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Aerotecture
The Return of the Rigid Airship

Edited by Charles L. Owen

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Detailed information on the Structured Planning process used for this project can be found in papers by Prof. Charles Owen on the Institute of Design web site: www.id.iit.edu
See also the Aerotecture presentation:
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Preface

Aerotecture was one of two projects conducted in the Institute of Design's 1992 Systems and Systematic Design course. It considered the ultra-large through speculation about possibilities at the outer limits of macro-airship technology. The other project, **Nanoplastics**, took the opposite end of the scale for its domain and considered what might be possible as the new science of molecular nanotechnology unfolds. Both projects were entered in international competitions, and both achieved success.

For 1993, the Japan Design Foundation in Osaka had announced the theme for its sixth International Design Competition to be: "air". Teams from the Institute of Design's Systems and Systematic Design course had won the Grand Prize in the first and third competitions and had been among the finalists in the fourth competition. The prospects for rigid airships seemed both fitting for the competition and appropriate to the moment. Interest worldwide in large airships was increasing after a long hiatus following the destruction of the German airship Hindenburg in 1937. As a contrast to the Nanoplastics study of the ultra small, the project was set to explore the ultralarge— a *floating city* in the air.

The importance of scale for airships was a lure in contemplating the ultralarge. Lift increases with the cube of dimensional scaling. A lifting body 1 unit by 1 unit by 1 unit doubled to 2 by 2 by 2 will increase its lift eight-fold. Very large lifting bodies can lift exceptionally large payloads. The challenge was to explore the edges of what might be possible. There were challenges in virtually every aspect of structural design, power, construction, and operation, but the payoffs for scale would be impressive.

When the results of the competition were disclosed, this project, **Aerotecture. The Return of the Rigid Airship**, had won the Bronze Prize from a field of 1,127 entries from 70 countries.

Publicity followed the win in Osaka and communications continue to come in—even to the date of this reissue of the project report. By the end of the 1990's, 24 articles in five countries plus the U.S. had been published and a number of presentations had been made in this country and others. Radio and television also conducted interviews and ran special shows, the most far-reaching being Episode 3 of Discovery Channel's ***Invention*** series—which continues to be rebroadcast periodically and carries a computer-produced animation of the Aerocarrier in operation.

Most surprising were the private communications. Individuals, groups, institutions and companies were interested in plans for the implementation of Aerotecture. The idea of large scale, point to point shipping and cruising in passenger volumes equivalent to those carried by ocean liners captured the imagination of many. Telephone calls, letters and Internet messages requested project report copies and solicited our help and thinking for special projects. These latter included moving oil drilling equipment into Siberia, replacing barge traffic on the Mississippi, creating a transshipping network between central China, central U.S. and inland locations on other continents—and taking a cult into the air when the Earth disintegrates in Armageddon. There was true disappointment when the purpose of the project was revealed to be the planning process, not airship development.

Of all the systems projects conducted over nearly 40 years, Aerotecture attracted the greatest interest. There is something about an airship that captures the imagination. They will be back.

Charles L. Owen, 2004

Figure 1 **AeroCarrier over Chicago**
The distance between the Sears Tower (black, middle left) and the AMOCO Tower (white, middle right) is about 1.7 kilometers.

Introduction

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Except for balloons and "blimps", lighter-than-air craft have all but disappeared from our skies since the fateful destruction of the German zeppelin Hindenburg on May 6, 1937. Military dirigibles, used extensively in World War I, were not used in World War II. Non-rigid blimps were developed and employed for surveillance and, after the war, promotional purposes (e.g., the Fuji and Goodyear blimps), but the great age of the rigid airship was over before the start of World War II. It ended effectively with the catastrophic burning of the Hindenburg, an event captured in all its horror on radio broadcast and relived annually in the United States and other countries as a riveting and classic example of the effectiveness of on-the-spot radio news reporting.

