ENTRY, DEPLOYMENT AND SCIENCE OF PLANETARY BALLOONS

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CONTENT

Introduction

Planetary balloons as science platforms

Planetary balloon mission concepts

Entry, deployment and inflation of planetary balloons

Deployment and inflation for Venus and Titan

Aerial deployment of Martian balloon

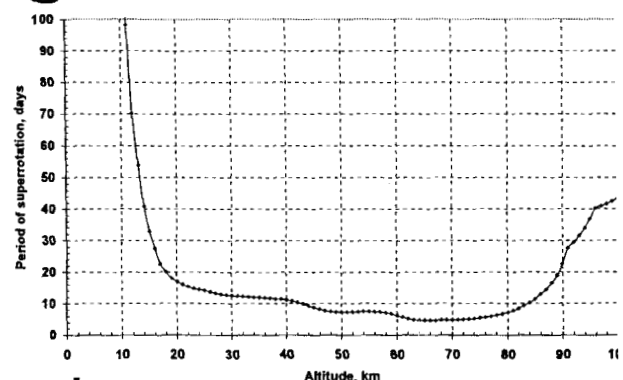
- Video demonstration of stratospheric deployment of Mylar balloon
- Video demonstration of stratospheric inflation of pumpkin PE balloon

Low-cost approach

Summary

VENUS BALLOON MISSION CONCEPTS

- Venus: wide variety of environments
  - Deep atmosphere
  - From Earth-like –75C & 5 mb @80 km, 20C & 0.45 b @55 km to +460C, 92 bar @surface
  - Super-rotation 4days @70 km to 20 days @15 km
  - Concentrated sulfuric acid haze/clouds (LA smog)
- Numerous balloon mission concepts
  - Independent science platform
  - Radio relay for the other *in situ* vehicles
  - Delivery vehicle for deep atmosphere and surface probes
  - Lift payloads from surface
- Mature technology
  - Super-pressure balloons: long duration flight at constant altitude
  - Zero-pressure balloons: short duration and vertical profiling up to 80-82 km
  - Developed and demonstrated aerial deployment and inflation
  - Materials available to float down to 15-20 km above surface



