TAO Group Airships

Peter Lobner, updated 10 March 2022

1. Introduction

TAO Trans. GmbH was founded in Germany in 2001 and evolved over the next decade, along with TAO Technologies GmbH in Stuttgart, into TAO Group GmbH, which has developed a range of airship technologies, including the solar powered airship *Lotte* and the segmented, high altitude airship *SkyDragon*.

Sources: (L) NAA Noon Balloon, Fall 2016, (R) TAO Group

Dr. Bernd Kröplin, president of TAO Technologies GmbH, developed the concept of the tadpole-like segmented airship as a means to provide lift while avoiding some of the structural and aerodynamic problems associated with very large airships. TAO first publicly presented the prototype of their patented, segmented *SkyDragon* airship in 2005. By then, TAO had already built more than 30 prototypes, the largest of which was 70 meters (230 feet) long.

In June 2008, TAO Group GmbH and the US firm GlobalTel Communications entered into a business arrangement and formed Sanswire-TAO LLC. Regarding this business arrangement, TAO Group provided this 2020 retrospective report on their website:

> "Starting in 2005, Sanswire, an American Company, was interested to learn more about our technology and airship '*Lotte*', the high altitude platform '*SkyDragon*' and the autonomous parachute system 'ALF.' In 2008 a Joint Company was established by the name of 'Sanswire-TAO' in Florida. The American partners should cover the marketing part of the

German products for the US, Mexico and Canada. In the year 2010 the cooperation was closed (ended). The rights of our technology still belong to our TAO-Group in Germany."

While the joint company Sanswire-TAO was in existence, TAO-developed technologies were rebranded for the US market:

- Starting in June 2008, *Lotte* was operated in the US by Sanswire-TAO and was renamed the Sanswire Autonomous Solar (SAS) airship, with the designation SAS-51.
- In early 2010 the STS-111 segmented airship was delivered to the US for demonstration flights, and was renamed *Argus One*.
- The ALF autonomous recovery system was rebranded for the US market as the Precision Air Drop Delivery System (PADDS).

A key business goal of the joint company was the development of a larger segmented airship based on the design of TAO's STS-111 and capable of operating in the stratosphere with larger payloads on long-duration missions.

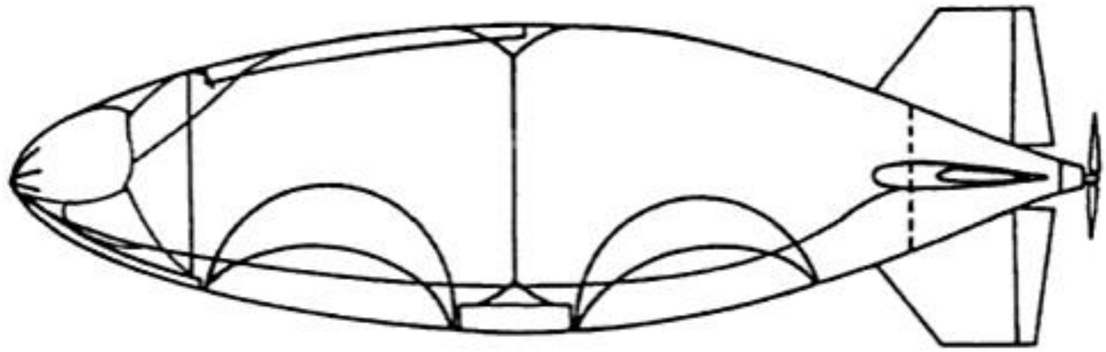
In 2020, the TAO Group consists of the independent companies TAO Trans Atmospheric Operations GmbH, TAO Technologies GmbH in Stuttgart and Berlin, TAO Neue Antriebstechnologien GmbH, TAO UK and cooperating companies with various partners. Since its breakup with Sanswire in 2010, TAO Group has been active in developing their segmented, high altitude platform *SkyDragon*.

The TAO Group website is at the following link: https://www.tao-group.de/en_index.html

2. TAO solar powered airship *Lotte*

In 1992, Prof. Dr. Bernd-Helmut Kröplin and student assistants designed and built the compact, semi-rigid, super-pressure, solar-powered airship named *Lotte* under a long-term airship development initiative between TAO Group and the University of Stuttgart. *Lotte* was 16 m (52.5 ft) long, with a maximum diameter of 4 m (13.1 ft), a total volume of 109 m^3 (3,849 ft^3) and a weight of about 100 kg (220 lb). The 7 m^2 (75.3 ft^2) photovoltaic array had a peak output of 1.123 kW, which supplemented 1.08 kWh available from the battery.

