Mem. S.A.It. Vol. 79, 849
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Airborne measurements and climatic change science: aircraft, balloons and UAV,s

G. Visconti

Centro di Eccellenza CETEMPS and Dipartimento di Fisica, Università degli studi di L'Aquila, via Vetoio, 67010 Coppito, L'Aquila.

Abstract. This short presentation is intended to inform the community that use of balloons for astrophysical and atmospheric research may find an adequate alternative in the near future in the use of aircraft. Actually for atmospheric research the use of aircraft dates back several decades as a matter of fact most of the fundamental results explaining the ozone hole mechanisms have been obtained using in situ measurements from high altitude aircraft (Anderson et al. 1989). Balloons are extensively used in meteorological research and they represent a very advanced technology like in the case of so called smart balloons. However for atmospheric chemistry, climatic and also some meteorological research aircraft are the more convenient and adapt means to conduct research. In the last few years a growing role has been played by Unmanned Aerial Vehicle (UAV) following a growing interest of the military and civil establishment.

Key words. Aircraft – Balloons – UAV,s

1. Introduction

High altitude balloons have been used extensively for atmospheric research. However as soon as it has been realized that chemical and meteorological tracers (potential vorticity) are equivalent the advantages of the aircraft over the balloons have become more clear. A simple meteorological forecast can give indications about the more suitable zone where measurements should be taken. The aircraft can then fly several times to take in situ or remote sensing measurements depending on the instrumentation aboard. In the case of ozone hole for example aircraft could penetrate meteorological barrier (like the polar vortex) and clarify the peculiar mechanism by which ozone hole was being produced. Balloons have the advantage of flying at higher altitude than aircraft and this feature may be relevant for some of the measurements being taken (see for example the contribution by Palchetti et al. in this workshop).

2. Balloons used for atmospheric research

Smart balloons are relatively small balloons that may adjust altitude using a ballast and an additional reservoir of helium gas. Smart balloon that have been used by NOAA and NASA starting at the end of the '90 heve been used extensively in a number of campaign like ACE (Aerosol Characterization Experiments) or more recently in the ICART (International Consortium on Atmospheric on Transport and Transportation). A smart balloon can cross the

Send offprint requests to: G. Visconti

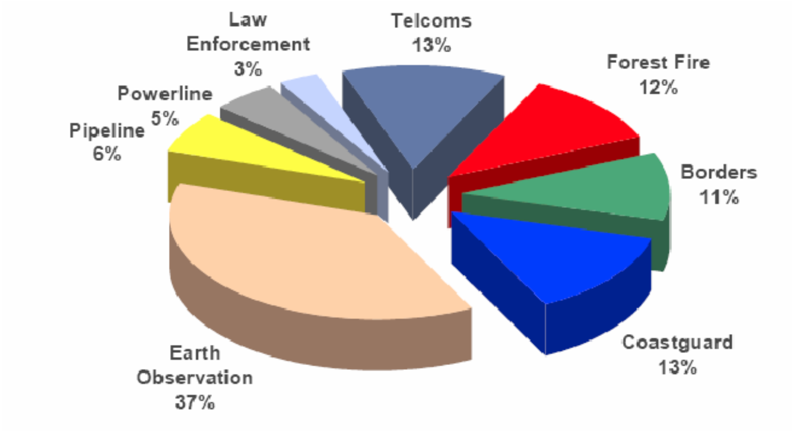

Fig. 1. The percentage for the different use for UAV.