Period of super-rotation

VENUS MULTISONDE CONCEPT

•*OBJECTIVE*: HIGH-RESOLUTION IMAGING OF SURFACE, DETAILED COMPOSITION AND ATMOSPHERIC STRUCTURE

• 6-m SPHERICAL SUPERPRESSURE BALLOON CARRYING 3 DROPSONDES AND HIGH-GAIN TRACKING ANTENNA FOR DIRECT-TO-EARTH LINK

• FLOAT ALTITUDE 60-62 km

• 60 g/m2 MYLAR-PBO SCRIM-TEFLON COMPOSITE

• FLOATING MASS 67 kg WITH 3 SONDES 3.5 kg EACH

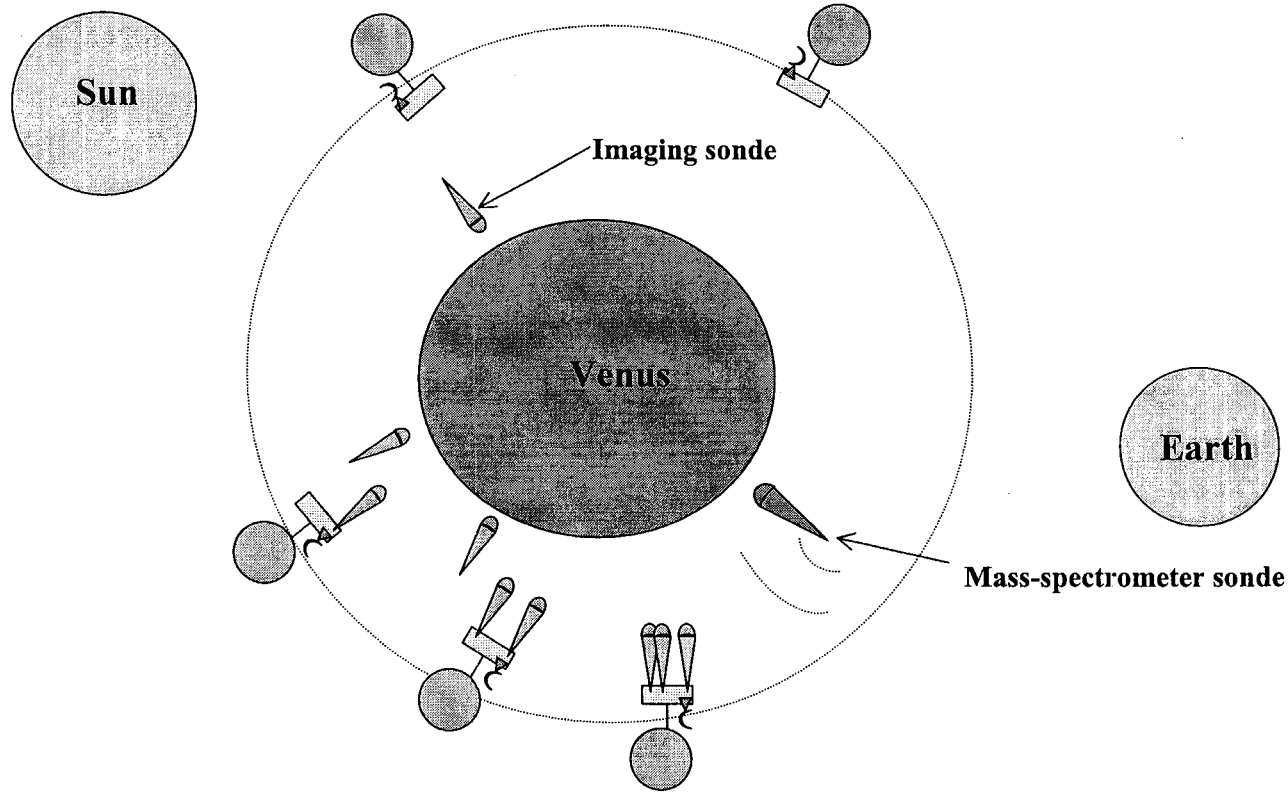
• 6 kg HELIUM

• BALLOON MASS 10 kg

• BALLOON AS HIGH DATA-RATE RELAY FOR DROP SONDE IMAGING AND AS ATMOSPHERIC INSTRUMENT PALFORM PLATFORM

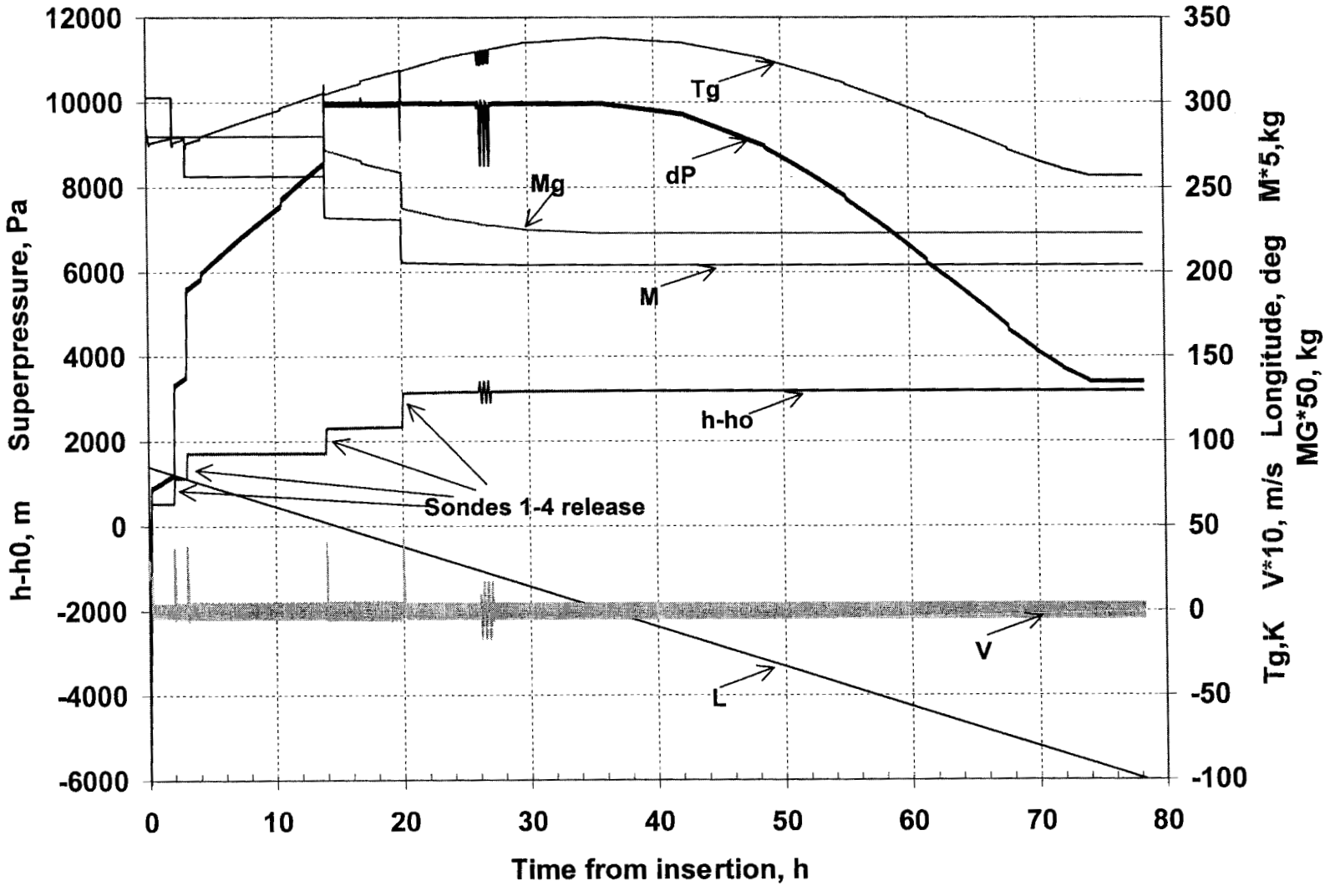
• LIFETIME 7 DAYS

•DELTA 2 CLASS LAUNCH VEHICLE

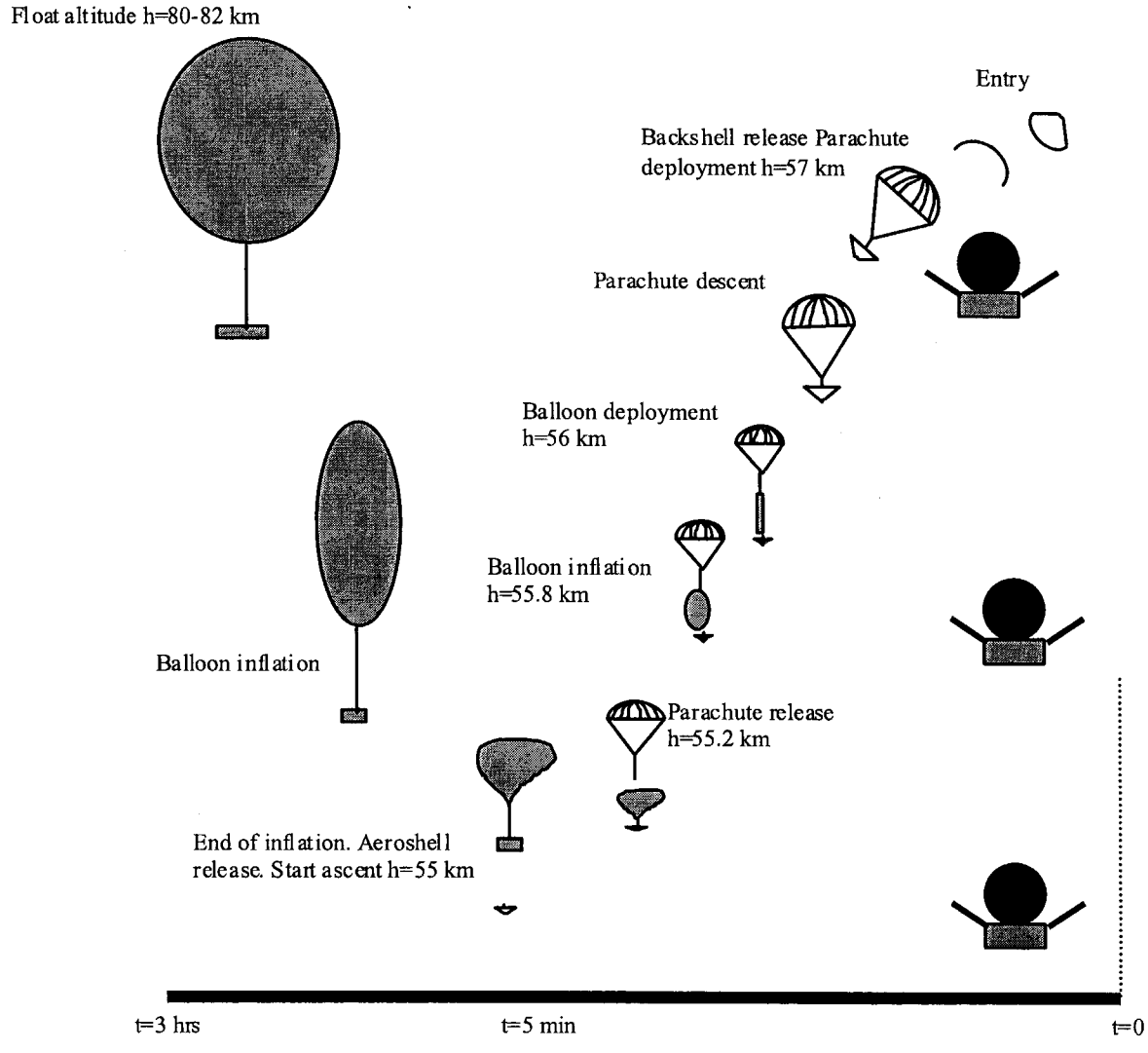


VEVA FLIGHT PROFILE

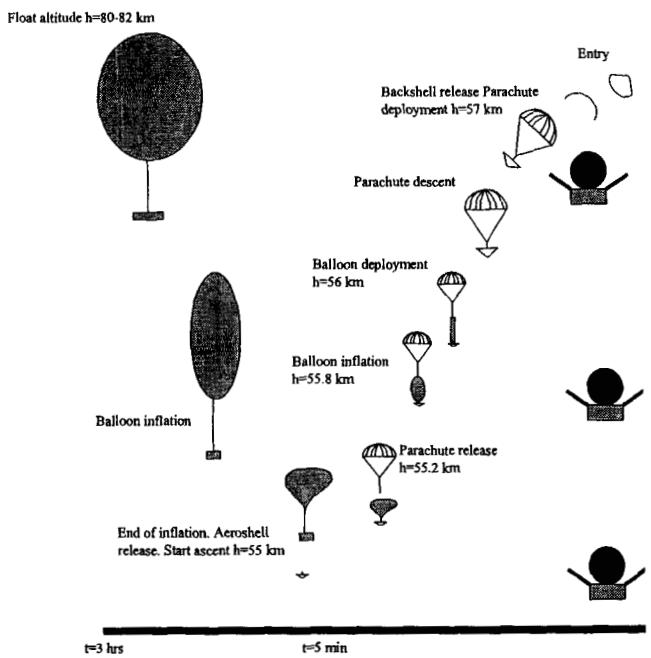
(SUPER-PRESSURE BALLOON WITH DROP-SONDES)



