DARPA Integrated Sensor is Structure (ISIS) airship

Peter Lobner, 21 December 2020

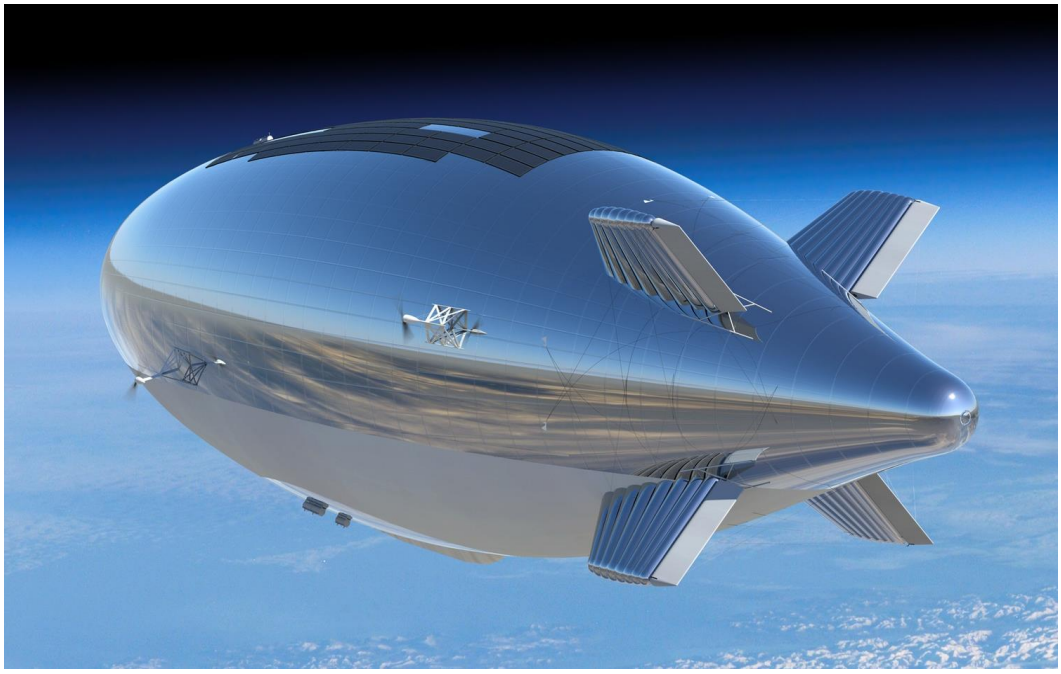
1. Introduction

ISIS (Integrated Sensor is Structure) was a joint Defense Advanced Research Projects Agency (DARPA) and Air Force Science and Technology (S&T) program that integrates advanced radars with tracking and moving target indication capabilities directly into the structure of a very large, solar-powered, stratosphere-roaming, non-rigid airship. DARPA initiated the program in 2004 with the following goals:

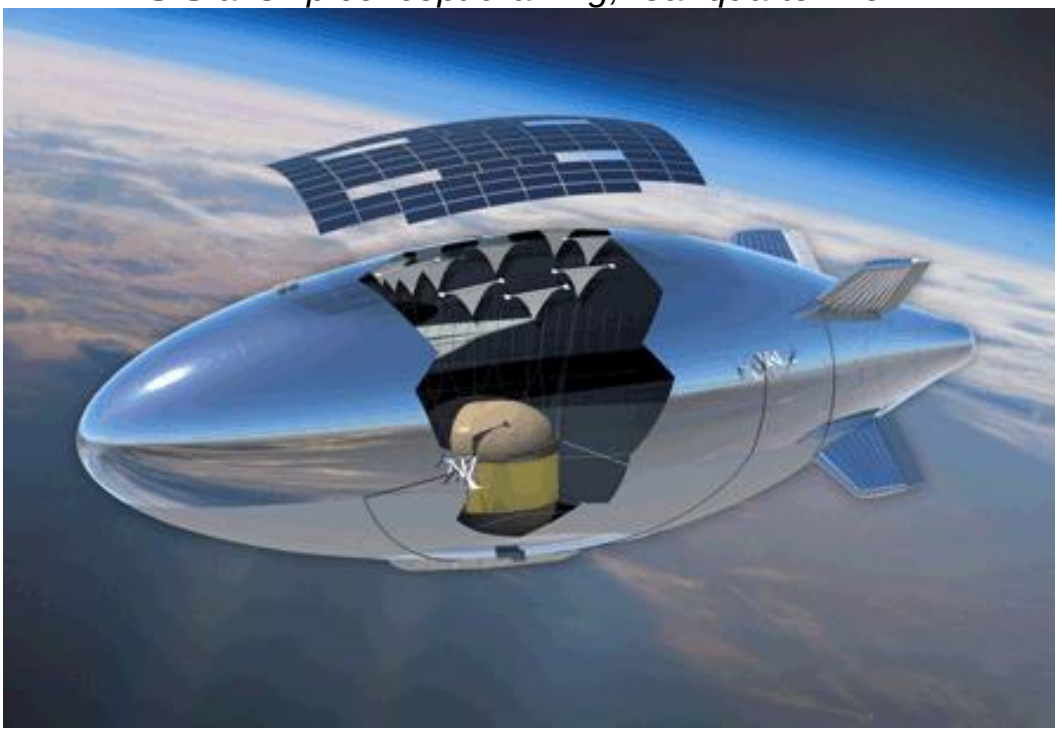
> "The joint DARPA/Air Force Integrated Sensor is Structure (ISIS) program is developing a sensor of unprecedented proportions to be fully integrated into a stratospheric airship. ISIS is designed to provide persistent wide-area surveillance, tracking, and engagement for hundreds of time-critical air and ground targets in deployed overseas urban and rural environments, without requiring in-theater support facilities or personnel. ISIS seeks radical sensor improvements by melding the next generation technologies for enormous lightweight antenna apertures and high-energy density components into a highly integrated, lightweight, multi-purpose airship structure, completely erasing the distinction between payload and platform."
>
> "The ISIS concept includes 99% on-station, 24/7/365 availability for simultaneous Airborne Moving Target Indicator (AMTI) (600 kilometers) and Ground-Based Moving Target Indicator (GMTI) (300 kilometers) operation; ten years of autonomous, unmanned flight; plus U.S.-based operation."

The original plan was for the USAF to take over the ISIS program after flight tests with a sub-scale "demonstration system" (DS) had been completed and the ISIS concept had been validated. The full-scale ISIS airship was known as the "objective system" (OS). In FY 2010, the USAF began contributing funds under a joint DARPA/Air Force initiative.

In 2009, the team of Lockheed Martin and Raytheon beat a Northrop Grumman team for a $400 million contract to design, build and fly the sub-scale (approximately 1/3 scale) DS airship.



ISIS airship concept drawing, rear quarter view.



ISIS airship exploded view showing the location of the ASEA radar within the hull and the solar photovoltaic array on the top of the hull. Source, both graphics: Lockheed Martin

The original timeline called for the technology demonstrator airship to make its first flight in late 2013 from the Lockheed Martin airship manufacturing site in Akron, Ohio. While the USAF had not yet committed funding, the full-scale ISIS airship (the OS airship) was expected to fly in about 2020.

2. Overview of the ISIS airship

ISIS is a very large, solar-powered, stratosphere-roaming, non-rigid airship (blimp) designed to be launched from a base in the continental U.S. to conduct very long duration ISR and communications missions anywhere in the world. After the mission, the ISIS airship would fly back and be recovered at its base in the continental U.S.

