Altaeros Energies, Inc. – Buoyant Airborne Turbine (BAT)

Peter Lobner, 31 October 2024

1. Introduction

ALTAEROS Ben Glass developed an original idea for a tethered Buoyant Airborne Turbine (BAT, a type of airborne wind turbine) while researching compact, efficient turbomachinery as part of his work at the Massachusetts Institute of Technology's Gas Turbine Laboratory. After developing and testing the initial prototypes of the toroidal aerostat, Glass and Adam Rein co-founded the privately-owned firm Altaeros Energies, Inc. in April 2010 in Somerville, Massachusetts. Originally, their goal was to develop the world's first commercial airborne wind turbine. Altaeros later established a research & development (R&D) center in Fremont, New Hampshire.

BAT circa 2014. Source: Altaeros Energies

The business case for the BAT was based in the fact that prevailing winds are stronger at higher altitudes and offer more energy for harvesting (higher energy density) than at ground level. This is the rationale for the trend toward taller, larger diameter stationary wind turbines that can harvest energy from winds at altitudes up to about 300 m (984 ft). Altaeros estimated that its BAT tethered aerostat could produce two to five times as much power as a comparable turbine on a 350-foot (107-meter) tall tower in the same location.

The BAT business case was not targeted at replacing conventional tower-mounted turbines. Instead, the goal was to bring reliable wind power to remote, off-grid areas where users typically relied on diesel generators for power and tower-mounted wind turbines weren't practically or economically feasible. At such locations, some users could be paying more than $1.00 per kilowatt-hour.

Altaeros planned to offer "wind power in a box'' by designing their BAT as a compact mobile system that could be packaged in two shipping container and sent to a deployment site (i.e., a remote oil field, island, or military post). Onsite, the mobile ground station and associated systems would be assembled and the BAT aerostat would be unpacked, installed on the mobile ground station, inflated with helium and checked out before being moved to its deployment site. Altaeros expected that the aerostat could be flying and generating electric power after just one day of set-up. Thereafter, the aerostat would only need to be recovered every three to four months for a helium top-off and a periodic maintenance check.

The transportation and installation costs of a deployed BAT were expected to be up to 90% lower than building a comparable tower-mounted wind turbine at a remote site. In operation, Altaeros estimated that a 30 kW BAT could deliver electric power at a cost of about 18 cents per kilowatt-hour. Altaeros projected that there was a US $17-billion worldwide remote power and microgrid market that could benefit from the BAT technology.

In spite of these favorable business prospects in 2010, Altaeros made a corporate decision in late 2015 to discontinue its work on the BAT and "pivot" its primary business focus to the development and commercialization of an aerial telecom platform, called the SuperTower, that can perform the functions of many cell towers and provide affordable, high speed connectivity to rural communities around the world. This second phase of the Altaeros Energies story is addressed in a separate article.

2. Funding overview

Altaeros received seed funding in the form of Small Business Innovation Research (SBIR) Phase I and Phase II grants from the U.S. Department of Agriculture (USDA) and the National Science Foundation (NSF).

The Alaska Energy Authority provided seed funding for a “High Capacity Airborne Wind Turbine” project to be deployed in Alaska. This originally was planned as a $1.3 million project that would have been Altaeros’ first long-term project to test the BAT technology in an operational environment.

Altaeros tasks under the USDA and NSF grants and the AEA project are described in this article.

Additional seed funding was provided by the Massachusetts Clean Energy Center, the Maine Technology Institute, Cleantech Innovations New England, and the California Energy Commission. In addition, Altaeros received the 2011 ConocoPhillips Energy Prize.

In December 2014, Altaeros raised $7 million dollars in Series A funding from SoftBank for the continued development and commercialization of its wind turbine technology, with additional Series A investments from Mitsubishi Heavy Industries, Ltd. and Oman-based Suhail Bahwan Group. Series A funding is the second stage of startup financing (after seed funding), and the first stage of venture capital financing.

3. Altaeros BAT patents

Altaeros was granted the following US and European patents related to their BAT technology:

- US8253265B2, "Power-augmenting shroud for energy-producing turbines," (2012)
- US9000605B2, "Lighter-than-air craft for energy-producing turbines," (2015)
- EP2344756B1, "Power-augmenting shroud for energy-producing turbines," (2017)

In patent US9000605B2, Altaeros describes their basic buoyant air turbine (BAT) concept:

> "A wind-based power generating system provides a wind energy converter for converting wind energy into another form of energy using a lighter-than-air craft configured to produce a positive net lift. The net lift includes both a net aerodynamic lift and a net buoyant lift. A tethering mechanism is configured to restrain the lighter-than-air craft with respect to the ground. The lighter-than-air craft defines an interior volume for containing a lighter-than-air gas, and the lighter-than-air craft has a fore section and an aft section. The tethering system has at least one attachment point on the fore section of the lighter-than-air craft and at least one attachment point on the aft section of the lighter-than-air craft. The lighter-than-air craft provides a stable aerodynamic moment with respect to a yaw axis about a center-of-mass of the lighter-than-air craft. The craft can be formed in a variety of aerodynamic profiles/shapes."

