POWER BEAMING TO ENERGY STORAGE AIRSHIPS

A Presentation for the
19th Annual Directed Energy Symposium

By
Les Johnson
and
Daniel O’Neil

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“We really do have a very large need for a better system of lifting bigger pieces and bigger sizes that you can’t fit into an airplane door, into all kinds of places ... A lot of places around the world are inaccessible.”

- Barry E. Prentice, professor in the department of supply chain management at the University of Manitoba’s I.H. Asper School of Business

Since trains, trucks, and cargo boats can’t reach many parts of the world, Prentice predicts airships will come to fill that void. And he says it would happen even sooner if world economies were “more serious” about climate change.

Companies are Buying Airships

Lockheed Martin strikes $480M deal to sell airships
Wednesday, 30 Mar 2016 | 5:39 AM ET

Lockheed Martin has landed its first contract for the hybrid airship it created inside its top secret Skunk Works division. In a deal valued at $480 million, Straightline Aviation (SLA) has signed a letter of intent to purchase 12 of the heavier-than-air airships that measure nearly a football field long. First delivery is scheduled for 2018, with the final airship expected no later than 2021.

Cargo Delivery Air Ships

Are not your parents’ blimp

Hybrid Air Vehicle (HAV)

- Airlander 10 made its maiden voyage August 17, 2016
- Manned: aloft for five days
- Unmanned: aloft for two weeks
- Four 325-hp (242-kW), turbocharged diesel engines
- Applications: Communication, Cargo transport, & Surveying

http://newatlas.com/airlander-10-first-flight/44956/
https://www.hybridairvehicles.com/aircraft/airlander-10

Current GZ-20A Blimp  New Zeppelin NT

<table>
<thead>
<tr>
<th></th>
<th>Current GZ-20A Blimp</th>
<th>New Zeppelin NT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>192’</td>
<td>246.4’</td>
</tr>
<tr>
<td>Maximum Width</td>
<td>50’</td>
<td>64.79</td>
</tr>
<tr>
<td>Envelope Volume</td>
<td>202,700 cubic feet</td>
<td>297,527 cubic feet</td>
</tr>
<tr>
<td>Maximum Speed</td>
<td>50 miles per hour</td>
<td>73 miles per hour</td>
</tr>
</tbody>
</table>

http://www.airships.net/goodyear-blimp/
Lockheed Martin’s

Available in 2018

Capacity
• 10’ x 10’ x 60’ cargo bay
• Flexible, customizable
• Roll-On Roll-Off, CAT D6, ATCO trailer
• Up to 44,000 lbs of payload
• Up to 19 passengers
• 5,000 gallon cargo fuel tanks built-in

A Potential Application:
Humanitarian Assistance

Ambri Liquid Metal Battery

$11M from ARPA-E & Total (French oil co.)

20KWH

$15M from Khosla Ventures

500KWH

Additional $25M from Bill Gates, KLP Enterprises, and Building Insurance Bern (GVB)

2016

2018

2020?

The 2MWH system is intended for the Power Grid.

URLs:
- https://www.technologyreview.com/s/511081/ambris-better-grid-battery/
Overall Dimensions:
- **Length:** 770 feet
- **Width:** 296 feet
- **Height:** 183 feet

Payload Deck Space:
- **Length:** 380 feet
- **Width:** 61 feet
- **Height:** 45 feet

Payload: 250 tons

Assume 8,000 kg available in each Liquid Metal Battery Container.

Liquid Metal Battery Capacity of one container (Can serve 200 households)

8 Liquid Metal Battery Containers

2 MW*hrs

With one sun energy flux of 1kW/m², the rectenna could receive 5.6 MW.

If only one third were usable at any point during the satellite passing overhead the usable area is 5,600 sq.meters.

If the line-of-time of a MEO SSP satellite were one hour, 2.8 batteries could be charged and four orbits could charge eight batteries.

Assume 8,000 kg available in each Liquid Metal Battery Container.

Available for a rectenna.

