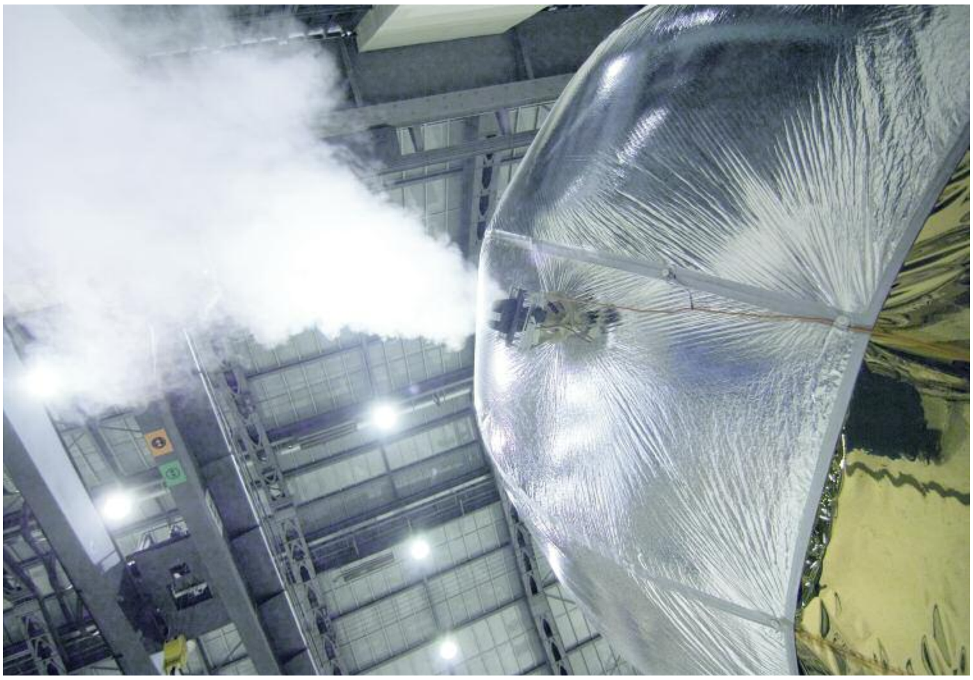
HeiDAS UH

World launch!
Hot-Steam Aerostat

Info

HeiDAS UH – An Innovative High-Flyer with Steam



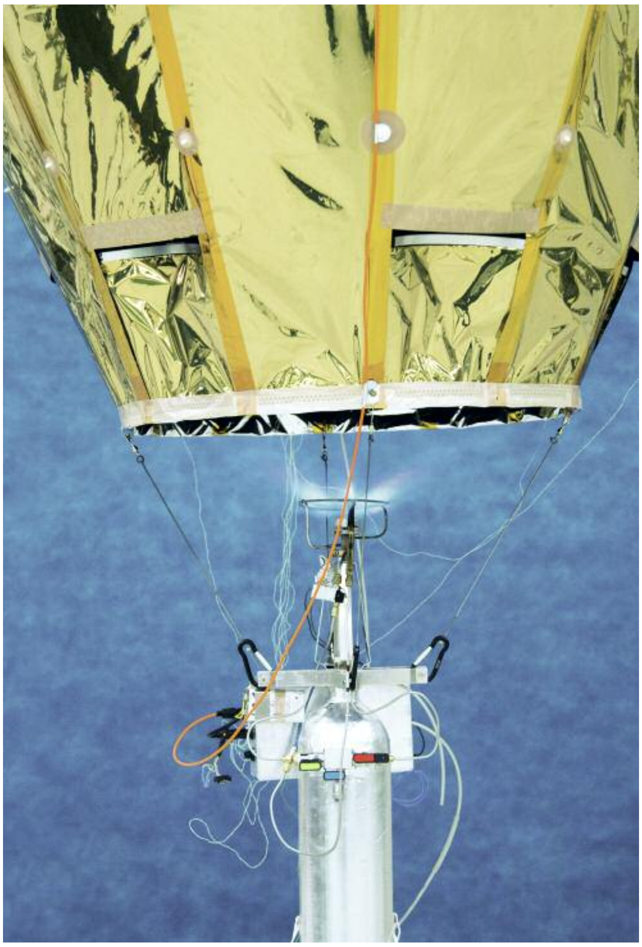
HeiDAS lets off steam. Short before take off in the hangar at the Technical University of Berlin.

