NASA / JPL - AS-800B prototype aerobot testbed

Peter Lobner, 4 November 2023

1. Introduction

In the early 2000s, the National Aeronautics and Space Administration’s (NASA) Jet Propulsion Laboratory (JPL) began developing the core autonomy technologies required for “aerobot” (robot airship) exploration of solar system bodies that have an atmosphere. While the primary target of exploration was Saturn's largest moon, Titan, the core aerobot autonomy technologies being developed also were directly applicable for Venus or terrestrial aerobots.

The JPL team explained (A. Elfes, et al., 2005) the challenges a Titan aerobot mission:

> “The main challenges for aerobot exploration of Titan include: large communication latencies, with a round trip light time of approximately 2.6 hours; extended communication blackout periods with a duration of up to 9 Earth days, caused by the rotation of Titan and its orbital occlusion by Saturn; extended mission duration, currently projected to be on the order of six months to one year; and operation in substantially unknown environments, with largely unknown wind patterns, meteorological conditions, and surface topography.”

This article focuses on the developmental work involving the NASA / JPL AS-800B blimp.

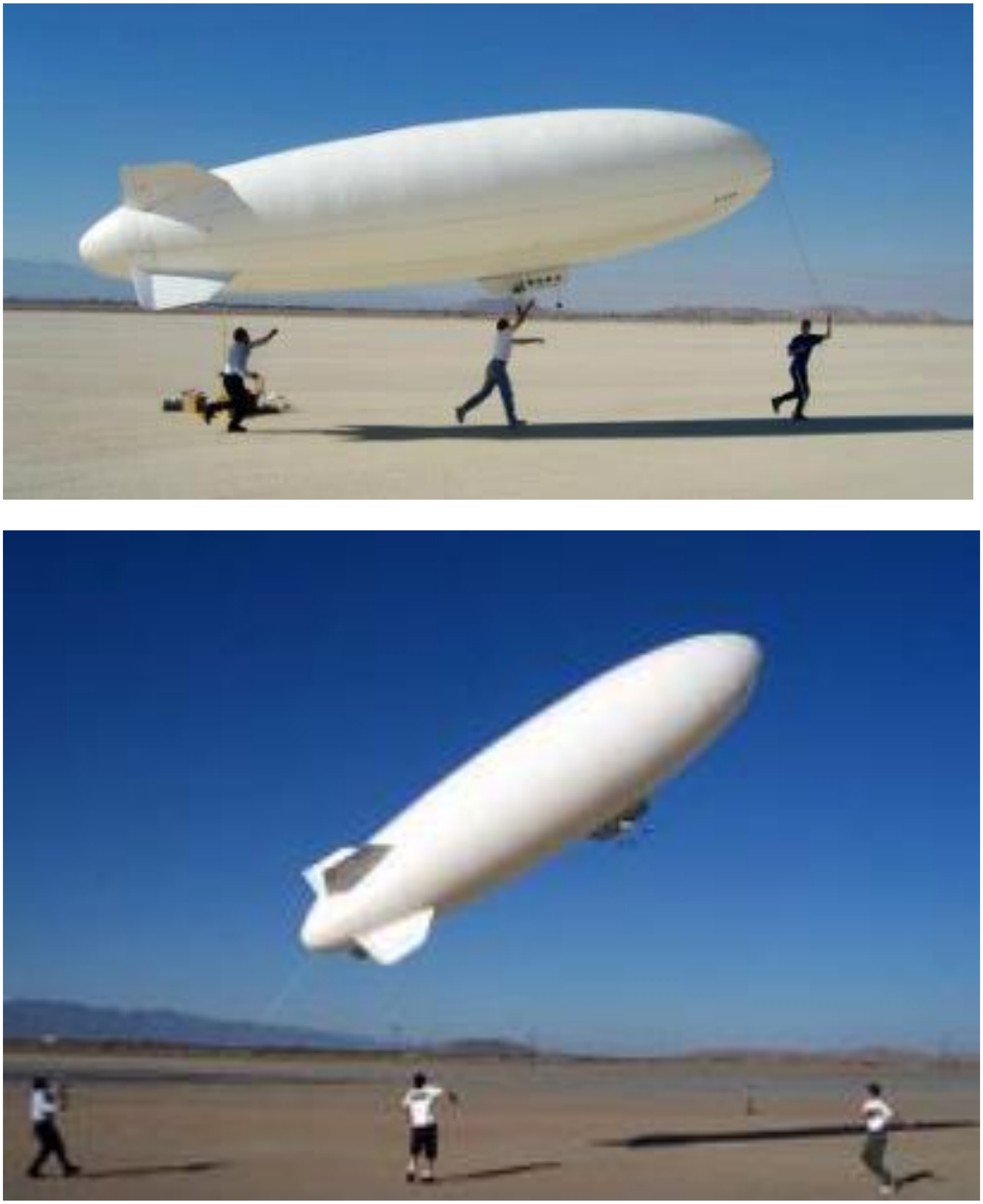
2. The prototype aerobot testbed

The JPL prototype aerobot testbed platform was an 11 m (36.1 ft) unmanned AS-800B blimp manufactured in the UK by the firm Airspeed Airships. The AS-800B was outfitted with avionics and navigation systems necessary to for conducting remotely-piloted and autonomous flights and for communications with a ground station.

AS-800B aerobot. Source: JPL (Oct 2006)

General design parameters of the AS-800B

Parameter	**Airspeed Airships AS-800B**
Type	Conventional, non-rigid
Length	11.0 m (36.1 ft)
Diameter	2.5 m (8.4 ft)
Fineness ratio	4.3
Volume, total	34 m^3 (1,201 ft^3)
Ballonet	Fed by air captured from the propeller slipstream
Aerodynamic controls	X-configured tail planes, ±25 degrees deflection