With one third usable: 5,600 sq.meters

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Sources:
- [http://www.ted.com/talks/donald_sadoway_the_missing_link_to_renewable_energy?language=en](http://www.ted.com/talks/donald_sadoway_the_missing_link_to_renewable_energy?language=en)
Three Generations of the Airship with Liquid Metal Batteries

Customers
- Disaster relief agencies
- Emerging nations
- Military logistics trains
- Explorers of oceans, deserts and jungles
- Outdoor venues for huge week-long events

Conceptual Design Benefits
- A moving receiver enables a lower orbit
- A lower orbit reduces system & launch cost
- Molten metal, in batteries, need the heat
- Three generations provide early revenue
- Mobile infrastructure enables swift response to large power needs

1st Gen.
“Milk-runs”

2nd Gen.
Solar powered airship and sustained heat

3rd Gen.
Beamed power for a long-duration global fleet
Power Beaming to a Model Airplane

• In 2002 and 2003, a team from Marshall Space Flight Center and Dryden Flight Research Center demonstrated power beaming to a radio controlled model aircraft.

• The 2002 demo involved manually directed spotlight that illuminated a solar panel, which powered a six watt motor in a model airplane that flew inside of a building.

• The 2003 demo involved a 1KW laser that transmitted power to a rotorcraft that operated along guide wires.

• Attempts to power model airplane at the Redstone Arsenal Laser range were unsuccessful due to gusty winds.

http://www.nasa.gov/centers/armstrong/news/FactSheets/FS-087-DFRC.html
In 2008, John Mankins and Prof. Nobuyuki Kaya of Kobe University beamed 20 watts with an array of eight transmitters on top of the volcano Haleakala on Maui and received by signal detectors at Mauna Loa Observatory on Hawaii's Big Island, 92 miles (148km) away.

The Discovery Channel sponsored demonstration was produced in less than five months with less than a million dollars.

[http://www.thespacereview.com/article/1210/1](http://www.thespacereview.com/article/1210/1)
Launch Costs for the SPS-Alpha

A 500MW system in GEO mass = 34,813,882 kg @ $20,000/kg to orbit, the launch cost > $696B

The mass of a 2MW system in Geosynchronous Earth Orbit (GEO) would be 232,610 kg @ $20,000/kg to orbit, the launch cost > $4.6B

The transmitter on the GEO system has a mass of 106,643. Moving the system to MEO could cut the mass of the transmitter by half and the launch cost to > $3.58B

A 2MW system in Middle Earth Orbit (MEO) could be sufficient to supply airships with Liquid Metal Batteries (LMB).

Middle Earth Orbit based Constellation of Solar Power Satellites
### Each Day

<table>
<thead>
<tr>
<th>Energy_Airship_1-To-MEO_SSP_1</th>
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<tbody>
<tr>
<td>Energy_Airship_1-To-MEO_SSP_2</td>
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<tr>
<td>Energy_Airship_1-To-MEO_SSP_3</td>
<td>1671 seconds</td>
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<tr>
<td>Energy_Airship_1-To-MEO_SSP_4</td>
<td>3274 seconds</td>
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</tbody>
</table>

**Total**

9,948 seconds

2.76 hours

1 MW * 2.76 hours = 2.76 MW-hours

= 17% of the 16MW-hr storage capacity
Conclusions

• First generation of energy air ships provide revenue
  • Enables development of solar-powered 2nd generation
  • Eliminates issue of revenue delay to “first light”
  • Provides franchise opportunities for power plants

• Flight plans for air ship fleets can be flexible
  • Flights can be timed for coverage by a small constellation
  • Larger constellations provide greater planning flexibility
  • A constellation of four satellites can “top-off-tanks” by 17% per day

• Customers in space: a new generation of LEO satellites with rectennas
  • When the Middle Earth Orbit (MEO) satellites are not beaming power to the air ships
  • Future satellites could replace bulky self-shadowing solar arrays with rectennas
  • Satellites would receive energy each time they pass under a MEO solar power satellite

• Customers in the air: cargo delivery electric airships
  • Solar arrays and rectennas would receive power for the electric propulsion
  • Electric airships would provide an alternative to trains and ships

• Customers on the ground: Fleets of energy storage airships could support
  • Disaster relief efforts
  • Temporary remote projects, such as expeditions
  • Military logistics
  • Remote villages