Propulsion was provided by a single, tail-mounted, electric motor driven, thrust vectoring propeller that enabled a maximum speed of 46 kph (28.6 mph).



Lotte profile view. Source: Airship Technology, Khoury, Fig15.21

After Lotte-1, Lotte-2 and -3 were built and continued flying until about 2014.

TAO Group describes their pressurized hull design as follows:

> "The airship was built in a semi-rigid construction. The hull, as a pneumatic supporting structure, is supported by rigid elements, known today as Tensegrity. The rigid structural parts of the airship are the nose structure, the system shaft, the central shaft, the tail unit cross and the stern pot with engine mount. The load-bearing stresses in the hull result from the internal pressure. In the bow area, a rigid bow cap with attached stringers provides the necessary stiffness. In the stern area, the unit consisting of the tail unit cross, connecting rods and stern pot forms a rigid unit which makes it possible to introduce both the propulsion forces caused by the thrust vector and those occurring obliquely to the center axis, as well as the tail unit forces into the hull."

The pressurized hull had a Tedlar outer skin and Mylar helium cells with a low helium diffusion rate of about one liter per day (there are 1,000 liters in a cubic meter). Buoyancy and trim angle were controlled with two ballonets (fore and aft) that accounted for up to 20% of the interior volume.

The solar electric power system was supplied with a maximum of 720 watts of power from flexible solar panels mounted on the top of hull. The solar panels charged onboard batteries that supplied electric power to airship systems (flight control, navigation and communications systems, propulsion system, rudder actuators, ballonet fans and vent valves) and payload systems. All systems could be monitored from a ground station in real time.

2007 test flight. Source: Screenshot from Sanswire YouTube video

You can watch a short video of a *Lotte* flight test here: https://www.youtube.com/watch?v=Md7w84yqB9I

In subsequent flight tests, *Lotte* achieved a maximum altitude of about 1,000 meters (3,280 ft.) and a maximum speed of 46 kph (28.5 mph). A 300 km (186 miles) flight could be accomplished in about 6 hours. Lotte participated in the 1993 solar race in Australia and a 2000 solar initiative in Switzerland.

From June 2008 until the dissolution of the joint company Sanswire-TAO in 2010, Lotte operated in the US under the designation SAS-51. After the joint company was dissolved, *Lotte* was returned to TAO Group. In November 2014, surviving parts of *Lotte* were presented to the Zeppelin Museum in Friedrichshafen, Germany.


A modern version of Lotte. Source, three photos: TAO Group

The TAO Group continues to offer a modern, small airship derived from the original design of *Lotte.*

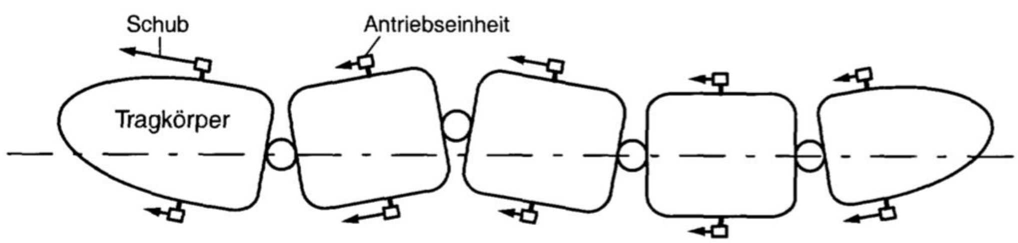
TAO Group claims that *Lotte*, which first flew in 1992, was “the first autonomously flying solar airship in the world.” Perhaps, but the first remotely controlled flying solar airship in the world was the XEM-1 designed by Michael Walden and built and flown in 1974 by US firm Lighter Than Air Solar (LTAS). The XEM-1 conducted additional flights in August 1977 for the US Department of Defense and Department of Energy. For more information, see my separate article on Michael Walden / LTAS.

