Japan’s Stratospheric Platform (SPF) & SkyNet

Peter Lobner, 21 December 2020

1. Introduction

Feasibility studies of Japan’s Stratospheric Platform (SPF) Program started in 1998 and lasted 18 months, under the leadership of the National Aerospace Laboratory (NAL). The objective of the SPF Program was to develop a system based on a large, unmanned, solar powered stratospheric airship that could maintain a geo-stationary position at about 20 km (12.4 miles, 65,600 feet) altitude and conduct a long duration mission to deliver a variety of telecommunications and Earth observation services via the SkyNet telcom infrastructure.

Since 2000, the SPF Program received financial support from the Millennium Project, promoted by the Prime Minister’s Office.

In 2003, the Japan Aerospace Exploration Agency (JAXA) was formed through the merger of three organizations: NAL, the Institute of Space and Astronautical Science (ISAS), and the National Space Development Agency of Japan (NASDA). The NAL organization, restructured under JAXA, retained its leadership role for SPF, which had evolved into a three-phase, eight year program:

- Phase 1 - Technology familiarization, including development and testing of key components / systems on sub-scale prototype platforms.
- Phase 2 - Development and testing of a full size Stratospheric Platform airship and prototype SkyNet infrastructure
- Phase 3 - Full commercialization of the Stratospheric Platform & SkyNet by Japanese industry.

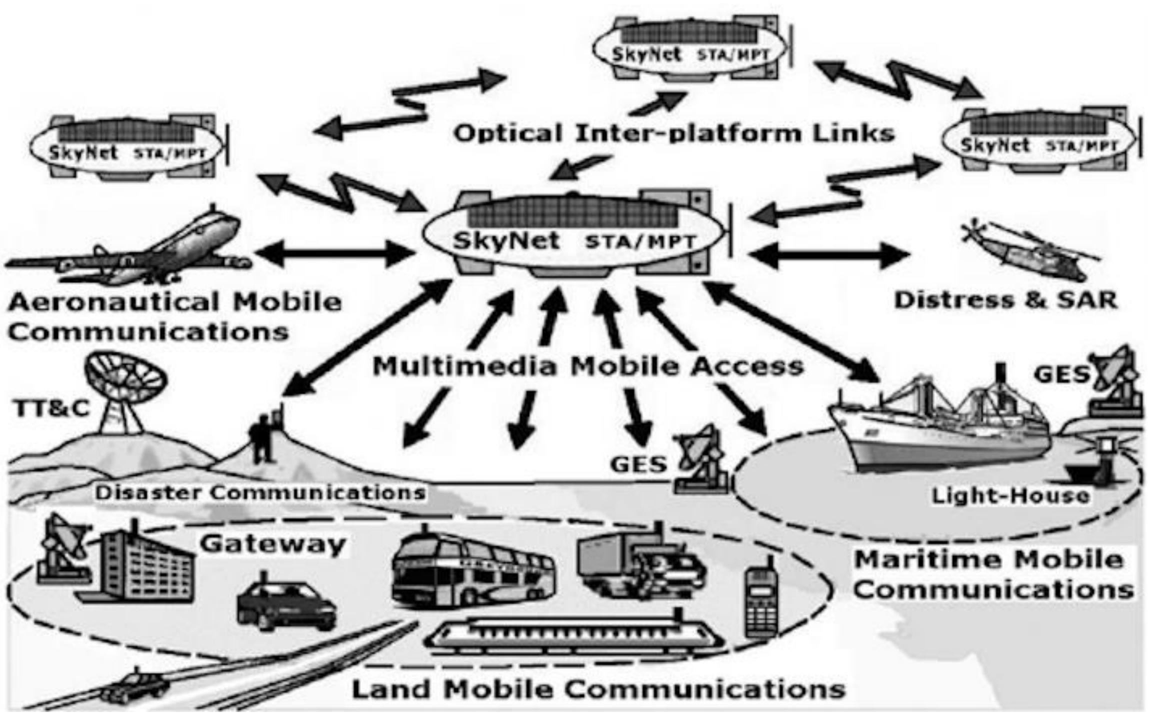
The Taiki Aerospace Research Field (TARF) on Hokkaido Island was selected as the base of operations for SPF Program flight tests. In 2000, facilities, including a large hanger, were built to support SPF flight operations.