Payload	• 12 kg (26.5 lb) static • 16 kg (35.3 lb) dynamic (blimp typically flies overweight) • The avionics and communication systems are installed in the gondola.
Propulsion	2 x 23 cm^3 (1.4 in^3) displacement petrol engines rated @ 2.3 kW (3 hp), each driving a thrust vectoring (0 to +90 degrees) shrouded propeller mounted to the gondola.
Speed, max	13 m/s (25 knots)
Altitude, max	500 m (1,640 ft)
Endurance, average	60 min



Takeoff of JPL’s AS-800B aerobot, conducted at the El Mirage dry lake in the Mojave desert. Source, both photos: JPL

3. Key aerobot systems

JPL described the aerobot electronic systems as follows:

- **Avionics system**
  “The aerobot avionics system is built around a dual PC-104+ computer architecture. One of the PC-104+ stacks is used for navigation and flight control, while the other is dedicated to image processing. The navigation stack also has a serial board interface to the navigation sensors and pan/tilt unit, a timer/counter board for reading pulse width modulated (PWM) signals from a human safety pilot and generating PWM signals based upon control surface commands from the avoidance software, and an IEEE 1394 board for sending commands to, and reading image data from, the navigation and science cameras. The perception processor is dedicated to image processing and image-based motion estimation (IBME). Wireless serial modems provide data/control telemetry to the ground station. The safety pilot can always reassert ‘pilot override’ control over the aerobot.”

- **Navigation system**
  “The navigation sensors currently consist of an Inertial Measurement Unit (IMU) which provides angular rates and linear accelerations, a compass/inclinometer which provides yaw, roll, and pitch angles, and a differential GPS(DGPS) for absolute 3D position. The vision sensors include two down-looking navigation cameras, one with a 360º x 180º field-of-view (FOV) and another with a narrower FOV. Additionally, we plan to integrate a laser altimeter (surface relative altitude), a barometric altimeter (absolute altitude against reference point), an ultrasonic anemometer (3D wind speed), and a science camera mounted on a pan/tilt unit.”