The BAT configuration, shown in patent Figures 1 and 2, is a tethered aerostat (1) in the form of an aerodynamic circular duct (6) that directs the captured ambient air flow to a suspended turbine (20) that generates electricity. Duct aerodynamics, tail fins (W) and fore and aft attachments (F, A) keep the aerostat pointed into the wind. Aerostat pitch can be adjusted (12). The tether (11) delivers generated electric power to a base station (10). Once aloft, the aerostat passively floats downwind of the base station and realigns as wind direction changes.

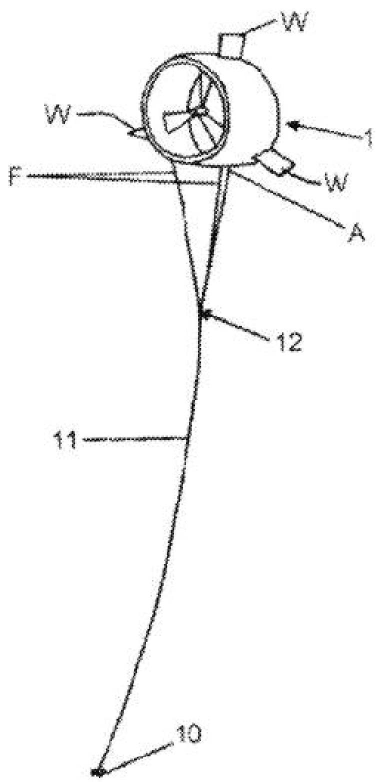


FIG. 1

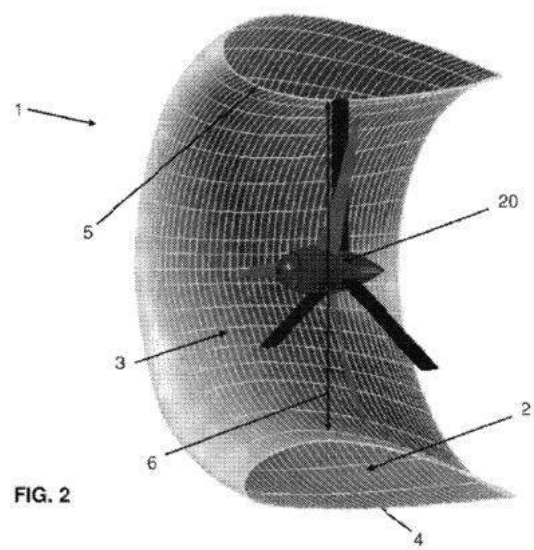


FIG. 2

Figure 1 shows the general arrangement of a deployed BAT. Figure 2 shows details of the aerodynamic, inflated, toroidal shell and the placement of the suspended wind turbine generator along the centerline of the of the shell.

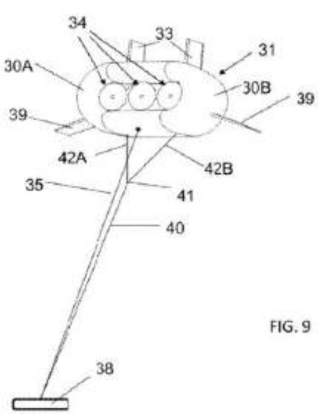


FIG. 9

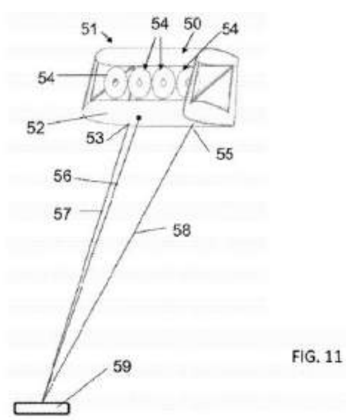


FIG. 11

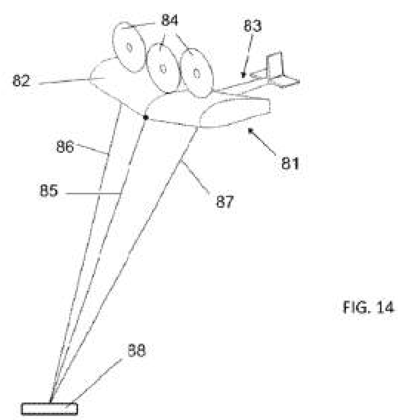


FIG. 14

Examples of other BAT configurations included in patent US9000605B2.

