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High-Altitude, Long-Endurance Airships for Coastal Surveillance

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February 2005

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Introduction

In August 2001, the Power and On-board Propulsion Division of NASA's Glenn Research Center began studying the technologies needed to build renewable electrical power systems for long-duration observation aircraft. The initial investigations examined power management and distribution architectures for a coast-observing, stratospheric airship concept proposed by Lockheed Martin NE&SS of Akron, Ohio. By November 2002, the studies had expanded to consider photovoltaic sources, energy storage systems, electrical propulsion systems, waste heat rejection, structural attachments, and mechanical modules to house the equipment.

In sum, the inquiry concluded that long-duration, coast-observing, stratospheric airships using renewable energy systems were feasible provided appropriate technology investments were made. Although feasible, such airships were not without many development challenges, and airship size was strongly influenced by the seasons and coastal latitudes.

At the time, NASA/Glenn was proposing the renewable energy airship to NASA's Vehicle Systems' Second Generation High Altitude Long Endurance (HALE) Remotely Operated Aircraft (ROA) program. Glenn's studies were undertaken to assess technology readiness and to propose development roadmaps that would insure successful high-altitude, long-duration airships. NASA's Glenn Research Center is pre-eminent in power and propulsion systems. For over 40 years, this Center has provided expertise for electrical components as well as integrated power systems. Some examples are:

1. Fuel cells for manned spacecraft.
2. Power systems and components for the International Space Station, Next Generation Launch Vehicle Project, and the Green Efficient Aircraft Project.
3. Multi-megawatt power beaming solar satellites.
4. Electric propulsion systems for Jupiter exploration.

This white paper summarizes the capabilities for existing high-altitude vehicles; identifies electric power system technology needs for a high-altitude, renewable energy airship; and identifies issues in deploying a system of airships for coastal surveillance.

Airships and Long-duration Surveillance

Wide-area surveillance for months at a time is presently impossible as neither satellites nor aircraft can provide these capabilities simultaneously. However, renewable energy technology has progressed enough to seriously consider building aircraft for ultra-long duration flights. In this arena, airships have significant potential. Airships, unlike aircraft, generate lift from buoyancy instead of through aerodynamics. Consequently, airships do not need to stay in motion to remain aloft. Therefore, they can loiter over a specific location as well as move to a new location. In addition, airships can carry large-volume, heavy payloads. These characteristics make airships superb candidates for long-endurance surveillance missions. However, a renewable energy airship, issues a challenge to design the power system, the propulsion system, and the craft's aerodynamics as an organic whole. This yields the minimum mass system that can balance solar power generation against propulsive energy consumption given seasonal variations in winds and daylight.

For a renewable energy airship, regenerative power technologies such as: thin film photovoltaic arrays, fuel cells, electrolyzers, and power management systems are the keys to achieving long-duration. Operating solely from the sun's energy necessitates striking a delicate balance between energy collection and energy consumption. This balance is influenced by a number of factors such as the atmospheric environment and the capabilities and efficiencies of the power system's components. Specifically, mission objectives such as where and when the vehicle must fly greatly influence the energy collected while payload power requirements, the airship's size, and the power and propulsion systems' efficiencies combine to determine the energy consumed. Since the basic power source, the sun, is not available throughout the whole day; effective designs for managing collecting, storing, and consuming energy are needed to make the airship a feasible alternative for surveillance missions.

When compared to fuel-powered aircraft, a sun-powered airship presents a unique design challenge; namely the surface area used for the photovoltaic arrays is directly affected by the size and layout of the airship. Therefore, changing airship size changes not only the thrust power required to overcome drag but also the amount of energy produced by the sun. This coupling of the available power to the vehicle's size and layout adds a complex interdependency to the airship's design process. Because the bulk of the renewable energy is used to fly the airship, sizing the power and propulsion systems necessitates addressing the requirements, capabilities, and limitations of the airship itself. To accomplish this, the power and propulsion systems must be designed as a single entity coupled to the vehicle's aerodynamics; not as two separate subsystems each with its own independent vehicle interactions.

The operational environment and mission requirements also have a significant influence on an airship's capabilities. Factors such as the time of the year and latitude will affect the available solar power. Operation at high latitudes reduces the incident sun energy; and this, when combined with seasonal variations in daylight, makes collecting power a significant challenge for winter operation in northern latitudes. The wind speed that the airship must overcome to maintain its position is also dependent on the time of year, latitude, and altitude. Although the wind does not affect the airship's power generation, it has a significant effect on its drag and therefore power consumption. So, flying in locations that have high winds poses a significant challenge to the power system design.

Alternative High-Altitude Aircraft

Several aircraft have operated at altitudes greater than 18 km (~60,000 ft). Unfortunately, these vehicles are payload limited, duration limited, or both. Aerostats, which are tethered balloons, are capable of lifting heavy payloads about a fixed location for extended durations. The aerostat's altitude is limited to 5 km by the weight of its tether cable. Carbon nanotube technology investments could someday yield extremely strong yet light-weight tethers which would allow aerostats to operate above 18 km.

The main issue in high altitude flight is generating lift in the low density atmosphere. The majority of the vehicles that operate at these altitudes do so by flying very fast. This high speed compensates for the low density air. Most notable of these high-speed, high-altitude vehicles are the U2 and SR71 shown in figures 1a and 1b, respectively. The U2 is capable of flight to altitudes up to 21 km (~70,000 ft) at a cruising speed of 692 km/hr (430 mph) and a flight endurance of approximately 7 hours (ref. 1). The SR71 is capable of flight to altitudes of 27 km (~90,000 ft) with a cruising speed of 3,380 km/hr (2,100 mph, Mach 3.2) and a flight endurance of approximately 1.5 hours (ref. 2). Although they are capable of high altitude flight, these aircraft have very limited endurance.

There has been an increase in high altitude endurance with the introduction of unmanned air vehicles (UAV). Examples of these are the *Condor* from the late 1980's and the present day *Global Hawk*. These aircraft are designed for surveillance and loitering over a particular site. They are shown in figures 2a and 2b, respectively. The *Condor* had limited use and was an experimental aircraft. It was propeller driven and capable of flights up to 21 km (~67,000 ft) (ref. 3). The *Global Hawk* is the latest in high altitude UAV development. It is capable of flight at 20 km (65,000 ft) with a cruise speed of 643 km/hr (400 mph) and endurance of 35 hours (ref. 4).

The *Global Hawk* pushes the high altitude flight duration limits of fuel-driven aircraft. To extend the duration beyond this, one must consider a renewable power system. The only current endeavor in renewable power for flight is Aerovironment's *Helios*.

