Karma – semi-autonomous airship

Peter Lobner, 4 November 2023

1. Introduction

The Karma autonomous airship project was initiated in 2001 by LAAS (Laboratory for Analysis and Architecture of Systems), located in Toulouse, France. LAAS is a research unit of CNRS, the French National Center for Scientific Research, within the Department of Information and Engineering Sciences and Technologies.

The objective of the Karma project was to demonstrate an airship with the ability to execute planned trajectories on the basis of its sensors, and in the long term, on the basis of the perception of ground elements. The Karma project initially focused on defining blimp trajectory control laws and on environment modeling issues using low altitude imagery.

2. The original Karma (V1) blimp

The AS-500 was selected as the flying test platform the Karma project and one was acquired by LAAS in 2001. The AS-500 is an 7.8-m (25.6-ft) long remotely-controlled airship manufactured in the UK by Airspeed Airships.

Scale wind tunnel model of the Karma V1 AS-500 was used to determine aerodynamic parameters later used in airship dynamic control models. L. Solaque & S.Lacroix, "Airship control" (2007)

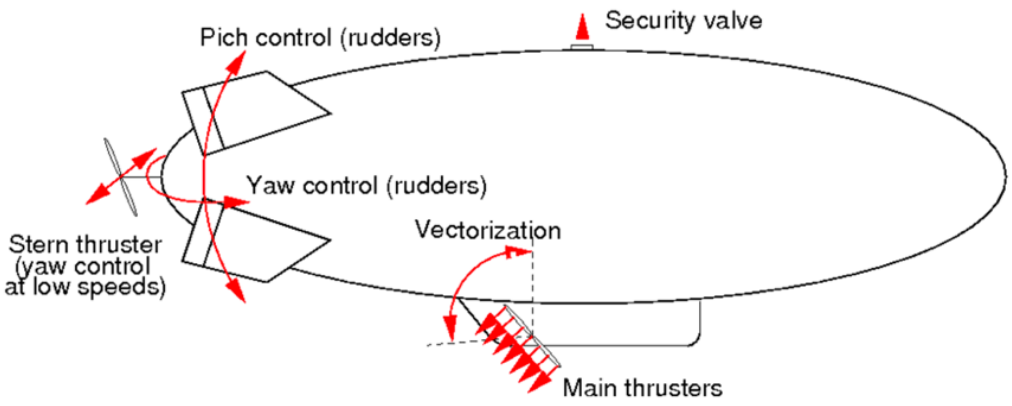
LAAS modified their AS-500 by replacing the original petrol engines with electric motors and adding a small electric motor-driven stern-mounted lateral thruster. In addition, onboard equipment was added to support autonomous flight. The LAAS team described their rationale for these modifications:

- **Electric motors**: “To have a finer controllability, we preferred to opt for electric motors. They do not weigh more than fuel engines nominally proposed for the AS-500, but are less powerful, thus reducing the maximum reachable speed and the possibility to fly in wind gusts. But the main drawback of this choice is the payload loss due to the required batteries.”

- **Stern thruster**: “The rudder control surfaces require a certain speed to allow changes in both the altitude and orientation of the blimp. In order to have the possibility to control the yaw angle while hovering, we choose to add a stern thruster. Note that after a few flight tests, it appeared that the blimp yaw angle can be controlled thanks to the rudders even at very low speeds: the stern thruster appeared to be rather useless.”