3. TAO segmented airship patents

Three key patents that illustrate the evolution of the design and operation of the TAO segmented airship are briefly summarized below:

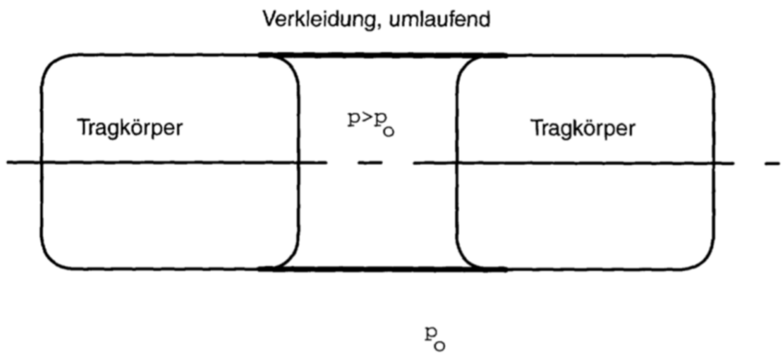
- **DE10010647A1**, "Aircraft composed of a number of linked bodies in succession has drives on the sides of the bodies with an automatic thrust control to give a controlled flight," filed 3 March 2000, published 6 September 2001, Inventors: Bernd-Helmut Kröplin, Frank Epperlein, Ralf Schubert & Ralf Kornmann

  This patent describes a segmented airship comprised of several movable, coupled "support bodies" (tragkörper) containing lift gas and arranged one behind the other, with their movement coordinated via thrust (schub) from drive units (antriebseinheit) on the sides of each support body. This operating principle is shown in the following patent figure.



Top view of the segmented airship

  This flexible design is intended to greatly reduce static and dynamic bending moments, allowing much lower structural strength and mass. Flight stability of the entire airship is achieved by automatic control of the support bodies. A lightweight aerodynamic fairing (verkleidung, umlaufend) attached between the support bodies maintains its shape by being inflated to a slight positive gas pressure, as shown in the following patent figure.

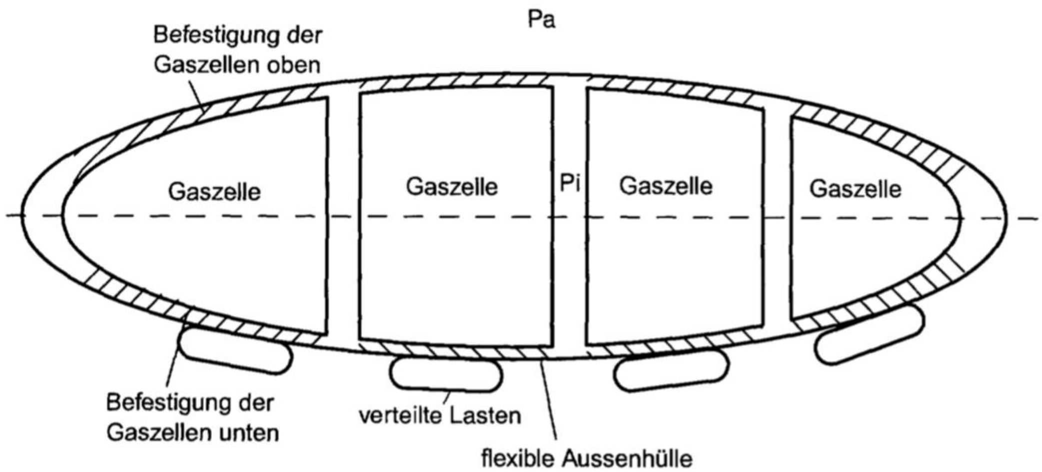


You can read this patent in English here:
https://patents.google.com/patent/DE10010647A1/en

The German version with figures is here:
https://depatisnet.dpma.de/DepatisNet/depatisnet?action=pdf&docid=DE000010010647A1&xxxfull=1

- **DE10053775A1**, "Air vehicle, lighter than air with flexible outer hull and several separated inner gas cells, has gas cells fastened above and below hull and stability of hull against bending moments generated by inner excess pressure," filed 30 October 2000, published 8 May 2002, Inventors: Bernd-Helmut Kröplin, Frank Epperlein, Ralf Schubert, Ralf Kornmann & Andreas Kunze

