NEW RECOVERY SYSTEMS FOR STRATOSPHERIC BALLOON GONDOLA

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ABSTRACT

In usual configurations of open stratospheric balloon systems, the load parachutes are deployed in line in the flight train just below the balloon. A few seconds after the separation between the balloon and the flight train, the parachutes are fully inflated and the descent starts at the altitude of balloon ceiling. Depending on balloon altitude, the gondola descent takes at least 30 minutes, inducing an horizontal drift, between the cut off location and the landing area, function of wind profile, often in the range from 5 km to 40 km. Due to the time and space wind variability, the uncertainty about the landing area could reach a few kilometres, inducing very strong operational constraints in the choices of flight trajectory and gondola recovery area.

To increase the accuracy of the landing area estimate, CNES Balloon Division is studying and testing two new systems :

- the parachute sequence : usual load parachutes are operated at a low altitude after a high speed descent with a pilot chute;
- GPS guided parafoil : the gliding capability of parafoil permits to reach a pre-determined landing area controlled by an autonomous guidance unit.

After ground level tests, these two systems have been tested with stratospheric balloon at the Esrange Rocket Range facility (Kiruna / Sweden) after releases over 30 km altitude.
In august 1998, the first stratospheric flight test of the parachute sequence was performed with a total drift reduced to an half kilometre.
The first stratospheric flight test with a GPS guided parafoil was performed during the same campaign. After a high speed descent from 33 km to 10 km, the parafoil was fully inflated and was autonomous controlled during a gliding drift of 30 minutes to reach a landing area 20 km away.
In February 1999, a second stratospheric parafoil test flight was done again from Kiruna, without autonomous control system, but with an emergency parachute system. All these tests were successful. This paper will present an overview of progress, status and flight tests results of theses new recovery systems for open stratospheric balloons gondola.

INTRODUCTION

The studies of these two new systems for recovery of stratospheric balloon gondola started by 1996.

The parachute sequence consists to descent as fast as possible using a drogue chute, and to operate the main chutes at low altitude to reduce the horizontal drift and the uncertainty on landing area. After 4 drop tests from helicopter in 1997 and 1998, the first flight test from stratospheric balloon occurred during the summer 1998.

The GPS guided parafoil comprises a parafoil and an associated guidance unit to control it. Before the flight, a landing area is programmed to the guidance unit. After parafoil opening, the guidance unit pilots the parafoil drift, using GPS localisation and magnetic compass, to reach the programmed landing area.
In 1996, the ORION™ and PEGASUS™ systems were available for military parachute operation from plane. During 1996 – 1997, laboratory tests of ORION™ guidance unit (Autonomous Guidance Unit - AGU) demonstrated that this parafoil system was suitable for stratospheric balloon operation.

The first balloon flight tests of ORION™ system was done during summer 1998. A second balloon flight test was performed with parafoil and an emergency parachute system during winter.
This paper is an overview of our recovery systems program with designing, manufacturing and testing of two demonstrators in full balloon environmental conditions.

SYSTEM STUDIES

The main challenge of these systems was to descend as fast as possible from the balloon cruise altitude to the altitude of main chutes / parafoil deployment with a drogue chute operated at very high altitude without any initial velocity. And this, without damage and twist, and with a maximum shock lower than 5 g during inflation of the main chutes / parafoil.

For missions analysis, we ran our simulation deployment and parachute software of the Martian Aerostat Project (Ref. 1 et 2). CAP and AERAZUR were CNES main contractors for all hardware design.

When the termination of a stratospheric balloon flight is decided, the operational team must have a very high level of confidence in the gondola landing area estimation, before cut off.
A precise landing prediction requires an accurate wind profile knowledge, and a fall as fast as possible with usual parachutes or, a guidance system with a gliding parachute (parafoil).

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Figure 1 shows statistical results obtained by computer simulations from the same altitude between :

- the actual recovery system with 40 minutes descent duration (landing at 5 m/s);
- the parachute sequence with an opening phase at 2 km altitude;
- the GPS guided parafoil operated from 10 Km altitude.