ocean keeping a fixed altitude or they may follows constant potential temperature surfaces. A very recent evolution of smart balloons is their integration with nanotechnology sensors (Manobianco et al. 2008). The prototype design features a super pressure balloon filled with helium to make it neutrally buoyant at different levels in the atmosphere. The prototypes being developed from commercial-off-the-shelf components cost roughly the same as standard dropsondes on the order of $600 per unit. When inflated, the balloon is pumpkin-shaped measuring ∼1.2 m in width by ∼0.6 m in height with a total mass of ∼150 grams. The prototype GEMS balloons are fabricated using 48-gauge (12-micron) thick MylarTM. The initial design within the framework of the GEMS (Global Environment Micron Sensors) project envisioned developing and deploying large numbers (thousands) of low-cost devices as small as 50-100 microns in one or more dimensions. At these sizes, the probes would have very small terminal velocities and be lightweight enough to pose virtually no threat to people or property including aircraft. The GEMS system features a wireless network of in situ, airborne probes that can monitor all regions of the Earth with unprecedented spatial and temporal resolution with potential to expand greatly the amount of in situ observations especially over data sparse oceanic regions. Such measurements could lead to dramatic improvements in basic science, including a more thorough understanding of physical processes in the atmosphere (e.g. cloud physics) and thereby improved representation of such processes in weather and climate models.

3. Aircraft

Earth scientist have extensively used aircraft and their use continue to grow. Currently aircraft are used for both in situ sampling or remote sensing of the atmosphere. Aircraft are used mainly in (1) field experiments (2) monitoring and applications (e.g., forest fire overflights and reconnaissance), (3) satellite validation, (4) instrument and algorithm development and in the future (5) as suborbital systems that are integrated into satellite programs. Aircraft are used to measure long term events that have time scales of months to years, short term events with time scales of days to weeks and mesoscale events with time scales of minutes to hours. Examples of long term events are the Antarctic ozone hole, the pollution systems and climate change. Long term events are of large spatial scale. Short term events are typical synoptic (1000-5000 km). These events although of short duration can be planned as long term events because they may recur on a reg-

UAV (Manufacturer)	Range (km)	Endurance (hrs)	Ceiling (km)	Payload (kg)
Global Hawk (Northrop Grumman)	25,000	36	19.8	910
Helios (Aeroenvironments)	200	15	30,0	16
Pathfinder ((Aeroenvironments)	200	14	24.5	11
Odysseus (Aurora)		<5 years	20 km	500
Proteus (Scaled Composites)	5000	14	16.7	1000
Altair (General Atomics)	4200	32	15.2	300
Altus-II (General Atomics)	5600	24	13.7	150
Aerosonde (Aerosonde)	3000	30	4.0	5
Sky-Y Alenia Aeronautica	10,000	30+	15	330

Table 1. Selective UAVs that have been used or proposed for science missions. Numbers are taken or calculated from manufacturers specifications. Actual performance will differ from these estimates. *Proteus is a manned aircraft that has only been used in a UAV demonstration. Notice we have included some UAV still in the design stage (Odysseus) and some Italian product.

ular basis (i.e. pollution episodes during summer). Again mesoscale meteorological systems are the most difficult to sample because the spatial scales are small (10km) and the evolution time short (a few hours). A typical aircraft mission may directed to sample data for study processes. Typical from this point of view is the CRYSTRAL-FACE campaign carried out to study the characteristics of formation and evolution of tropical anvils and cirrus layers. Aircraft however are also used for observations related to air quality, atmospheric composition including aerosols. Sometimes aircraft of opportunities are use to make routine measurements of meteorological parameters and atmospheric composition like the MOZAIC experiment.

4. Unmanned (or Uninhabited) Aerial Vehicles (UAV)

Manned aircraft and unmanned aerial vehicles have many similarities as well significant differences. The advantage of manned aircraft over the UAV are (1) their long heritage, (2) the wide varieties, (3) the payload, power and volume capacities, (4) airspace access, (5) real time command and control, (6) possibilities to carry passenger and human operators. The drawback for manned aircraft are (1) the short duration capabilities, (2) modest range (< 3500 km), (3) inhability to fly in dangerous situations and (4) inhability to fly in dirty environments (ash, nuclear debris, etc.). UAV can overcome many of the limitation of manned aircraft. They can fly longer (up to 36 hours or several days) and consequently they have longer ranges (> 5000 km) and are more suitable for surveillance rather than simply reconnaissance. UAV can fly in a 3D environment: Dumb, Dangerous and Dirty missions. Table 1 list a number of UAV used or proposed for future missions

UAV may have important applications in several field. Figure 1 shows the total market share in Europe for the period 2006-2015. The largest share is Earth observation s which include scientific and application market.