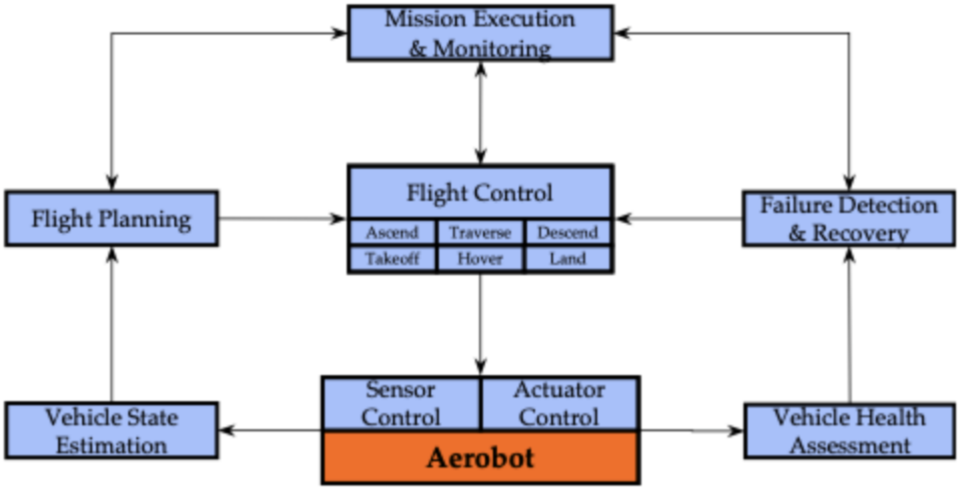
- **Ground station**
  “The ground station is composed of a laptop, a graphics user interface to the vehicle, wireless data and video links, video monitors and VCRs, and a differential GPS (DGPS) base station that provides differential corrections to the GPS receiver onboard the aerobot. This provides vehicle 3D position estimates accurate to several centimeters.”

4. Core autonomy technologies

Under this program, the JPL project team developed core autonomy technologies associated with the following functions:

- **Vehicle 'safing:'** This capability is intended to ensure the safety and integrity of the aerobot over the full duration of the mission, including extended communication blackouts;
- **Accurate and robust autonomous flight controls:** Such controls include deployment / lift-off, long traverses, hovering/station-keeping, and touch-and-go surface sampling;
- **Spatial mapping and self-localization:** This capability will enable extended geographical surveys; and
- **Advanced perceptual hazard and target recognition, tracking and avoidance**: These capabilities enable the aerobot to detect and avoid atmospheric and topographic hazards, and also to identify, home in on, and keep station over predefined science targets or terrain features.

The JPL team developed the following aerobot autonomy architecture that integrates accurate and robust vehicle and flight trajectory control, perception-based state estimation, hazard detection and avoidance, vehicle health monitoring and reflexive safing actions, vision-based localization and mapping, and long-range mission planning and monitoring."



Source: A. Elfes, et al. (2005)

Performance of the autonomy system was validated in an aerobot flight simulation environment and flight tests with the AS-800B prototype aerobot testbed.