For each system, statistical studies were made using 20 years of wind soundings over the same place, at a rate of 1 wind profile measurement every 6 hours. The statistical results are the average drift descent (wind) and the difference between the estimated landing area in a wind profile and the 'real' landing area obtained in the 6 hours later wind profile (similar with an operational process). With the guided parafoil, the system tries to reach the area and has just to compensate wind variations. A simple parafoil simulation software (L/D=3, 30°/s maximum turn rate, perfect GPS) was used. Results give an idea of the potential performances, in term of accuracy, of these two new recovery systems.

SEQUENCE PARACHUTE SYSTEM

Development program

At the beginning of 1996, a parachute sequence study was started with the conventional main chutes packed into bags and a drogue chute deployed in line. The parachute sequence consists to go down as fast as possible (Mach number < 0.8) using the drogue chute, and to operate the main chutes as low as possible but with a maximum deceleration level lower than 5 g.
For the drogue parachute, a kind of ballute (called RSE : Ralentisseur Stabilisateur Extracteur) was chosen and operated without swivel

After computer simulations, a light flight train for 200-250 kg payload and a heavy flight train for 600-800 kg were designed and manufactured by DGA/CAP (Centre Aéro Porté de Toulouse).

The two configurations are similar, just loads and surfaces of parachutes are different:

- 1 m² drogue chute and 4 x 50 m² for the 200-250 kg system;
- 3 m² drogue chute and 4 x 200 m² for the 600-800 kg system.

In March 97, the two configurations have been tested from an helicopter at 0.7 km altitude. The main chutes were deployed 250 m above the ground at 50 m/s. Some problems, concerning the relaxation of our very long flight train and the strength of the drogue chute, appeared. But, the shock level during deployment and inflation of the main chutes was within the required range.

After flight train stiffness modification and drogue chute reinforcements, these two configurations were tested again from an altitude of 5 km in February 1998. The main chutes were deployed 500 m above the ground.

The behaviour of the two systems was correct and we decided to perform the real flight test with a stratospheric balloon during summer 1998 (scientific campaign at Esrange – Kiruna/Sweden).
For all these development tests, total mass of the heavy flight train was limited to 500 kg for reducing costs of helicopter rental and balloon tests.

Sequence parachute configuration

The flight trains are the "operational" flight trains with, from the top to the bottom : drogue chute, NSO (gondola for balloon flight controls : TM/TC, GPS, ballast...), a tether of 75 m length and a mock-up of a scientific gondola.

The main changes in regard to the operational flight train are the following :

- the drogue chute takes the place of usual main chutes, deployed in line between the balloon and the NSO;
- the 4 main chutes are compacted in 2 bags on the NSO. A Vectra tether replaces the usual Polyamide tether for drag and stiffness purpose.

Mock-up of the scientific gondola is a metal box, for which the mass can be adjusted using ballast. It was equipped with video camera and electronics for real time transmission.
NSO gondola contains specific TM/TC electronics, high speed data storage, load cells, inclinometers, accelerometers, GPS receiver, video camera and electronics (timer and atmospheric pressure systems) to operate the deployment of the main chutes.

Stratospheric balloon test of parachute sequence

The heavy flight train was dropped from 30 Km altitude over the Esrange Rocket Facility of Kiruna on august 1998 the 7th , two hours and 5 minutes after balloon launch. Drogue chute was fully inflated, and began to drag 6 seconds after cut off. The maximum velocity of 250 m/s was reached 50 seconds later. Deployment of the main chutes was initiated by pressure system 1000 m above ground after a 4.5 minutes descent with drogue chute. The maximum shock was 4 g. Landing of gondola occurred 1 minute later with a velocity of 5 m/s. The landing area was just half kilometre far from the cut off location. After recovery and checks, all components were in perfect conditions.
Figures 2 and 3 show altitude profile and a record of the load cell during the sequence.