4. Description of the BAT system

Altaeros notes that their BAT system integrates proven aerospace and wind turbine technology. The toroidal lifting platform is adapted from tethered aerostats, which have reliably lifted heavy communications and other payloads into the air for decades.

The Altaeros BAT system if comprised of the following four main components:

- Shell
- Turbine generator
- Tether
- Mobile ground station

Features of these components are described below.

Shell (or Shroud)

This is a lightweight, non-rigid, pressure-stabilized, toroidal gas envelope with an aerodynamic circular cross-section that directs the captured ambient air flow into a venturi to accelerate the air before it encounters the onboard turbine generator in the “throat” of the venturi. The shell produces both buoyant and aerodynamic lift and is aerodynamically self-stabilizing.

The helium-filled, multi-layer gas envelope is made from high-performance, low-leakage industrial fabrics. Onboard air ballonets control the helium gas pressure. A venting system can discharge helium lifting gas rapidly if the BAT needs to be brought back to ground level in an emergency (i.e., sudden extreme weather, one or both mechanical tethers break).

Wind turbine generator

A lightweight, conventional, horizontal axis wind turbine coupled to an AC generator form an integral unit that is suspended by cables along the central axis of the venturi formed by the inflated shell. The wind turbine can generate power when it is deployed aloft or when it is docked on the mobile ground station.

Tether

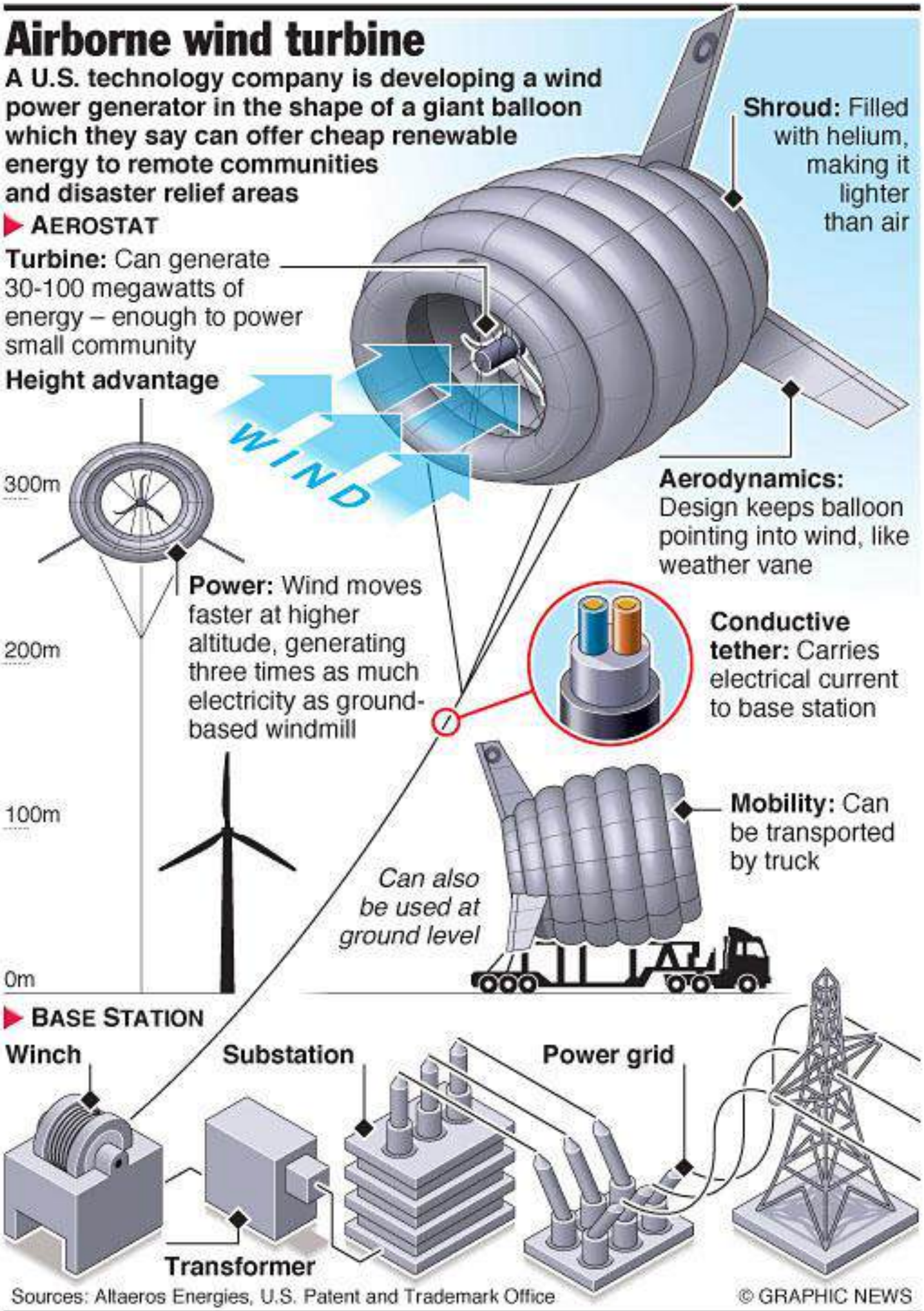
A lightweight, high strength, multi-element tether cable connects the BAT to the ground station. This tether cable includes redundant strength elements, a power conductor element and a control signal element. The tether deploys and recovers the aerostat, holds the aerostat in place in all weather conditions and delivers electric power from the airborne generator to the ground station. The aerostat control system autonomously adjusts the flying altitude and attitude of the shell to seek an optimal wind speed and shell orientation for power generation.