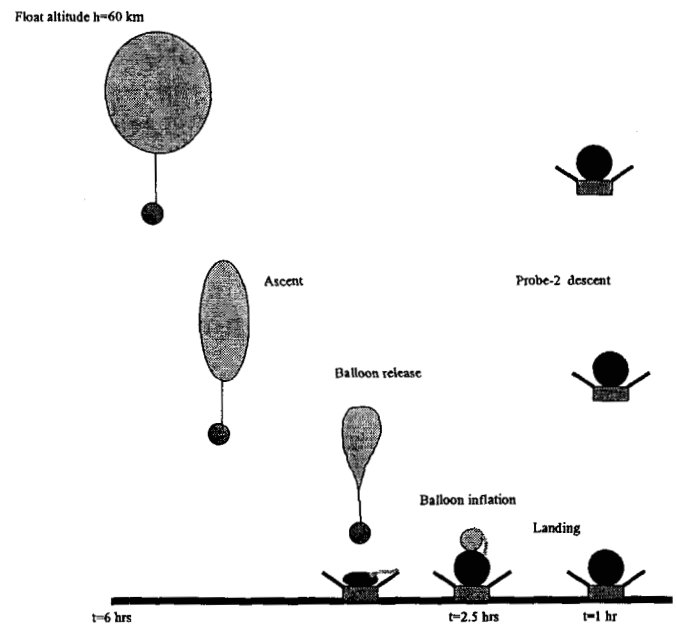
ENTRY AND LANDER FLIGHT PROFILE



VENUS SURFACE SAMPLE RETURN PRECURSOR CONCEPT



Probe 1 flight profile



Probe 2 flight profile

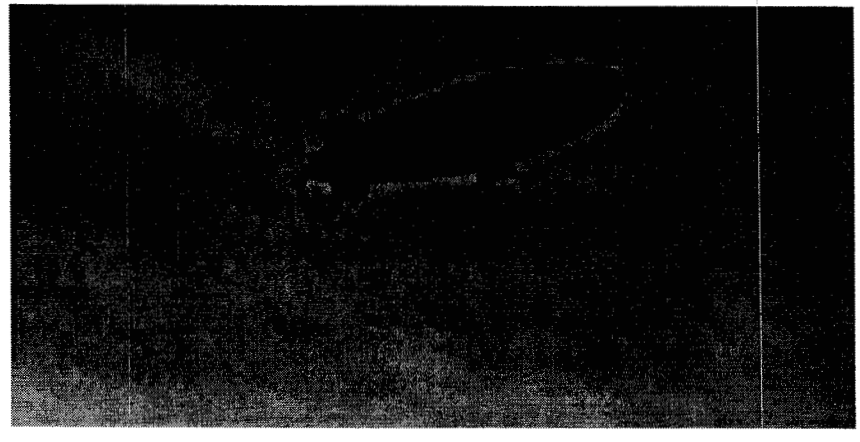
- *OBJECTIVE*: VALIDATION OF CORE TECHNOLOGIES FOR VENUS SURFACE SAMPLE RETURN MISSION (VSSR) NOT DEVELOPED FOR MARS SAMPLE RETURN (BALLUTE, THERMAL PROTECTION, HI-TEMPERATURE BALLOON) + *IN SITU* DETAILED STRUCTURE OF LOWER ATMOSPHERE AND OF MESOSPHERE
- PROBE 1: 12-15 m ZERO-PRESSURE POLYETHYLENE BALLOON
- PAYLOAD 5 kg
- ANALOG OF RADIOSONDE
- ASCENT FROM 56 TO 80-82 km
- LIFETIME 3-8 hrs

- PROBE 2: LANDER WITH HIGH-TEMPERATURATURE BALLOON
- FREE FALL TO SURFACE; LANDING VELOCITY ~5 m/s
- THERMAL INSULATION SIMILAR TO VSSR
- 4-m DIAMETER ZERO-PRESSURE BALLOON
- TEFLON WITH PBO REINFOCEMENT
- SURFACE INFLATION AND LAUNCH
- ATMOSPHERIC STRUCTURE AND ENGINEERING MEASUREMENT ON LANDER AND BALLOON
- DIRECT-TO-EARTH DATA TRANSMISSION

TITAN AIRSHIP EXPLORER

TITAN ATMOSPHERE IDEAL FOR BALLOONS

- *DENSE ATMOSPHERE (OVER 4 TIMES OF EARTH'S)* – ENABLE HIGH PAYLOAD MASS FRACTION, AERODYNAMICALLY OPTIMIZED SHAPES, ROBUST ENVELOPE MATERIALS, SMALL SIZE, LOW-RISK AERIAL DEPLOYMENT
- *LOW GRAVITY (LESS THAN 1/7 OF EARTH'S)* – LOWER DEPLOYMENT LOADS
- *SMALL THERMAL CONTRASTS* –LONG DURATION FLIGHT WITH LOW OVERPRESSURE, LOW ENVELOPE STRESSES,
- *LOW TEMPERATURE OF ATMOSPHERE (3 TIMES LESS THAN EARTH'S)* – VIRTUALLY NO BUOYANT GAS DIFFUSION, PRACTICALLY UNLIMITED FLIGHT TIME, EFFICIENT THERMAL-MECHANICAL CONVERSION
- *LARGE SCALE HEIGHT (OVER 2.5 TIMES OF EARTH'S)* – EFFICIENT VERTICAL FLIGHT CONTROL
- *VIRTUALLY LOW WINDS* – GLOBAL CONTROLLED FLIGHT, STATIONKEEPING HOVERING
- *OVERCAST SKY* – ONLY AERIAL VEHICLES CAN PROVIDE HIGH RESOLUTION VISUAL IMAGING OF SURFACE WITH GLOBAL COVERAGE



TITAN AIRSHIP FEATURES

- GLOBAL ACCESS, DESIRED DESTINATION
- GLOBAL COVERAGE
- YEAR
- FLOAT ALTITUDE 0-5 km
- IDEAL VERTICAL ORIENTATION
- HORIZONTAL AND VERTICAL CONTROL
- NO LANDING RISKS
- NO AERIAL DEPLOYMENT RISK
- HIGH RESOLUTION SURFACE SURVEY IN VISUAL, IR AND RADAR
- *IN SITU* SURFACE STUDIES IN MULTIPLE LOCATIONS (WINCHING DOWN/UP SURFACE EXPLORATION MODULE IN STATIONKEEPING MODE)
- DEPLOYMENT OF *IN SITU* NETWORK SURFACE PACKAGES

AIRSHIP POINT DESIGN

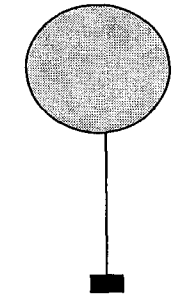
- PAYLOAD MASS 75 kg *(PROPULSION INCLUDED)*
- AIRSHIP DIAMETER 2.1 m
- AIRSHIP 8.4 m
- HULL MASS 10.6 kg
- HELIUM MASS 14.5 kg
- PAYLOAD MASS FRACTION 75%
- POWER 110 We
- PROPELLER DIAMETER 0.3-0.5 m
- AIRSPEED 4-5 m/s
- ENTRY VEHICLE MASS 300 kg

