AURORA – semi-autonomous blimp

Peter Lobner, 4 November 2023

1. Introduction

Project AURORA (an acronym for Autonomous Unmanned Remote mOnitoring Robotic Airship) was a collaborative project involving the following participants:

- Information Technology Institute (DRVC/CenPRA), Campinas, Brazil
- Instituto Superior Técnico (IST), Lisbon, Portugal
- INRIA (National Institute for Research in Digital Science and Technology), ICARE project (Instrumentation, Control and Architecture of Advanced Robots), Paris, France

The AURORA project was initiated in 1997 to develop sensing, control, navigation, and inference technologies required for semi-autonomous operation of robotic airships for aerial inspection. In his 1998 paper, project founder Alberto Elfes clarified: “This includes the ability to perform mission, navigation, and sensor deployment planning and execution, failure diagnosis and recovery, and adaptive replanning of mission tasks based on real-time evaluation of sensor information and constraints on the airship and its surroundings.”

AURORA originally was conceived as a three-phase project with progressively more capable airships.

Parameter	AURORA I	AURORA II	AURORA III
Mission duration	1 – 2 h	8 h	>24 h
Typical distance	1 – 10 km (0.6 to 6.2 mi)	10 – 50 km (6.2 to 31 mi)	>100 km (>62 mi)
Typical payload	10 kg (22 lb)	50 kg (110 lb)	>100 kg (>220 lb)

Source: Alberto Elfes, et al. (1998)

The project team completed the first phase and the project ended in 2016, after almost two decades of research and development for autonomous airship controls.

2. The original AS-800 AURORA I blimp

The original AURORA I lighter-than-air (LTA) platform was a 9 m (29.5 ft) AS-800 blimp manufactured in the UK by Airspeed Airships. The basic blimp was fitted with on-board equipment needed to support semi-autonomous flight and performance of the aerial inspection mission.

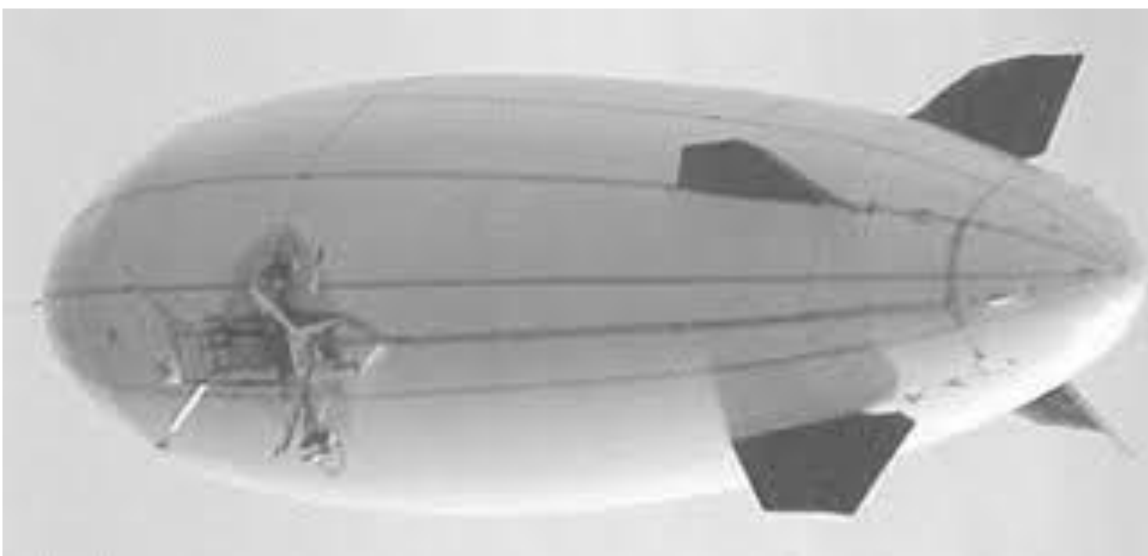
AURORA I airship is a modified Airspeed Airships AS-800.
Source: Josué Ramos, et al. (2001)

AURORA 1 airship. Source: SS Bueno, et al. (2002)