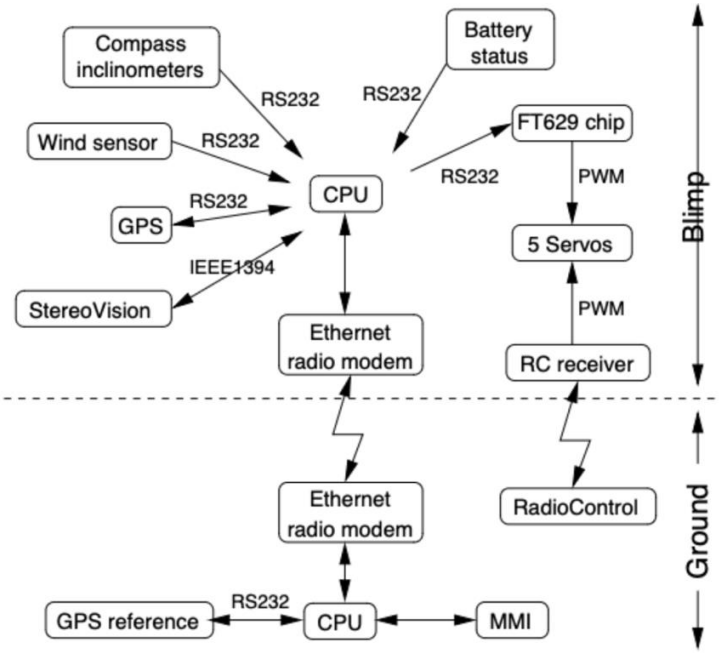
- **On-board equipment:** “To transform the blimp from a radio-controlled machine to a robot, we are currently equipping it with a set of proprioceptive and exteroceptive sensors, and with computing and communications capabilities.” These include black & white stereovision cameras, blimp state sensors (differential GPS, pitch, roll and wind sensors), on-board computer, and autonomous actuator controls with manual override. This equipment is installed in the AS-500 gondola. “The total equipment weight is 1.52 kg (3.35 lb), which leaves only 1.30 kg (2.87 lb) for the various mechanical parts, wires and batteries that must provide the necessary additional 40 W” (of electrical power).

Gondola & thrust-vectoring propellers of the Karma V1.
Source: L. Solaque & S.Lacroix, “Airship control” (2007)



Karma V1 control features with stern thruster added to basic AS-500 configuration. Source: LAAS, 2002

The hardware communications architecture for the on-board equipment and a ground station are shown in the following diagram.



Karma V1 hardware communications architecture. Source: Lacroix, et al. (2002)

The control surfaces and motor servos on the blimp are PWM (pulse wave modulated)-controlled modelist devices. Most devices communicate with the on-board CPU via RS-232 links, except the

stereovision system with communicates via an IEEE 1394 link. The primary data link between the blimp and the ground station is an Ethernet radio modem. The autonomous actuator commands from the on-board CPU can be overridden by an operator commands from the ground station. This is accomplished with a radio-controlled switch that cuts the PWM signals coming from the FT629 chip.

General design parameters of the AS-500 (Karma V1)

Parameter	Airspeed Airships AS-500	Karma V1
Type	Conventional, non-rigid	
Length	7.8 m (25.6 ft)	
Diameter	1.8 m (5.9 ft)	
Fineness ratio	4.25	
Volume, total	15 m^3 (530 ft^3)	
Envelope	• Welded mylar construction • Radio-controlled emergency helium release valve on top of the envelope	
Ballonet	Fed by air captured from the propeller slipstream	
Aerodynamic controls	X-configured tail planes	
Payload	• 3.5 kg (7.7 lb) static • 5.0 kg (11 lb) dynamic (blimp typically flies 1.5 – 2.0 kg overweight)	• 1.5 kg (3.3 lb) static • reduced due to batteries • 2.8 kg (6.2 lb) dynamic (1.3 kg overweight)
Propulsion	2 x 7.5 cm^3 (0.46 in^3) petrol engines, each driving a thrust vectoring (100º range) propeller transversely mounted to the gondola	2 x electric motors, each driving a thrust vectoring (100º range) propeller transversely mounted to the gondola
Speed, max	45 kph (28 mph)	< 45 kph (<28 mph)
Stern thruster	None	1 x stern thruster added for yaw control while hovering, but later removed
Wind speed, operational	25 kph (15.5 mph) with petrol engines	10 kph (6 mph) with electric motors
Endurance	40 min on 1.0 kg (2.2 lb) of fuel	12 to 15 minutes on batteries

Source: Lacroix, et al. (2002)

Karma V1 first tethered flight (November 2001)
Source: (L) LAAS, (R) Hygounenc, et al. / LAAS / CNRS

Karma V1 first radio-controlled free flight, with stern thruster installed (July 2002)
Source, both photos: LAAS

Karma V1 first radio-controlled flight, with stern thruster installed (July 2002)

Karma V1 ready for fifth flight, with stern thruster removed (August 2002). Source, both photos: LAAS

Karma V1 during its fifth flight (August 2002). Source: LAAS

Remotely piloting Karma V1 turned out to be very easy, as long as the mean wind speed didn't exceed 10 kph (6.2 mph). The rudders were very effective, even at low speed, enabling a turning radius of about 15 m (49 ft) at 10 kph. Based on this good performance, the decision was made to remove the stern lateral thruster, which was rather difficult to control.