MARS BALLOON MISSION CONCEPTS

- **Mars challenges**
  - Very low density
  - Great temperature variations
  - High topography
- **Martian balloons have to be**
  - Big + strong + light
  - Rapidly deployed and inflated during descent
- **Three viable balloon concepts**
  - Super-pressure: long duration flights, platform for hi-res camera, magnetometer and radar
  - Solar Montgolfiere: day-light flight, potential long-duration in summer polar areas, decelerator for landing of surface packages
  - Zero-overpressure balloon with guiderope: medium duration flights, risk of snagging

FIRST GENERATION MARTIAN BALLOON

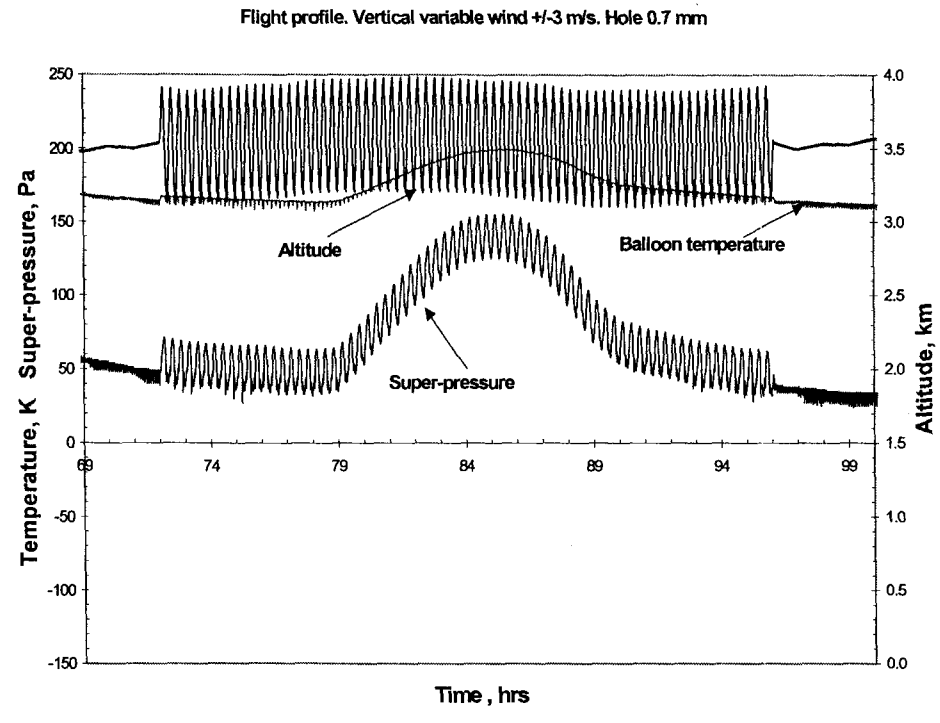
MARS - ALTIMATE CHALLENGE FOR BALLOONS



- *LOW DENSITY* – LARGE THIN FILM BALLOONS
- *HIGH DJIURAL TEMPERATURE VARIATIONS NOT MODERATED BY ATMOSPHERE* – STRONG MATERIALS FOR SUPERPRESSURE BALLOONS; PROHIBITIVE BALLAST MASS FOR ZERO-PRESSURE BALLOONS
- *SHALLOW ATMOSPHERE* – RAPID DEPLOYMENT AND INFLATION

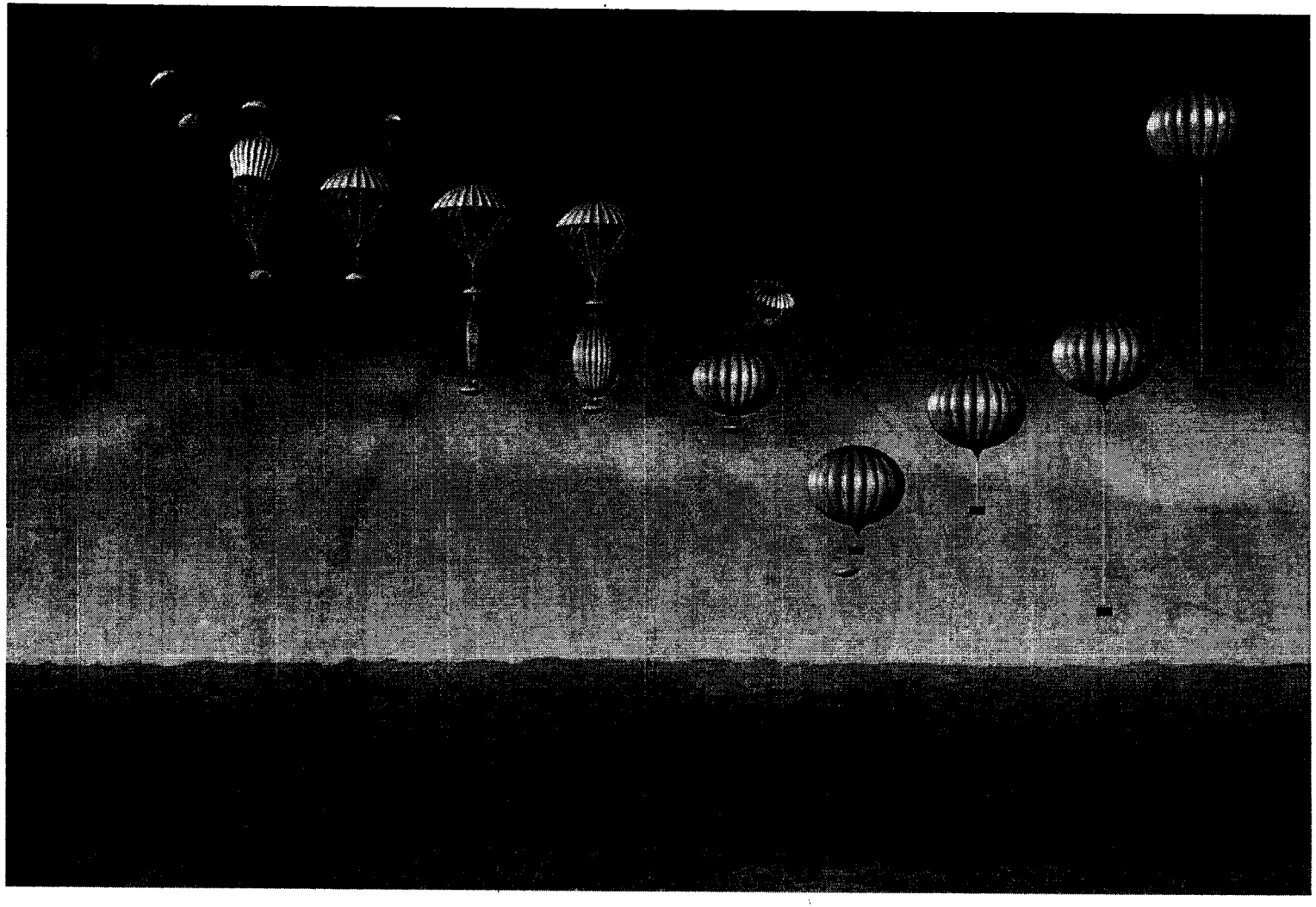
RISK AND COST INCREASE WITH BALLOON SIZE

- *FIRST BALLOON MISSION OBJECTIVE*: BALLOON TECHNOLOGY VALIDATION WITH LOW-COST FOCUSED SCIENCE MISSION
- 11-12 m SUPERPRESSURE BALLOON
- SPHERICAL OR PUMPKIN SHAPE
- MYLAR C 8 μm (SPHERICAL) OR 5 μm (PUMPKIN)
- PAYLOAD 1-2 kg
- FLOAT ALTITUDE 7 km ABOVE REFERENCE ELLIPSOID (2.5 km ABOVE TERRAIN IN SOUTHERN HEMISPHERE)
- MIDSEASON – BENIGN ENVIRONMENT
- 5-7 DAYS LIFETIME
- ENTRY VEHICLE 40-70 kg, MICROMISSION COMPATIBLE