GPS GUIDED PARAFOIL SYSTEM

Development program

First of all (1996-1997), it was necessary to assess if "on the shelf" ORION™ or PEGASUS™ systems were suitable for stratospheric balloon operation.
The problem was partially solved at the beginning of 1998, when the French Air Army lent its ORION™ Autonomous Guidance Unit (AGU) to CNES for vacuum , thermal and GPS simulation tests. AGU is the parafoil control device developed by SSE, including sensors (GPS receiver, compass and atmospheric pressure sensor) and electronics to control the parafoil flight, using two powered winches to roll up / unroll the two control lines.

The results showed that a short balloon mission was possible with ORION™ and we decided to use the SSE AGU and the PIONNER 700 ft^2 parafoil.
With AERAZUR (French ORION™ importer), we decided to change only the drogue chute (type, size, configuration) to adapt it to the balloon environment. A conical parachute with 4 windows and with a swivel was designed to limit shock and risk during parafoil deployment and inflation at 10 km altitude. In this configuration, the drogue and the parafoil bag are lost during the test.
A technological gondola was designed and manufactured at CNES during the last three months, just before the KIRUNA 1998 summer campaign.

Summer 1998 configuration and balloon test

A 26 m² drogue chute is deployed in line between balloon and gondola. As it is not possible to control a very long flight train of 75 m with two gondola under a parafoil, NSO gondola was withdrawn.
AGU and parafoil bag are tied on the gondola and released by electrical pyrotechnics at 10 km altitude. There is a swivel between the AGU and the gondola.
Gondola contains TM/TC electronics, video camera , real time video transmission, GPS receiver, gyrometers, accelerometer, inclinometers, compass...
Two aerodynamic fins were added to the gondola to keep it in the flight direction.

The first ORION™ flight was dropped from 33 Km altitude over Esrange impact area on August 1998 the 15th, one hour and 45 minutes after balloon launch. Cut off was activated when the balloon was at 19 km in the south east of the target area. With drogue chute, the maximum velocity reached 230 m/s. Fives minutes after separation, the ORION™ deployment phase is initiated at 9600 m altitude. Fourteen seconds later, at 9 km altitude, parafoil is extracted and partially inflated. Twelve seconds later, parafoil is fully inflated in good conditions. A very high instability occurs when the brakes were released.
Gliding flight started at 8.6 km in the opposite direction of the target following the wind. AGU control started 3 minutes later and the system took the right direction 22 km far from the target, at 6.5 km altitude. Too late and too low to reach the target area against the wind direction.
AGU control was taken by manual remote control 2.5 minutes before landing, 6 km far from the initial target.
Figures 4, 5, and 7 show altitude, vertical speed and horizontal trajectory during the Orion deployment phase. The load cell record during the same events is presented figure 6.
All components were undamaged after recovery. The guidance problem was due to altitude limitation of the AGU GPS receiver. During laboratory tests, the French Air Army AGU did not present this altitude limitation.

Winter 1999 configuration and balloon test

After these first test results, size and configuration of the drogue chute were changed (a strong relaxation effect was observed with the first drogue chute in line).
A 36 m² drogue chute is packed into a bag over the parafoil. It is extracted by the balloon after cut off.
A mechanical mock-up takes place of the AGU (SSE AGU not available) and stays tied on the gondola during the flight (no swivel between parafoil and gondola).

Two 30 m² spare chutes are packaged in a bag between the fins of the gondola. This emergency parachute system has two functions :
- to reduce the glide ratio in case of loss of control by AGU;
- to obtain a reasonable landing velocity in case of damages of the parafoil during inflation.

This emergency device is initiated by telecommand control and extracted by spring.

The second ORION™ flight test was dropped at Esrange from 31.5 Km altitude on February 1999 the 22nd, two hours and a half after balloon launch. With drogue chute, the maximum velocity reached 180 m/s. Six minutes after separation, the parafoil deployment phase is initiated at 10 km altitude. After soft inflation, the free gliding flight starts at 9.4 km, in the wind stream with large circles.

Ten minutes later, at 6.3 km altitude, a telecommand to deploy the emergency parachutes was transmitted. The effect was to reduce the lift on drag ratio from 3.5 to 1. Vertical velocity was 5 m/s under parafoil and 10 m/s under parafoil and emergency parachutes.
Altitude and vertical velocity are shown figure 8 and 9, and load cell record figure 10.