The LAAS research team developed a global control strategy that integrated a path planner, a path follower and elementary controllers. This prototype autonomous control system for cruise flight stabilization was flight tested on the Karma V1 blimp.

Karma V1 on its fifth flight (August 2002).
Source: LAAS

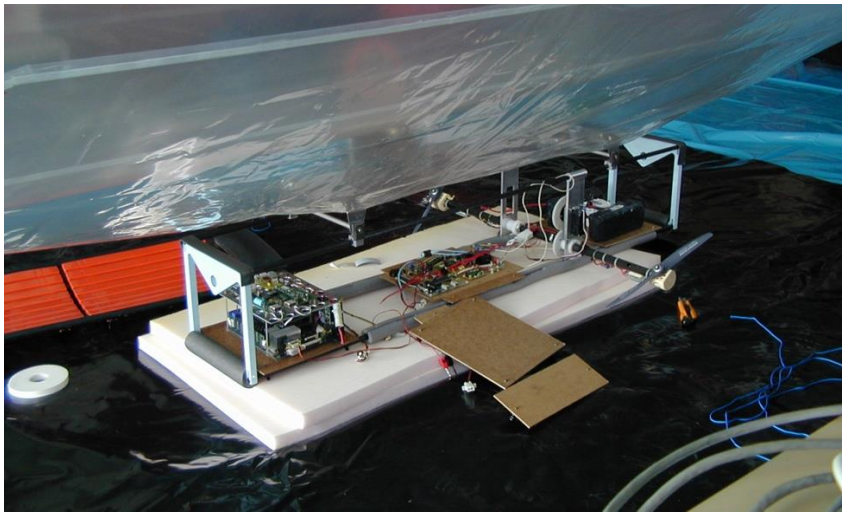
3. Karma V2.0 blimp

A second version of the Karma airship known as V2.0 was developed and first flew in 2003 with the following features:

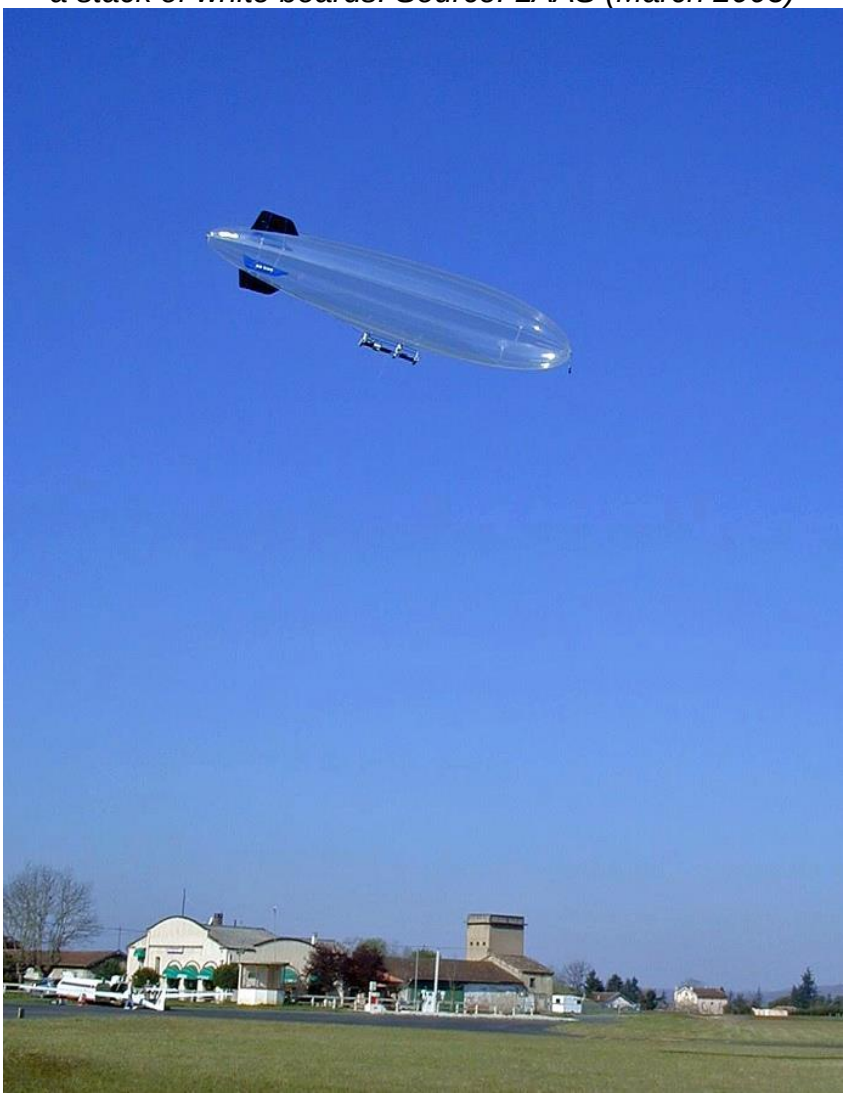
- New transparent envelope with a volume of 18 m^3 (3 m^3 / 106 ft^3 larger), allowing more payload
- Totally redesigned “minimalist” gondola
- Brushless motors, generating greater thrust
- Additional sensors to enable automated takeoff and landing