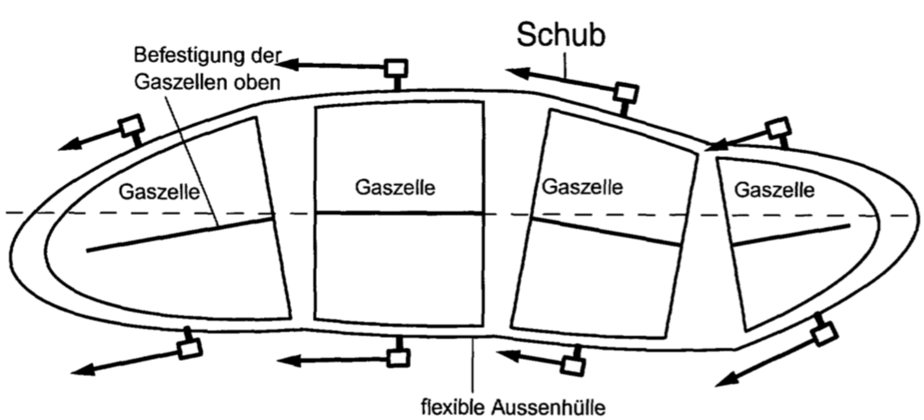
  This patent describes a segmented airship with a flexible outer hull (Aussenhülle) and several separated inner gas cells (Gaszelle) that are aligned one behind the other and are fastened top and bottom to the outer hull (befestigung der Gaszelle oben / unten). As shown in the following side view, static bending moments between sections of the outer hull are largely avoided by distributing loads (verteilte Lasten) among the different gas cells, each of which contains lift gas.



Side view of the segmented airship

A slightly positive pressure inside the outer hull (Pi > Pa) maintains the stability of the outer hull against dynamic and static bending moments while allowing for relative movement of the gas cells.

The following top view of a segmented airship shows the separated gas cells (Gaszelle) within the flexible outer shell (Aussenhülle) and the degree of flexibility allowed by the separate connections between the gas cells and the outer shell (befestigung der Gaszelle oben). Flight control is maintained with thrusters (schub) on each segment.



Top view of the segmented airship

You can read this patent in English here:
https://patents.google.com/patent/DE10053775A1/en

The German version with figures is here:
https://depatisnet.dpma.de/DepatisNet/depatisnet?action=pdf&docid=DE000010053775A1&xxxfull=1

- **DE102008002939A1**, "Segmented aircraft with energy medium," filed 11 July 2008, published 14 January 2010, Inventor: Bernd-Helmut Kröplin

  With reference to patent Figure 1 (side view, below), this patent describes a segmented airship with a flexible outer shell (28), within which are a series of interconnected air cells (11,12,13 & 14), and, within these, a series of interconnected gas cells (21, 22, 23 & 24) that form a continuous volume surrounded by the air cells. A fan (5) in segment 1 introduces ambient air to the air cell volume and generates a slight overpressure within that continuous volume, enabling the airship to maintain the dimensional stability of the flexible outer shell (28).

  The interconnected gas cells (22, 23 & 24) carry a gaseous "energy medium" that has the approximate density of air. This neutrally buoyant energy medium is a mixture of suitable low density hydrocarbon gases (propane-butane or other mixture) known as "fuel gas," which is used to fuel the engine that propels the airship.

  A thrust vectoring propulsion unit (4), consisting of an engine, propeller, and flight controls, and a landing gear (3) are mounted beneath segment 1. The vectored thrust of the engine (T1, T2) generates enough dynamic lift for stable flight as the airship moves through the air.

  With reference to patent Figure 2 (top view, below), lift generation is aided by a canard wing (8) on segment 1 and smaller wings (7) on the trailing segments. A banner (6) attached to the tail can help improve positional stability.