The *Helios*, shown in figure 3, is a solar powered aircraft with a regenerative fuel cell system for energy storage. The craft's performance is estimated to be to 21 km altitude (~70,000 ft) for month-long durations (ref. 5). If successful, the *Helios* will be capable of extended duration over a desired site. Its main drawback is a very limited payload capacity – 250 kg – coupled with a requirement to distribute the payload along the wing.

Figure 1a.—U2 High Altitude Aircraft.

Figure 1b.—SR71 High Altitude Aircraft.

Figure 2a.—Condor High Altitude UAV.

Figure 2b.—Global Hawk High Altitude UAV.

Figure 3.—Helios High Altitude Long Endurance Solar Powered UAV.

This capacity, though sufficient for small science experiments, is insufficient for surveillance radar systems which need an aircraft with a heavy, centralized payload capability. For this, the *Helios* falls short.

None of the aircraft discussed thus far can carry large payloads (2,000 kg or more) at high altitudes and remain aloft for months at a time. An airship can do this. Because the airship uses buoyancy for its lift, it does not require as much power as a vehicle that derives its lift by propelling itself through the atmosphere. This is a big advantage because renewable energy systems are considerably heavier than fueled systems.

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atmosphere. This is a big advantage because renewable energy systems are considerably heavier than fueled systems.

Many lighter-than-air vehicles are in use today for either high altitude or long-duration missions. Weather balloons, for example, routinely operate at high altitudes. Such balloons carry heavy payloads to altitudes of 36 km (120,000 ft). These balloons, used for scientific research and weather observation, are uncontrolled and operate for short durations. An example is the Air Force's High Altitude Balloon Experiment (HABE), shown in figure 4a (ref. 6). For stationary observations, balloons are secured to the ground with a tether cable. This configuration is known as an *aerostat*.

Aerostats are very common and have been used for many military and civilian applications. Figure 4b shows Lockheed Martin's Tethered Aerostat Radar System (ref. 7). It is capable of flights up to 5 km for durations of up to a week. Like balloons, aerostats can be used for gathering scientific data, observing the weather, relaying communications, and surveying ground activities. However, significant improvement in tether materials is needed to produce a tether that is light enough and strong enough to maintain an aerostat above 18 km altitude (refs. 8 and 9). The aerostat can be a viable alternative for high-altitude, long-endurance missions given technology advancements in materials such as carbon nanotube wires.

Figure 4a.—Air Force High Altitude Balloon (HABE).

Figure 4b.—Lockheed Martin Tethered Aerostat.

Airships at High Altitudes

To date, no airship has attained the 18 km altitude mark, but the idea is attractive enough to spur international interest in renewable energy stratospheric airships.

The altitudes on record belong to the German Zeppelins of the early 1900's. These ships reached altitudes of 7.5 km (25,000 ft) (ref. 10) – quite an accomplishment since there were no environmental controls for the crew. The concept of a high-altitude airship began with the United States Navy in the late 1970's. This initial Navy program was titled *High Altitude Super-Pressure Powered Aerostat* (HASPA) and was followed in the 1980s by the *High Surveillance Platform for Over-the-Horizon Targeting* (HI-SPOT) program. These efforts were the first serious look at high-altitude airship design. The programs were classified so there is little information available on their outcomes. Since then, there have been a number of studies conducted throughout the world on concepts for high-altitude airship flight, construction, and operation. These studies have identified and, in some cases, solved many of the challenges in designing a long-endurance, stratospheric airship.

The current thinking for an airship's renewable energy system is to employ a photovoltaic array coupled to an electrochemical energy storage system such as a fuel cell or battery. The other most frequently studied alternative energy production scheme considers beaming power from the earth's surface to the airship. This would eliminate the mass penalties for energy storage, but requires significant investments to develop a safe and effective power beaming system. Further, the beam range limits the airship's possible operating locations.

The Airship as a Stationary, High-Altitude Radar Platform

The best approach for all-weather, coastal surveillance is to use strategically stationed radars. Radar positioned at high altitudes permits viewing a large area with few stations. A stratospherically-stationed airship's radar can observe approximately 500 km in any direction. With this viewing ability, a fleet of six airships could provide continuous coverage of the entire east coast.

Because of the airship's excellent lifting capacity, it can carry payloads that other types of high-altitude, long-endurance vehicles cannot – a radar system for example. Radar systems have unmatched observational capability. They can penetrate clouds and rain and provide continuous observation of a selected area. Radars work equally well during day or night.

Radar systems are line-of-site devices; consequently, they benefit from the high-altitude operation because range increases with altitude. Therefore, positioning the airship higher in the atmosphere increases the view or coverage area. The coverage area of the airship is determined by calculating the distance to the horizon from the airship. This radial distance (S) is calculated based on the height of the airship (h) and the Earth's radius (r). It is given by equation 1 and is shown in figure 5. This coverage radius for a range of altitudes is plotted in figure 6.

$$S = \cos^{-1}\left(\frac{r}{r+h}\right)r \qquad (1)$$

Figure 6 shows an approximate horizon distance of 500 km (310 miles) at a 20 km altitude. This enables a single airship to provide coverage over a significant amount of surface area. For example, deploying only six airships at 20 km would completely observe the east coast of the United States. In contrast, it would take approximately 60 ships or land-based towers to observe the same territory. Besides the littoral coverage, the stratospherically stationed airships observe 500 km out to sea. This translates to additional reaction time for intercepting unknown vehicles.

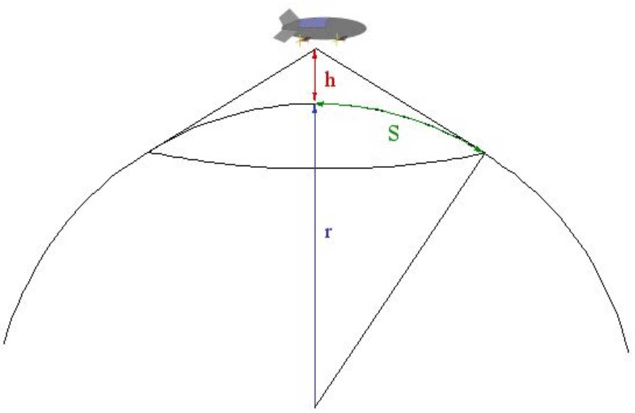

Figure 5.—Horizon as seen from the Airship (not to scale).