5. History and UAV limits

The characteristics of UAVs are engineered to suit specific roles. UAVs originally evolved from target drones. The U. S. military extensively used the first UAVs during the 1960's in Vietnam and during the 1991 Gulf War, UAVs began to show their potential for flying in hostile conditions. UAVs are now extensively used by militaries around the world, and are being further developed by many countries. As with manned aircraft, there is a trade-off between maximum altitude, payload, range, and airspeed. Two altitude aircraft can be used for comparison. The Helios had a large wing and a low weight, reaching a very small wing loading of 4.12 kg/m^2. This low wing loading al-

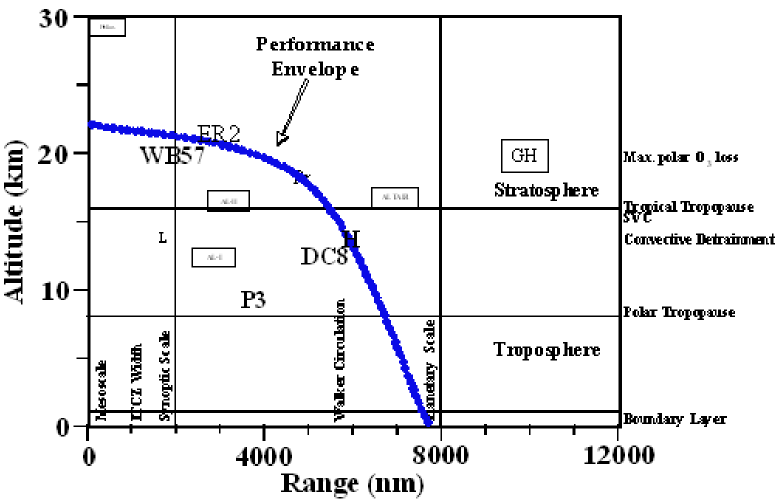

Fig. 2. Altitude vs. range plot for manned aircraft and UAVs (in boxes). The aircraft payload weight is proportional to font size (truncated at 2000 lb. and 600 lb.), and the bold-faced font indicates payloads greater than 2000 lb. The blue line indicates the performance envelope for manned aircraft. The L indicates a Learjet, while the H indicates the NSF Hiaper Gulfstream V aircraft. The scales of various atmospheric phenomena are indicated for perspective.

lowed the Helios to achieve altitudes near 30 km. In contrast to the Helios, the Global Hawk has a gross weight of 11,700 kg. and a wing area of 48.6 m^2, giving a wing loading of 240 kg/m^2. The Global Hawk flies much faster than the Helios to gain the lift necessary to fly at18 km. The Global Hawk has an airspeed of about 600 km/h at 20 km, while the Helios has an airspeed of about 270 kts at 30 km. Adding payload reduces the maximum altitude attainable by these aircraft. The drawback of a low wing loading comes from the necessity for a large wing. A UAV with large wing and a low weight is very susceptible to ground weather and cross winds. A take-off becomes extremely difficult, since the aircraft wing acts as a large sail that can easily overturn the very light UAV. This creates the necessity for a very calm wind for both takeoff and landing. Airfields with extremely calm winds over significant periods are difficult to find. Figure 2 is a plot of aircraft range and altitude for a number of UAVs and manned aircraft. Also included on Figure 2 are the horizontal and vertical dimensions of various atmospheric phenomena. Some UAVs (e. g., the Global Hawk) significantly expand the envelope beyond our current manned aircraft capability. The main problems of UAVs at the present them are they unreliability and some very high ratio between maintenance and flight hours.

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