Aerostat
Balloons and airships are called aerostats – derived from aerostatics, which is the type of aviation specifically based on the difference in gas densities. Similar to a boot on water, and thanks to their static buoyancy, balloons and airships float on air. As a consequence, their motion is called cruising or lighter-than-air cruising, respectively – planes and helicopters, on the contrary, create dynamic lift by moving through air actively (generating directional or rotational velocity). The latter is called flying.

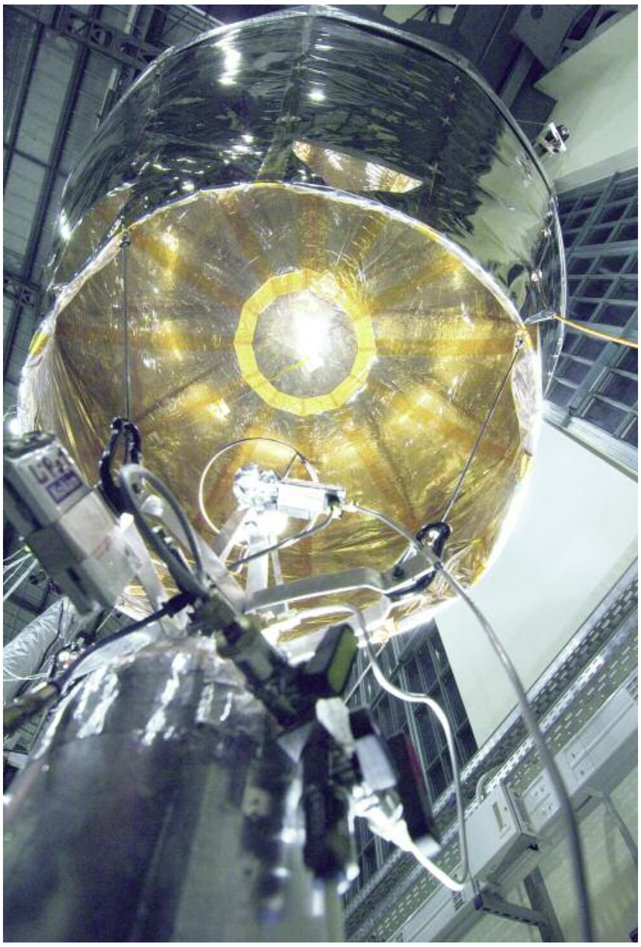
“If you intend to view the land, if you plan on rising or sinking as you please, this won’t be able to do without loosing gas! Until now there weren’t any other means of cruising, though, and gas leakage has always been an obstacle to long distance airship travelling!”… “My way of sinking and rising depends solely on gas compression and expansion – gas that has been captured inside the envelope – by means of different temperatures.” Cited from Jules Verne: “Fife weeks on a balloon”.

HeiDAS stands for HeißDampfAeroStat (Hot-Steam AeroStat) and it refers to the first operable balloon ever that became buoyant by means of superheated steam.
The performance of HeiDAS UH (UH = ultra-hot) ranks between that of a helium balloon and that of a hot-air balloon, however, HeiDAS UH uses a downright cheap, non-flammable, and invisible buoyancy-gas, which is steam. Steam shows almost three quarters of the buoyancy of helium and two and half times the buoyancy of regular hot-air balloons.

When beginning the multidisciplinary research on HeiDAS there was the question of what other and cheaper buoyancy-gas could be used for lighter-than-air aviation. Helium is expensive, whereas hot-air only facilitates payloads one third the amount of those for helium. This leads to voluminous, low-performing structures that are susceptible to winds. Hydrogen is less expensive and more powerful, yet it is flammable and therefore ruled out due to regulatory constraints. When the idea “steam?!” came up for the first time, it was smirked at initially, however, reflected more seriously after-



Gondola with flight measurement and controller box.