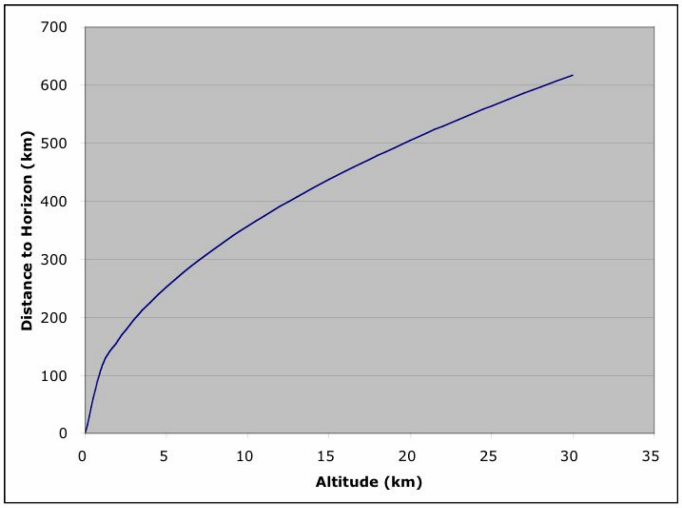

Figure 6.—Horizon Distance as a Function of Altitude.

Altitude can also affect the airship's station-keeping performance. Operating the airship under minimum aerodynamic drag conditions will produce the maximum performance with the minimum size. For observation missions where the airship remains stationary, the station-keeping drag is a function of the mean wind velocity, airship size needed to lift the payload, and the air density at altitude.

Assuming that the airship's mass is linearly proportional to its volume, the drag (D) on an airship can be expressed in terms of the wind velocity (V) and air density (ρ). This proportionality is given in equation 2. Note that the drag varies inversely with the atmospheric density; consequently, drag will generally increase with altitude.

$$D \propto \frac{V^2}{\rho^{(2/3)}} \qquad (2)$$

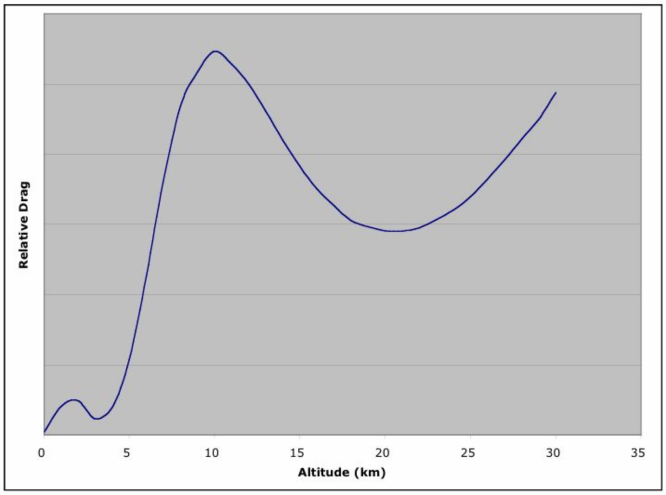

Figure 7.—Relative Drag on an Airship Sized to Carry a Fixed Payload at a Given Altitude at 38° N Latitude along the East Coast.

The relationship given in equation 2 is plotted in figure 7 using atmospheric data. This figure shows the airship's drag for an altitude range from the surface to 30 km. The figure is based on the mean wind speed profile for the winter months at 38° N latitude along the east coast. The aerodynamic drag translates into propulsion power requirements for a specified payload. Fortunately, there is a dip in the curve at 22 km stratospheric altitude. This high-altitude minimum drag provides modest power requirements while allowing a 500 km observation radius.

Possible Configurations for the Airship

The traditional airship configuration is either a cylindrical or ellipsoidal surface. Several non-traditional shapes have been proposed; of these, the most appealing for a solar-powered application is the *Skycat 1000.*

A number of airship configurations for high-altitude long-endurance airships have been studied by both government and private organizations. These designs range from conventional cylindrical shapes to spherical or saucer shaped vehicles. An example of a conventional airship layout is Lockheed's high altitude airship concept shown in figure 8 (ref. 11). This airship is an ellipsoid with three conventional tail fins for stability and four side-mounted engine pods for propulsion and control.

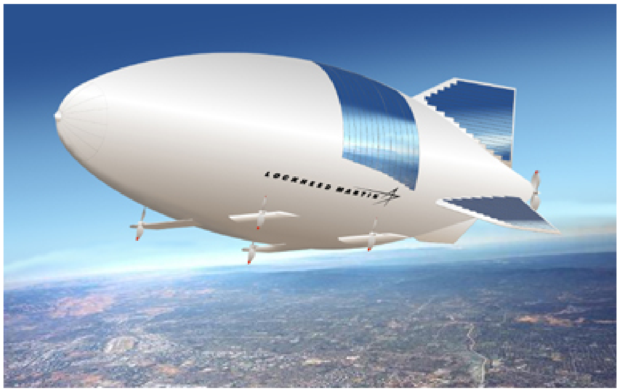

Figure 8.—Lockheed Martin's High Altitude Airship Concept.

Besides Lockheed, Japan's National Aerospace Laboratory (ref. 12) has proposed a similar ellipsoidal configuration. In general, the ellipsoid shape has good drag characteristics and capitalizes on generations of experience with low-altitude airship designs. There are other variations on the elliptical airship. For example, a design for the European Space Agency (ESA) was performed through their contractor, Lindstrand Balloons, Ltd. (LBL), for a high-altitude, long-endurance (HALE) aerostatic platform (ref. 13). The ESA design, shown in figure 9a, is a half elliptical body with a modified tail section.

Non-traditional configurations abound. The *Skycat 1000*, shown in figure 9b, is an airfoil-shaped airship designed for heavy lift applications for the Air Force by Skycat Technologies (ref. 14). Although designed for carrying heavy loads at low altitudes, *Skycat 1000* is appealing for high-altitude applications because its immense gas volume could be dedicated to producing buoyant lift in the rarefied stratosphere rather than lifting huge payloads near the ground. Also, the *Skycat 1000*'s shape presents an interesting configuration for a solar-powered, long-endurance airship because the airfoil is relatively flat on top. Mounting a solar array there would allow complete illumination throughout the day. In comparison, a cylindrical or elliptical configuration always has a section of the superstructure shaded. This means that the full potential of an array draped across the superstructure is never utilized.

Other non-traditional configurations are symmetrical designs either spherical or saucer shaped. Examples of these are Techsphere Systems International's spherical high altitude airship concept (ref. 15) and LTAS/Cambot's saucer shaped high altitude airship concept (ref. 16).

These concepts are shown in figures 10a and 10b. The designs present an interesting deviation from the traditional elliptical or cylindrical configurations. These designs will produce a much better volume to surface

Figure 9a.—ESA High Altitude Airship Concept.

Figure 9b.—Skycat Heavy Lift Airship Concept.

area ratio, thereby minimizing envelope mass. However, the reduced mass comes at the expense of increased aerodynamic drag due to flow separation. Perhaps additional systems can be incorporated to control the flow separation, but they too will have mass and consume power. It is unclear whether on not the savings in mass significantly offsets the mass, power, and complexities of controlling the flow separation.

A Note on the Operating Environment

Our atmosphere is a very dynamic environment with great fluctuations in temperature, density, pressure, wind speed, and solar intensity. The environment's influence is greater on a long-endurance, renewable energy airship than it is on conventional aircraft.