Basic characteristics of the ISIS platform are outlined below:

- **Length:** 450 ft (137 m)
- **Volume:** > 14,000,000 cubic feet (> 396,435 cubic meters)
- **Operating altitude:** 65,600 – 70,000 feet (20,000 – 21,300 m)
    - From this altitude, the horizon is about 373 miles (600 km) away
- **Hull material:** Composite-laminate fabric hull with an extremely high strength-to-weight ratio
    - 4X reduction in fabric mass over current state of the art.
    - Will last 10X longer than conventional blimp hull material.
- **Airspeed:** 60 knots sustained, 100 knots maximum
    - Capable of deploying globally within 10 days from a permanent ground station in the continental U.S
- **Radar:** Dual-band (UHF and X-band) active electronically scanned array (ASEA) radar system with a shared aperture with backend digital beam forming.
- **Signal processing:** A continental U.S. center will process all ISIS data. No in-theater processing facilities are required.
- **Payload mass:** The radar sensor itself will account for about 30% of the total mass of the airship.
- **Power system:** A solar photovoltaic array on the top surface of the airship is paired with regenerative hydrogen fuel cells to deliver 24/7 power for the mission package and for propulsion.

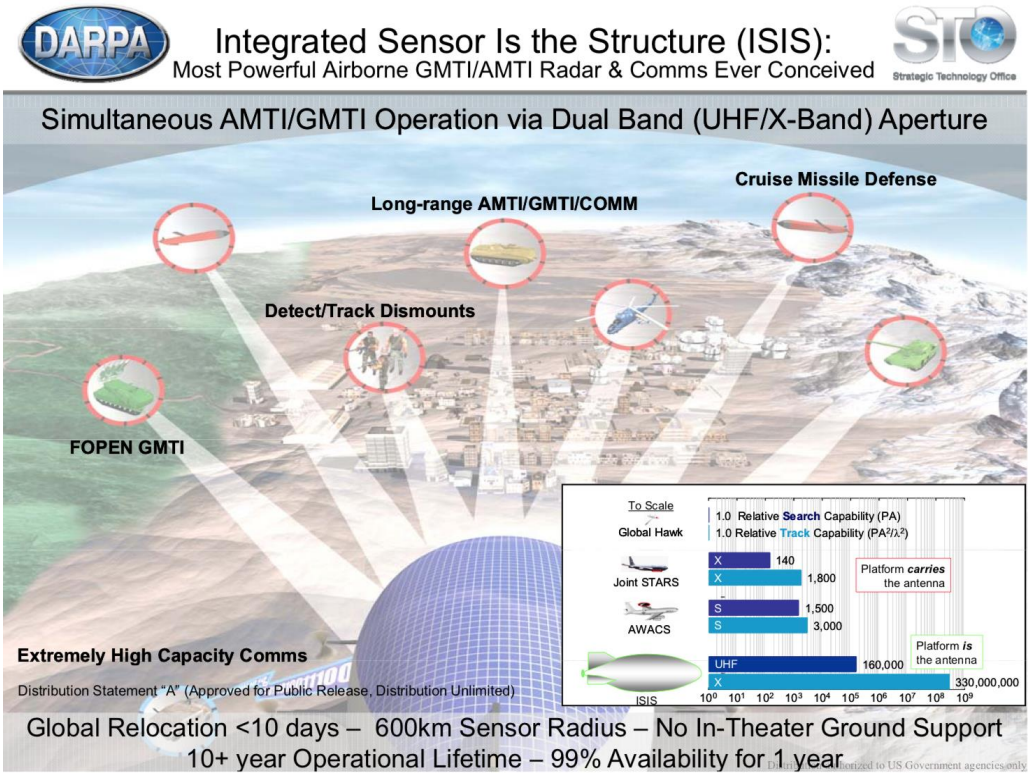
- During the day, solar cells generate electricity and provide power for electrolysis of water to produce hydrogen and oxygen for the fuel cell.
- At night, hydrogen and oxygen are recombined in the fuel cell, which generates electricity and produces water.