At the inception of the SPF Program, the interests of Japan’s commercial communications industry were represented by the

Communications Research Laboratory of Japan (CRL) and the Telecommunications Advancement Organization (TAO). In 2004, CRL and TAO were merged to form the National Institute of Information and Communications Technology (NICT), which continued supporting SPF and SkyNet through the development of communications, broadcasting and radio-location payloads for high-altitude platforms (HAPs), with the goal of developing systems to deliver the following types of communications services:

- Disaster relief / event servicing
- Broadcast HDTV
- Broadband fixed access to users
- Broadband mobile access to long distance trains and other vehicles.

The basic architecture for SkyNet, which was designed to serve a diverse range of customers via air-to-ground and air-to-air communications links, is shown in the following diagram.



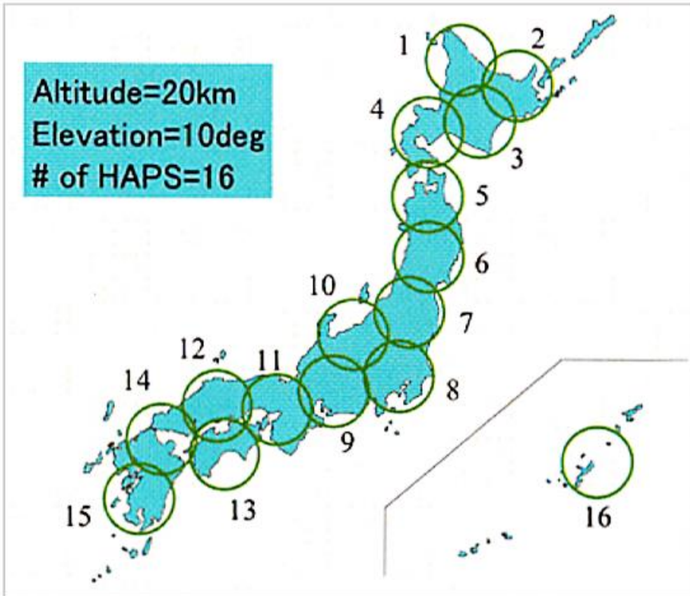
Japan's SkyNet architecture. Source: TAO via S.D. Ilcev, 2005

SkyNet poster. Source: The University of York

The USE-HAAS report (2005) stated:

> "These applications were selected primarily because HAPs have the potential to provide users over a wide area with various services at reasonable cost. For example, the project has calculated that 15,000 HDTV terrestrial transmitters are

needed to deliver broadcast TV over Japan’s mountainous terrain, (and) can be delivered with around 15 HAPs.”



Example of regional SkyNet coverage for Japan with 16 SPS airships. Source: R. Miura & M. Oodo (2001)

Two different sub-scale test vehicles were flown in 2003 and 2004. An unpowered balloon designated SPF-1 made a single flight in 2003, reaching an altitude of 16 km (9.9 miles). A low altitude airship designated SPF-2 made eight flights in 2004 to demonstrate key SPF technologies.

After failing to get financial support to initiate Phase 2 and develop the first full-scale airship, the SPF Program was terminated in 2005, after spending a total of about US $200 million. Phase 2 funding was intended to be a combination of public and industry funding.

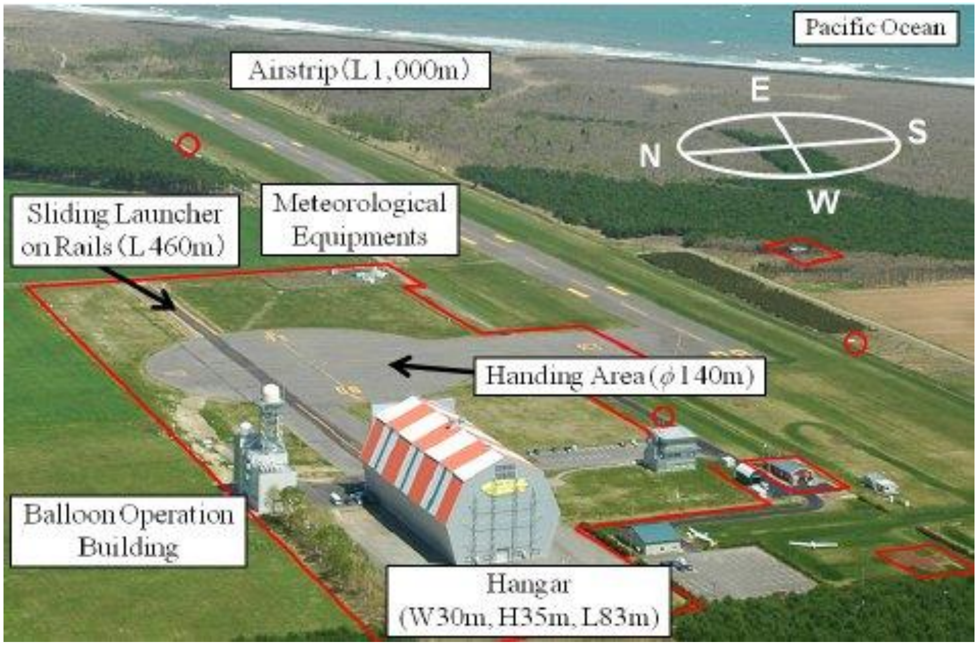
Key airship system / component technologies demonstrated during the SPF Program were:

- Lightweight materials for the envelope and construction techniques suitable for long-term stratospheric flights.
- Regenerative fuel cell (RFC): By 2004, an RFC working prototype was capable of delivering 400 Watt-hours/kg and the design for an RFC delivering 700 Wh/kg had been developed.

2. TARF: Japan's stratospheric airship / balloon base

Established in the early 1990s, Taiki Aerospace Research Field (TARF) is located in an expansive, flat coastal area on the eastern shore of Hokkaido Island in the northern part of Japan. Details on balloon operations at the TARF site are available on the StratoCat website here: http://stratocat.com.ar/bases/74e.htm

> StratoCat reports, "In 2000 great improvements were carried out to the site with the addition of a paved landing strip measuring 1000 meter long and 60 meters wide. Also a flight test building was constructed to control the operations of test aircraft and to perform some data processing.
>
> At that time, under the aegis of the Stratospheric Platform (SPF) project devoted to built an airship capable of stratospheric flight, a big hangar was erected to offer shelter for the airship ……….. with a paved circular field measuring 140 meters of diameter known as the handling area. Also a flight control tower, and a full weather observation facility were built. Station-keeping flight tests of the SPF airship (the sub-scale SPF-2) were performed in Taiki and surroundings between 2001 and 2004."



TARF general site layout. Source: H. Fuke, et al. (2010)

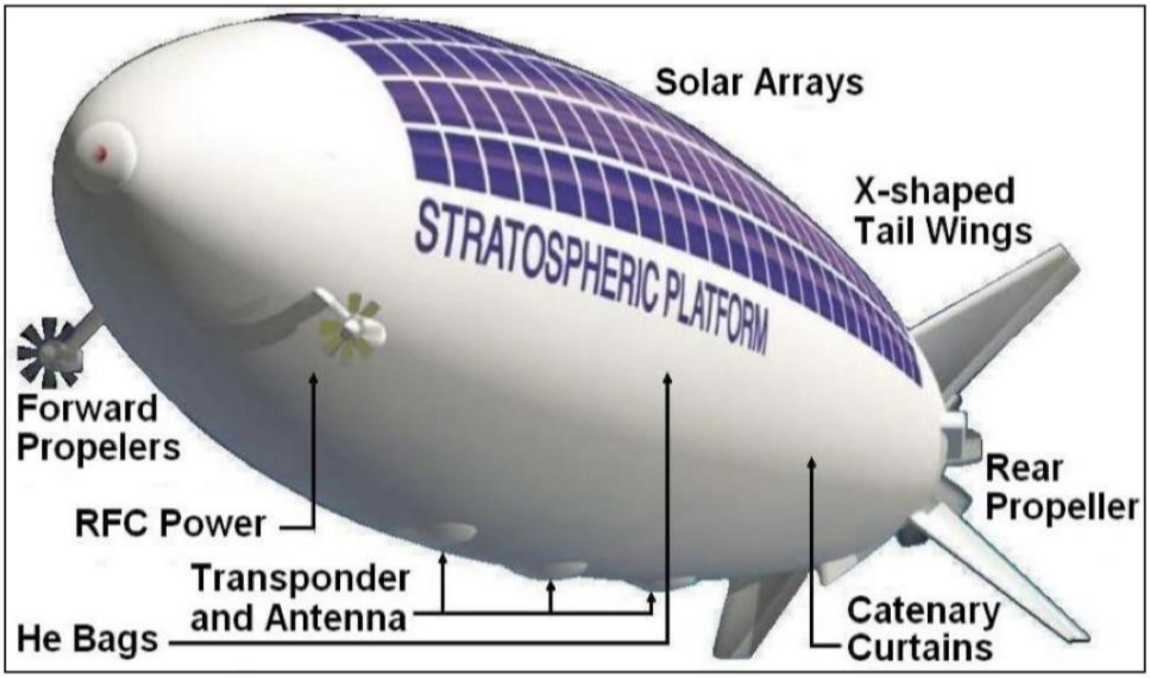
TARF, viewed from the runway.
Source: JAXA