Mobile ground station

The mobile ground station is built onto a semi-trailer platform for ease of transport at the remote site and to simplify relocating the system when needed. The mobile ground station includes the following:

- Helium supply to inflate the BAT,
- Winches to deploy and recover the BAT,
- A swivel mount that allows the aerostat and tether to rotate as the wind direction changes,
- An autonomous control system that can optimize aerostat operating conditions (i.e., altitude, pitch angle, helium pressure),
- Electric power conditioning equipment (a transformer) and connectivity to a local substation.

The system doesn't require on-site personnel once it is in place. It can be monitored remotely, requiring only periodic on-site maintenance checks and aerostat helium top-off.



Source: Graphic News

5. BAT early development and SBIR projects

Early work, before SBIR seed funding (2010 – 2011)

The first flight test of a BAT-style toroidal aerostat occurred in November 2010 when Ben Glass and Adam Rein inflated their custom-made, hollow-centered aerostat and attached a video camera and sensors to collect information about its motion in the wind. One of the team members worked a pulley system to launch the aerostat while the other team members took notes and shot video from the ground.

Hollow cylindrical aerostat test, November 2010.
Sources: (L) RadioLocman (30 April 2011), (R) Altaeros

By early 2011, Altaeros had installed a small wind turbine in the central annulus of their toroidal aerostat and planned to flight test it in the summer of 2011. The turbine was capable of producing 2.5 kilowatts of electricity - about the size of a “backyard’’ turbine that could supply power to a single-family residence.

Cylindrical aerostat with wind turbine installed
Source: RadioLocman (30 April 2011)

<u>USDA SBIR Phase I project: “Robust Airborne Wind Turbine Shroud for Production of Low Cost Renewable Energy,” 1 July 2011 – 29 February 2012</u>

USDA reported the following:

> “One finding was that the vast majority of U.S. sites have low enough extreme wind speeds to make a shroud-lifted wind turbine feasible. In addition, most U.S. sites have a sufficient wind power density increase at 600 meter altitude relative to 30 meter altitude to make the economics of a shroud-lifted turbine viable.
>
> The project also developed a better understanding of where loads are most highly concentrated for the shroud design, and how the modeling correlates with physical testing. This work led to a more cost effective shroud design that meets environmental loading requirements at the vast majority of U.S. sites.”

USDA SBIR Phase II project: "Robust Airborne Wind Turbine," 1 September 2012 – 31 Aug 2014

USDA reported the following:

> "Altaeros successfully demonstrated a stable, second-generation flight platform for the BAT, as well as made significant progress on the turbine development and remote communication and control architecture."…." Overall, the Phase II project significantly furthered Altaeros' objectives of delivering the first commercially viable airborne wind turbine."

NSF SBIR Phase I project: "Low-cost, High Performance Fabrics for Inflatable Structures," January 2013 – September 2013

The original goal of this $155,000 SBIR Phase I project and test results are summarized in the NSF award abstract:

> "The primary goal of the Phase I project was to advance the understanding of low-cost fabrics in long-term, helium-inflatable applications, in order to develop a lower cost alternative to the current standard laminate fabrics used in aerostats and airships…..
>
> The test results indicate that a high-tenacity woven polyester base cloth laminated with aliphatic urethane and UV blockers, such as TiO_2, will provide good performance for low-cost, helium-inflatable structures. Such a material, which will be similar in structure to the commercial woven fabric tested in Phase I, will require an optimized seam structure and improved process control to achieve satisfactory helium retention and long-term seam strength. The cost of this proposed fabric is projected to be well below the target 60 percent cost reduction compared with the current standard airship and aerostat fabric options."