Intentionally withheld from the public was the possibility that the Hindenburg was the victim of sabotage. It burned dramatically because its lifting gas was explosively flammable hydrogen, the only lighter-than-air gas available in quantity to then-Nazi Germany. Although the Germans had built and flown 118 dirigibles over a period of 40 years without an accident caused by fire, no hydrogen-supported airship was immune to an incendiary bomb. Ironically, an important mission of the Hindenburg's senior captain on this first flight to America of 1937 was another appeal to the U.S. government for removal of the ban on sale to Germany of the inert gas, helium. Helium, a slightly heavier, but perfectly suitable lifting gas for dirigibles, was available only in the U.S. Had the Hindenburg's gas chambers been filled with helium, the fire could not have occurred and, no matter how

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determined any saboteurs, the zeppelin would have been very difficult to bring down.

In the 34 seconds it took for fire to completely consume the 245-meter-long Hindenburg, the curtain descended on the great age of airships. Germany discontinued plans for further airships, and the U.S., the other leading airship builder, followed suit. The two most advanced U.S. dirigibles, the U.S. Navy's Akron and Macon, had already been lost in storms at sea in 1933 and 1935, both within four years of their construction.

What has been forgotten today is that travel and commerce by airship had, until 1937, been successful business. German, and to a lesser extent, British and French airships carried passengers and cargo between many cities in Europe before World War I. After the war, commerce by air continued with larger, faster and more luxurious airships, extending to international routes.

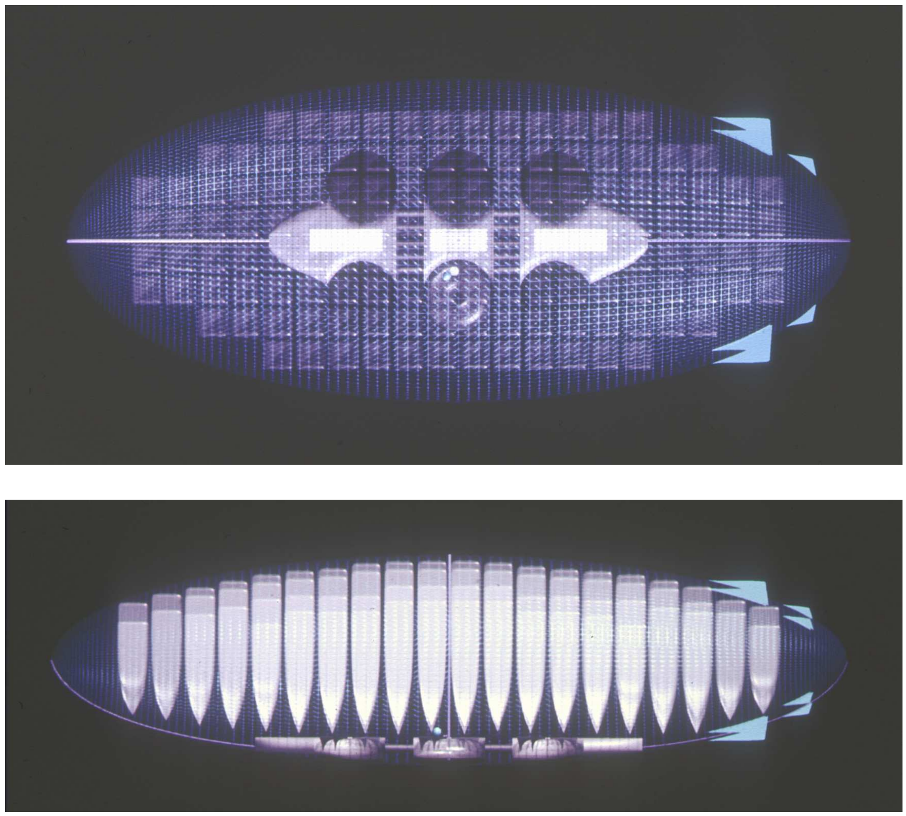
In 1928, one year after the American Charles Lindbergh struggled to fly a specially-modified monoplane across the Atlantic to Paris, the newly-constructed Graf Zeppelin made the first cross-Atlantic passage by airship from Friedrichshafen, Germany to New York City. It effortlessly carried 40 crew members, 20 passengers and 12 tons of freight. The voyage covered 9600 kilometers and took 111 hours. Within a year, the Graf Zeppelin had flown around the world in 21 days, starting from Lakehurst, New Jersey in the U.S. and stopping only at Friedrichshafen, Tokyo and Los Angeles. Scheduled international travel followed, by 1935 becoming routine. The trip from Germany to Brazil took five days—in contrast to almost five weeks by ship. Airship travel was legitimate and expected to grow rapidly in demand. The tower of the world's then tallest building, New York's Empire State Building, was designed and built as a "mast" for mooring dirigibles. During her years of service the Graf Zeppelin alone made 650 flights (144 of them across the Atlantic), flew more than 1,600,000 kilometers, and carried more than 18,000 passengers.