A new stratospheric balloon base was established at TARF between July 2007 and March 2008, repurposing the big hanger to handle high-altitude balloons, and supporting a variety of stratospheric research programs.

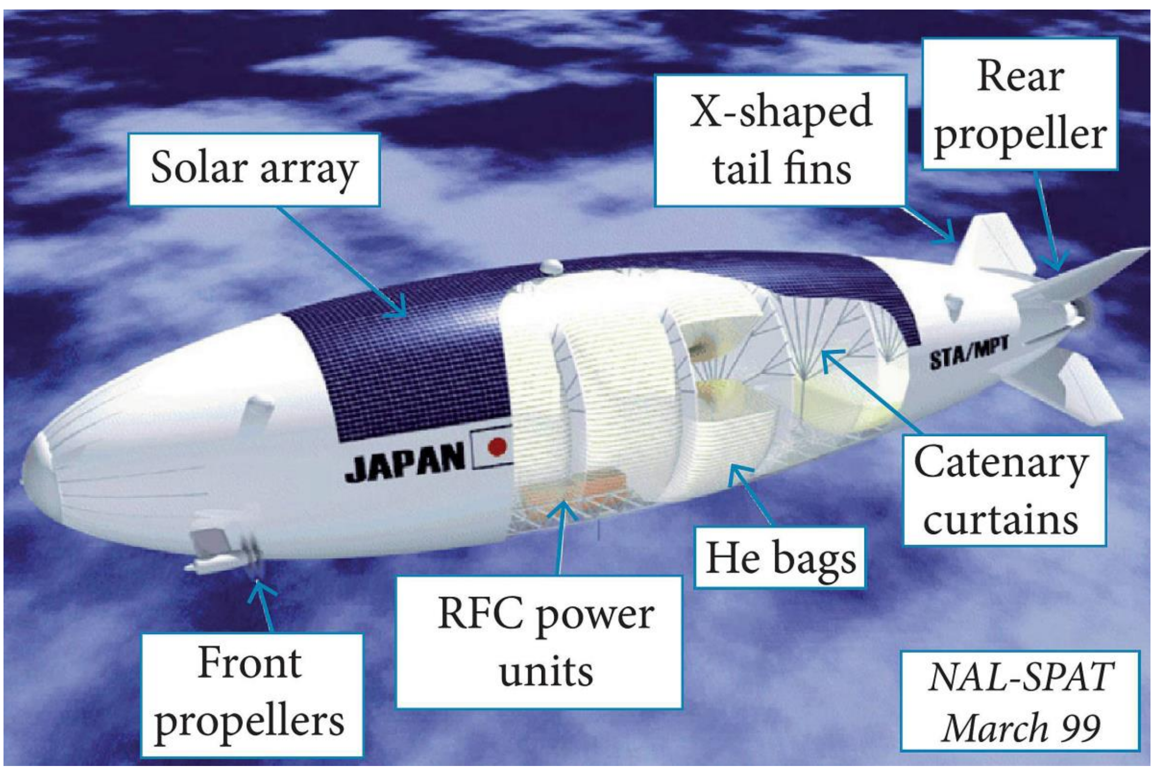
3. The full-scale SPF airship

SPF was designed as a large, semi-rigid, solar powered ellipsoidal airship with two flank-mounted propellers near the nose and a single propeller at the tail. The non-rigid hull is slightly pressurized with air to maintain the shape of the fixed volume hull. Large air ballonets inside the hull are used to manage buoyancy and trim from sea level to the operating altitude at 20 km (12.4 miles), where air density is about $1/15^{th}$ that at sea level. At launch, SPF carries a specified volume of helium in its lift cells. As the airship ascends, the helium expands. At the prescribed operating altitude, the lift cells should be fully expanded, displacing almost all of the air from the ballonets. The airship is at its minimum weight and maximum altitude (pressure altitude).