This is due to two factors: the airship's large size making it very sensitive to atmospheric winds and available sunlight limiting the power produced by the airship's solar panels. In general, the airship can operate at any location that has sufficient solar intensity to generate the power needed to overcome wind drag and an atmosphere dense enough to maintain buoyancy.

Figure 10a.—Techsphere System's Spherical Concept.

Figure 10b.—LTAS/Cabot's Saucer Airship Concept.

Daily solar intensity profiles will vary only with the time of year and latitude; whereas, the statistical mean and 99th percentile wind speeds will vary with the time of year, latitude, longitude, and altitude.

Besides wind and sunlight, other unique high-altitude environmental conditions will also influence the airship design. These include ultraviolet radiation, cosmic rays, temperature, and electrical discharges from lower altitude storm clouds.

A Renewable Power and Propulsion System for Airships

The heart of a renewable energy airship is its power and propulsion system. This system consists of the components that collect, generate, and store energy and convert that energy into useable power and thrust. The power part collects, stores, and distributes power to the propulsion part. The propulsion part produces thrust on the airship; and, in doing so, consumes the bulk of the generated power. *Because the airship's thrust needs dominate the electric power requirements, the power and propulsion systems are interdependent and must be* *designed to operate as a single system.* This allows optimizing the airship design by maximizing overall efficiency.

The following list comprises the typical main components for an airship's power and propulsion system.

- Photovoltaic Array
- Fuel Cell (Hydrogen/Oxygen, PEM)
- Electrolyzer
- Power Management
- Electric Motors/Gearbox
- Propeller

Configuring the power and propulsion system as a set of modules will minimize the need for long wire and piping runs, thus minimizing mass. Each modular element uses a dedicated segment of the photovoltaic array. Each modular element also has its own fuel cell, electrolyzer, gas storage tanks, control electronics, thermal management system, electric motors, and propellers. Figure 11 shows the components of a typical module.

A Case Study

In November 2002, the Power and On-board Propulsion Division of NASA's Glenn Research Center undertook a study of the performance capabilities and power and propulsion technology needs for a renewable, high-altitude airship (ref. 17). The study evaluated state-of-the-art technology levels for two observation missions: west coast and east coast surveillance.

The study showed that maintaining station at 42° east coast latitude in winter required one of the following: a very large airship; lighter, more powerful energy systems; or clever operating protocols. Overall, the study concluded that long-duration, high-altitude coastal surveillance airships powered by renewable energy technology:

1. Are feasible using state-of-the-art power system technologies.
2. Can provide coastal surveillance for both east and west coasts. However, winter operation at 42° latitude on the east coast is a problem.
3. Have significant payload advantages over vehicles that derive lift from propulsion through the atmosphere.
4. Require unprecedented 300 kW, flight-rated, renewable power systems.
5. Require focused development of specific renewable energy technologies to guarantee that they are effective in such a large-scale application.
6. Have many engineering challenges.

To simplify the geometry, a cylindrical airship with hemispherical ends was chosen as the baseline configuration. The airship was given a three tail fin arrangement and four engine pods. The engine pods and the support structure were arranged in groupings of two (one on the left and one on the right side) evenly spaced along the bottom of the airship. The solar array was positioned on the upper half of the cylindrical section. The full upper half of the cylinder was not completely covered with the solar array. The amount of array needed depended on the airship sizing and mission details. A diagram of the airship configuration used throughout the analysis is shown in figure 12.

The size was based on the largest airship that could be constructed using existing airship hangers in the United States (185 meter length). The details of this baseline design are given in table 1.

For east coast operation, this airship, outlined in table 1, would be capable of operating at latitudes below 29° and between latitudes of 33 and 38°. For latitudes outside of these ranges, the main problem occurs during the winter months.

The high mean and 99th percentile winter winds produce a significant increase in drag and therefore power requirement. This coupled with winter's shorter daylight and lower sun angles makes wintertime operation impossible for the baseline airship between 29 and 33° and between 38 and 46° over the east coast. However, spring, summer, and autumn operations over the complete latitude range of the east coast are possible with the 185 meter baseline airship.

For west coast operation, the summer months provide the greatest challenge due to the higher 99th percentile wind speeds. However, because these higher wind speeds occur during the summer months, they are offset by the longer daylight and higher sun angles that occur during this season. The airship configuration listed in table 1 for west coast operation was capable of continuous year-long flight over the full latitude range.

Figures 13 and 14 show a breakdown of the mass distribution of the east and west coast airship. Figure 15 shows coastal cities and their latitudes.

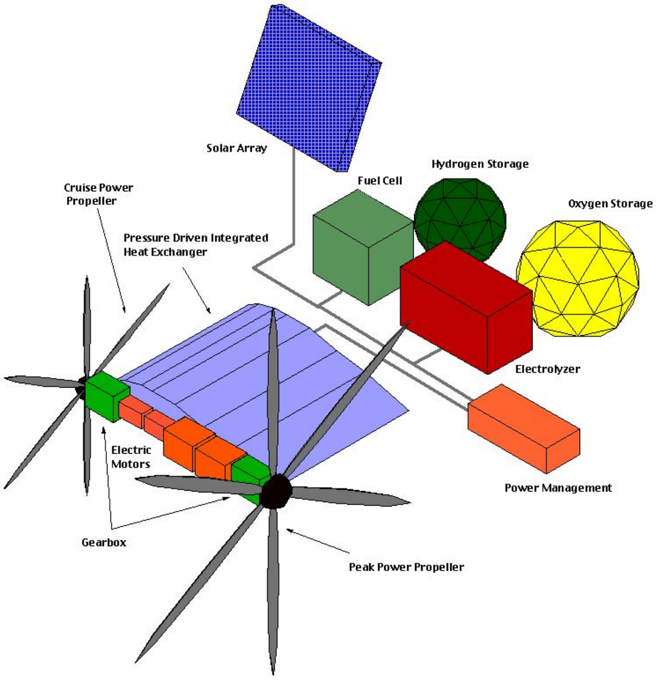

Figure 11.—Component Breakdown for a Power/Propulsion System Module (drawing is not to scale).

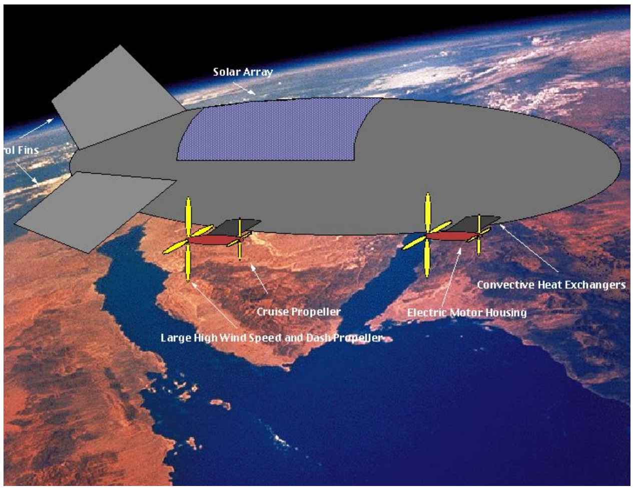

Figure 12.—Study Airship Configuration.