Heat-exchanger. Tested under temperatures above 300 °C.

wards. But what materials could resist steam, how do you keep up steam temperature, and how do you avoid steam condensing along the balloon envelope? As initial experiments showed, droplets of condensed water increased envelope weight, and hence, water had to be re-evaporated causing additional effort – effort that almost led to the abandonment of this novel approach. Only through the application of a new, ultra-light and flocked insulation material superheated steam could be maintained also close to the envelope. In retrospect, this turned out to be the onset of one of the most exciting and comprehensive innovations of lighter-than-air aviation. In 2003, the first HeiDAS prototype was finished and successfully tested under laboratory conditions. However, it was not until the materials as well as the operational concept were further improved that initial outdoor-cruises became possible.

The second HeiDAS prototype is a novelty in terms of type and construction – it consists of an insulated gas-container holding 6,8 cubic meters of steam combined with a cone-shaped bottom part holding hot-air. A remote-controlled, adjustable propane-gas burner heats up the gas-container bottom, and thus, allows for heat loss compensation as well as vertical steering. Thanks to the insulation this prototype uses only a fraction of the fuel a regular hot-air balloon of comparable lift consumes. As far as we know, HeiDAS UH is the hottest aerostat ever rising up into the air. It provides a new and tangible vision concerning the field of lighter-than-air technology.

Historical facts

Benjamin Franklin, then American ambassador to France, watched the first launch of a hydrogen balloon on August 27, 1783.
When asked by somebody about the purpose of this new invention, he replied: “What purpose does a new-borne child have?”

On November 21, 1783, the Marquis d’Arlandes and Pilâtre de Rozière were the first men lifting off into the air for a half hour trip in a Montgolfière – named after the brothers Joseph und Etienne Montgolfière. Just ten days later, on December 1, 1783, Professor Jacques Charles, together with his assistant Marie-Noel Robert, embarked on a one hour cruise – including a deliberate stop-over – on board the “Charlière” from the Tuileries in Paris. While the Montgolfière used hot-air for buoyancy, the “Charlière” applied the most powerful buoyancy-gas – hydrogen.

As early as 1816, Sir George Cayley wrote an essay on aerial navigation in “The Philosophical Magazine and Journal”, discussing the advantage of using steam instead of air. Moreover, he also elaborates on the fact that, although the initial amount of gas needed represents more energy, reduced friction of the resulting smaller aerostat makes up for that. Almost 100 years later, in 1908, Dr. Hugo Erdmann claimed a patent on deploying superheated steam as buoyancy-gas for aircrafts in Charlottenburg. His patent also comprised any kind of buoyancy-gas made from a mixture of steam and other gases. In addition, he suggested using eiderdowns for balloon insulation. However, it wasn’t before innovative materials, designs,

Steam leaving the diffusor. Condensation makes the steam visible.

Steam
Commonly, what is considered steam is visible water vapour from partially condensed saturated steam, such as clouds and fog. Technically and scientifically speaking, however, steam is gaseous water, and thus, invisible as air. A super heater is part of a boiler, which superheats saturated steam beyond its evaporation point. To do so, saturated steam is further heated, which leads to superheated steam. Superheated steam is completely dry and temperature wise lies beyond the saturation temperature (re-condensation point).

and development strategies have become available today that patents that have been around for 100 years can be put into practice.