CONCLUSIONS AND FUTURE PLANS

Demonstrations of new systems for increasing the accuracy of stratospheric balloon gondola landings are done. Problems for long duration and high velocity drogue chute are solved. Now, we have to take into account operational constraints before introducing them in operational flights. In any case, one of them is to adapt scientific gondola to fast descent.

For parachutes sequence, as the flight train configuration is quite the same than the operational one (2 separate house-keeping and science gondola – drogue in line instead of load parachutes), the work will be reduced.

The ORION™ system, for which the modifications are stronger (1 gondola for science and house keeping), inducing a lot of work in electronics, mechanics and launch procedure, will induce a most important workload.

AKNOWLEGMENTS

All these tests were prepared and performed within a very tight schedule. Thanks to all the teams : Christian Larré and Josette Causserand from DGA/CAP; Patrick Chavanon from AERAZUR; AIRLANDES and HELIMONTAGNE; Börje Sjöholm and all from Esrange, balloon launch team from CNES Aire sur l'Adour, and Jacques Lebreton from CNES Toulouse.

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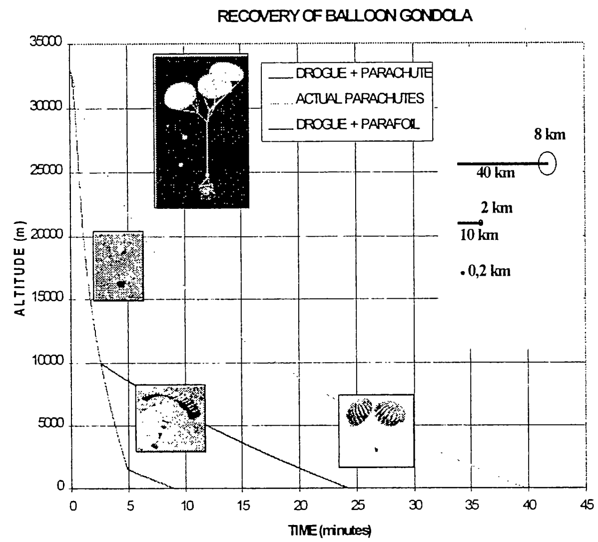


