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A METHOD OF EXPLORATION OF
THE ATMOSPHERE OF TITAN

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ABSTRACT

A new type of hot-air balloon, with the air heated by natural sources, is described here. The vehicle was developed at the Service d'Aéronomie du CNRS, in Paris. France. Buoyancy is accomplished by either solar heating or utilizing the IR thermal flux of the planet to heat the gas in the balloon. Altitude control is provided by a valve which is opened and closed by a barometer. The balloon is made of an organic material which has to absorb radiant energy and to emit as little as possible.

THE SELF-BUOYANT MONTGOLFIERE

Principle

A new type of vehicle was developed at the Service d'Aeronomie du CNRS, in Paris, France, during 1977 by J.-P. Pommereau and A. Hauchecorne (1977).

It is a hot-air balloon, where the air is heated by natural sources. We call *solar montgolfiere* a hot-air balloon whose buoyancy is provided by solar heating and *infrared montgolfiere* a hot-air balloon whose buoyancy is provided by the IR thermal flux of the planet (Earth or other).

A montgolfiere is a balloon made of an organic material defined by its weight g (gm^{-2}), its emissivity ϵ and its transmissivity α, both thermooptical coefficients defined over all wavelengths. The balloon is open at the bottom and at the top by two very large apertures. The aperture at the top can be closed by a valve.

The potential of the system can be discussed with the help of the thermal buoyancy per unit volume P defined as

$$P = \left| \frac{T_b - T_a}{T_b} \right| \rho_a$$

where T_b is the temperature of the balloon, T_a and ρ_a respectively the temperature and the density of the ambient atmosphere.

A model of the system relating the parameters defining the balloon (radius r, g, α and ϵ) to the buoyancy and therefore to the total weight of the balloon (weight of the balloon and payload), including the spectral dependence of α and ϵ , the actual shape of the balloon, convection inside and outside the balloon has been computed for different types of atmospheres (Pommereau and Hauchecorne, 1977).

The Solar Montgolfiere

Because of the large value of the solar flux, the system is fairly simple. In this case, the balloon is made of a single material which has to absorb the solar light and to emit as little as possible (α large, ϵ small). When the top valve is closed, the solar energy heats the inner gas and the balloon ascends; a barometer opens the valve at a predetermined altitude and the balloon descends to another predetermined altitude where the barometer closes the valve. A series of vertical explorations is thus obtained during the day.

The Infrared Montgolfiere

Because of the geometry, the balloon is made of two hemispheres of different infrared emissivity. Ideally, the emissivity has to be zero for the upper hemisphere and one for the lower hemisphere. Over a region when the upward IR flux is defined by a brightness temperature T_R, the temperature of the gas inside the balloon T_B would become equal to T_R in the absence of convection losses.

Detailed computations show that the thermal buoyancy is not large in the majority of circumstances and therefore acrobatics permitted to the solar montgolfiere may not be permitted to the IR montgolfiere: a mere survival of the balloon during the

night can be hoped for. A typical value of the buoyancy on the Earth is 100 g m^{-3} during the day and 10 g m^{-3} during the night for a flux coming from the sun of 1940 W m^{-2} at the top of the atmosphere and a flux generated by the Earth at night varying with the nature of the clouds from 110 W m^{-2} to 300 W m^{-2}.

It is obvious that when the buoyancy is small the payload is also small and therefore the IR montgolfiere has to be very large. A limit is set to its dimensions by the mechanical properties of a thin structure.

State of the Art

The first launches of solar montgolfieres were performed with complete success in Pretoria (Union of South Africa) on Feb. 17th and Feb. 25th, 1977 by a crew of the Service d'Aeronomie. The volume was 300 m^{3}, the weight 50 g m^{-2}, and the payload 2 kg. As predicted, the two balloons performed a series of 4 vertical excursions between 15 and 19 km of altitude. The measured temperatures inside and outside the balloon were fitted to the theoretical model; their value. showed that the IR montogolfiere should work (Pommereau *et al.*, 1977a). The program was then adopted by CNES which developed, according to the specifications of the Service d'Aeronomie, and launched from Aire-sur-l'Adour (France) an IR montgolfiere on December 19th, 1977, with complete success. The volume was 5800 m^{3}, the weight 25 g m^{-2}, and the payload 10 kg. The balloon had no top valve since the test was only intended to prove the survivability during the night. It drifted during 66 hours over Southern Europe performing as predicted, culminating at noon at 24 km and bottoming at the end of the night around 19 km, and was destroyed by a preset timer without which it would still be flying today (Pommereau *et at.*, 1977b; Bezaudun, 1977).