<u>NSF SBIR Phase II/IIB: “Ultra-light, Modular Wind Turbine,” October 2014 – February 2018</u>

This SBIR Phase II project originally was funded at $740,679. The original project goal is summarized in the NSF award abstract:

> “This SBIR Phase II project will focus on reducing the total weight of the wind turbine system. Turbine weight is one of the most critical cost drivers of buoyant airborne wind energy systems. For each kilogram removed from the turbine, an additional kilogram can be removed from the inflatable shell and tethers, resulting in a significantly smaller and lower cost system. The lightest commercially available small- to medium-sized wind turbine weighs 31.1 kilograms per kilowatt of capacity, which is too heavy for an economically-viable airborne turbine. By incorporating a compact, modular architecture, a lightweight permanent magnet direct-drive (PMDD) generator and high-strength composite materials, the proposed Phase II research effort aims to double the power density of traditional medium size turbines, making the proposed system suitable for use in an airborne application, while maintaining a high level of reliability and cost performance.”

There’s more to the story about this SBIR project, but that will be discussed later.

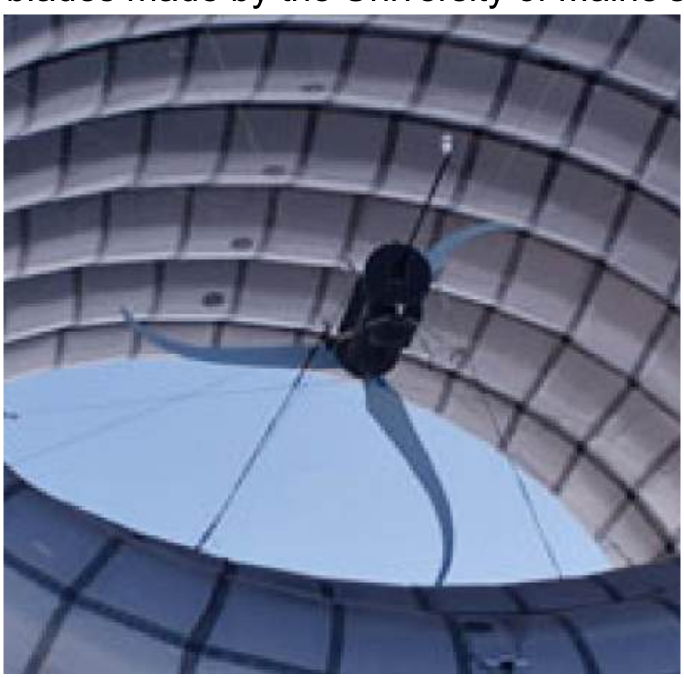
6. Prototype tests, 2012 - 2014

Altaeros reported that it brought its BAT technology to Technology Readiness Level 5 (TRL-5) with the testing of a 35-foot long, 30-foot diameter proof-of-concept prototype at the former Loring Air Force Base in northern, Maine in Jan – Feb 2012. NASA describes TRL-5 as follows: "Component and/or breadboard validation in relevant environment."

This prototype demonstrated autonomous operations while lifting a modified wind turbine to over 300 feet (92 m) altitude and producing power both at altitude and when docked on the mobile ground station.

BAT in flight at Loring AFB. Source: Altaeros

Composite World reported that the proof-of-concept BAT prototype uses a 2.5 kW *SkyStream* turbine from XZERES Wind Corp. (formerly Southwest, Wilsonville, Ore.), with carbon fiber composite blades made by the University of Maine's Advanced Structures and Composites Center (Orono, Maine). Altaeros also replaced the turbine's aluminum nacelle with one made in-house to reduce turbine weight using a sandwich construction of three-ply carbon fiber skins over an aramid honeycomb core.



The wind turbine is suspended within the toroidal shell. Source: Altaeros

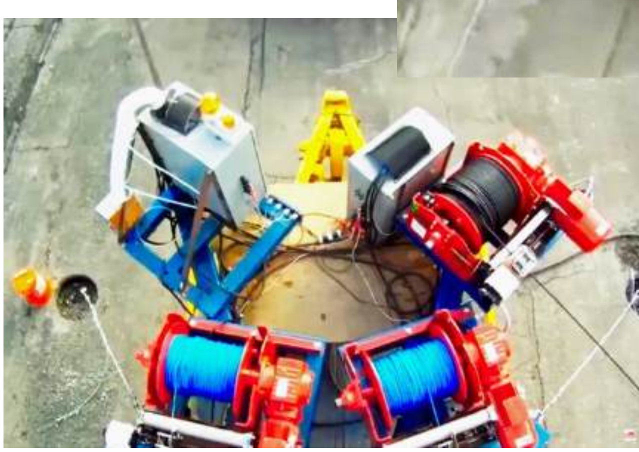
In 2013, Altaeros successfully tested its proof-of-concept BAT in 45-mph (72 kph) winds at a height of 500 ft (152 m) in Maine.

