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High Altitude Drones for Science

Near space in the near future

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Abstract—Space experiments require qualification of instruments and even in the case of nano-satellites, it is a long and expensive way to achieve a flight model. A new generation of high altitude vehicles, now entering an industrial phase, may offer an alternate access to near space. Such solar powered drones are able to fly in the stratosphere for much longer missions than stratospheric balloons. The purpose of this paper is to explore characteristics of the environment, conditions of flight, and define ways to take on board scientific instruments. Small payloads are expected, in the range of several units cubesats.

Keywords—Drone (UAV), near space, stratosphere, experiment

I. INTRODUCTION

After more than half a century of space exploration, the access to the celestial world remains both a technical and economic challenge. Representative environments are needed throughout instrument development, in early "proof of concept" steps, up to qualification of flight models. Some characteristics of space environment and transportation are easily simulated on ground (pressure, temperature, vibration), some others with difficulty (radiations, cosmic rays).

Nevertheless, there are several available ways to reach true space or near space environment. With Helium-filled balloons, it is possible to fly up the stratosphere, at 40 km, above clouds and ozone layer, in a black sky. But these experiments are expensive and flight duration is mainly limited to one day. In France, large platforms (up to three tons) are operated by CNES, the French space agency.

By adopting a different approach, reducing drastically the payload allows to operate a small but really orbiting nano-satellite at low cost. Launch expense is generally covered by the main payload commercial operator, and quality requirements are simplified. The prototype of such missions is the Cubesat architecture. At this time, more than 300 Cubesats have been developed and a hundred of them are in flight. In France, all nanosat or Cubesat projects are managed in a student program, called Janus, and headed up by CNES [1].

II. EMERGING CONCEPTS OF NEAR SPACE VEHICLES

Since the beginning of the decade, the need for network anywhere and anytime has driven innovation in multiple domains, especially in space communications. Several projects of communication satellite constellations have been initiated, counting hundreds of platforms, if not thousands. For example, the OneWeb constellation should involve 640 small satellites, ten times more than Iridium.

Other atypical projects involve stratospheric balloons, either semi-passive (Google Loon), or motorized (Thales Stratobus). The former claims to benefit from wind layers by adjusting flight altitude to move around, while the latter claims to remain static, fighting against the wind.

The Stratobus platform (Fig. 1) was designed to remain geostationary in the lower stratosphere. At an altitude of 20 km, jet streams are reduced and the engine power needed to counter the wind is compatible with the flux of solar energy collected on board, leaving enough extra power to recharge batteries to keep running at night, and to supply the payload. Such a balance being achieved, this drone remains above a target site 24/7.



Fig. 1. Stratobus vehicle (concept by Thales). The solar power is collected through the transparent portion of the envelope and reflected toward the lower face of double sided photovoltaic cells, complementing the flux collected directly on their upper face.

Preliminary design phase is completed and the concept has gained notoriety. It has been selected in the French governmental investment plan, and a prototyping phase is now running for a few years, leading to a demonstration model by year 2020.

The applications targeted by this hybrid vehicle between satellite, drone and balloon (sometimes called pseudolite, for pseudo-satellite), are multiple. The most obvious is earth observation, for either civil or defence purpose: surveillance of borders, coasts, forests, monitoring of industrial activity, management of traffic, accurate diagnosis after disaster, etc.

Telecommunications will also benefit from the relay to provide internet and phone call, routing data from/to ground and also between other Stratobus platforms of a network, just like satellite constellations mentioned above [2].

In the following, we consider High Altitude Pseudo-Satellites (HAPS) for space science applications.

III. NEAR SPACE ENVIRONMENT

Usual orbiting satellites are not so well suited for continuous observation of a particular site. GEO cruising satellites are located 1800 times farther, and LEO cruising satellites do not revisit the same place within days. The relative low cost of such near space platforms, together with advantages such as soft launch conditions, or the certainty to recover the payload after flight, led us to evaluate the potential for scientific experiment.

A. Astrophysics

Looking up to the sky instead of down to the ground, the altitude of 20 km offers a cloud-free observing point, which thus allows more continuous observations than from the ground, permitting survey-type observations for long and uninterrupted periods. Such an observation altitude leaves only 3 % of the atmosphere above the instrument, at a pressure of 50 mbar. Almost all water vapor disappeared, making the sky transparent to near infrared (1-10 μm). UVC (100-280 nm) are still strongly attenuated by N_2 , O_2 , O_3 , monoatomic O and N, but UVA (320-400 nm) and UVB (280-320 nm) are partially recovered.