Steam used as buoyancy-gas

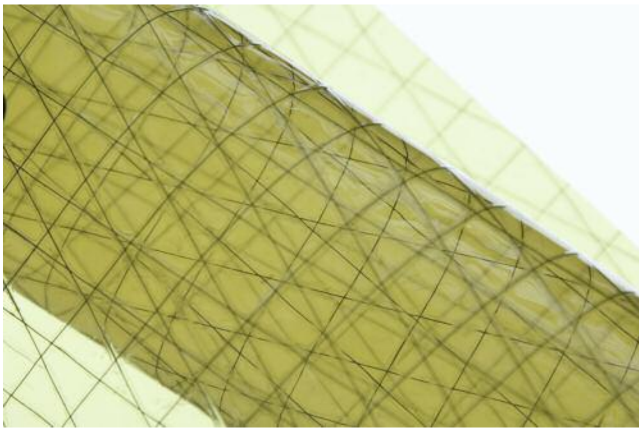
At 120 °C, the weight of steam is about half the weight of air – which means, steam is generating twice the buoyancy of air at the same temperature. The energy content of one kg of propane-gas allows for evaporating 15 kg of water – which generates 25 cubic meters of steam representing 15 kg in lifting capacity. In comparison, to achieve equal buoyancy requires 15 cubic meters of helium at a cost of some 100 Euros – about ten times the cost of steam.

To fill the superheated steam aerostat requires a huge amount of steam over a short period of time. A classic steam generator, using a boiler, creates saturated steam, which then has to be dried and superheated in a subsequent super heater to produce steam of more than 100 °C. In contrary, HeiDAS uses a novel way of steam generation, which is derived from aerospace science. Like in a rocket engine, hydrogen and oxygen react at 3000 °C inside a steam reactor in order to generate steam. The reactor itself is the size of a tennis ball. By mixing in cooling water the desired steam temperature can be brought down to 120° to 300 °C. Operated in parallel, two of these mini-reactors can provide 30 kW of power filling a steam balloon of 6.8 cubic meters in less than 6 minutes. This forward looking steam generation principle deploys hydrogen as the energy carrier of the future. Steam reactors like these are capable of providing high purity steam in short periods of time. For the future, not only steam generators will be operated on hydrogen but also various kinds of other propulsion- and blower systems.

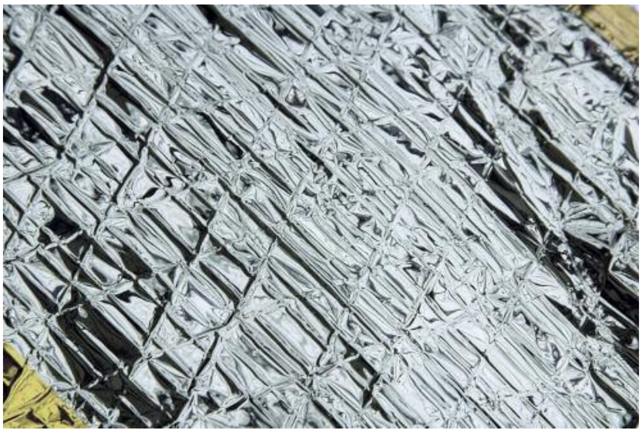
Design and operation principle

The HeiDAS-balloon is modelled after the Rozière-principle, that is, the buoyancy-gas is stored in a spherical and sealed container made from polymer film. The container is filled once before launch. In order for the steam to maintain its temperature of up to 150 °C during flight and to avoid condensation, the container is insulated and diffusing heat is recharged using a heat exchanger. Placed between heat exchanger and gondola, a propane super heater generates an adjustable hot-air stream which heats up the heat exchanger to 260 °C and more.

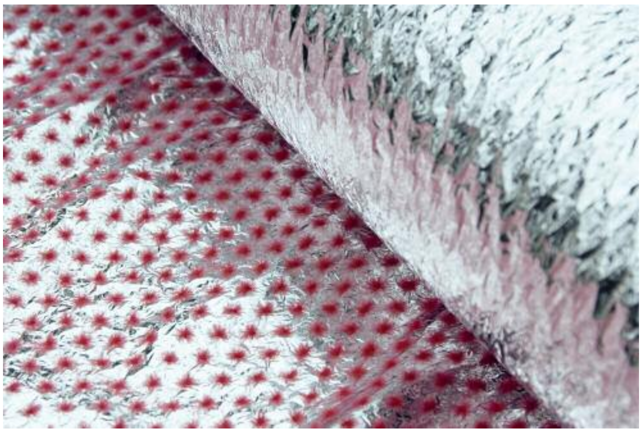
Similar to a hot-air balloon, buoyancy can be boosted through increased heat supply from the burner. Conversely, the balloon sinks if the buoyancy-gas cools down. Hence, unlike a gas-balloon there is no need for HeiDAS to carry along ballast weight as weight reduction during the cruise can be compensated for through steam and temperature control. As a result, the boost in buoyancy through the application of steam fully benefits an increased carrying capacity. Moreover, the necessary insulation reduces fuel consumption, and thus, makes up for its own additional weight especially during longer cruises.