Fig.1: Statistical results

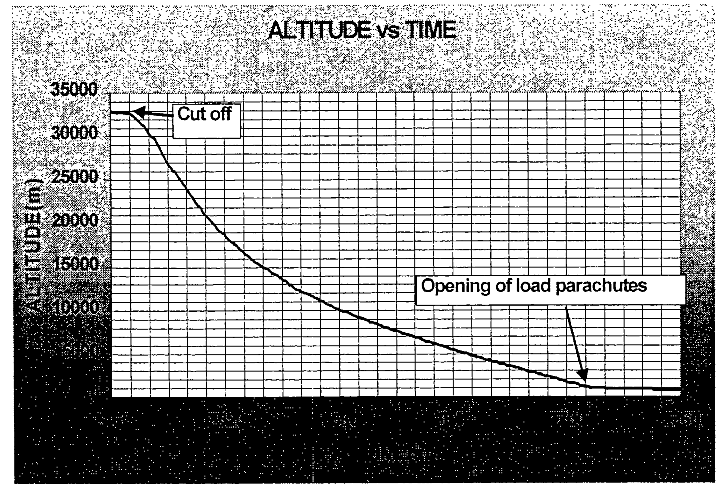


Fig. 2: Parachute sequence

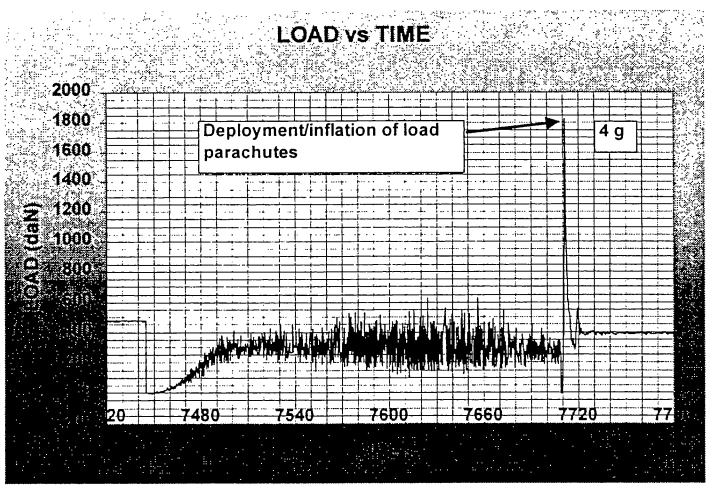


Fig. 3: Parachute sequence

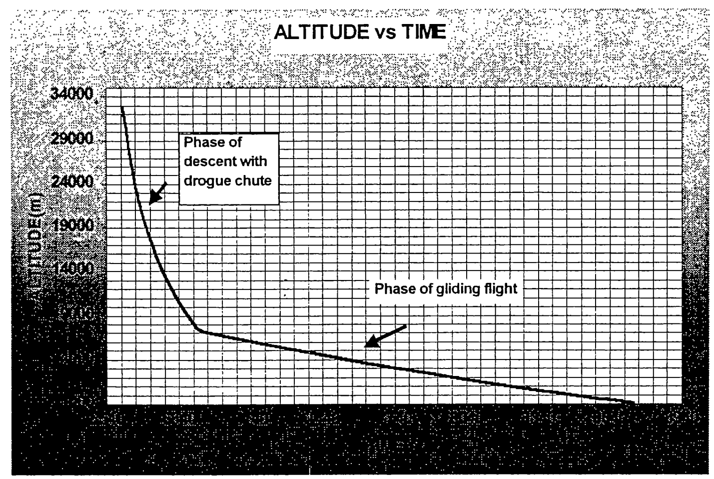


Fig. 4: ORION™ flight test n°1

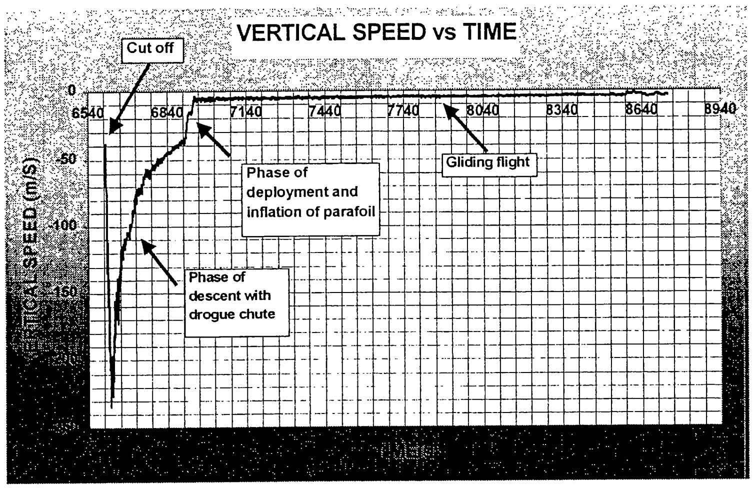