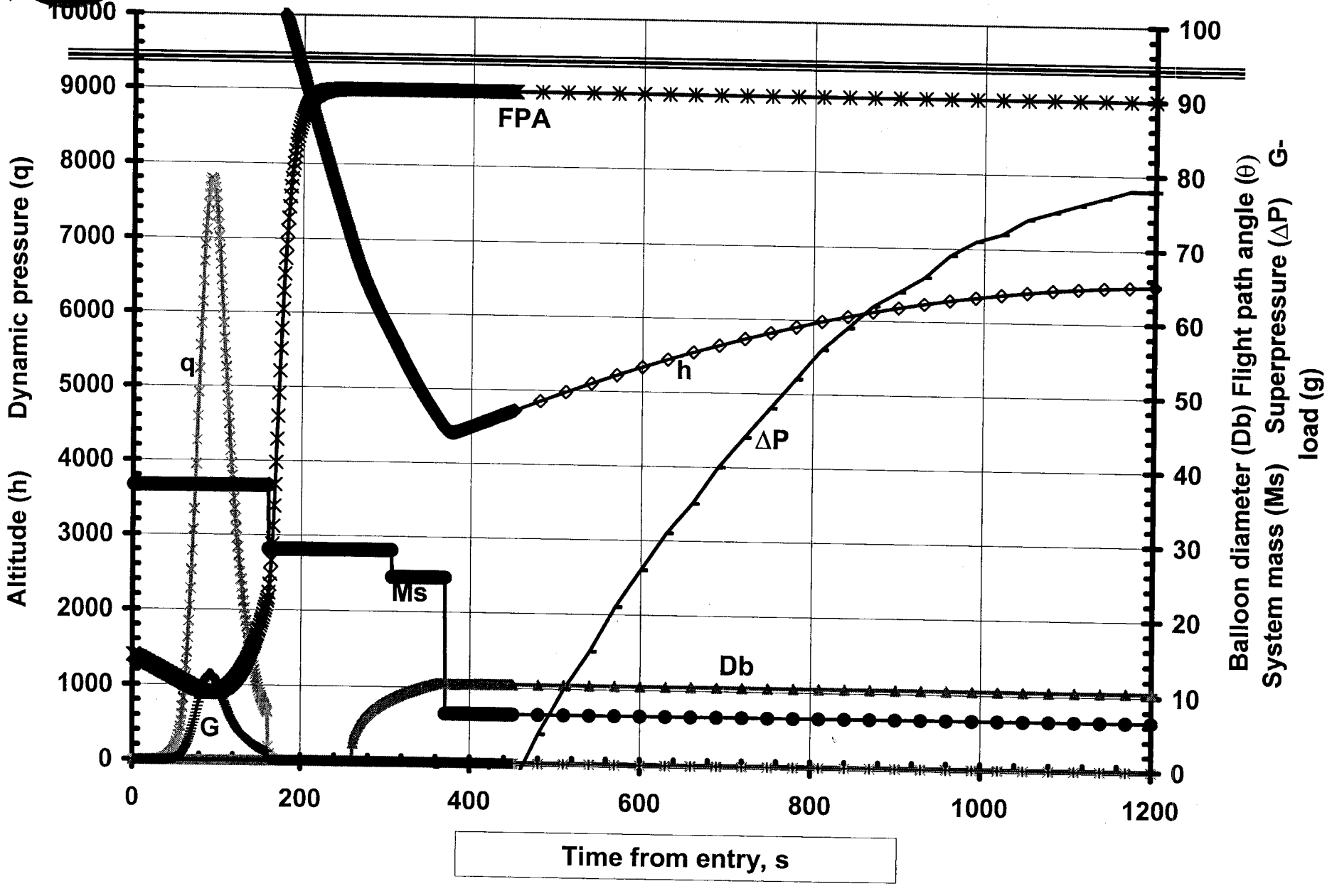


Flight profile simulation in vertical wind +/-3 m/s

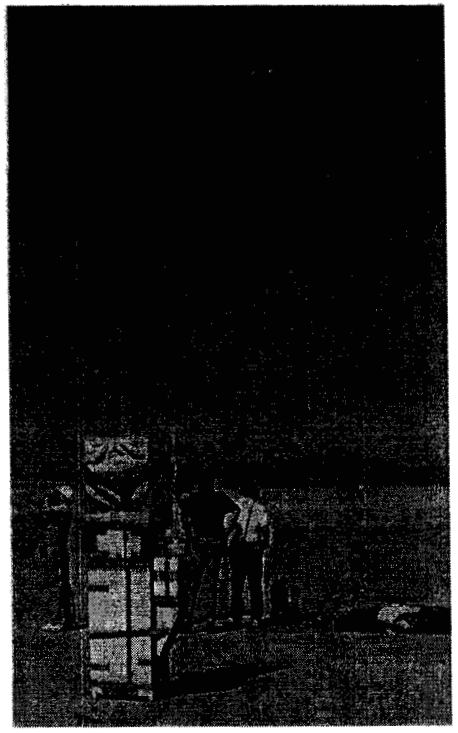
MARS BALLOON ENTRY, DEPLOYMENT AND INFLATION (EDI)



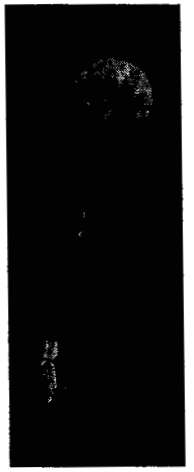
Entry, Deployment and Inflation Trajectory