CNES and the Service d'Aéronomie have initiated a program of applications of the system to the study of the stratosphere, starting with two launches from Pretoria in April 1978.

During the same time, CNES is studying the possible use of the concept for the exploration of the Venus atmosphere, a joint venture with the Soviet Union, with an approved launch in 1983.

THE MONTGOLFIERE IN THE ATMOSPHERE OF TITAN

A preliminary study (Hauchecorne and Pommereau, 1978) has been completed of the feasibility of both solar and IR montgolfieres in the atmosphere of Titan for the three atmospheric models described in the NASA document "The environment of Titan" (1975) (NASA, 1976).

The Titan IR Montgolfiere

The emissivity ϵ of the upper hemisphere of the balloon is assumed to be 0.05 towards the outside and 0.90 towards the inside; the lower hemisphere is assumed to be transparent.

With the "thin" and "nominal" models, the temperature of the atmosphere is higher than the temperature on the ground: the buoyancy is therefore zero and the montgolfiere cannot work.

With the thick model, using the albedo measurements of Younkin (A = 0.20 and T_B = 85 K) the upward infrared flux can be assumed to be 3.0 W m^{-2} at the tropopause. Below the tropopause, we suppose that the difference between the upward IR flux and the black body emission at the atmospheric temperature increases linearly from zero on the ground to 1.1 W m^{-2} at the tropopause. Figure 1 shows that the buoyancy of the balloon in this model is inferior to 3 g m^{-3}; therefore the IR montogolfiere is impossible in practice.

The Titan Solar Montgolfiere

The balloon is completely covered by a thin metallic film in order to reduce the IR emissivity and by a thin varnish for total absorption of visible solar light.

$$\epsilon_{IR} = 0.05 \qquad \alpha_{sol} = 0.60$$

The visible solar flux above the atmosphere is 15 W m^{-2} and is supposed not to be absorbed by the atmosphere. No cloud can exist in the "thin" and "nominal" models, but there is a strong possibility of clouds below the tropopause in the "thick"

model; the buoyancy of the solar montgolfiere is plotted on Figure 1. With the "thin" model, a buoyancy of only 8 g m^{-3} is obtained on the ground, which makes the system very hard to fly. However with the two other models, the solar montgolfiere flies easily: a montgolfiere with a buoyancy of 20 g m^{-3} could explore the region from 0 to 35 km in the "nominal" model and from 0 to 75 km in the "thick" model.

Figure 2 shows the payload available with a montgolfiere made with a material weighing 20 g m^{-2} and a buoyancy of 20 g m^{-3}. A typical example would be a relatively small balloon of 4000 m^3 whose weight would be 25 kg and the payload 50 kg. This balloon is in the class of the successful IR montgolfiere of December 1977.

The temperature of the fabric would be low. With the skin temperature above the ambient temperature by 100°C, we are faced with a temperature of the material of -100°C. A large number of products (fiber glass, kevlar, polypropylene film) retain their mechanical properties in this range, even down to -200°C.
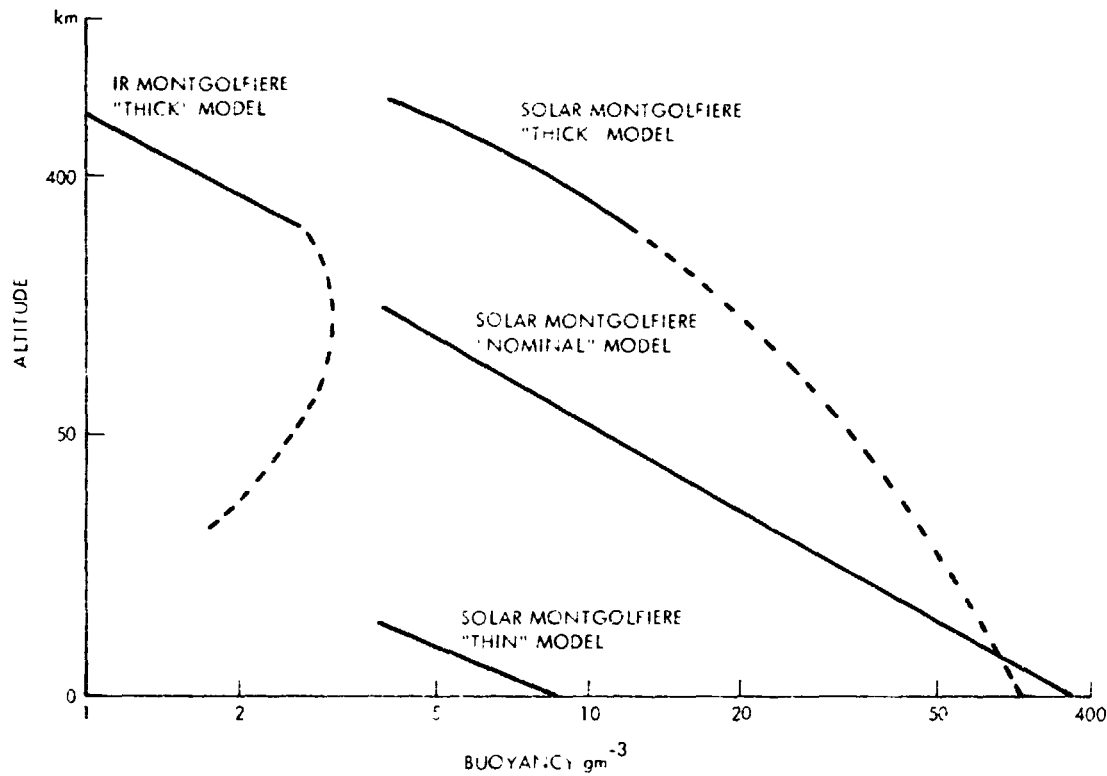