TABLE 1.—BASELINE AIRSHIP DESIGN

Airship Characteristic	***East Coast***	***West Coast***
Lifting Gas	Helium	Helium
Shape	Cylindrical with Spherical Ends	Cylindrical with Spherical Ends
Length	185 m (607 ft)	185 m (607 ft)
Diameter	46 m (150 ft)	46 m (150 ft)
Volume	2.8E5 m^3 (9.9E6 ft^3)	2.8E5 m^3 (9.9E6 ft^3)
Fins	3	3
Payload Mass	2000 kg (4400 lbs)	4000 kg (8800 lbs)
Payload Power	10 kW	10 kW
System and Communications Power	1 kW	1 kW
Solar Array Efficiency & Specific Mass	8%, 0.12 kg/m^2	8%, 0.12 kg/m^2
Fuel Cell Efficiency	50%	50%
Electrolyzer Efficiency	50%	50%
Mean Power Level	35.3 kW	17.1 kW
Maximum Power Level	308.5 kW	301.6 kW
Operating Latitude Range (year long flight)	28° to 29° & 33° to 38°	35° to 48°

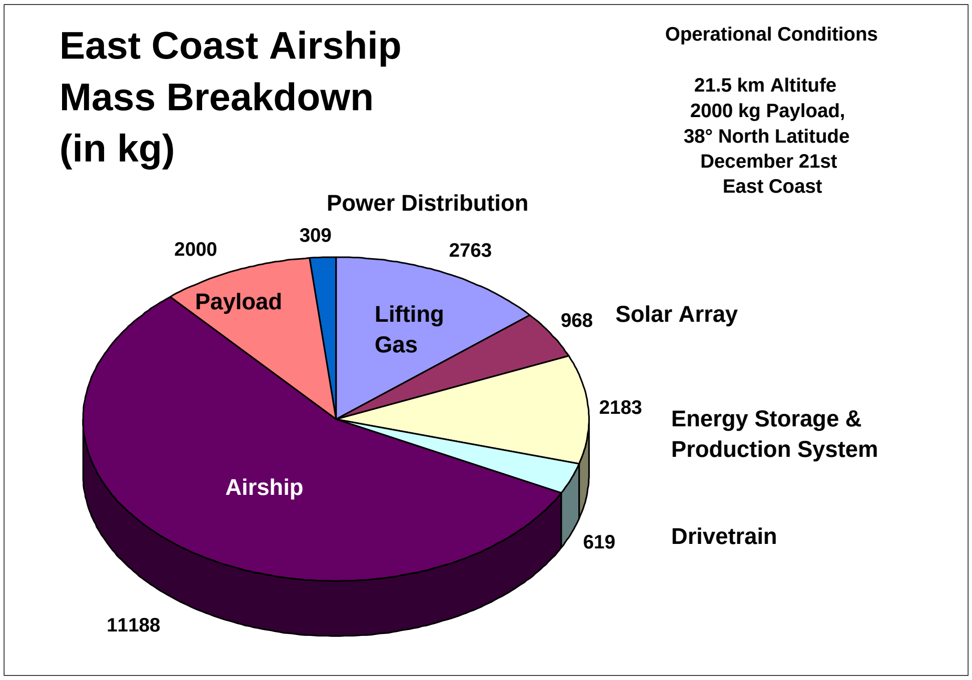

Figure 13.—Mass Breakdown for East Coast Airship.

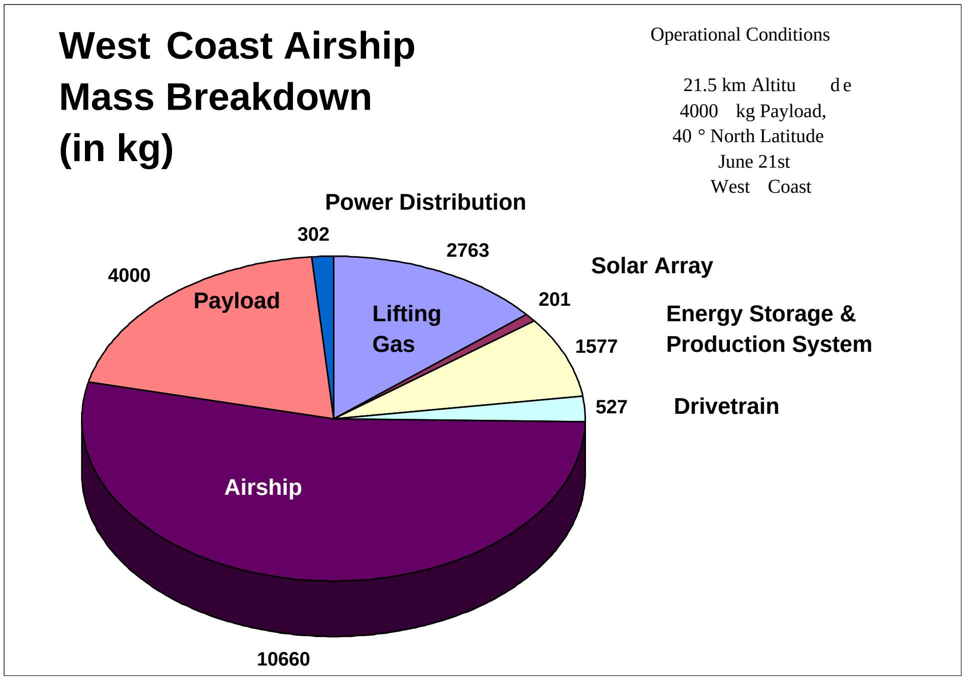

Figure 14.—Mass Breakdown for West Coast Airship.