- **Propulsion:** Four electric motor-driven vectorable propellers are installed on the flanks of the hull

3. The ISIS dual-band (UHF and X-band) radar

The ISIS radar system had the following key functional capabilities for engaging hundreds of time-critical targets:

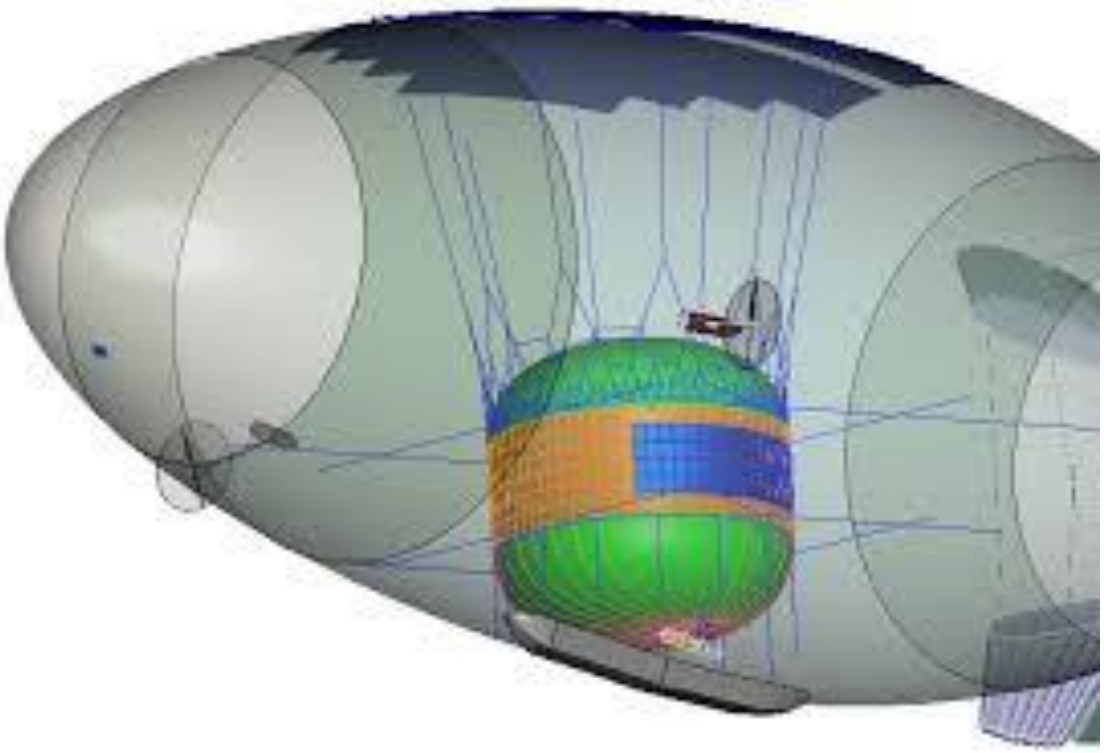
- Simultaneous Airborne Moving Target Indicator (AMTI) at 373 miles (600 km) and Ground-Based Moving Target Indicator (GMTI) at 186 miles (300 km) with the X-band aperture
- Tracking human-sized targets or vehicles hidden under foliage or camouflage nets at 186 miles (300 km) with the UHF aperture



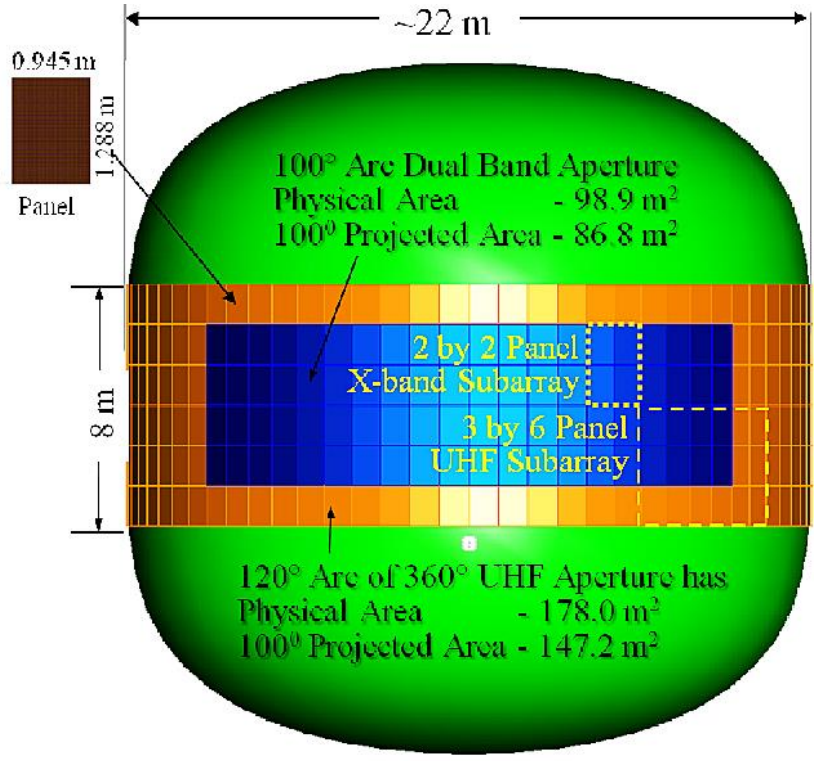
Concept of operations for employing the ISIS radar
Source: Tim Clark / "DARPA Investment in Large Apertures"