General design parameters of the AS-800 (AURORA I)

Parameter	**Airspeed Airships AS-800 (AURORA I)**
Type	Conventional, non-rigid
Length	9.0 m (29.5 ft)
Diameter	2.25 m (7.4 ft)
Fineness ratio	4.0
Volume, total	30 m^3 (1,059 ft^3)
Ballonet	Fed by air captured from the propeller slipstream
Aerodynamic controls	• X-configured tail planes, ±25 degrees deflection. • Controls become ineffective at low speed, below 4 m/s (14.4 kph, 9 mph)
Payload	10 kg (22 lb)
Propulsion	• 2 x thrust vectoring (-30 to +90 degrees) two-stroke petrol engines transversely mounted on the gondola, each driving a shrouded propeller • Can operate collectively or differentially • At low speed, control actuation is accomplished by vector thrusting and, as needed, differential control.

Source: Josué Ramos , et al., et al. (2001)



AURORA I in flight. Source: Josué Ramos (2003)

The airship actuators are its four X-configured tail deflection surfaces and two main thrust-vectoring propellers extending transversely from each side of the gondola. The four tail deflection surfaces have a deflection range of ±25 degrees and can be operated to generate the equivalent rudder and elevator commands of a classical cruciform tail configuration. The two propellers are driven by two-stroke engines that can be operated collectively or differentially and vectored vertically over a range from -30 to +90 degrees.

The project team installed the following mission-specific on-board equipment:

- **Onboard CPU:** The onboard Linux-based CPU is responsible for sensor data acquisition, control and navigation calculations, and actuator commands. By activating algorithms and intelligent strategies for autonomous operation, it assures the execution of mission flight profiles uploaded from the ground station and, most important, it takes into account all the features required for a safe flight.

- **Sensor package**: The following sensors support the control and navigation subsystems and provide vehicle state and diagnostic information:

  - **Vehicle state sensors:** Parameters monitored include control surface deflection and propeller vectoring positions, engine temperature, fuel level and battery level.
  - **GPS with differential correction**: Another GPS receiver at the ground station sends correction data to the onboard GPS.
  - **Wind sensor:** It measures the relative airship air speed in all three axes, the aerodynamic incidence angles and the barometric altitude.
  - **Vision system:** A digital camera mounted on the airship's gondola is part of the perception / vision-based navigation system. The camera provides aerial images to on-board segmentation algorithms for ground object identification and tracking, as well as for the operator on the ground.

A ground station provides the interface between the airship and the on-site operator. The ground station can be fixed or mobile. A mobile base station enables continuous communications with the AURORA I blimp on a long-distance mission.

Elfes (1998) described the AURORA flight control system as follows:

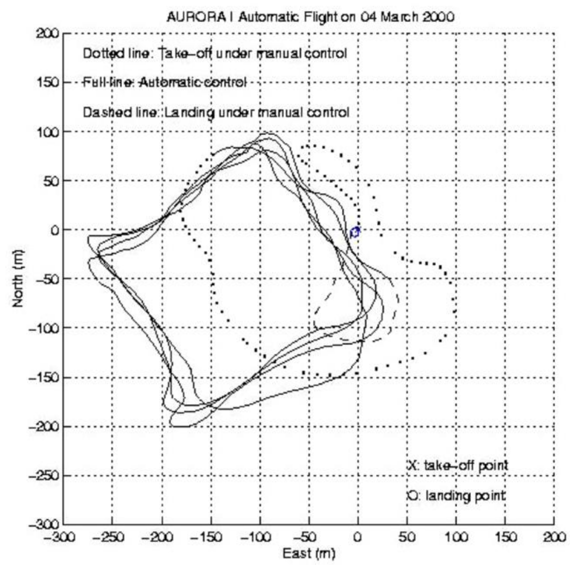
> "The AURORA I control system is designed as a 3-layer hierarchical structure. At the bottom level, actuators provide the means for maneuvering the airship along its course. At the intermediate level, control algorithms with different gains are available; they command the actuators based on decisions taken on the top level. The top level, a shared supervisory one, decides on which control algorithm is to be activated, its set-point, and the related actuators, depending on which is the current flight part - take-off, cruise, turning, landing, hovering, etc."