BAT in a hangar at Loring AFB, Maine.

BAT being transported at Loring AFB, Maine
Source, both graphics: Altaeros

BAT launching at Loring AFB, Maine

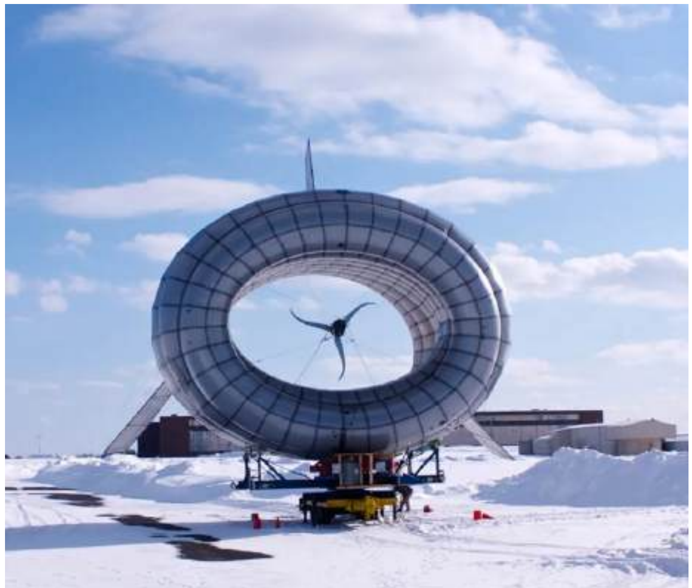
BAT's eye view of the mobile ground station. Source: Screenshot from Altaeros video



BAT. Source, three graphics: Altaeros

The proof-of-concept BAT tested at Loring AFB, Maine in 2012.
Source: Altaeros (filing with Alaska Energy Authority, 2012)

The proof-of-concept BAT being transported at Loring AFB, Maine.
Source: Altaeros



Launching a BAT at Loring AFB, Maine.
Source, both graphics: Altaeros

BAT in flight at Loring AFB, Maine.
Source, both graphics: Altaeros

7. Alaska Energy Authority (AEA) High Capacity Airborne Wind Turbine Project, 2014 – 2015

The High Capacity Airborne Wind Turbine project, was an 18-month trial, funded by the Alaska Energy Authority, to demonstrate the ability of an Altaeros BAT to power a microgrid at a remote site in Alaska. This was intended to be the first long-term project to test the BAT technology in an operational environment.

The $1.3 million project was financed AEA's Emerging Energy Technology Fund and RNT Associates International, an organization owned by the former chairman of the Indian conglomerate Tata Group, which includes Tata Power, India's largest integrated power company. The project was managed by Alan Baldivieso, the AEA program manager for emerging energy.

In rural Alaska, people at many remote sites depend on gas and diesel generators for electric power, paying up to $1.00 per kilowatt-hour (kW-h) for electricity using fuel that has to be delivered to the remote sites. In this trial, a BAT rated at 30 kW was expected to deliver electricity to a remote microgrid at a cost of about $0.18 (18 cents) per kW-h (about half of the average price of off-grid electricity in Alaska) and supply the power needs of about 12 homes. At the time of the planned Alaska test, average U.S. consumers in the lower 48 states paid about $0.134 (13.4 cents) per kW-h.

The Alaska Energy Authority summarized the high capacity airborne wind turbine project as follows:

- Phase I: Design, permitting, and prototype assembly work conducted at the offices of Altaeros Energies in Boston, MA and TDX Power in Anchorage, AK.
- Phase II: Installation and operation of the wind turbine prototype at the Delta Wind Farm.
- Phase III: Airborne Wind Turbine will be relocated from Delta Junction to a diesel-powered remote village upon evaluation and review of potential candidate sites.

The 30 kW Altaeros BAT prototype for the Alaska trials was designed to operate at an altitude of 1,000 ft (308 m). A BAT prototype had been operationally tested on the U.S. east coast in 45 mph (70 kph) winds, but it was expected to be able to withstand stronger gusts likely to be encountered in Alaska, up to 100 mph (161 kph).