The UV and near-UV ranges are of high relevance for many astrophysical processes involving hot plasmas. For example, a spectral line of the ionized Calcium at 393 nm is well known to be very good proxy for the investigation of solar or stellar magnetism [3]. At this wavelength, the transmission in the Earth atmosphere increases rapidly with altitude (about a factor 3 between 19 and 24 km). Moreover, observations from a stable platform at 20 km or higher, above most clouds, allow a continuity that is out of reach of ground-based telescopes.

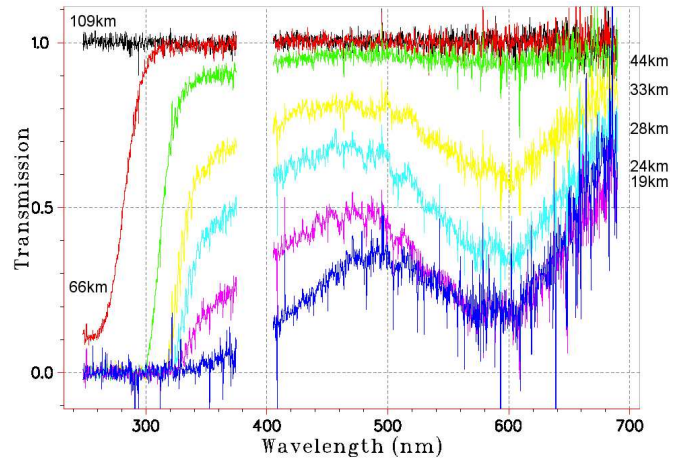


Fig. 2. UV absorption by the Earth atmosphere for several altitudes (GOMOS instrument on ENVISAT). The lack of data in the 375-405 nm region is due to the instrument.

High energy particles from outer space are intercepted by residual gas as soon as they enter the upper thermosphere, and generate secondary particles cascades (also called air showers) with energy decay down to ground. At the altitude of 20 km the particle flux comes to a maximum, known as Pfozter maximum. Therefore, special care has to be taken in the design of electronic circuits and systems, but this altitude is a position of choice for the study of cosmic rays [4].

B. Earth atmosphere

In atmospheric sciences, balloons are widely used to provide profiles of meteorological variables: weather balloons are launched each day in hundreds of stations over the globe to feed numerical weather prediction systems. Larger balloons carrying heavier payloads are sporadically launched to measure trace gases involved in the radiative budget of the Earth (e.g., greenhouse gases) or in atmospheric chemistry. A few space agencies (notably including CNES in France) have furthermore developed capabilities to perform long-duration balloon flights with essentially super-pressure (i.e., closed) balloons. Such balloons can fly for months at a nearly constant altitude, generally in the lower stratosphere (i.e., around 20-30 km), and perform circum-terrestrial flights (Fig. 3), while carrying loads of ~ 50 kg. They drift with the winds, and are used to study atmospheric dynamics and transport [5] [6]. These balloons are for instance in the core of the upcoming CNES Stratéole 2 campaign, aimed at better understanding the transport of trace gases through the tropical tropopause, as well as the forcing of the Quasi-Biennial Oscillation in equatorial zonal-mean zonal winds.

Drones able to remain for about 1 year in station over a given location provide further opportunities to complement the current observing system of the Earth atmosphere. Recently, light and low-power in-situ instruments (< 5 kg), able to measure either meteorological variables (pressure, temperature, winds), greenhouse gases (water vapor, carbon dioxide, methane) or atmospheric particles, have been developed for