Fig. 5: ORION™ flight test n°1

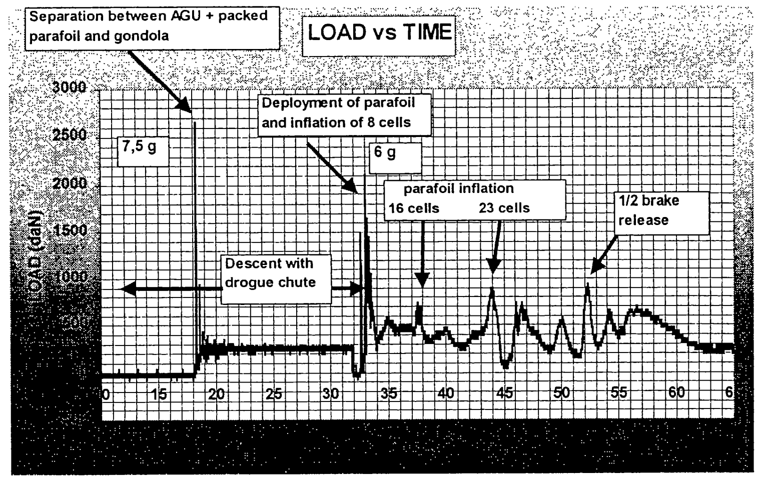


Fig. 6: ORION™ flight test n°1

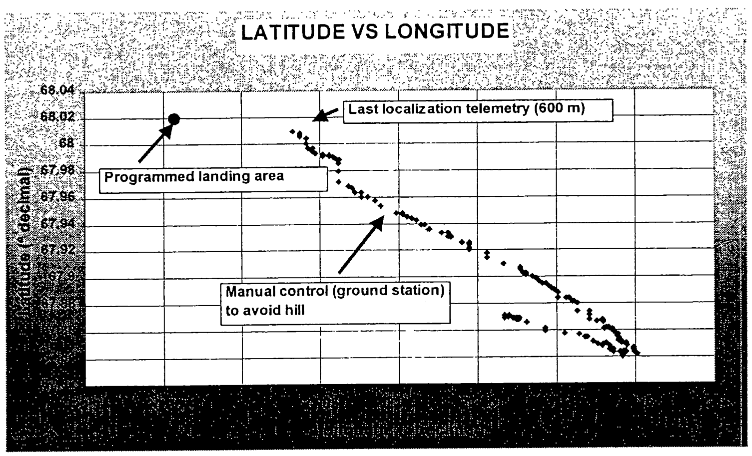


Fig. 7: ORION™ flight test n°1

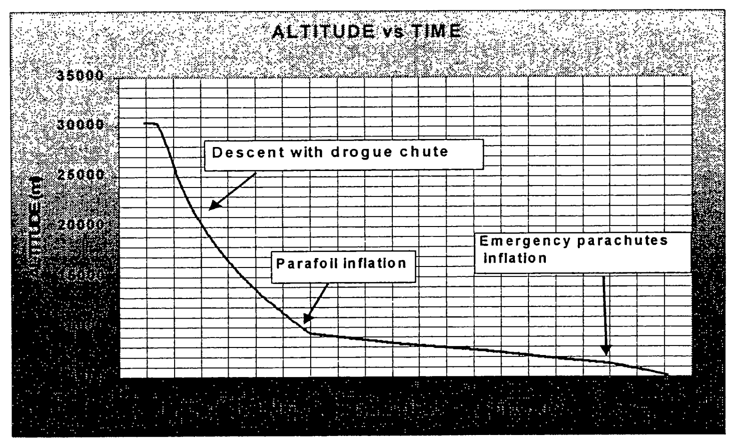


Fig. 8 : ORION™ flight test n°2