The BAT system was expected to have the following features:

- Autonomous operation, including:
  - Optimizing the aerostat's altitude and pitch to efficiently harvest available wind energy, and
  - Recovering and docking the aerostat when a severe storm is detected in the vicinity and then redeploying the aerostat when conditions improve.
- Remote monitoring.
- Periodic maintenance: Specialists would only be deployed to the site to periodically top off helium and perform routine maintenance.

The wind turbine selected by Altaeros for the AEA trial was described as "conventional" and not specifically qualified for Arctic conditions. In tower-mounted wind turbine applications in Alaska, the Northern Power Systems 100, a popular 100 kW wind turbine built for cold, harsh climates, is capable of operating in conditions as low as -40° C (also -40° F). The ability of the Altaeros BAT to operate in Arctic conditions will be an important result of the AEA trial.

This project was expected to bring BAT development to TRL-6: "System / subsystem model or prototype demonstration in a relevant environment."

In February 2015, the AEA reported the High Capacity Airborne Wind Turbine project status as follows:

Alaska Emerging Energy Technology Fund Project Status Updates February 2015

High Capacity Airborne Wind Turbine
Project Lead: Altaeros Energies, Inc. **Location: Fairbanks** Altaeros Energies, Inc. proposes to demonstrate a 30 kilowatt (kW) wind turbine suspended 1,000 feet above ground in a helium-filled shell. The project seeks to take advantage of higher and more consistent wind speeds and to demonstrate an improved capacity factor relative to tower-mounted wind turbines. By tethering to a portable trailer, a substantial decrease in installed capital costs is expected. Altaeros plans to commercialize both 30 and 100 kW models.
Project Status Altaeros has identified candidate sites throughout Alaska, visited a selection of sites, and selected the Eva Creek wind farm as the deployment site. In Maine, construction and testing of a half-scale prototype has progressed and the project team has raised additional capital to complete full-scale construction.
What's Next Permitting from FAA is the critical next step for the project. The agency has been drafting policy regarding airborne wind energy system deployment, and extended testing of any system awaits clarification from FAA regarding the permitting process.

Altaeros made a corporate decision in late 2015 to discontinue its work on the BAT and focus instead on development of an aerostat for telecommunications applications.

Altaeros did not complete the High Capacity Airborne Wind Turbine project for the Alaska Energy Authority. Originally, this was expected to be a $1.3 million project. In February 2023, AEA reported that a total of $199,888 in state and federal funds had been spent on this project, with $118,671 in matching funds from Altaeros.

8. Plans for a commercial BAT

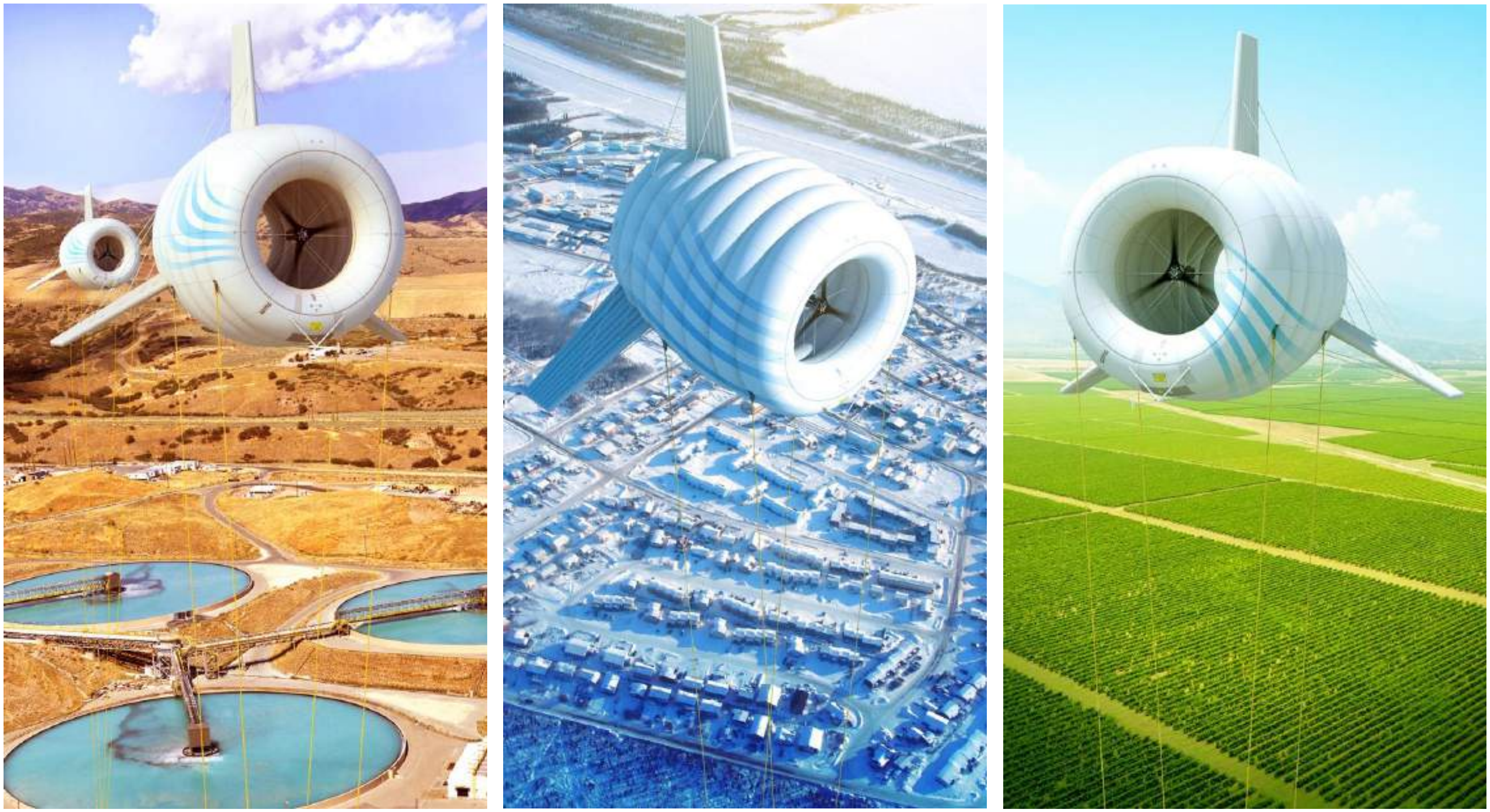
Altaeros planned to scale up its 30 kW Alaska prototype BAT to an initial commercial product with a generating capacity in the 100 to 200 kW range. Without affecting its power generating capability, the BAT could be equipped with one or more supplementary payloads that could deliver a variety of value-adding services at remote deployment sites. For example, a BAT could provide full-time community cell phone, Wi-Fi and weather monitoring services.