Fig 1

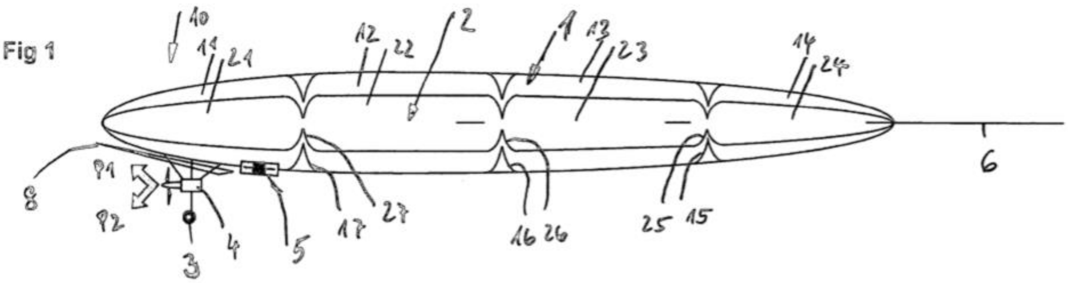
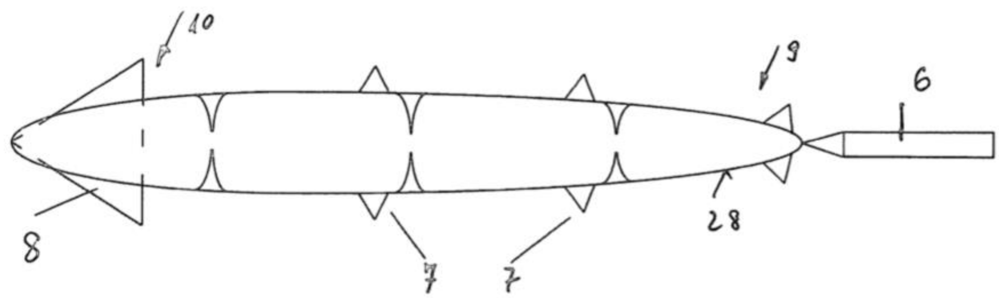


Fig 2



The patent also describes the option to use a lift gas to partially fill the gas cells. This design, with lift gas in segment 1 rather than fuel gas, was implemented by TAO in their STS-111 prototype.

You can read this patent in English here:
https://patents.google.com/patent/DE102008002939A1/en

The German version with figures is here:
https://depatisnet.dpma.de/DepatisNet/depatisnet?action=pdf&docid=DE102008002939A1&xxxfull=1

4. The TAO STS-111 segmented airship

The STS-111 is a 111-foot (33.8-meter) long, 11.2-foot (3.4-meter) diameter, non-rigid, four-segment airship. It is designed to operate as a surveillance platform at medium altitudes between 10,000 and 30,000 feet (1.9 to 5.7 miles, 3 to 9.1 km). From this operating altitude, an STS-111 can provide an operational line of sight of up to a 124 mile (200 km). Propulsion is provided by a small, one-cylinder, four-stroke engine mounted under the first segment of the airship. The engine has a 360° azimuthal thrust vectoring capability.

STS-111 mid-altitude, long-endurance UAV segmented airship shown on the ground in 2009. Source: Sanswire-TAO

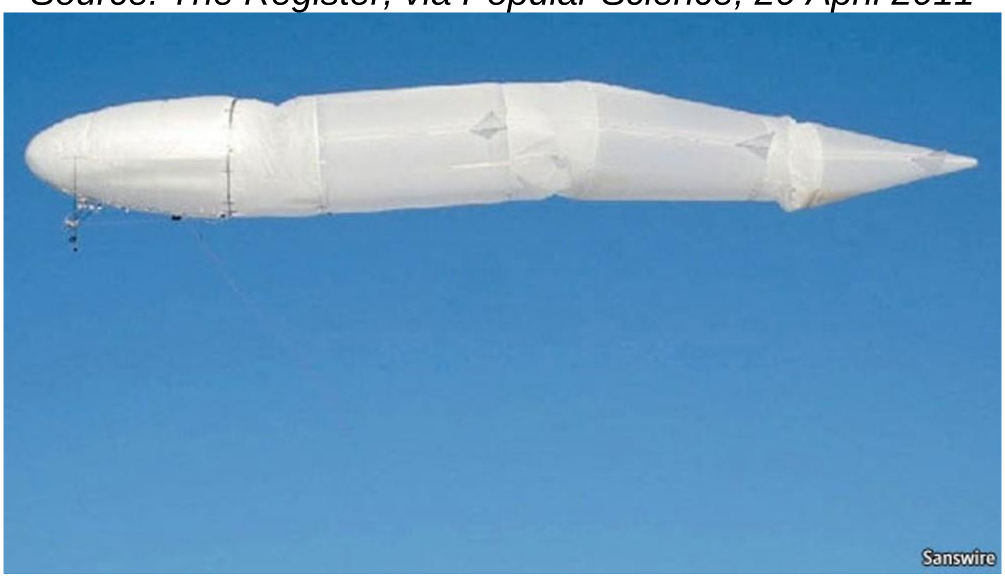
Only the first segment of the airship contains helium lift gas. The engine runs on fuel gas, which is a neutrally buoyant mixture of low density hydrocarbon gases (propane – ethane was used) stored in segments 2, 3 and 4. Since the fuel gas has the same density as atmospheric air, the airship's buoyancy remains the same as it burns off its fuel supply. The gas cells are surrounded by air cells within the flexible outer shell. As the fuel gas is consumed, the gas cells contract and the air cells expand to maintain the airship's mass and shape. The 1930s dirigible *Graf Zeppelin* also used fuel gas.