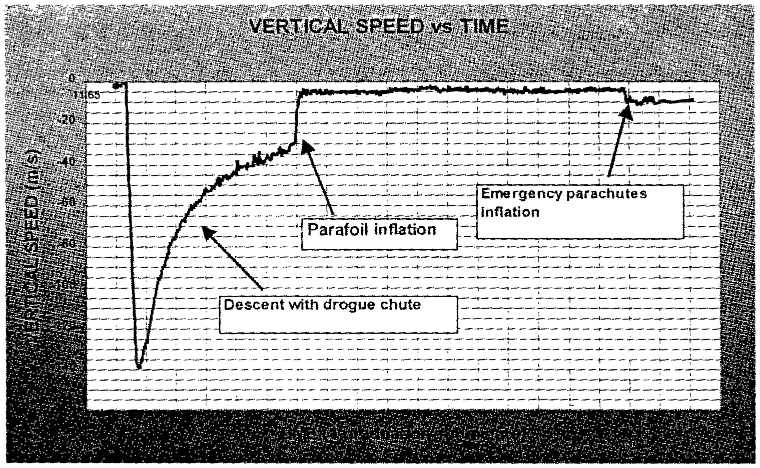


Fig. 9 : ORION™ flight test n°2

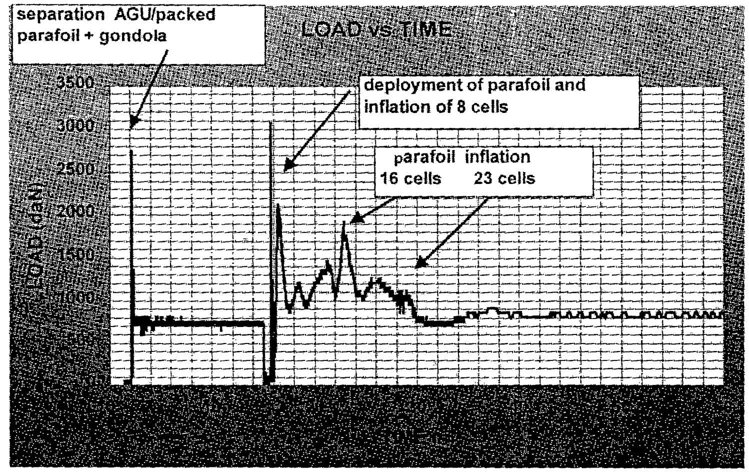
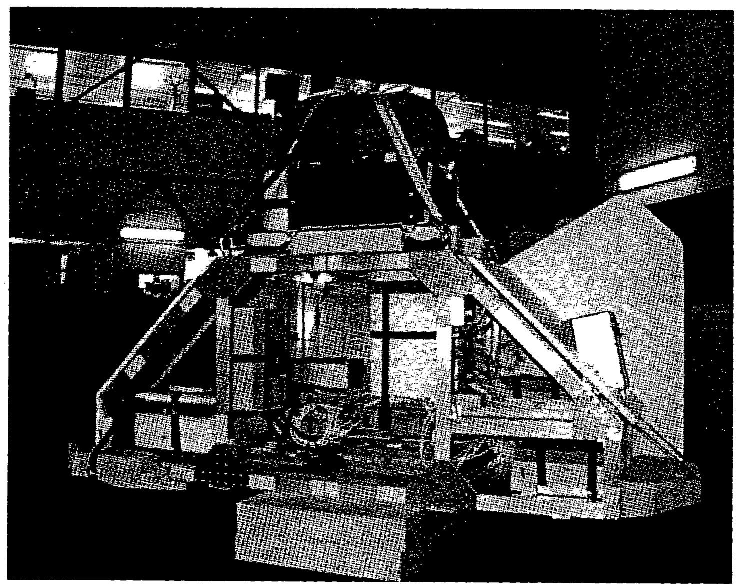
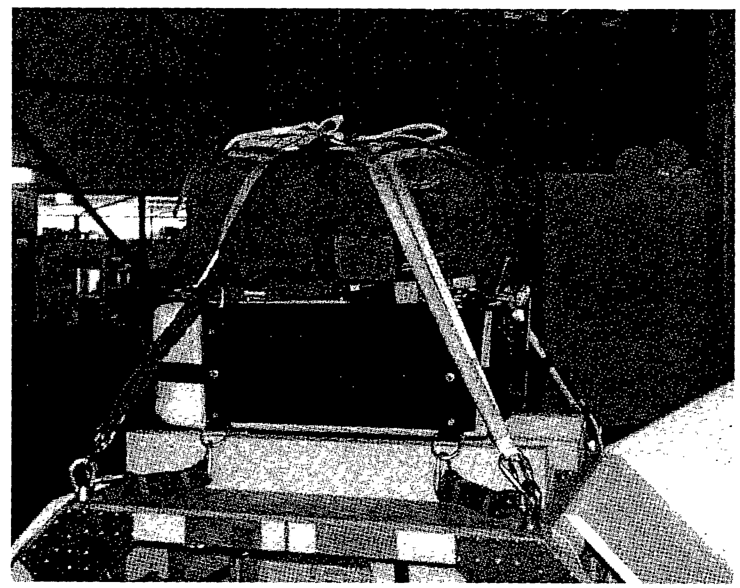


Fig. 10 : ORION™ flight test n°2





ORION™ flight test gondola