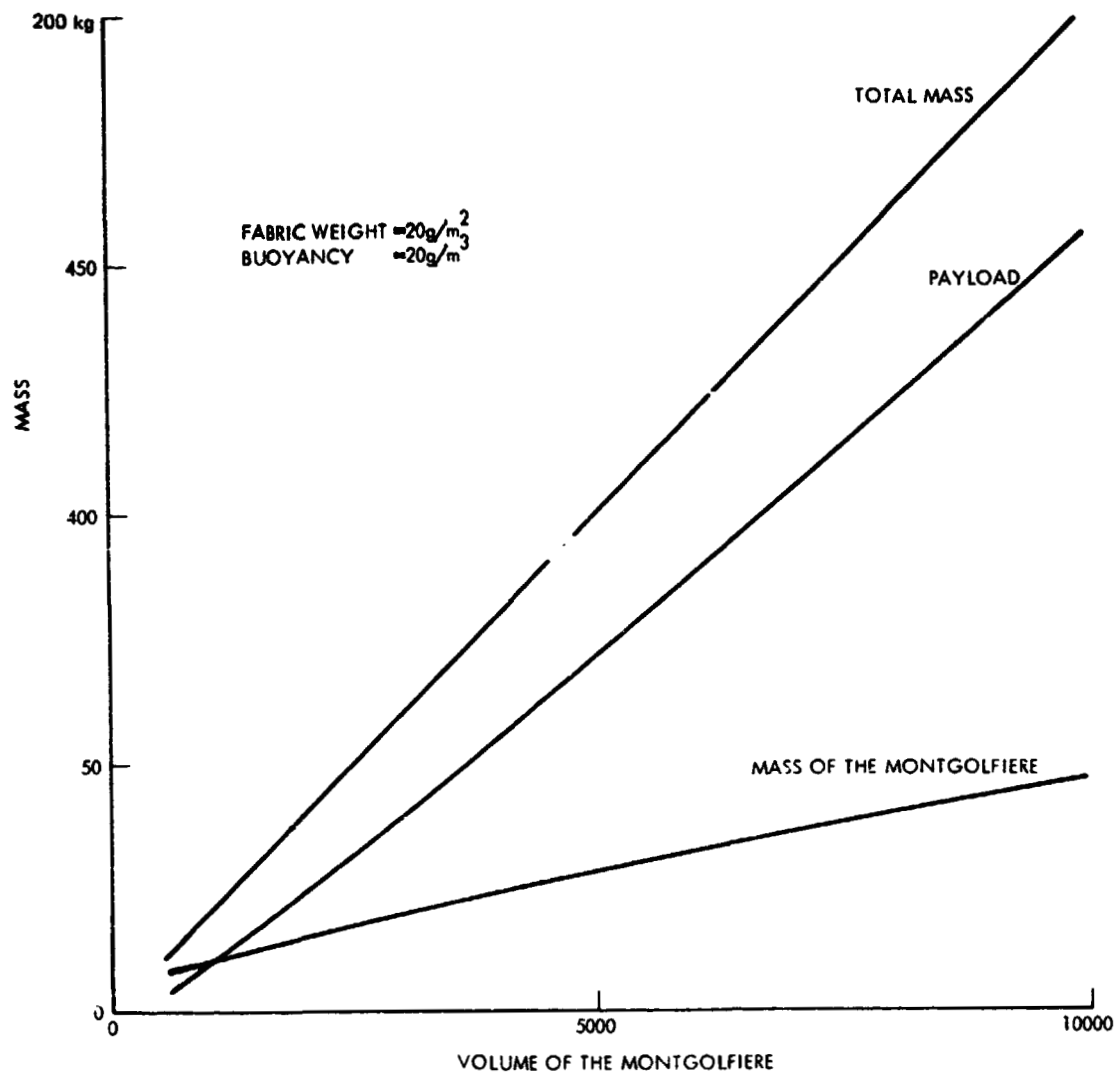Figure 1   Buoyancy of a Montgolfiere in the Atmosphere of Titan