TAO claims that the segmented airship can maintain its heading into the wind while the "tail" wiggles with the wind. This makes the segmented airship a more stable platform than traditional LTA designs in the face of wind gusts or wind shear, providing better station keeping and takeoff / landing characteristics.

The STS-111 has been designed to rapidly unfold from its standard-size crate and be prepared and tactically launched from virtually anywhere with minimal ground crew and no need for a large hangar or runway.

You can watch a short (4:09 minute) video of the 18 December 2009 test flight of the STS-111 in Stuttgart, Germany here: https://www.youtube.com/watch?v=uMZvVcqmg1E

STS-111 segmented airship in flight.
Source: The Register, via Popular Science, 20 April 2011



STS-111 segmented airship in flight.
Source: Sanswire-TAO, via The Economist, 6 May 2010

In early 2010 the STS-111 completed initial flight testing in Germany and was delivered to the US for demonstration flights. See my separate article on Sanswire and World Surveillance Group Inc. (WSGI) airships for more information on STS-111 / *Argus One*.

Artist's rendering of an STS-111 with carbon fiber winglets on all of the trailing segments to aid with lift, steering and overall stability. Source: Sanswire-TAO Corp.

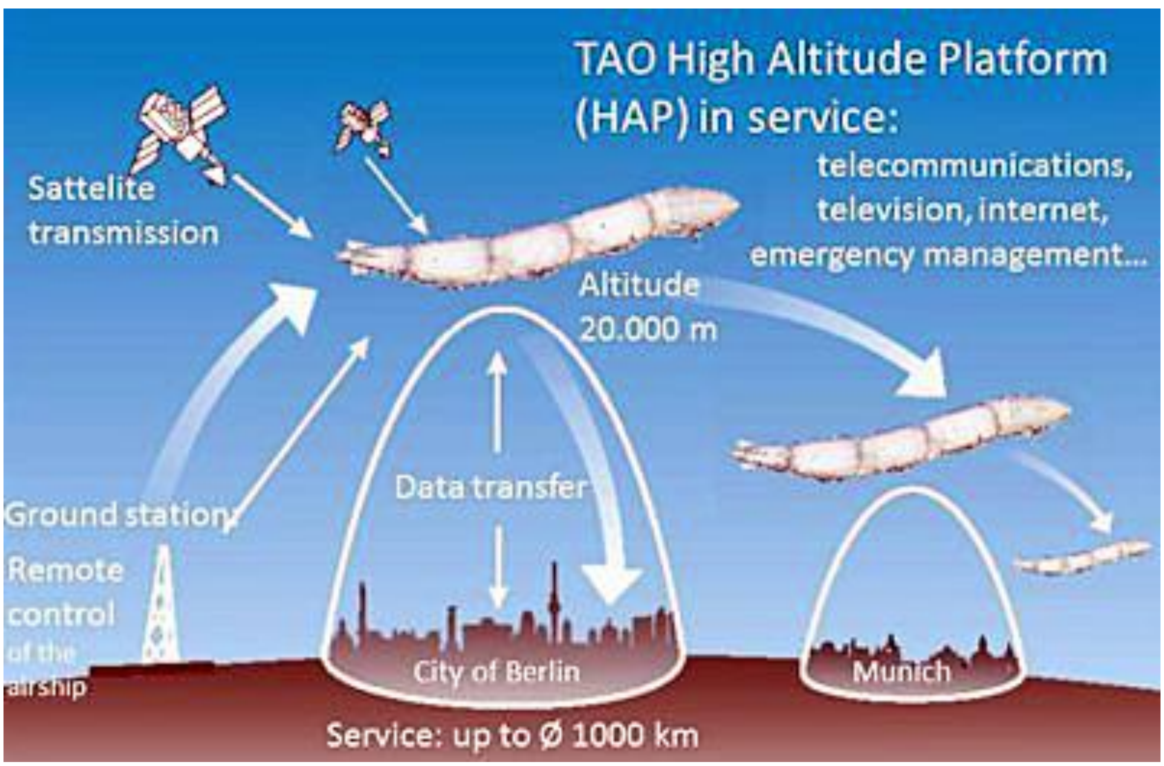
5. TAO *SkyDragon* segmented airship (after 2010)