Altaeros proposed including BAT deployment in natural disaster response plans for cases where the local or regional electric power grid was unavailable. At disaster sites, a BAT also could help restore communications and provide emergency responders with local area surveillance for better situation awareness, resource management and security.

A commercial BAT on its mobile ground station being transported to its deployment site. Source: Altaeros

A BAT being moved on its mobile base station to its deployment site.

Rendering of BATs deploying at a remote construction site.
Source, both graphics: Altaeros



Visualizations of BATs deployed in three remote applications; (L to R) industrial, residential & agricultural.
Source: graphic designer Anton Weaver via Behance (1 March 2015) and http://antonweaver.com/graphic-design

9. The end of the Altaeros BAT

About one year after the start of work on the NSF SBIR Phase II project, Altaeros made a corporate decision in late 2015 to discontinue its work on the BAT. This resulted in a significant redefinition of the project scope of work, as summarized below:

> "During the course of this Phase II/IIB project, Altaeros pivoted its primary business focus from developing a buoyant airborne wind turbine to the development and commercialization of an aerial telecom platform, called the SuperTower, that can replace a network of 15 regular cell towers to provide affordable, high speed connectivity to rural communities around the world. Altaeros filed a Change of Scope in December, 2015, after which the Phase II project focused on furthering the state of autonomous aerostat technology through demonstration of an automated aerostat platform in real world conditions."

This was the end of the line for the Altaeros BAT. You'll find the next chapter of the Altaeros Energies story in my separate article on their tethered telcom aerostats.

10. For more information

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- Anmar Frangoul, “Generating power, 600m up in the air,” CNBC, 22 July 2015: https://www.cnbc.com/2015/07/22/generating-power-600m-up-in-the-air.html
- Blake Wilson, “Buoyant Airborne Turbine – Rural Energy, Telcom, Security,” Altaeros Energies (slide presentation on Slideplayer), 4 September 2015: https://slideplayer.com/slide/9132365/
- “Will They Fly? Wind-Power Alternatives Buffeted by Technical Squalls,” NBC News, 27 September 2014: https://www.nbcnews.com/business/energy/will-they-fly-wind-power-alternatives-buffeted-technical-squalls-n211571
- Dr. Jack M. Wilson, “Case - Altaeros Energy,” 2019: http://www.jackmwilson.net/Entrepreneurship/Cases/Case-AltaerosEnergy.pdf

Videos

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- “Floating wind turbine takes to the sky,” (1:41 min), posted by BBC Click, 7 April 2015: https://www.youtube.com/watch?v=RzCK9Ht0SWk
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SBIR-funded BAT development contracts

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