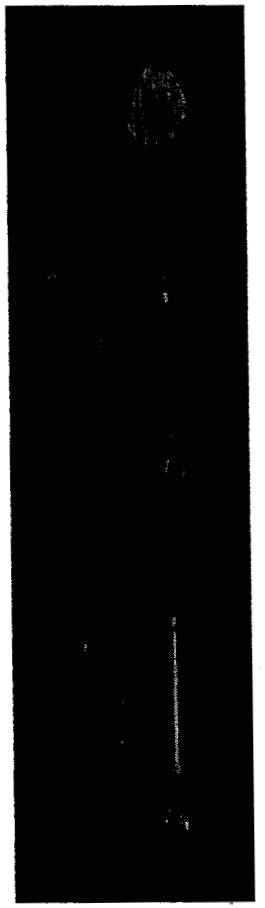
AERIAL DEPLOYMENT AND INFLATION OF THIN FILM BALLOONS VALIDATED FOR VENUS



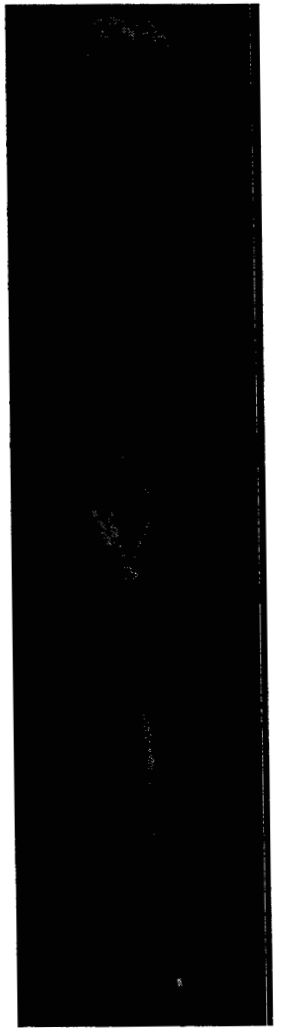
Helicopter lifting payload



Parachute released



Balloon deployed

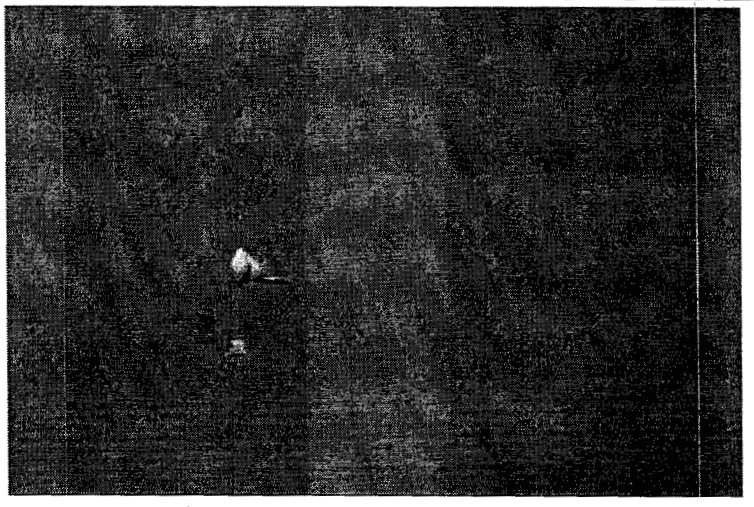


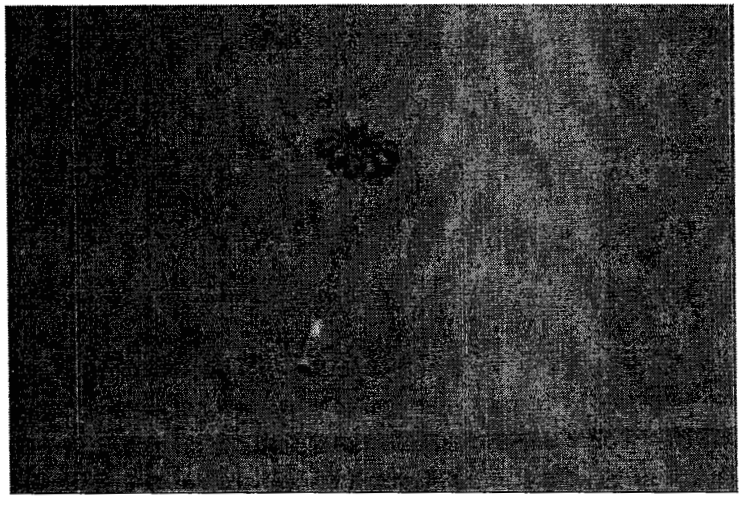
Balloon inflated

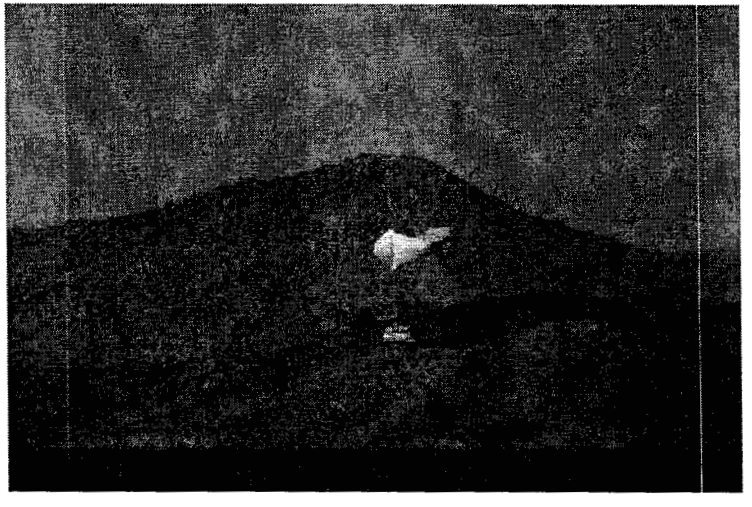
Flight test of 3-m 12-μm Mylar balloon with 40-kg test module

El Mirage Dry Lake, California, August 1998

DEPLOYMENT AND INFLATION OF TITAN BLIMP PROTOTYPE







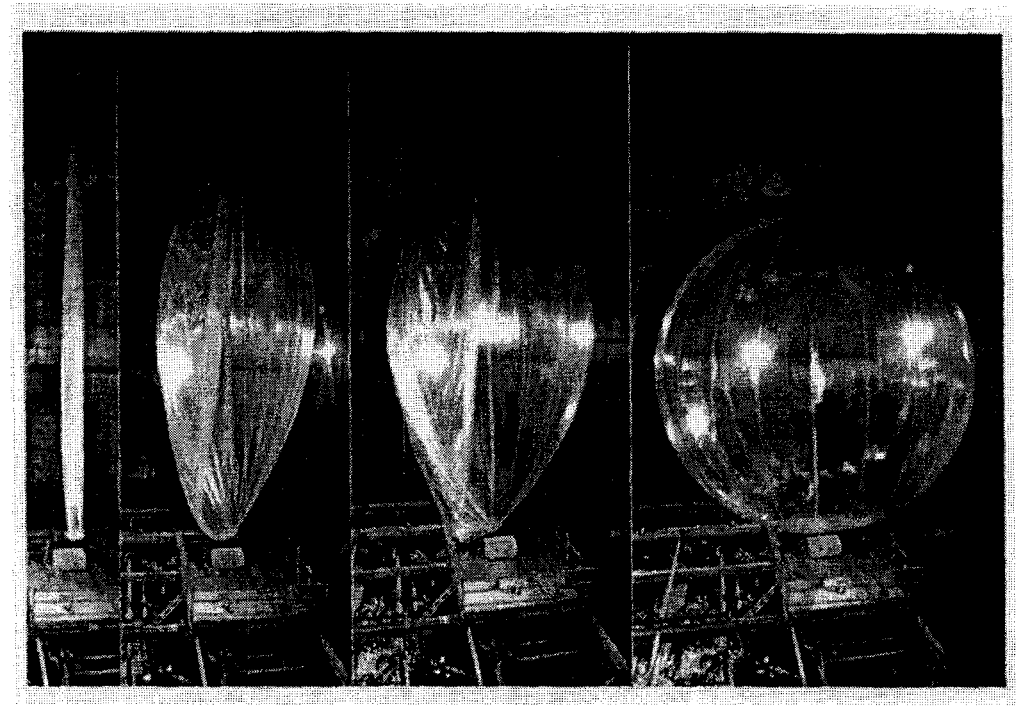
El Mirage Dry Lake, January 2002

AERIAL DEPLOYMENT AND INFLATION – CRITICAL TECHNOLOGY FOR PLANETARY BALLOONS

- MANAGEABLE RISKS FOR VENUS AND TITAN
- EXTREME CHALLENGES FOR MARS
  - DEPLOYMENT SHOCK FORCES ON THIN BALLOON FILM
  - COLD TEMPERATURE BRITTLENESS
  - AERODYNAMIC INSTABILITIES DURING INFLATION
  - SHORT TIME (2-3 min) TO COMPLETE DEPLOYMENT AND INFLATION
  - DIFFICULT TO SIMULATE

AERIAL DEPLOYMENT AND INFLATION OF MARS BALLOONS

- The most challenging and less understood process, major showstopper for Mars balloons
- Approach
  - Leverage CNES experience with Russian-French Mars Aerostat
  - Comprehensive tests of full-scale balloons rather sub-scale models
  - Improved modeling and simulation
  - Cycle of laboratory, hangar deployment, static inflation and tropospheric tests – all successful
  - Five stratospheric test attempts in 1998-2001 of 10-m 12-mm spherical Mylar balloon: two failed near the launch, three deployed in stratosphere: first successful, two other failed