Today, more than fifty years later, the time has come to reconsider the airship. Since the 1930's, revolutionary changes have occurred in nearly all the sciences and technologies associated with airship construction and operation. From materials science have come new structural materials substantially lighter and stronger than those available in the 1930's. Electrical and mechanical engineering technologies have developed a host of alternative means for generating power and new and more efficient means for applying it. Advancements in computer and communication technologies now allow an aircraft to navigate anywhere with precision, anticipate storms long before they can be seen and respond instantly and appropriately to a storm's unpredictable forces should the aircraft be caught within them. Complex operational problems are now smoothly and routinely handled with the help of command and control systems able to integrate vast amounts of information and action requirements.

Today's technology holds the key to a vastly expanded vision of travel in the sky. Through the means of lighter-than-air technology, Aerotecture explores that vision. More importantly, Aerotecture boldly applies design thinking to new uses of the air for working and living purposes. Aerotecture is not just airship design; it is the serious extension of human activities to a previously under-utilized environment.

General Description

Aerotecture in this project is applied to the design of multi-purpose transport. Elements of the system include an ultra-large rigid-airship Aerocarrier, shuttle pods for travel to and from it and a construction site.
The Aerocarrier is a mother ship, operating in the lower levels of the atmosphere at speeds to 160 kilometers per hour and, except for infrequent periods of special maintenance or repair, remaining aloft permanently. In form, the Aerocarrier is an ellipsoid 2,400 meters long, 1,000 meters wide and 640 meters high.



Figures 2 and 3 **The AeroCarrier**
Top and side views of the AeroCarrier with its hull rendered translucent for internal viewing. Helium bags, shuttles and passenger space are visible.

At full speed, the Aerocarrier is powered by 160 electric motors in two banks of 60 on its flanks and banks of 20 each at the bow and stern. A series of 24 fins at the stern act as elevators and rudders for attitude control. Additional attitude control as well as vertical motion can be provided by the engines each capable of rotation through 360 degrees.

Covering the greater part of the Aerocarrier's upper surface are arrays of photovoltaic solar cells, used to meet part of the Aerocarrier's power needs. On the lower surface are ultra-large display screens for the presentation of images and information to the inhabitants of towns and cities over which the Aerocarrier passes. Also on the underside of the Aerocarrier is the complex of living and working structures for the crew, passengers, cargo and Shuttle Pods that are the primary means of entry to and departure from the Aerocarrier.

A secondary form of access is a runway on the top of the Aerocarrier on which STOL and VTOL aircraft and helicopters can land for the transfer of passengers and light cargo.

Ports for six Shuttle Pods, three on a side, flank the keel-like living and working structure on the underside of the Aerocarrier. Toroidal in form, the Pods are themselves lighter-than-air craft designed primarily for vertical movement between the AeroCarrier and the ground. Each is 240 meters in outside diameter with an interior circular space 30 meters in diameter. In cross section, the toroidal lifting body is elliptical, 60 meters in the vertical dimension, 105 meters in the horizontal. Eight engines, individually rotatable, power the shuttle pods' movements vertically and horizontally.