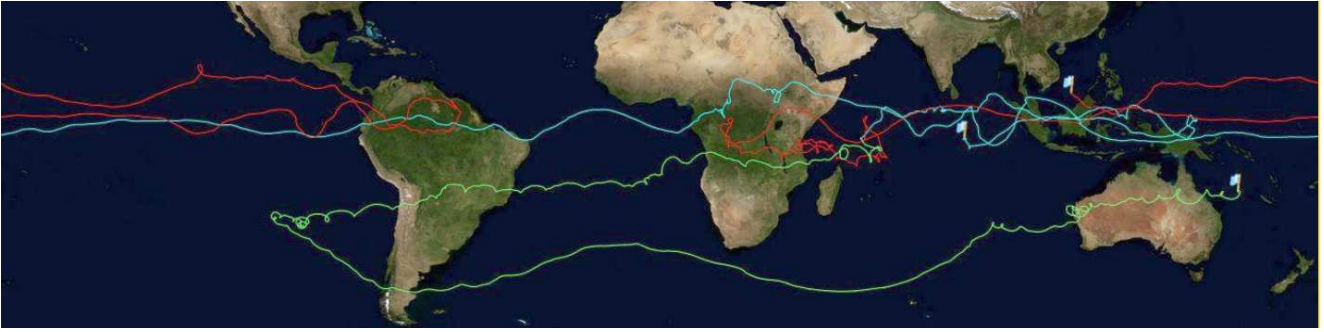


Fig. 3. Trajectories of 3 long-duration balloons launched from Seychelles Islands in February 2010, during the CNES pre-Concordiasi campaign. The flights lasted for 3 months each. The balloons flew at an altitude of ~ 19 km.

balloon applications (including long-duration flights), and could likely be relatively easily fit to stratospheric drones.

As will be done during Stratéole 2, these instruments could furthermore be reeled down and up from the carrying platform, which allows to perform measurements not only at the drone flight altitude, but also over a few kilometers below it. If energy onboard the stratospheric drone is sufficient, light remote sensing instruments measuring temperature or clouds may also be used to even increase the vertical range of observations.

Such measurements onboard stratospheric drones thus offer to continuously monitor the atmospheric dynamics and composition over long periods of time. They could for instance be used to enhance current meteorological observations over regions which are poorly sampled by in-situ measurements (i.e., oceans, tropics). They could also serve as reference measurements for space-borne observations, as stratospheric drones allows to regularly control the calibration of onboard instruments.

C. Electromagnetism

Pointing back to nadir, as the transmission path to the ground integrates almost all the atmosphere, the resulting path loss is close to the one relative to higher satellite communication, for most of radio bands. The current trend of data rate and number of channel increase pushes up the use of higher radio bands. In recent years, a growing interest has been observed for W band (70-80 GHz). The European Space Agency published an ITT to design, develop and launch a cubesat to characterize the atmosphere in this microwave band [7]. A direct qualification flight of the instrument onboard a Stratobus platform would significantly reduce the cost of the qualification process of the expected cubesat, making the drone a “TRL booster”.

IV. CONDITIONS OF FLIGHT

The main payload mass is about 200 kg, while the available power on board is about 2000 W. As a first step, taking 1% of this (2 kg, 20 W) is an order of magnitude of what should be acceptable as secondary passenger payload. Numerous experiments have already been performed in nanosats, within this budget. Going farther than this 1% range in a second step

opens new possibilities for high quality observations for a cost still much lower than space-borne platforms.

Moreover, the short distance of transmission, and the ability to set a fixed antenna on ground, right below the airship, will simplify the embedded emitter and reduce power, while collecting data continuously and massively, avoiding telemetry concerns. The Stratobus platform is already attitude controlled, in the weatherless, non turbulent, stratosphere.

V. SCIENCE MISSIONS HOSTING

The prospective action consists in collecting and evaluating ideas of instrument and mission that are compatible with the vehicle: small mass and size, cubesat scale.

Parallel to that, we will seek future drone owners who will host the research payloads, and initiate conventions with agencies to validate and fund the activity.

From a management point of view, a possible model for this kind of project is to adapt a nanosat development strategy: student driven, space agency accompanied, research lab cautioned. Working on the mechanical and electrical definition of the science rack is already a project in itself.

As discussed in the above examples, several classes of payload are foreseen:

- Instrumental proof of concept – opportunity of flight experience
- Instrument calibration in near space – representative environment
- Nanosat qualification – reusable payload after flight
- Complementary mission of traditional space mission – provide additional data of long term observation on objects of interest.

Indeed, space missions rely more and more on observations of the same astrophysical objects but with different methods (for example in the case of exoplanet search and characterization). HAPS would be an efficient and affordable way to optimize space mission scientific exploitation.

VI. CONCLUSION

Compared to intermittent LEO and distant GEO, the example of the Stratobus hybrid vehicle, floating above the atmosphere, is raising interest for science applications in near space. Mission duration is expected much longer than those on stratospheric balloons.

Along with the nanosat roadmap of SONDRRA, there are opportunities to consider other access to space, or to introduce such HAPS in the development plan of a nanosat.

The easiest model under construction is a small cubesat-scale Science Rack, installed as secondary passenger next to the main application payload, the same way cubesats are embedded on commercial launches.

Besides, other emerging vehicle from this HAPS class should be investigated.

ACKNOWLEDGMENT

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