The project team developed a full non-linear, 6 degrees-of-freedom, dynamic mathematical model of the AURORA blimp for use in autonomous control system development. The performance of proposed control solutions were tested in a simulation environment and further validated in test flights of the AURORA I blimp.

AURORA I flight simulator & virtual cockpit instruments.
Source: Alberto Elfes, et al. (1998)

In 2000, the AURORA I blimp accomplished one of the first successful autonomous flights by an airship through a set of pre-defined points. The project team (Ramos, et al., 2001) reported"

> "This flight was achieved with a PI (proportional-integral) control-based guidance strategy for trajectory path following. The horizontal trajectory is controlled automatically by the onboard system, while altitude is controlled manually by the ground pilot."…"On March 4th, 2000, the airship was …. manually flown for a few minutes before automatic control was switched on. The mission path was defined as a square with vertices distant 150 m (492 ft) from each other. Wind speed was on the range of 0 to 10 km/h (0 to 6.2 mph), blowing approximately in the southwest direction.



> (In the accompanying figure, the) "…dotted line represents the airship motion under manual control from take-off until automatic control was switched on. The continuous line represents the airship motion under PI path tracking control. Finally, the dashed line shows the motion of the airship under manual control until landing. In this figure, one can clearly see the adherence to the mission path (on four laps of the designated course), as well as an overshoot when the airship turns from southwest to northwest due to the wind disturbance."

Experiments also were performed with the AURORA I blimp flying at low altitude to demonstrate the ability to autonomously identify, recognize and track man-made targets using aerial imagery. For example, the project team reported (Bueno, et al., 2002) on a paved road identification and tracking experiment in which "….Identification and segmentation of the roads in the images was done using probabilistic measures based on the spectral characteristics of the targets in the visible RGB (red-green-blue) bands.” The results showed a higher correct classification rate for road portions closer to the airborne camera, while misclassifying parts of the imagery that were further away. As the AURORA I flew forward, the observations were updated, leading to a correct reclassification as the road segments became closer.

Identification and tracking of a paved road using an airborne camera.
The aerial imagery is shown on the left, and
the results of the target classification procedure on the right.
Source: Bueno, et al., (2002)

The project team continued autonomous flight control system and perception / vision-based navigation experiments with the original AS-800 AURORA I blimp until they transitioned to an “evolved” AURORA I blimp with a larger gas envelope in about 2006.

3. Evolved AURORA I blimp

The original Airspeed Airships AS-800 AURORA I blimp was replaced in about 2006 by an evolutionary design with a longer, fatter gas envelope.

The evolved AURORA I airship with different gas.
Source: A. Moutinho, et al. (2016)

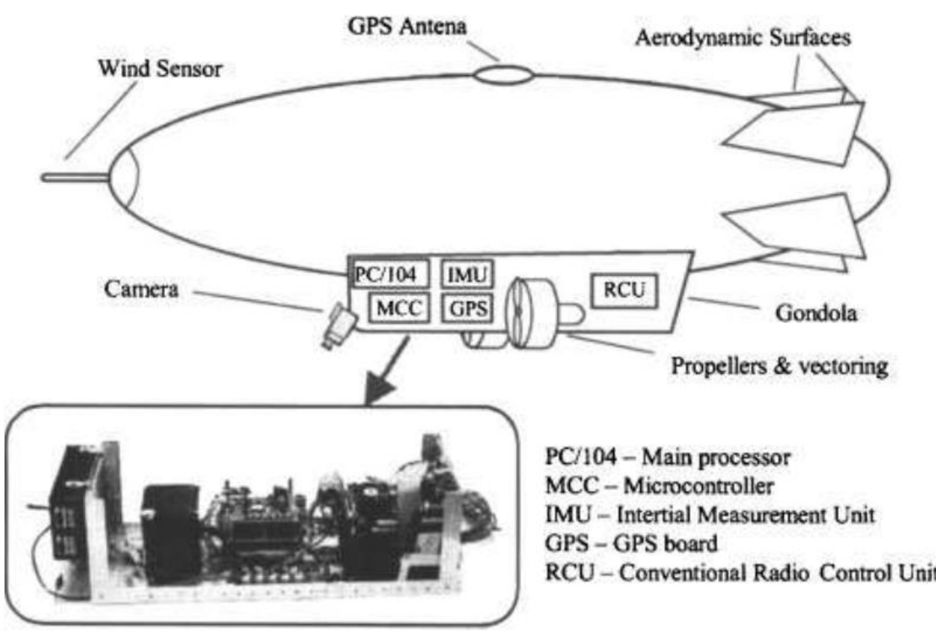
General design parameters of the evolved AURORA I