Figure 2. Payload of the Montgolfiere as a Function of the Volume

A Possible Mission

The scientific objective is a vertical exploration of the Titan atmosphere. A solar montgolfiere is injected near the subsolar point, drifts in the winds, exploring an extended range of altitudes. The value of the range cannot be determined today as it depends on the model chosen. The advantage of the use of the montgolfiere can be best understood by considering it as *a parachute which can ascend* in specified conditions.

A 4,000 m^3 montgolfiere could fly up to a pressure of around 50 millibars and down to an altitude determined by the solar flux available after absorption through the clouds. Should the "ultrathick" model of Hunten be proven to describe the situation, the system would fly from 180 km down to at least the tropopause level at 100 km of altitude where the pressure is 1 bar, and explore even the region below the clouds if their optical thickness is not too great.

When the balloon approaches the terminator, it slowly descends to the ground and allows an exploration of the lower layers. The vertical structure of the wind velocity field can be deduced from the measurement of the position of the montgolfiere. Therefore, if a real time analysis can be obtained, it could become feasible to maintain the system a long time in the sunlit hemisphere by commanding the valve from the Earth in order to either maintain the system at an altitude where the wind velocity is minimum, or vary the altitude in a vertical gradient around an altitude of zero wind velocity.

With a nominal payload of 50 kg, a scientific package of 15 kg could be accommodated, the remnant of the weight being allocated to a RTG, a transmitter, an omnidirectional antenna, a command receiver and a mechanical structure.

In these 15 kg, a measurement of the vertical structure of temperature and pressure, a chemical analysis of the atmosphere (organic molecule mass spectrometer and gas chromatograph similar to Pioneer Venus's of a weight of 3 kg) a nephelometer, an IR radiometer, a measurement of the nature of the cloud particles (α backscattering, X ray fluorescence spectrometer and other) perhaps a camera for obtaining pictures of the clouds or of the landscape could be placed. Data on general circulation, wind velocity and field including vertical gradients and vertical motions are deduced from the motion of the balloon. The main interest of the mission is that transport phenomena and their interaction with the physicochemical properties of the atmosphere are investigated.

In this configuration, the total payload is 75 kg (50 kg for the gondola and 25 kg for the montgolfiere). A comparison with the Galileo probe where the total weight is 250 kg for a heat shield of 100 kg and a science payload of 25 kg, shows that a Titan probe of less than 250 kg which would need a heat shield of less than 20 kg, could accommodate a payload of 100 kg, and therefore the 4,000 m^3 montgolfiere and its gondola. The proposed Titan probe therefore would be in the class of the Galileo probe and of the Saturn probe.

The data would be transmitted to the orbiter which would also have to locate the gondola. The necessity of maintaining a communication link suggests a circular orbit in the equatorial plane of Titan, since it is likely that the general circulation and therefore the motions of the balloon would have a large zonal component. The altitude would have to be chosen as a trade off between different requirements but 20,000 km could be a reasonable figure.

More than one balloon could be released; the exact number would depend on the payload capacity at injection.

The mission can be defined with more accuracy after the Pioneer and Voyager encounters with Titan.

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DISCUSSION

J. POLLACK: In your evaluations of the buoyancy, what assumptions did you make about the absorption of sunlight by the Axel dust above the balloon?

J. BLAMONT: I supposed that the balloon was above the clouds. There was no allowance for absorption by a haze at higher altitudes.