TAO Group's current high altitude platform (HAP), *SkyDragon*, is an evolutionary development of the segmented STS-111.

Artist's rendering of SkyDragon flying in the stratosphere. Source: TAO Group

You can watch a short video introducing the *SkyDragon* on the TAO Group website here: https://www.tao-group.de/filme/SkyDragon_Video.mp4

SkyDragon is designed to launch and land on the ground and fly with its own propulsion to a designated station keeping point in the stratosphere at altitudes up to 20 km (12.6 miles). At that altitude, *SkyDragon* has a terrestrial line-of-sight coverage area that is about 300 km (186.4 miles) in diameter, within which it can deliver a consistent level of service to urban, suburban and rural customers. Managing data transfer among satellites, ground infrastructure, and other airborne communication nodes, *SkyDragon* is intended to deliver network & connectivity services for a wide range of applications. This concept of operations is illustrated in the following TAO Group graphic.



SkyDragon concept of operations. Source: TAO Group

SkyDragon also has been proposed as a high-altitude test platform for systems intended for future orbital applications.

Scale of SkyDragon is evident in the hangar. Source: TAO Group

In an emergency management role, *SkyDragon,* coupled with the "ALF" autonomous parachute system, could be used as a medium-to-low altitude delivery vehicle. TAO explains:

"An immediate help with medical products, accommodations, clean water and food can be provided by the GPS directed autonomously controlled airborne support system ALF. The ALF parachute system allows a pinpointed preprogrammed autonomous landing of products from aero planes or airships. Substantial losses of goods by unprecise landings as has been lived with the actual systems can be avoided by the new internal intelligence of the ALF system."

Rendering showing emergency supplies being dropped from SkyDragon using ALF for pinpoint delivery. Source: TAO Group.

6. For more information

Lotte

- Thorsten Lutz, et al., "Summary of Aerodynamic Studies on the Lotte Airship," Institute for Aerodynamics and Gas Dynamics, University of Stuttgart, 4th International Airship Convention and Exhibition, 28-31 July 2002,, Cambridge, UK: https://www.yumpu.com/en/document/read/22414078/summary-of-aerodynamic-studies-on-the-lotte-airship-iag-
- U. Ruger, F. Blank & B. Kroplin, "Acquisition of Flight Data Such as Drag and Propeller Thrust by a Remote Controlled Solar Airship," AIAA, Aerospace Research Council, 22 August 2012: https://arc.aiaa.org/doi/10.2514/6.1999-3908

STS-111 / SkyDragon

- Michael Klesius, "Sky Snake – Flexible blimps are bending the rules on UAV design," Air & Space, 18 December 2009: https://www.airspacemag.com/flight-today/sky-snake-2630679/
- "SkyDragon (HAP) testing in Scotland by TAO Tech. UK Ltd," TAO Tech UK / Trans Atmospheric Operations, 21 September 2018: http://www.taotechuk.com/news/skydragon-hap-testing-scotland-tao-tech-uk-ltd/

Other *Modern Airships* articles

- *Modern Airships - Part 1*: https://lynceans.org/all-posts/modern-airships-part-1/
  - Walden LTAS Part 1_Lenticular toroidal DCB airships
- *Modern Airships - Part 2*: https://lynceans.org/all-posts/modern-airships-part-2/
  - Sanswire & WSGI airships

Modern Airships - Part 3: https://lynceans.org/all-posts/modern-airships-part-3/