A long equipment bay forms a rigid keel suspended under the gas envelope. Catenary curtains support the rigid keel and distribute loads directly into the envelope.



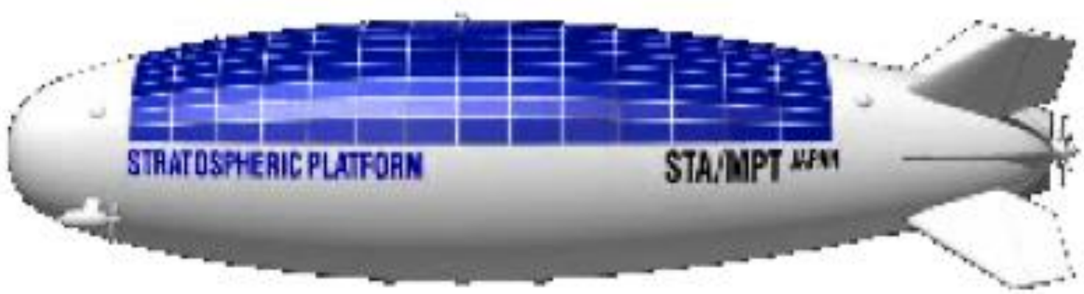
Exterior view of SPF Airship. Source: D. S. Ilcev (2016)



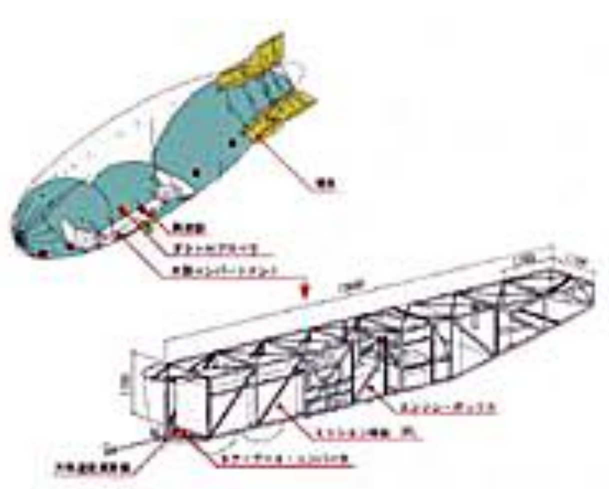
Cut-away view of SPF airship. Source: NAL (now JAXA) circa 1999

Basic airship and mission characteristics are listed below:

- Length: 245 m (804 ft)
- Diameter: 60 m (197 ft)
- Airship mass: 32 metric tons (35.3 tons); about half is the mass of the envelope
- Operating altitude: 20 km (12.4 miles, 65,600 ft)
- Station keeping: hold position in winds up to 30 m/s (67 mph)
- Payload (mission equipment): 1 metric ton (1,000 kg)
- Power source: photovoltaic cells during the day and regenerative fuel cells (RFC) at night
- Power delivery capability: 200 kW continuous power for propulsion & electronics
- Propulsion: 3 x electric motor driven propellers
- Mission duration: 3 years, limited by maintenance requirements
- Airship operating life: about 10 years



Above: Profile view of SPF airship. Source: The University of York



Left: A long, internal equipment bay containing one metric ton of mission-related equipment forms a rigid keel under the gas envelope. Catenary curtains support the equipment bay and distribute the loads into the gas envelope. Source: JAXA, Expectations soar… (2003)

4. The sub-scale technology demonstrators: SPF-1 and SPF-2

SPF-1

The SPF-1 was a 47 m (154 ft) long unpowered, unmanned, blimp-shaped balloon. Using a vertical launch technique developed by Advanced Technologies Group (ATG), SPF-1 was launched at Hitachi Port in Ibaraki, on Honshu Island in August 2003. It reached an altitude of 16 km (9.9 miles, 52,500 ft).

This flight test demonstrated that JAXA could make an airship capable of reaching the stratosphere. SPF-1 carried a small payload that collected samples of green house gases in the atmosphere.
In addition, the flight validated the choice of envelope materials and the buoyancy control and deflation strategies. Deflation was initiated by a small explosive charge that opened up a hole in the envelope to ensure controlled decent under parachute. SPF-1 landed at sea about 29 km (24 miles) from its launch point and was successfully recovered for further examination.