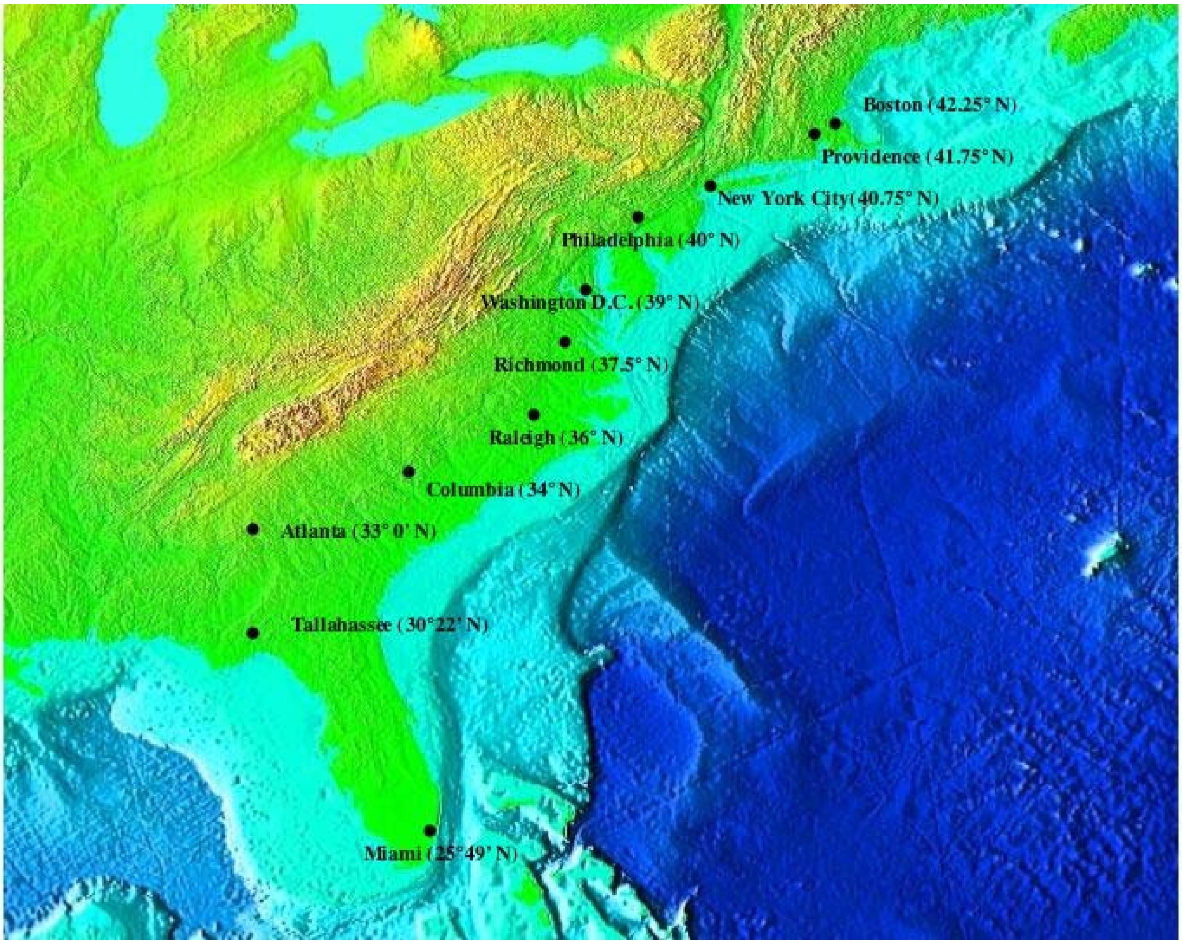

Figure 15.—East Coast Cities and Their Latitudes.

The goal of the study was to investigate continuous, year-long coverage on both the east and west coasts while carrying a sufficient radar payload. Such operation is feasible on the west coast but not on the east coast. A number of options were examined to determine what it would take to produce an airship that could operate continuously anywhere along the east coast. The options were: increasing the airship's size, changing its operating protocols, and advancing its power system's state-of-the-art.

A sizing analysis was performed to determine how large an airship was required to carry 2,000 kg at various latitudes along the east coast in wintertime. The results are shown in figure 16. The required airship grows to 270 m long and requires 1.8 MW of power to meet the 42° latitude operating requirement. This brute-force method requires the airship to be grossly oversized for all other latitudes of operation along the east coast. This large airship method of

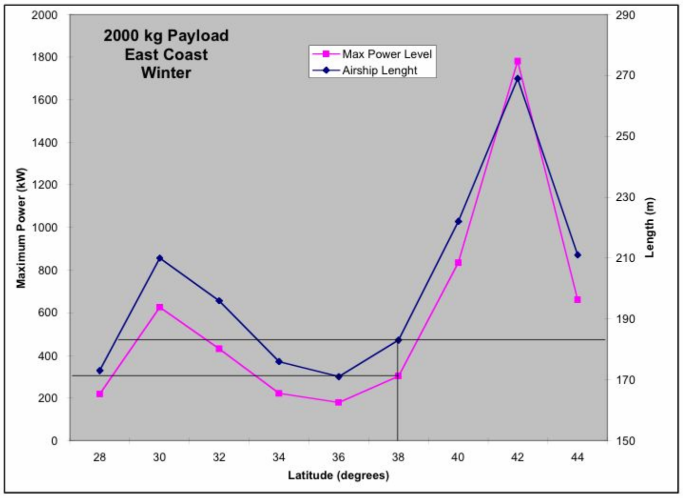

Figure 16.—Airship Length and Maximum Power Needed for Continuous Operation Along the East Coast with a Payload of 2000 kg.

meeting the observation goal is illustrated in figure 17.

Another alternative is to avoid flying at the 42° latitude point. Notice that in figure 16 the required airship size drops off significantly on either side of 42°. With a 500 km viewing radius, airships could be stationed at more benign latitudes while still providing coverage at 42° latitude. The study showed that operating at 38° and at 46° would provide the observational coverage with no blind spots and hold the airship to 185 m long. This option of observing into the areas where the airships cannot operate is shown in figure 18.

Another operational approach is to employ multiple airships which cycle through the high wind area. This would allow them to drift with the wind and still maintain continuous coverage. Once they drifted out of observational range, they could move to a low wind area and fly back inland for another cycle. This concept is illustrated in figure 19.

The last operating option is to change altitude to avoid the high wind conditions since the high winds are transient and do not occur at all altitudes simultaneously. This concept is illustrated in figure 20.

The study also identified advancements in the power and propulsion system that would enable year-long airship operation. Variation in the baseline power and propulsion system specifications (described in table 1) were made to identify what technology improvements would be necessary to achieve continuous, year-long coverage along the east coast. Efficiencies and specific masses of various power and propulsion system components were improved until the baseline airship was capable of operating year long at the 42° latitude location with a 2000 kg payload. The advances from the baseline systems to achieve this are listed in table 2. No improvements to the airship structure or design (drag) were assumed.