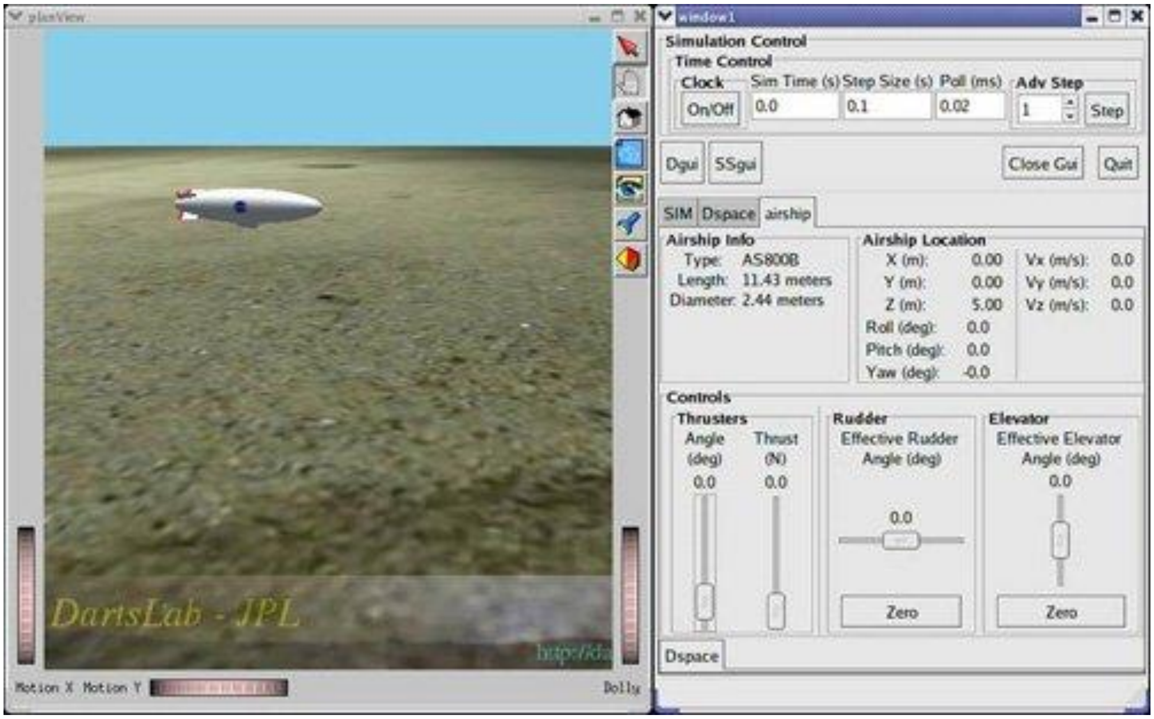
5. Aerobot Laboratory

Aerobot flight testing was supported by JPL's Aerobot Laboratory, which has 139.4 m^2 (1,500 ft^2) of floor space, a 7.6-m (25-ft) high bay and a 18.3-m (60-ft) long table for balloon and payload assembly, inspection and testing. The Laboratory has assorted small machine and hand tools for construction of aerobot payloads and avionics, plus computer and video processing equipment for flight test data acquisition and post-flight data analysis. Large doors at one end allow a fully inflated blimp to enter or leave the facility. The other end has elevated balconies from which balloon suspension and inflation is performed.

AS-800B aerobot in the JPL Aerobot Laboratory. Source: JPL

6. Aerobot flight simulation

JPL’s Dynamics And Real-Time Simulation (DARTS) Laboratory used its advanced, high-fidelity, multi-mission modeling and simulation tools for the closed-loop development and testing of the aerobot’s autonomous systems. Simulation results were validated against AS-800B autonomous flight test performance.



Sim Time (s): 0.0
Step Size (s): 0.1
Poll (ms): 0.02
Adv Step: 1

Type: AS800B
Length: 11.43 meters
Diameter: 2.44 meters

X (m): 0.00
Y (m): 0.00
Z (m): 5.00
Roll (deg): 0.0
Pitch (deg): 0.0
Yaw (deg): -0.0
Vx (m/s): 0.0
Vy (m/s): 0.0
Vz (m/s): 0.0

Angle (deg): 0.0
Thrust (N): 0.0
Effective Rudder Angle (deg): 0.0
Effective Elevator Angle (deg): 0.0

A screenshot of the DARTS-based aerobot simulation, showing the airship on the left, and controls on the right. Source: JPL (2006)

7. Prototype aerobot testbed flight test program

Initial field tests of the JPL aerobot testbed were conducted at the Southern California Logistics Airport in Victorville, CA. The initial flights were remotely-piloted to allow extensive testing of the onboard avionics and data acquisition systems.

Extensive field tests of the JPL aerobot testbed and the autonomous flight control system were conducted at the El Mirage dry lake site in the Mojave desert, and robust waypoint navigation was demonstrated.

Autonomous flight of the JPL aerobot, conducted at the El Mirage dry lake in the Mojave desert. Source: A. Elfes, et al. (2014)

8. For more information

- "The JPL Aerobot," Jet Propulsion Laboratory: https://www-robotics.jpl.nasa.gov/how-we-do-it/systems/the-jpl-aerobot/
- A. Elfes, et al., "Autonomous Flight Control for a Planetary Exploration Aerobot," Jet Propulsion Laboratory & University of California, 2005: https://www.researchgate.net/publication/228409685_Autonomous_Flight_Control_for_a_Planetary_Exploration_Aerobot
- EA Kulczyki, et al., "On The Development of Parameterized Linear Analytical Longitudinal Airship Models," Jet Propulsion Laboratory & Clemson University, 2008: https://www.researchgate.net/publication/237809040_On_The_Development_of_Parameterized_Linear_Analytical_Longitudinal_Airship_Models

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