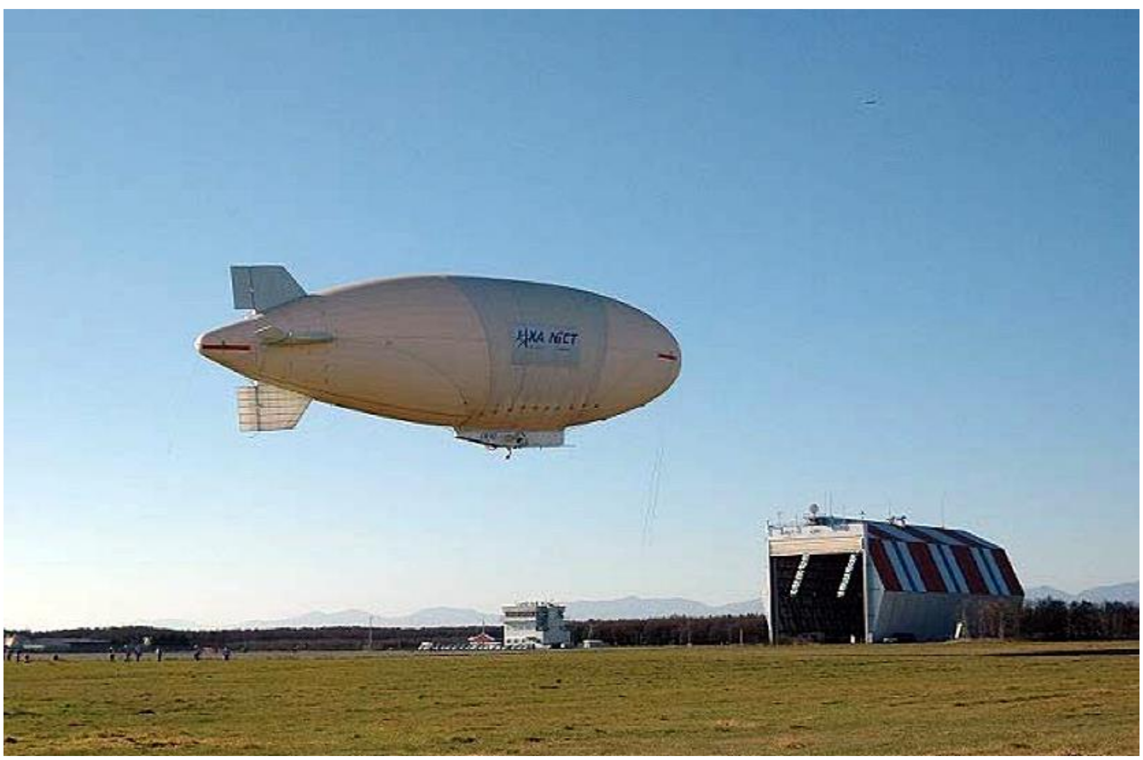
SPF-1 launch at Hitachi Port. Source: USE-HAAS, 2005

SPF-2

Fuji Heavy Industries was the prime contractor for the development of SPF-2, which was a 67 m (220 ft) long, unmanned, non-rigid, fixed-volume airship with a mass of 6.4 tons. The airship maintains its shape from the tension of its outer layer (film) maintained by the pressure difference between gas inside and ambient atmosphere outside. The pressure difference on the ground is very small.

A key technology demonstrated by SPF-2 was the specific strength of the material that comprised the gas envelope. The outer layer of the aircraft was a sandwich structure in which Vectran and a resin film called "EVAL" are sandwiched by urethane. The gas envelope accounted for half of that mass of the airship. JAXA reported: “The thickness of the film is about 0.2 mm (about the same size as a postcard), but it is strong enough to bear 70 kgf of tension even if it is cut into a 1-cm wide rectangular piece.”

The SPF-2 was designed for low-altitude operations while carrying a payload of 400 kg (882 lb), including the mission battery.



SPF-2 low-altitude airship at TARF. Source: USE-HAAS, 2005

In 2004, the SPF-2 conducted eight test flights from TARF and operated at altitudes up to 4 km (2.5 miles, 13,100 ft). The last flight was in November 2004.