TABLE 2.—ADVANCEMENTS NEEDED FOR BASELINE AIRSHIP TO OPERATE AT 42° N LATITUDE YEAR-LONG

Component	***Baseline***	***Advanced***
Solar Cell Efficiency	8%	12% (50% increase)
Drive Train	2.39 kg/kw	1.79 kg/kw (25% reduction)
Power Distribution Specific Mass	1 kg/kw	0.5 kg/kw (50% reduction)
Fuel Cell/Electrolyzer Specific Energy	240 W-hr/kg	625 W-hr/kg (160% increase)
Fuel Cell Efficiency	50%	65% (30% increase)
Electrolyzer Efficiency	50%	65% (30% increase)
Lifting Gas	Helium	Hydrogen

Recommendations

- Provide a cost-effective network of renewable energy, long-duration airships to monitor possible air and maritime threats to the coastal United States.
- Reduce the development risk for the airship's renewable power and propulsion system by capitalizing on NASA Glenn's expertise in power system technology. Specifically, we recommend that NASA Glenn design and test an *Integrated Power and Propulsion Advanced Engineering Prototype* module. This module will act as a pathfinder for the full-scale production airship. The module's subsystems are: Propulsion system consisting of high-altitude propellers with motors, transmissions, and controls; thermal management systems for both solar array and electronics; regenerative fuel cell energy system; photovoltaic array generation system; and power management and distribution system

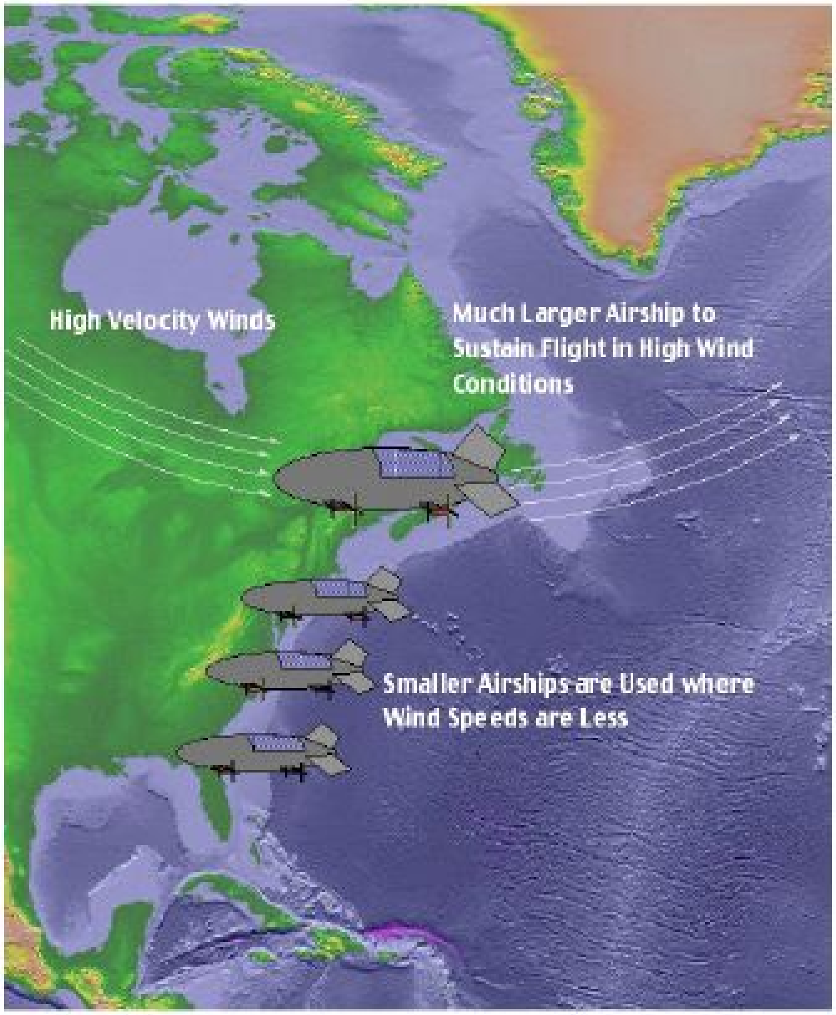

Figure 17.—Large Airship Solution for Observing in High Wind Areas.

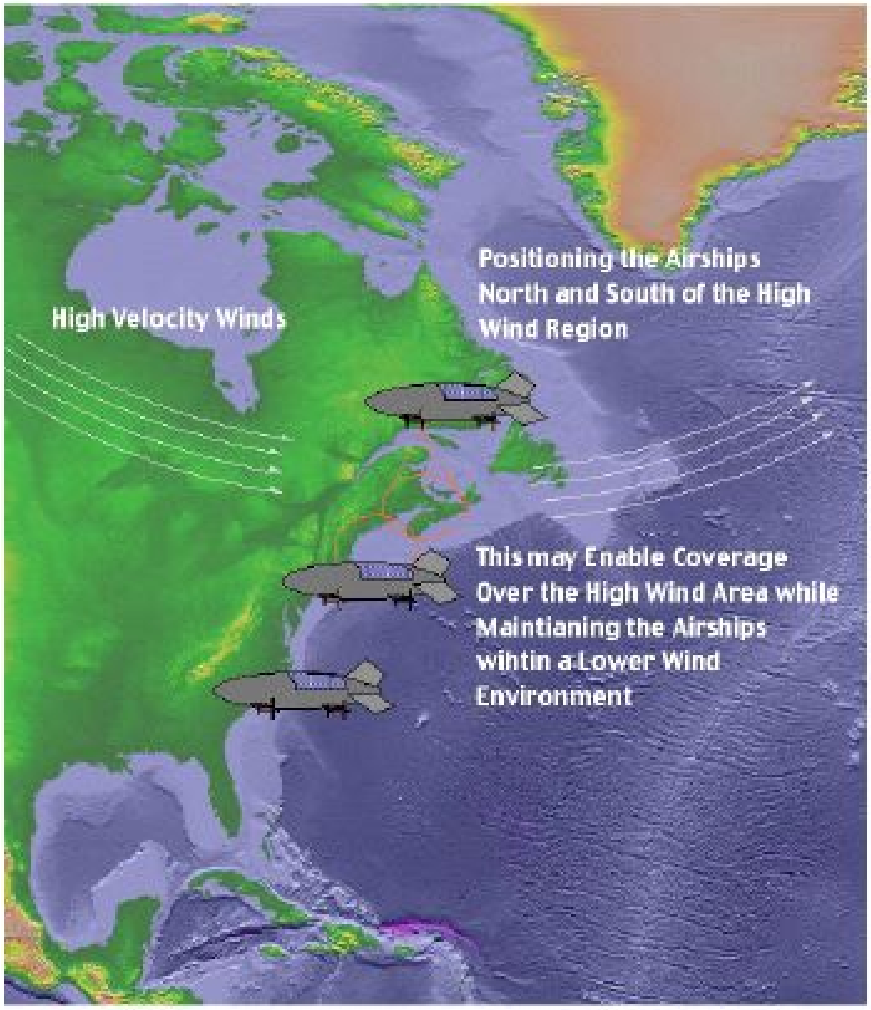

Figure 18.—Observation Solution for Observing Within High Wind Areas.