About all that was left of the original AS-500 blimp were the X-configured tail fins, still with the original AS-500 markings.

Karma V2.0 in its hangar. Note the original AS-500 tail fins.
Source: LAAS (May 2003)



Karma V2.0 “minimalist” gondola sitting on a stack of white boards. Source: LAAS (March 2003)



Karma V2.0 first flight. Source: LAAS (April 2003)

Karma V2.0 first flight. Source: LAAS (April 2003)

General design parameters of the Karma V2.0

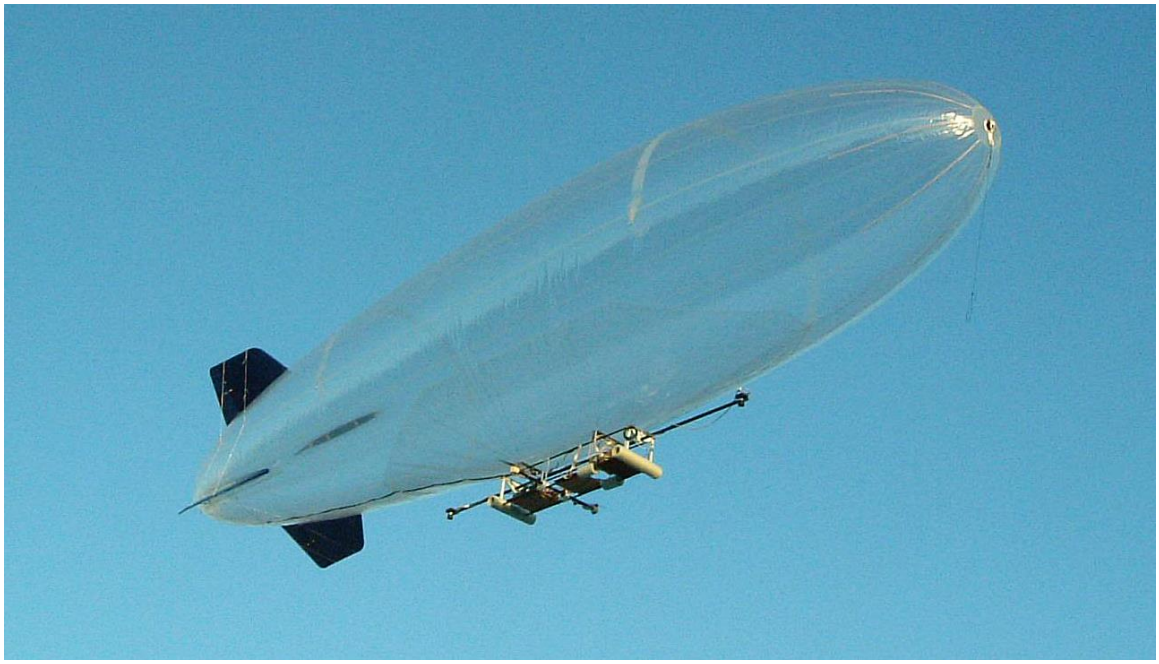
Parameter	**Karma V2.0**
Type	Conventional, non-rigid
Length	9 m (29.5 ft)
Diameter	2 m (6.6 ft)
Fineness ratio	4.5
Height, overall	2.4 m (7.9 ft)
Weight, overall	20 kg (44.1 lb)
Volume, total	18 m^3 (635.6 ft^3)
Envelope	Mylar construction, hull designed by Zodiac
Ballonet	Not specified
Aerodynamic controls	X-configured tail planes from the AS-500 Karma V1
Payload	More than Karma V1
Propulsion	2 x brushless electric motors powered by a 12 V battery, each driving a thrust vectoring propeller mounted to the gondola
Stern thruster	None