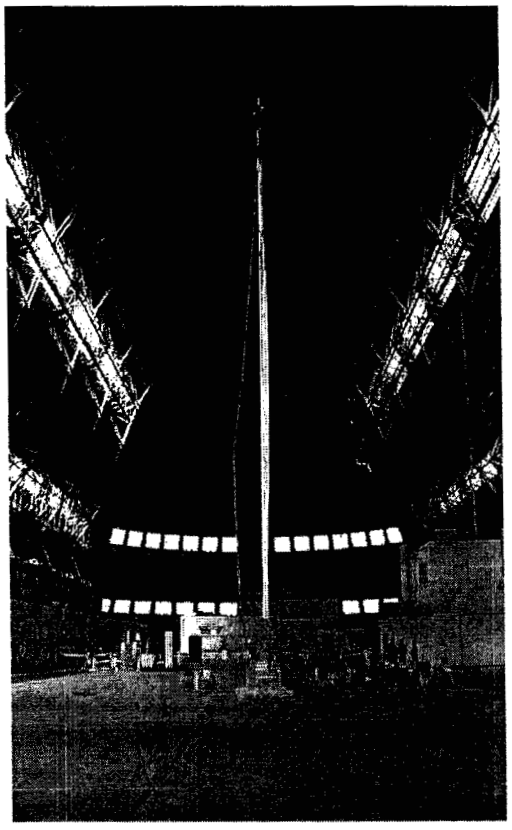


INFLATION TEST OF
10-m MYLAR BALLOON

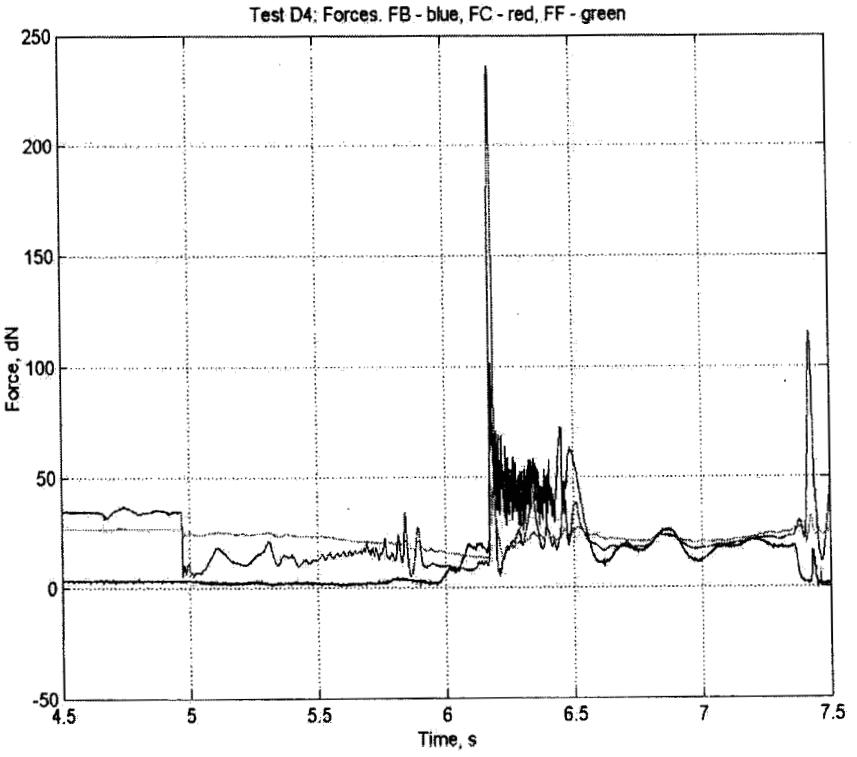
JULY 1998, NASA GLENN
RESEARCH CENTER

ARC Hangar Tests

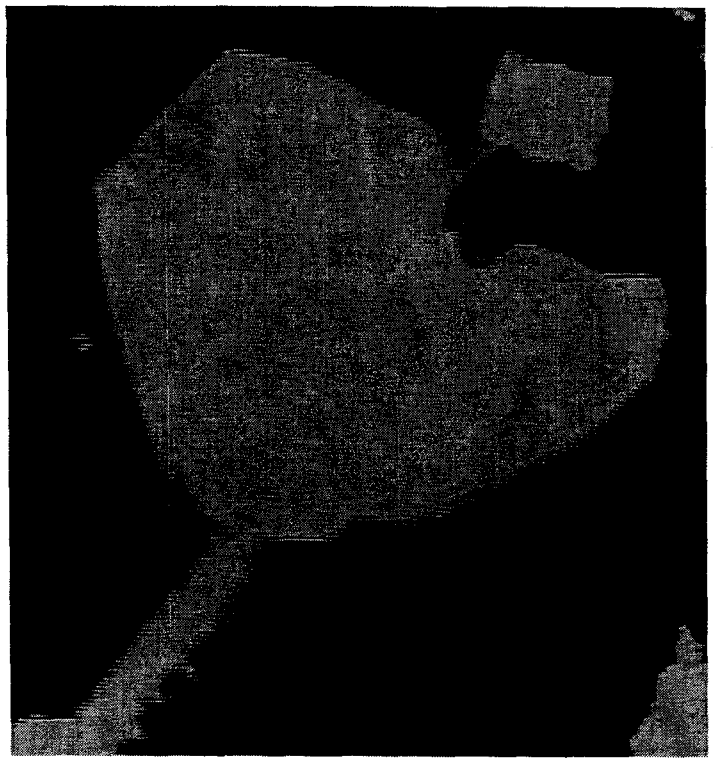
- Modeling identified separation speed at deployment as critical parameter
- Simulation of stratospheric deployment in hangar with system of bungees



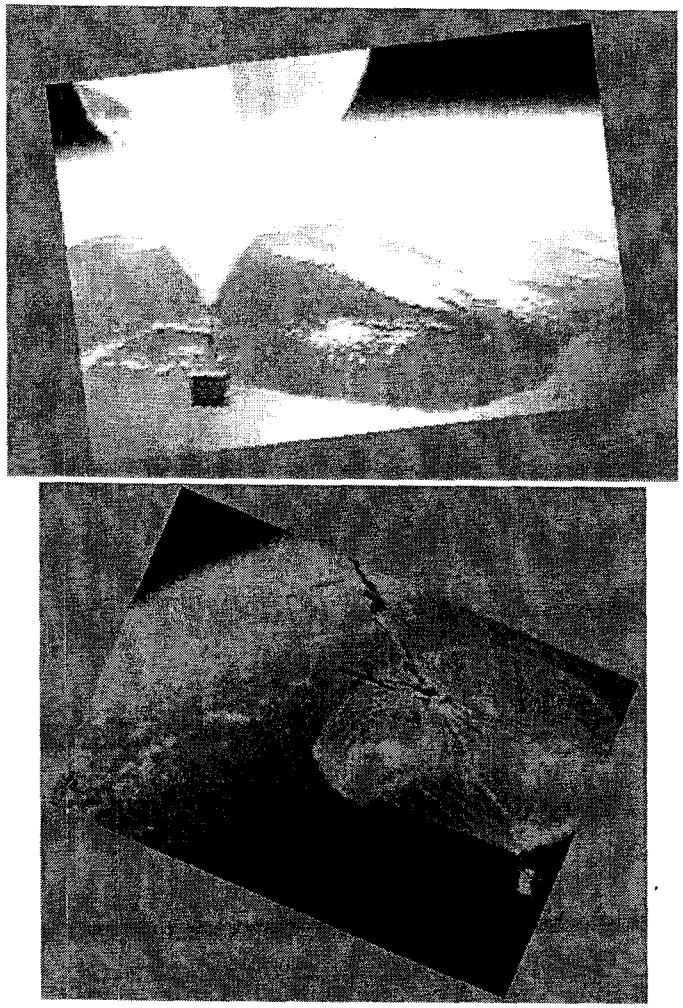
Test B1



FIRST SUCCESSFUL STRATOSPHERIC TESTS OF MARS BALLOON PROTOTYPES – BREAKTHROUGH IN MARS BALLOON TECHNOLOGY



10-m spherical Mylar balloon during inflation in stratosphere. Image by up-looking camera