Comparative Facts

	U.S. Dirigible Akron	***Zeppelin Hindenburg***	***Aerotecture Shuttle Pod***	***Aerotecture AeroCarrier***
Length	239 meters	246 meters	240 meters (diam.)	2,400 meters
Width	40.5 meters	42.7 meters	240 meters (diam.)	1,000 meters
Height	50.5 meters	49 meters	60 meters	640 meters
Internal volume			4,087,750 meters^3	677,000,000 meters^3
Nominal gas volume	184,000 meters^3	204,000 meters^3	4,087,750 meters^3	169,400,000 meters^3
Gross lift	183 tonnes	214 tonnes	4,537 tonnes	752,136 tonnes
Useful lift	83 tonnes	18 tonnes	740 tonnes	32,000 tonnes
Number of engines	8	4	8	160
Maximum speed	135 km/hr	145 km/hr	50 km/hr	160 km/hr
Range at cruising speed without refueling	17,000 km	16,000 km	2,000 km	unlimited

Table 1 **Comparisons of Rigid Airships**

Two famous airships compared with the AeroCarrier and its Shuttle Pod. The Akron, and its sister ship, Macon, were the last U.S. airships built, The Hindenburg was Germany's last and most advanced airship.

Components of the System

AeroCarrier: Mothership and primary transportation vehicle

The AeroCarrier is the prime mover of the Aerotecture system. It is built on an ultra-large scale to take maximum advantage of the fact that lift increases with the cube of multiplication in scale. A cube 1 meter on a side filled with helium will lift 1.11 kilograms at sea level; a cube 2 meters on a side will lift 8.88 kilograms. At 3 meters on a side, the lift increases to 29.97 kilograms.

The volume of the AeroCarrier is 794,697,579 cubic meters, nearly 85 percent of which is available for lift. With this enormous volume, the available lift greatly exceeds the weight of the structure necessary to enclose it, permitting very large payloads to be carried. At the scales projected for Aerotecture, limits are more determined by economics and structural ingenuity than weight.

Aerodynamics. The ideal aerodynamic form for the AeroCarrier is one that is rounded and smooth to minimize turbulence and drag (air resistance). For minimum drag at the speeds of up to 160 km/hr planned for the airship, the optimal aerodynamic shape is an ellipsoid, approximately three times as long as its cross sectional diameter. Because the AeroCarrier's cross section is more practically elliptical than circular, its width and height dimensions are determined by scaling the area of its elliptical cross section to be equal to the area of a circle of diameter one-third of the AeroCarrier's length.

The drag produced by the ship's movement through the air increases with the square of the ship's velocity. Drag is also affected by the density of the air (lower at higher altitudes) and the surface area of the ship (greater with increased area). Because of its immense surface area, the AeroCarrier's engines must overcome drag of approximately 22,000,000 newtons at its highest projected speed, 160 km/hr,

Structure. One of nature's strongest structures is the egg. Its continuously curved surface geometry allows it to withstand extremely large compressive forces relative to its weight. The AeroCarrier's primary structure is a 3-meter-thick "shell" made of a stressed-skin sandwich of space-age materials. The "skins" are specialized surfaces with properties of strength and hardness appropriate for their location in the shell (harder and stronger, for example, where aircraft might land on the top of the AeroCarrier). These are bonded to thick layers of honeycomb for extraordinary strength-to-weight ratios. For the AeroCarrier's shell, three meters thick, the total weight is only 429,000 metric tons.

To take advantage of the ellipsoid's ability to withstand compressive forces so efficiently, the helium lift forces are anchored as directly as possible to the lower surface of the stressed-skin shell, in effect, pulling it upward. For the same reason, the weight of the ship's interior structures and payload is hung as much as possible from the upper surface of the shell, pulling it downward. The extensive cabling necessary for this also takes advantage of the properties of materials that have greater strength in tension than compression, improving overall strength-to-weight ratios. Cabling from shell wall to shell wall across the width of the ship resists the tendency of the opposing vertical forces to buckle the shell at the sides. To prevent overloading of the shell, some of the weight of the interior structures and payload is supported directly by the lifting cells. This capability allows loads to be distributed and variations in loading to be compensated directly without change to the distribution of forces on the shell.