Unlike conventional radars, the ISIS radar performance is based on array (aperture) size rather than power. As aperture size increases, the tracking performance increases exponentially.
The very large ISIS radar aperture is built up from a very large number of small, low-power transmit / receive modules that are based on low-cost cell phone technology. By employing low-power electronics, there was no need for an electronics cooling system, which is common in high-power radar systems. The combined effect of low-power electronics and no electronics cooling system greatly decreased the electric power required to operate the ISIS sensor system, thereby enabling the airship to run on solar power.

As the ISIS (Integrated Sensor is Structure) name implies, lightweight flexible array panels are bonded onto airship structures to create a large, cylindrical radar antenna within the hull of the airship. These lightweight array panels have an average mass density of only 0.4 pounds/ft^2 (2 kg/m^2).



Location and suspension of the dual-band ASEA radar within the ISIS technology demonstrator (DS) airship hull.
Source: Tim Clark, DOI: 10.1109/ARRAY.2010.5613396



Details of the dual-band ASEA radar array for the ISIS technology demonstrator (DS) airship.
Source: Tim Clark, DOI: 10.1109/ARRAY.2010.5613396

The relative scale of the DS and OS airships and their respective dual-band radars is summarized in the following table.

	DS	OS
Altitude	20 km	21.3 km
Airship Length	150 m	300 m
Airship Diameter	50 m	100 m
Antenna Height	8 m	36 m
Antenna Diameter	22 m	50.5 m
UHF Aperture Area	530 m^2	5725 m^2
UHF Elements	3,922	42,365
X-Band Aperture Area	98 m^2	5725 m^2
X-Band Elements	347,500	20,300,000
First Launch	2013	2020

Relative scale of the ISIS DS and OS systems.
Source: Source: Tim Clark, DOI: 10.1109/ARRAY.2010.5613396

4. The ISIS demonstration system (DS)

The ISIS demonstration system (DS) is an approximately 1/3-scale prototype of the full-scale ISIS objective system (OS). In its own right, the DS is a very large airship, with an overall length of 492 feet (150 m) and a diameter of 164 feet (50 m). The contract for developing the DS was awarded in 2009 to the team of Lockheed Martin (for the airship) and Raytheon (for the radar).

The AESA radar for the DS airship is comprised of two arrays of lightweight, digital transmitter/receivers bonded to a cylindrical structure measuring 26.2 feet (8 m) high and 72.2 feet (22 m) in diameter. DARPA reported, “these sizes will be large enough to validate manufacturing and calibration for the objective system and will provide an early glimpse of the air and ground target tracking performance possible with an operational system.” The DS radar system had a total mass is about 6,600 pounds (2,994 kg).

Lockheed Martin was developing a 200 kW solar array for the DS.

The original plan was for a one-year DS flight test program that culminated in a three-month on-station flight demonstration in FY 2013.

