop to make cognitive decisions that are not possible with present fully autonomous system.

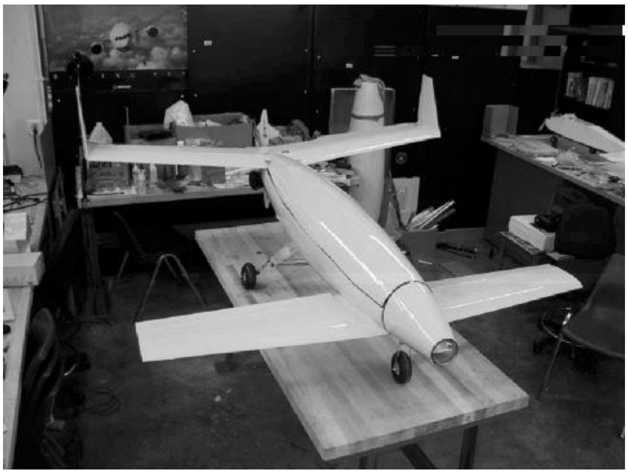

Fig. 5 TornadoChaser prototype [18]

5 CONCLUSION

This article gives an overview of basic meteorological quantities such as temperature, pressure, wind and phenomena such as turbulence, icing or storm and described are also measurement principles, sensors or devices, including airborne radars used on aircraft boards for their measurement or observation. Also volcanic activity that adversely affects aircraft engines and its influence is mentioned.

In the last part of the article unmanned aircraft (UAV) are mentioned, which could be used in many application areas and meteorology isn't an exception. These unmanned aerial vehicles have on board various meteorological sensors, cameras and scanners to scan the surface of the Earth. They have great benefits because during a flight aircrew is not in danger and information obtained during the flight can be transferred directly into a regional center where it is further processed and can be utilized for increasing flight safety and elimination of collisions in aviation.

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