Groundbreaking – steam proof films resists temperatures of 350 °C.



Smart – reflective coatings are reducing heat losses and temperature peaks.



Ingenious – ultra-light, compressible flock insulation.

New materials and material concepts

A technical revolution was achieved not only through the application of steam but also by developing novel envelope and insulation materials and concepts.

The HeiDAS envelope – a kettle made from polymer film

The HeiDAS envelope is made from flexible polymer films. In most cases, steam and high temperatures degrade plastic materials leading to brittleness and reduced stability. Although new materials, such as silicones and fluoric polymers are much more resistant, they aren't proof enough to hold back steam. A gas-tight silicone coating was applied with the first HeiDAS prototype that was able to even retain large amounts of air and helium. However, steam was permeating the membrane about 200 times faster than the much smaller rare-gas molecules, challenging the design team to develop an entirely new material. The result is the HeiDAS laminate – a polyimide film reinforced by aramid filament yarn.

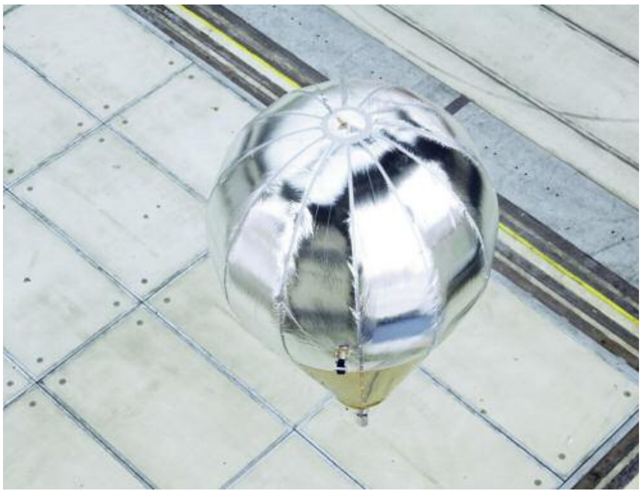
According to the design specifications, the HeiDAS heat exchanger is exposed to temperatures of up to 260 °C, which is tolerated not only by the polymer films but also the high-performance bonds made from Polysiloxan. The materials and bonds were pre-tested under high-temperature and steam conditions for more than 1000 hours. Even when exposed to combined thermal and mechanical stress, stability losses for both, materials and bonds were low and the remaining performance was still ways above minimal requirements. As such, all obstacles were cleared concerning the built of a model balloon prototype.

Even temperatures of more than 310 °C over a short period of time during the tests didn't do any harm to the envelope. This was probably the highest temperature ever deliberately generated against a balloon envelope. The envelope of the HeiDAS UH prototype, thus, has been proven to not only resist degradation from steam and heat but to also prevent steam from permeating the membrane. Reflective coating was applied to the polymer films in order to minimize heat loss.

Super-insulation-flock-material

The HeiDAS development yielded the lightest and most powerful reversibly compressible insulation currently available. The new super-insulation-flock-material prevents steam from condensing along the inner-envelope and reduces the energy consumption necessary for keeping the buoyancy gas at temperatures of up to 150 °C. The optimised insulation for HeiDAS weighs only 8.5 kg/m^2 and shows a very low thermal conductivity of just 0.035 W/mK even at high median-temperatures of nearly 100 °C. The super-insulation-flock-material consists of multiple membranes stacked evenly through flocked fibres. This generates a cluster of layers of air showing a thermal conductivity similar to that of steady air. HeiDAS is the prototypical application for the super-insulation-flock-

Burner with swirl-nozzle. Last check before flight.