Source: LAAS

The Karma V2.0 had an on-board equipment suite that was similar to Karma V1: Two black & white IEEE-1394 cameras for the stereovision system, differential GPS, compass, wind sensor and battery status monitor. The on-board computer communicated with the ground station via an IEEE-802.11b Ethernet radio modem.

Karma V2.0 outside its hangar in Portugal.
Source, both photos: LAAS (May 2003)

Karma V2.0 ready to launch in Portugal.



Karma V2.0 in flight in Portugal.
Source, both photos: LAAS (May 2003)

Karma V2.0 in flight. Source: LAAS

Simon Lacroix (LAASA / CNRS) reported on the Karma project, circa 2005:

> "In addition to the development of the prototype and its use to carry out work on environmental mapping…., various work relating to flight control was carried out: modeling of the system and identification of model parameters (in a wind tunnel in collaboration with SupAéro, or from flight data), development of different controllers (stabilization of flight parameters and trajectory tracking), and more recently trajectory planning.
>
> All of this work has been evaluated in simulation, but none has yet led to effective control of the balloon, which is still remotely operated during its flights."

4. For more information

AS-500, Karma V1

- "Karma, the Blimp," LAAS website, February 2002: https://homepages.laas.fr/simon/eden/robots/blimp.php
- Karma photo gallery, LAAS website: https://homepages.laas.fr/simon/eden/gallery/karma.php
- Simon Lacroix, et al., "The autonomous blimp project of LAAS/CNRS - Current status and research challenges," paper presented at Experimental Robotics VIII (ISER 2002), Sant'

Angelo d'Ischia, Italy, July 2002: https://homepages.laas.fr/simon/publis/LACROIX-ISER-2002.pdf
- Emmanuel Hygounenc, et al., "The Autonomous Blimp Project of LAAS-CNRS: Achievements in Flight Control and Terrain Mapping," LAAS/CNRS paper, 2003: http://www.comets-uavs.org/papers/HYGOUNENC-IJRR-2003.pdf
- Leonardo Solaque & Simon Lacroix, "Airship control," This is a chapter In: A. Ollero & I. Maza (eds.) "Multiple Heterogeneous Unmanned Aerial Vehicles," Springer Tracts in Advanced Robotics, Vol. 37, Springer, 2007: https://homepages.laas.fr/simon/laasTheses/SOLAQUE-TESIS-SUMMARY-2007.pdf

Karma V2.0

- Simon Lacroix, "Ballons dirigeables autonomes," ("Autonomous airships," original in French), LAAS/CNRS, circa 2005: http://jnrr05.irisa.fr/document/jnrr-007-01-lacroix.pdf
- Yiwei Liu, et al., "Control of autonomous airship," Proceedings of the 2009 IEEE International Conference on Robotics and Biomimetics," Guilin, China, December 2009: https://www.researchgate.net/publication/224118488_Control_of_Autonomous_Airship

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