These flights were used to build familiarity with airship flight operations and demonstrate the following SPF airship technologies:

- Heat and buoyancy control
- Flight controls
- Station keeping
- Ground handling

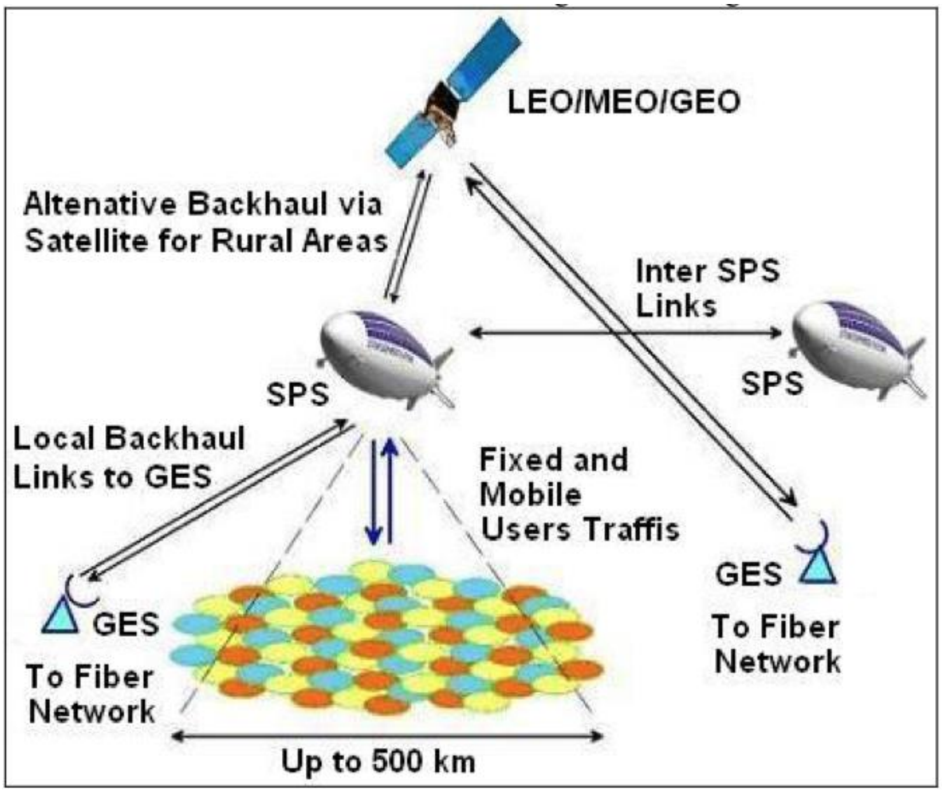
In addition, experiments were conducted with telecommunications and Earth observation payloads from September to November 2004. Specific telecommunications tests included:

- Evaluation of airship-to-ground channel at 2 GHz
- Evaluation of conventional digital HDTV receiver coverage
- Radio location from platform-to-ground
- Free space optical communications ground-platform (acquisition and tracking only)