HeiDAS UH in the air – more than 30 successful test flights.

material. Thanks to optimization work conducted at HeiDAS UH, the insulation necessary could be reduced from 21 to 7.5 mm in thickness. 7.5 mm is exactly the gap width which shows the highest efficiency concerning a single layer of insulation; beyond that point, the insulating air shows an increased tendency for convection.

Balloon burner with swirl-nozzle

A typical standard balloon-burner system consists of tank, valve, supply hoses, super heater coils, and injection nozzles. The mixing of fuel and oxygen occurs in a quasi open combustion chamber after the propane gas exited the nozzle. Developing HeiDAS required the design of special burner, for the Rozière-construction allows for only a small distance between the gondola and the balloon envelope around the heat exchanger. With regular pointed flames the local temperature peak would be either too high or, when throttling the burner, the resulting heat flow would be too low. As such, the custom designed HeiDAS UH-burner uses particular nozzles allowing for better mixing of fuel and air, and thus, improving the flame pattern as well as temperature distribution around the heat exchanger. Efforts to minimize burner size hit technological limits when it came to designing nozzles of less than two tens of a millimetre in diameter. Moreover, these efforts were not only directed at improved power ratings but weight reduction as well. As a result, the HeiDAS UH-burner tops all comparable burners existing – weighing only 58 grams at a power output of 70 kW.

The HeiDAS on-board computer

A 16bit micro-controller uses an internal 12bit-analogue-digital converter to track data on temperature, gas pressure, altitude, and vertical velocity as well as acceleration. Also, it analyses the data and subsequently conveys it to a PC on the ground by means of a safe digital radio link (DECT standard). Ultimately, the ground-PC records and displays the performance data. The balloon can be controlled either via a standard remote control – as used for model planes – or via the ground-PC attached to the DECT-radio link. Using the manual mode, the balloon can be manoeuvred directly by managing the burner as needed. In automatic mode, certain cruising parameters, such as altitude or rising and sinking, can be pre-set and automatically commanded by the micro-controller as well as an integrated control unit.

The micro-controller also covers critical safety features – e.g. it shuts down the burner if the temperature exceeds the approved limit of 260 °C. Similarly, the burner stops and a pressure valve opens as soon as the internal pressure hits 500 Pa.

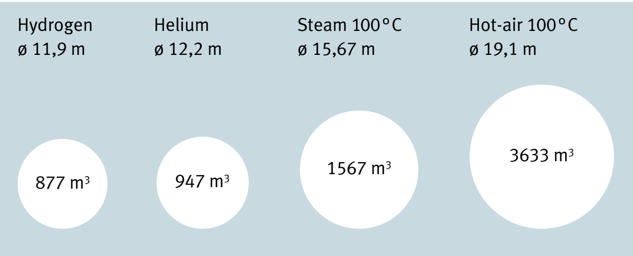
More than just an experiment

In general, it is easier to build large aerostats as membrane thickness isn't an issue mainly due to lower surface/volume ratios. However, since large balloons are more costly and testing becomes more difficult under laboratory conditions, the HeiDAS UH-prototype has been designed to the smallest size possible. Design and optimization of HeiDAS UH is based on complex numerical simulations taking into account various technical aspects, such as heat transmission, convection, and radiation. These simulations were validated through earlier tests using the HeiDAS UH-prototype, and thus, allow for precise predictions of potential buoyancy as well as temperature distributions depending on burner heat flows and resulting heating temperature. Combining theoretical and experimental insights from the HeiDAS-project provides for powerful tools to describe and quantify the design of large steam balloons in the future. These tools outperform current design standards by far and offer critical support for later approval of this novel technology.

Helium lifts approx. 1000 g/m³.

Steam lifts approx. 735 g/m³.