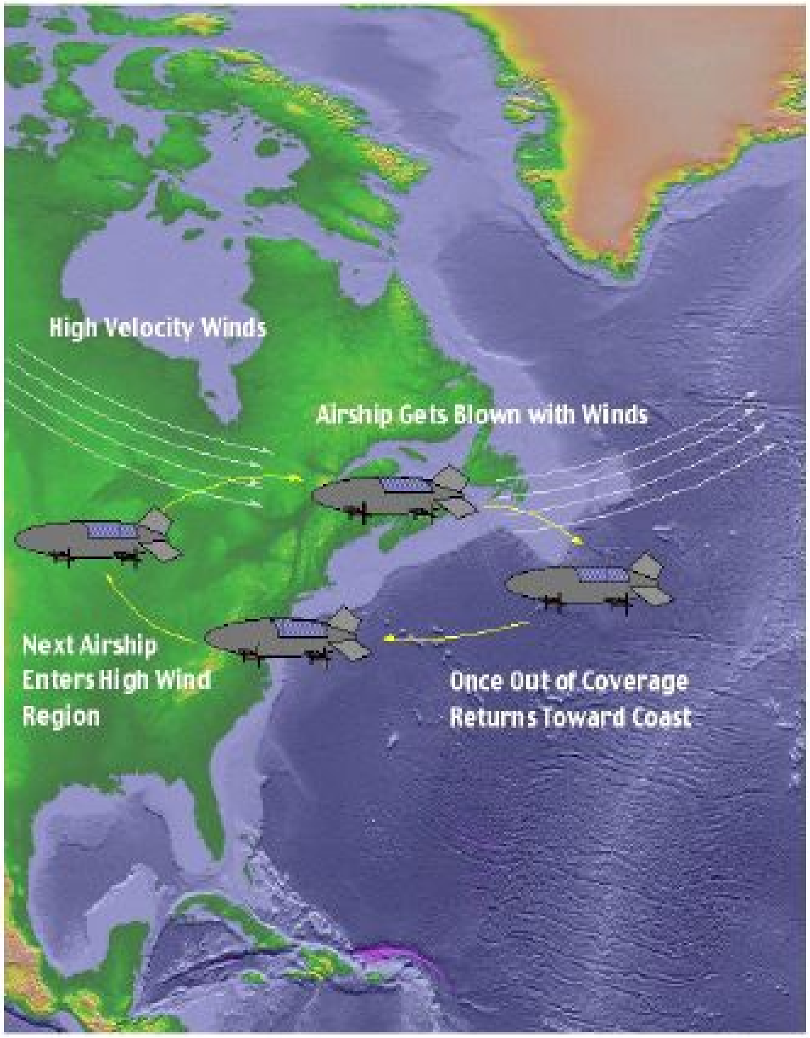

Figure 19.—Rotate Airship Solution for Observing in High Wind Areas.

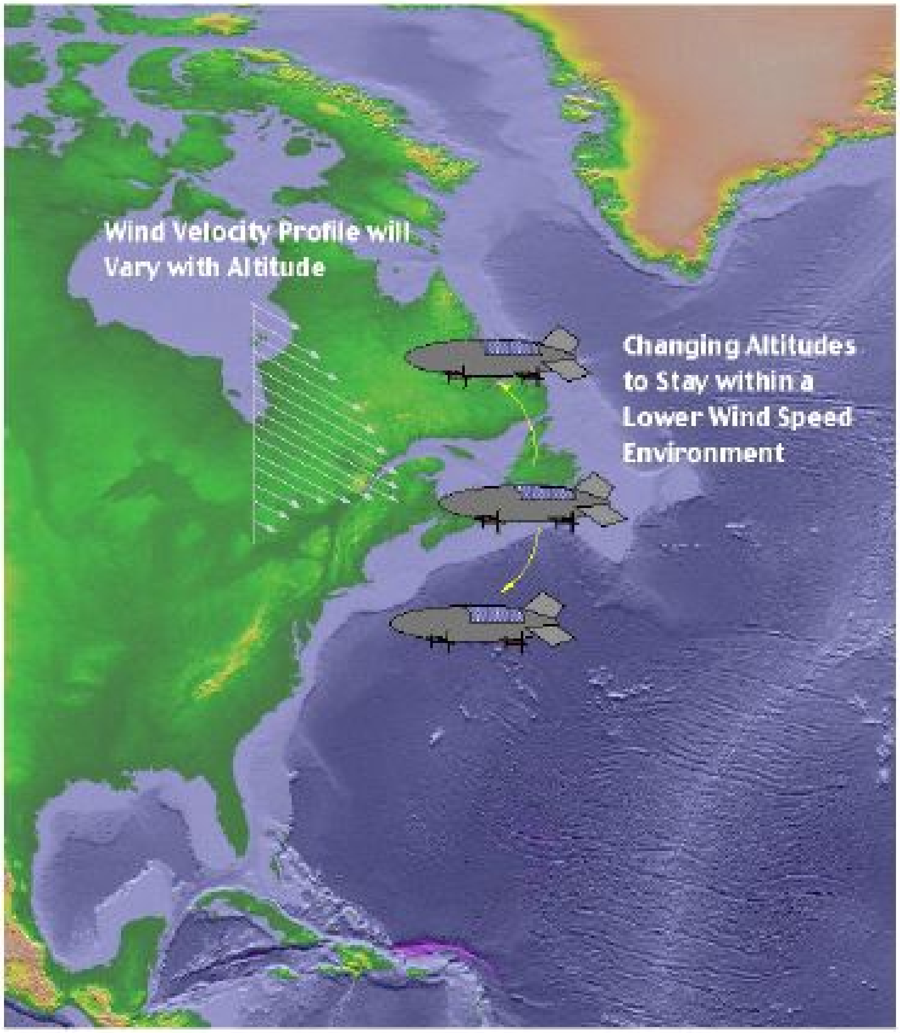

Figure 20.—Altitude Change Solution for Observing in High Wind Areas.

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13. ABSTRACT ***(Maximum 200 words)***

A high altitude solar powered airship provides the ability to carry large payloads to high altitudes and remain on station for extended periods of time. This study examines applications and background of this type of concept vehicle, reviews the history of high altitude flight and provides a point design analysis. The capabilities and limitations of the airship are demonstrated and possible solutions are proposed. Factors such as time of year, latitude, wind speeds, and payload are considered in establishing the capabilities of the airship. East and west coast operation is evaluated. The key aspect to success of this type of airship is the design and operation of the propulsion and power system. A preliminary propulsion/power system design was produced based on a regenerative fuel cell energy storage system and solar photovoltaic array for energy production. Results on power system requirements for year long operation is presented.

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