Pumpkin balloon during inflation in the stratosphere. Images from the camera suspended under the parachute

JUNE 2002, HAWAII

LOW-COST MISSION APPROACH

"Low-cost" deep space mission of Discovery/Mars Scout class

Low-cost principles

- Cruise spacecraft simple with no additional tasks
- Light-weight balloon payload: 1-3 kg for Mars and 5-15 kg for Venus
- Simple payload
- No orbiter, if possible: direct-to-Earth transmission (Venus), relay via available orbiter (Mars)
- Compromise between science objectives and balloon capabilities – do not push technology too far beyond its level

Small 50-70 kg 0.8-0.9 m diameter entry vehicle may carry Mars or Venus balloon

- Single balloon as piggy-back on other mission
- Multiple balloons on dedicated mission

SUMMARY

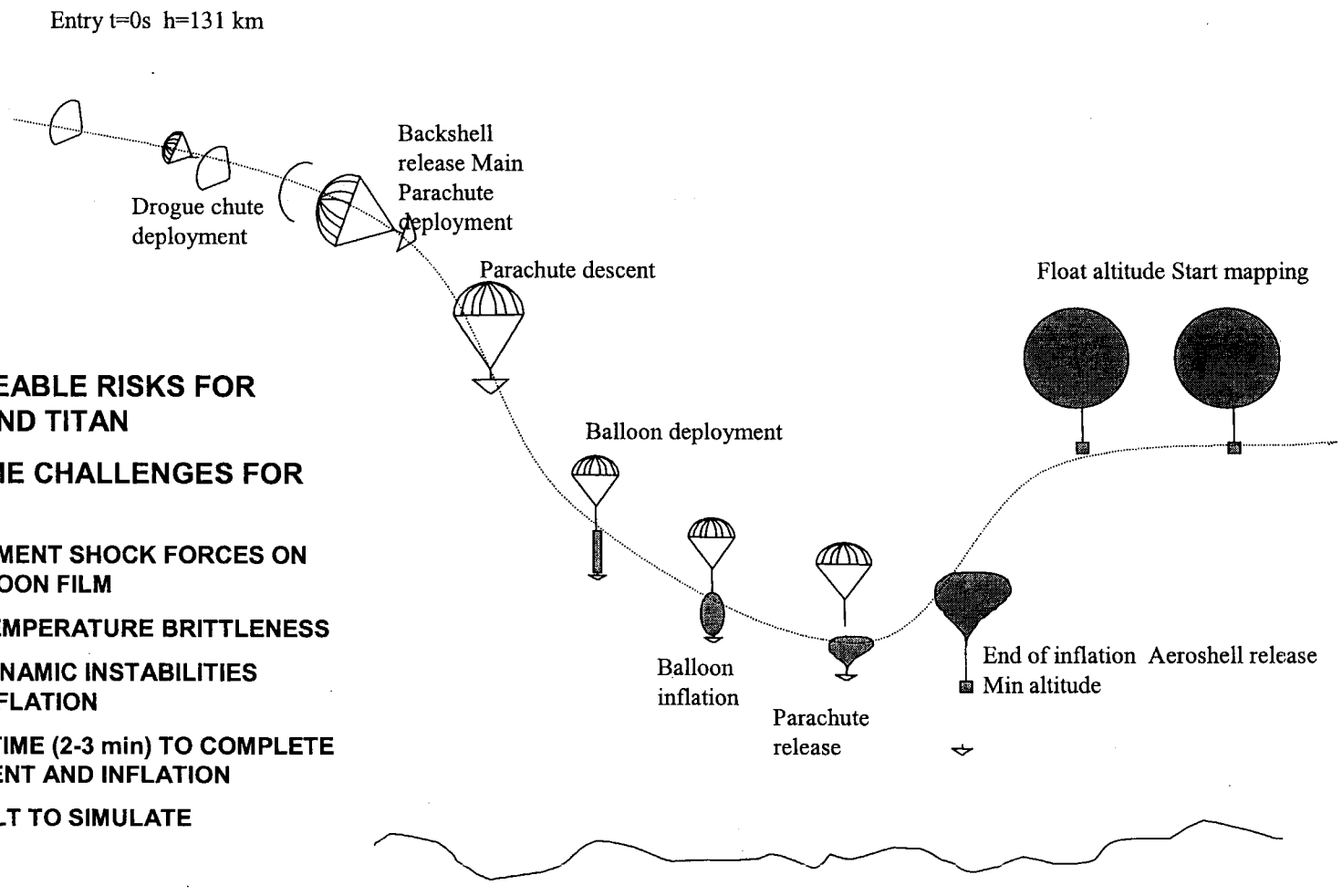
Balloons enable large variety of concepts that can be implemented as a low-cost dedicated or piggy-back missions to Mars and Venus

Re-introduction of the pumpkin design augmented capabilities of both Venus and Mars balloons

Recent progress in development and tests of aerial deployment brought Venus and Mars balloons to the new degree of maturity

Need more advocacy of science and balloon communities to be selected for the future space mission

ENTRY, DEPLOYMENT AND



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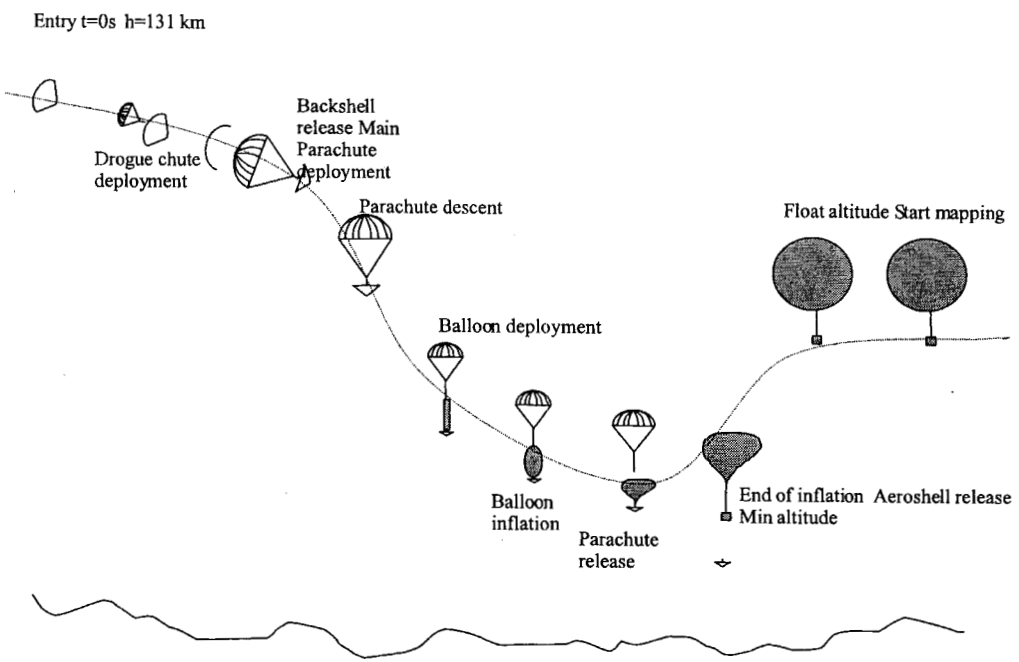
ENTRY, DEPLOYMENT AND INFLATION (EDI) CONCEPT