Parameter	Evolved AURORA I
Type	Conventional, non-rigid
Length	10.5 m (32.8 ft)
Diameter	3.0 m (9.8 ft)
Fineness ratio	3.5
Volume, total	34 m^3 (1,201 ft^3)
Ballonet	No details, likely similar to AURORA I
Aerodynamic controls	X-configured tail planes, ±25 degrees deflection
Airship weight, gross	33 kg (72.6 lb)
Payload	10 kg (22 lb)
Propulsion	• 2 x thrust vectoring (-30 to +120 degrees), two-stroke, petrol engines transversely mounted on the gondola, each driving a shrouded propeller. • Can operate collectively or differentially
Stern thruster	A small lateral stern thruster was considered for improving lateral control during hovering without wind. It may not have been implemented.
Speed, max.	50 kph (31 mph)

Source: A. Moutinho, et al. (2016)

The evolved AURORA I airship
. Source: A. Moutinho & JR Azinheira (2006)

In addition to the mission-specific on-board computer and sensor suite carried by the original AURORA I blimp, the evolved AURORA I blimp was reported to also carry an Inertial Measurement Unit (IMU). This instrument provides airship roll, pitch and yaw (heading) attitude and angular rates and body axes linear acceleration data, and also serves as an inclinometer and compass.



Evolved AURORA I onboard components.
Source: E. Carneiro de Piava, et al. (2006)

After a decade of autonomous controls research with the evolved AURORA I airship, a multi-national team led by Alexandra Moutinho reported in 2016 on their development of a control approach whereby an autonomous control system can cover the complete aerodynamic range encountered by an airship, from hover to cruise flight, and handle the abrupt dynamics transitions between the two flight regions and the different use of actuators necessary within each region. Their 2016 paper presents a non-linear gain-scheduling airship control design methodology encompassing both aerodynamic and hover flight and offering the following attributes:

- Valid over the entire flight envelope, enabling the execution of complete missions
- Simultaneously controls lateral and longitudinal motions
- Robust to wind disturbances (constant wind & gusts)
- Takes into account actuation limitations
- Easy to tune and to implement

The AURORA project ended in 2016.

4. For more information

AS-800 AURORA I blimp

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<u>Evolved AURORA I blimp</u>

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- José Raul Azinheira, Alexandra Moutinho and Ely Carneiro de Paiva, “Airship Hover Stabilization Using a Backstepping Control Approach,” Journal of Guidance, Control and Dynamics, Vol. 29, No. 4, July – August 2006: https://www.researchgate.net/publication/238189077_Airship_Hover_Stabilization_Using_a_Backstepping_Control_Approach
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https://www.researchgate.net/publication/275348285_A_gain-scheduling_approach_for_airship_path-tracking/figures?lo=1

- Alexandra Bento Moutinho, "Modeling and Nonlinear Control for Airship Autonomous Flight," Dissertation for Doctorate in Mechanical Engineering, Universidade Tecnica de Lisboa, Instituto Superior Technico, available via ResearchGate, December 2007: https://www.researchgate.net/publication/267567521_Modeling_and_nonlinear_control_for_airship_autonomous_flight
- Alexandra Moutinho, et al., "Airship robust path-tracking: a tutorial on airship modelling and gain-scheduling control design," Preprint submitted to Control Engineering Practice, 15 January 2016: https://www.researchgate.net/publication/294901907_Airship_robust_path-tracking_A_tutorial_on_airship_modelling_and_gain-scheduling_control_design

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