In October 2012, the General Accountancy Office (GAO) reported:

> “ISIS has experienced technical challenges stemming from subsystem development and radar antenna panel manufacturing. Consequently, earlier this year DARPA temporarily delayed airframe development activities, and instead will mainly focus on radar risk reduction activities. During this time period, the ISIS team will develop an airship risk reduction plan and conduct limited airship activities. Based on the radar and airship risk reduction studies, DARPA will reassess the future plan for ISIS with the Air Force.”

The USAF RDT&E budget for FY 2016 reported that the ISIS program was “complete in FY 2015.” A total of $471 million had been spent on the program from 2007 through 2012 with $15.2 million of additional USAF funding in FY 2013 and 2014. No airship was built.

5. The full-scale ISIS objective system (OS)

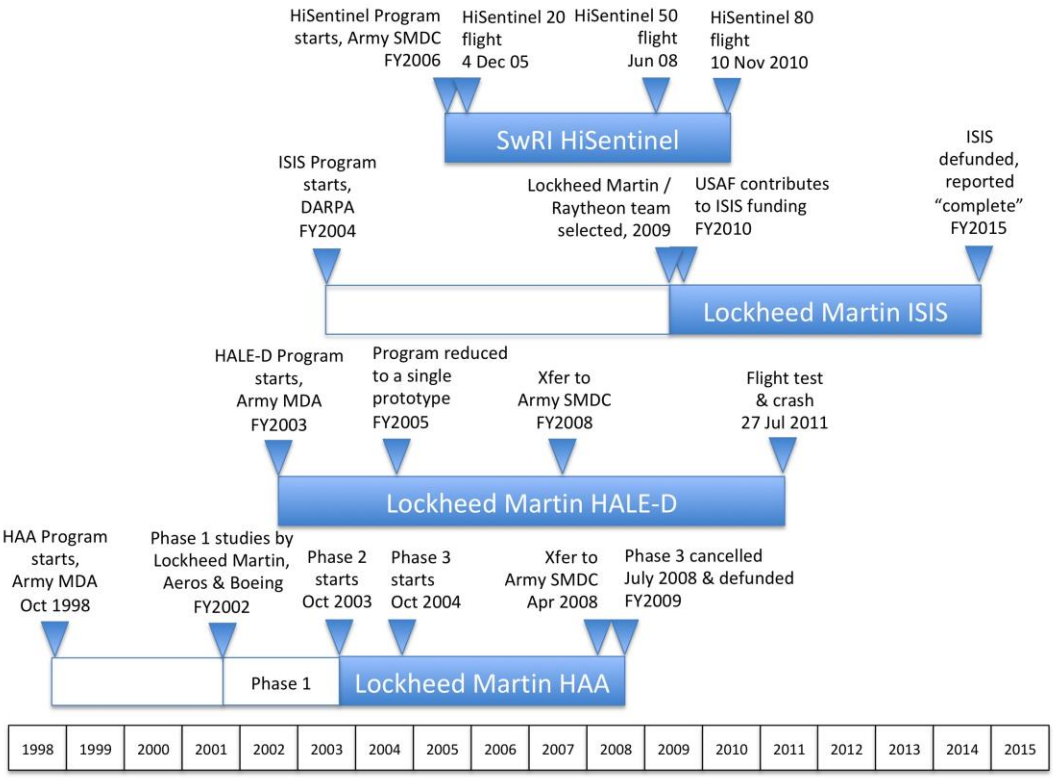
The full-scale ISIS airship would have been huge, with an overall length of 984 feet (300 m) and a diameter of 328 feet (100 m). In comparison, the Hindenburg Zeppelin had a length of 803.8 feet (245 m) and a diameter of 135.1 feet (41.4 meters).

The massive cylindrical radar antenna inside the hull would have provided 360° azimuth coverage with an array measuring 118 feet (36 m) in height and 166 feet (50.5 m) in diameter.