Lift of a hot-air balloon – approx. 275 g/m³.



Comparison of spherical volumes needed to provide 1000 kg of lift.

Steam-balloon vs. hot-air- and gas-balloon

Conventional hot-air balloons generate buoyancies of 0.275 kg/m³. Concerning the HeiDAS UH the buoyancy measured, relative to gas volume, is 0.735 kg/m³. As such, the HeiDAS UH-steam balloon yields a lifting capacity of 2.5 times the lifting capacity of a same-size hot-air balloon and three quarters the lifting capacity of a same-size helium balloon. While the costs for the buoyancy-gas for the HeiDAS UH are considerably lower, the effort for insulation and envelope is higher. Compared to a helium balloon – once filled with the rare-gas, it stays in operation as long as possible –, hot-air balloons as well as the HeiDAS UH can be set up and broken down more quickly allowing for increased flexibly.
The table above demonstrates the difference in temperature levels

Temperatures in °C	Heidas UH	HeiDAS 2003	Hot-air balloon
Maximum envelope	260	160	120
Average gas	150	110	90
Average envelope inside	140	100	50
Average envelope outside	80	45	50
Ambient temperature	23	23	10

between steam aerostats and regular hot-air balloons. What becomes obvious too is the tremendous progress made concerning the 2nd generation HeiDAS, the HeiDAS UH. Increased temperature levels with the HeiDAS UH allow for reduced insulation strength from formerly 23 to now 7.5 millimetres. It would be possible to reduce insulation even further; however, this would come at the cost of higher fuel use. Thanks to its insulation and despite higher temperature levels, HeiDAS consumes about 1.0 kg of propane gas per hour – which is less than the fuel consumed by a hot-air balloon of equal take-off-weight. In case longer cruising times are required, fuel consumption could be reduced even more by increasing up insulation; however this also would drive up dead weight.

Future prospects

Due to the novelty and complexity involved with hot-steam aerostats, developmental efforts were undertaken across a number of disciplines. The potential for increased buoyancy, reduced fuel consumption, and testing of new materials and calculation methods, however, reaches far beyond the academic realm. The development of HeiDAS UH, as the second prototype, has been proven successful throughout various test cruises. An extensive laboratory testing phase has just been concluded in fall 2005. Upon that, HeiDAS UH went for its first remote-controlled and independent cruise inside the Peter Behrens hall in Berlin in November 2005. At this point, an automated cruise control is under development for use on the prototype – it will also allow for steering and testing of larger balloons.

Before steam-balloons and steam-airships might pick up more regular tasks, however, more work needs to be done in terms of detail development and optimization. In any case, applied steam technologies may open up completely novel perspectives for lighter-than-air aviation.

After the projects upside-down twin, gas balloon, UNICEF-flyer, pneumatic gas balloon and pneumatic hot-air balloon basket, hot-air airship, airfish and b-IONIC airfish, HeiDAS UH is another innovation developed for lighter-than-air aviation under Festo “Air in Air”. Across both, the domain of event marketing as well as its core expertise in pneumatic and electric actuators, once again, Festo is presenting itself as an industry leader in industrial automation.

Projectteam of the Technical University Berlin

Specifications for HeiDAS UH 6.8

Geometry:	
Steam volume	6.8 m^3
Diameter	2.35 m
Height	3.8 m
Surface	20 m^2
Surface material used	25 m^2
Mass:	
Envelope, total	2235 g
Insulation	870 g
Dead weight (large tank)	4060 g
Dead weight (small Tank)	3580 g
Mass at lift off	4995 g
Max. carrying capacity	1000 g
Operations parameter:	
Steam temperature	110° bis 150 °C
Max. heating temperature	260 °C
Max. steam pressure inside balloon	500 Pa
Thermal conductivity at 90° C	0.035 W/mK
Measured stationary flight performance at 25 °C:	
Buoyancy at 150 °C	
steam temperature	5045 g
Propane gas consumption	
(60 sec. average)	1.0 kg/hr
Max. flight duration	35 min

Project partners

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