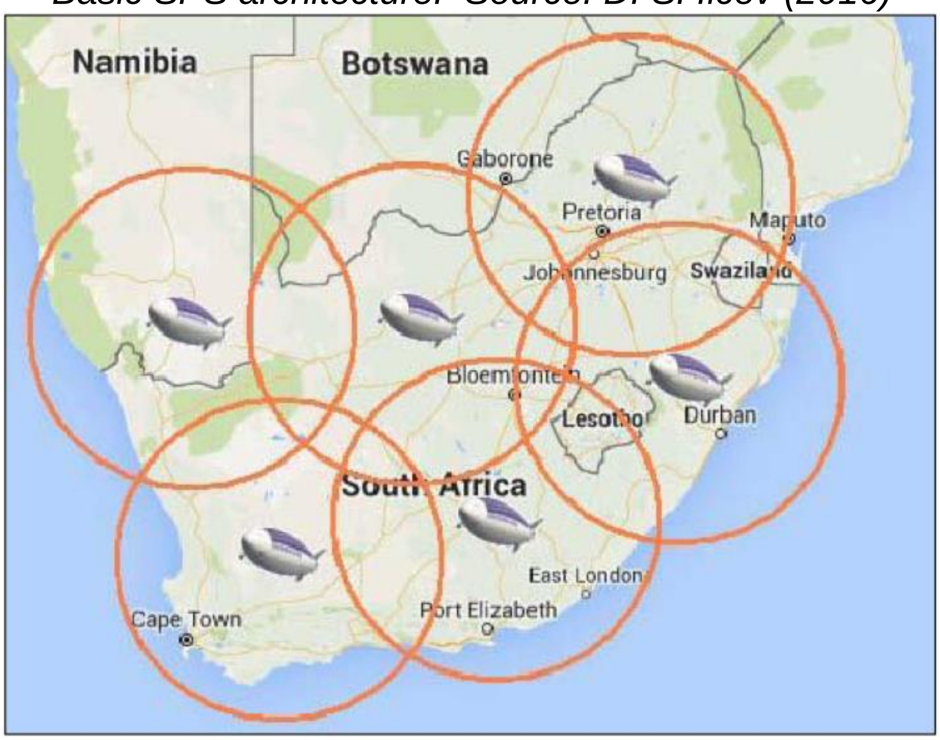
5. The South African connection

In his 2016 paper, “Development of Airship Stratospheric Platform Systems (SPS),” author D. S. Ilcev describes the use of a constellation of SPF-type airships as a component of a Stratospheric Platform System (SPS) that also could include fixed-wing high altitude platforms. The following diagram shows a basic SPS network architecture with interconnections among high-altitude airships, ground stations, orbiting satellites and users on the ground. From its 20 km (12.4 mile) operating altitude, a single airship can serve users within a 500 km (311 mile) diameter coverage area. Coverage for the entire nation of South Africa could be provided by six SPS airships.

You can read this paper here: https://knowledgecenter.ubt-uni.net/cgi/viewcontent.cgi?article=1053&context=conference



Basic SPS architecture. Source: D. S. Ilcev (2016)



Example of regional coverage for South Africa with six SPS airships. Source: D. S. Ilcev (2016)

6. For more information:

- D. S. Ilcev, “Development of Airship Stratospheric Platform Systems (SPS),” International Conference on Computer Science and Communication Engineering, pp. 65 – 75, 28 – 30 October 2016: https://knowledgecenter.ubt-uni.net/cgi/viewcontent.cgi?article=1053&context=conference
- Flavio Araripe d’Oliveira, Francisco Cristovão Lourenço de Melo, and Tessaleno Campos Devezas, “High-Altitude Platforms — Present Situation and Technology Trends,” Journal of Aerospace Technology and Management, Vol. 8, No. 3, July/Sep 2016: https://www.scielo.br/scielo.php?pid=S2175-91462016000300249&script=sci_arttext&tlng=en
- K. Eguchi, et al., “Feasibility Study Program on Stratospheric Platform Airship Technology in Japan,” AIAA, Aerospace Research Central, 22 August 2012: https://arc.aiaa.org/doi/10.2514/6.1999-3912
- H. Naito, et al., “Design and analysis of solar power system for SPF airship operations,” AIAA, Aerospace Research Central, 22 August 2012: https://arc.aiaa.org/doi/10.2514/6.1999-3913
- H. Fuke, et al., “Opening of the New Japanese Balloon Base at the Taiki Aerospace Research Field, Transactions of the Japan Society for Aeronautical and Space Sciences, December 2010: https://www.jstage.jst.go.jp/article/tastj/8/ists27/8_ists27_Tm_25/_pdf/-char/en
- T. Tozer & D. Grace, “USE-HAAS, WP2, 1st Deliverable - Analysis of works and underway programmes,” Creative Technologies Israel Ltd., 27 July 2005: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.607.291&rep=rep1&type=pdf
- D. S. Ilcev, “Global Mobile Satellite Communications for Maritime, Land and Aeronautical Applications”, ISBN: 978-1-4419-5436-7, Springer, Boston, 2005
- Toru Shimizu, “Expectations soar for our huge new airship,” JAXA, 2003: https://global.jaxa.jp/article/interview/no11/index_e.html
- “Stratospheric Balloon Bases of the World, Japan, Taiki Aerospace Research Field, Hokkaido,” StratoCat, http://stratocat.com.ar/bases/74e.htm

- R. Miura & M. Oodo, “Wireless Communications System Using Stratospheric Platforms,” Journal of the Communications Research Laboratory, Vol.48, No.4, pp 33 – 48, 2001: http://www.nict.go.jp/publication/shuppan/kihou-journal/journal-vol48no4/toku3-2-1.pdf