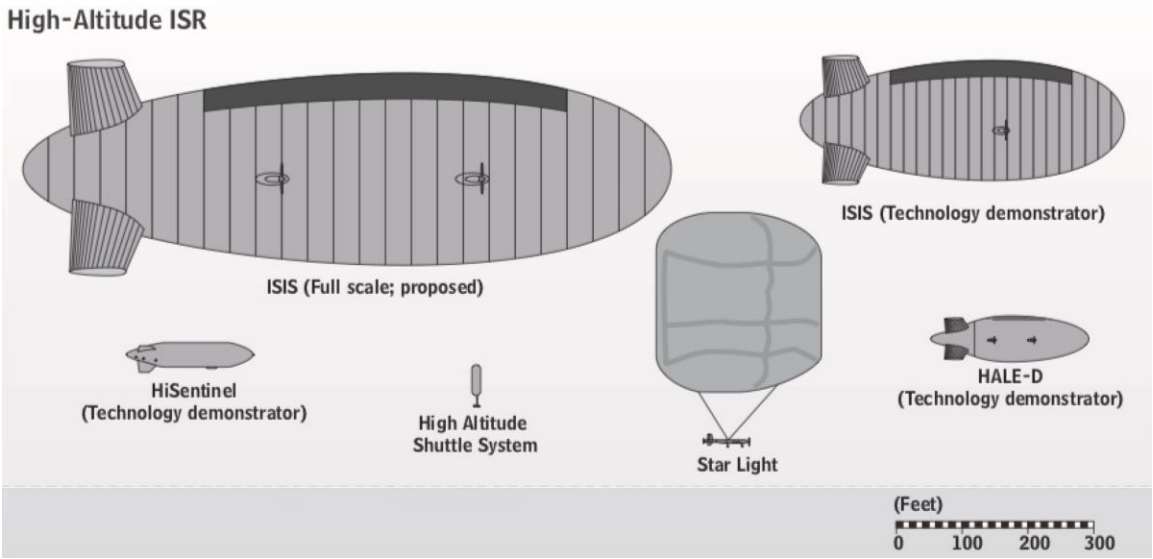
The solar-powered ISIS OS was designed to operate for up to 10 years as a “pseudo-satellite” without having to land for maintenance or refueling, while demonstrating a 99% average annual availability of mission systems. The airship would have been launched and recovered at a base in the continental U.S. and would not have required any in-theater support facilities.

ISIS concept drawing showing solar panels and hull-mounted propulsors. Source: Lockheed Martin

6. Timelines for US military high altitude airship programs



Timelines for the US Military High Altitude Airship Programs



Relative scale of ISIS and other U.S. ISR airships and two-component balloons.
Source: Congressional Budget Office, Nov. 2011

7. For more information:

- DARPA's ISIS webpage is here: https://www.darpa.mil/program/integrated-sensor-is-structure
- Tim Clark, "DARPA Investment in Large Apertures," DARPA Strategic Technology Office: https://kiss.caltech.edu/workshops/apertures/presentations/clark.pdf
- "DARPA Contracts Lockheed Martin to Build High Altitude, Long Endurance Airship," Defense Update, 28 April 2009: https://defense-update.com/20090428_isis-hale.html
- Tim Clark and Esko Jaska, "Million element ISIS array," 2010 IEEE International Symposium on Phased Array Systems and Technology, Waltham, MA, 2010, pp. 29-36, DOI: 10.1109/ARRAY.2010.5613396: https://www.semanticscholar.org/paper/Million-element-ISIS-array-Clark-Jaska/efeac6e9981aedbd08d06d0a5e35b55d2daa5bcc
- "12 Miles High: An Integrated Airship – Radar on the Horizon," MITRE, March 2010: https://www.mitre.org/publications/project-stories/12-miles-high-an-integrated-airshipradar-is-on-the-horizon
- "Recent Development Efforts for Military Airships," Congressional Budget Office, November 2011: https://www.cbo.gov/sites/default/files/112th-congress-2011-2012/reports/11-01-Airships.pdf
- Report to Congress, "Summary Report of DoD Funded Lighter-Than-Air-Vehicles," DoD Office of the Assistant Secretary of Defense for Research and Engineering, 1 November 2012: https://www.hsdl.org/?view&did=728733