Structure

Force distribution.

(1) Some lift is applied directly to internal structures

(2) some lift pulls the shell up

(3) some weight pulls the shell down

(4) cross-tensioning resists squeeze

(5) The composite uses the shell form optimally

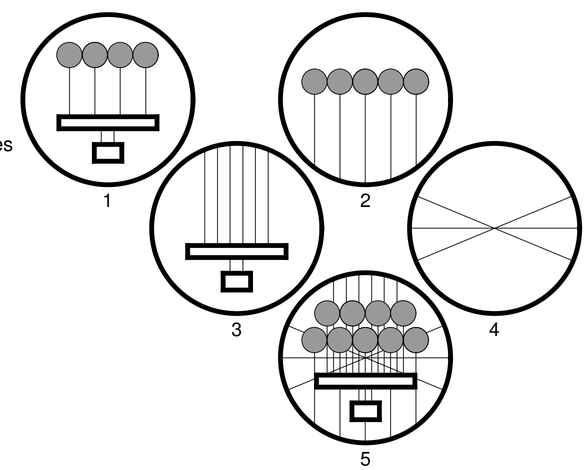


Table 2 **Structure**

The enormous weight and size of the AeroCarrier require special structural strategies. Taking advantage of the strength of the egg-shell form in compression, weight, lift and lateral tensioning are used to put compressive forces on the hull.

Lifting Force. Helium used for lift is held in individual gas cells, roughly square in horizontal cross section (100 meters by 100 meters) and of different heights, from 250 meters to 520 meters, corresponding to where in the ship they are located. Occupying approximately 85 percent of the AeroCarrier's volume, the gas cells are tethered in eight rows along the length of the ship, four rows of 22 cells at the center, flanked by a row of 20 and an outboard row of 16 on both sides. Total volume for all 160 gas cells is 677,600,000 cubic meters. If all cells were filled with helium, the total lift would be 752,136 metric tons.

The gas cells are constructed of thick polyester film for high strength at relatively low weight. Because helium gas is notoriously difficult to contain, they are also coated to further reduce their permeability. Under the best of circumstances, however, helium will escape through the walls of its container. To salvage escaped helium, the air at the top of the ship is continuously collected and passed through 40 gas purifiers, each capable of processing over 1,200 cubic meters per hour. Helium not in use is stored at 50 atmospheres pressure in 1-meter-diameter tanks, 12 meters long.

Holding the gas cells in place and transferring the forces of their lift to the AeroCarrier's shell are nets that cover the top three fifths or more of each cell. These nets, constructed from polyester ropes 8.6 centimeters in diameter, are spaced to ensure that forces are distributed evenly; ropes in the net are never more than 7 meters apart. 80 steel-reinforced cables, 20 on each side of the cell, are integrated into each net so that they criss-cross over the top of the cell. Through the cables, the lifting forces are tied to the shell or interior structures below. Total weight for the gas cells and holding nets is 96,000 metric tons.

All gas cells are not filled with helium. If they were, the total lift possible would be significantly greater than required for the weight of the ship and its payload. In operation, some cells may be empty and some may be partially filled to approximately balance lift and load. Other cells are used to dynamically regulate lift. These cells are filled with air warmed to a temperature appropriate to add the lift necessary for trim as altitude and temperature change. Air at constant pressure decreases in density by 12 percent as its temperature rises from 15 degrees Celsius to 50 degrees Celsius; a rise in temperature to 100 degrees Celsius decreases its density by 30 percent. Heating air in a 520-meter gas cell adds additional lift of up to 1,900 metric tons as the temperature is raised from 15 to 100 degrees.

Ballast in the form of water is also stored aboard for infrequent situations in which increased lift is required quickly. When necessary, large amounts of water can be released simultaneously from ballasting tanks. These tanks are a part of the general water supply system, acting as major elements of the ship's reservoir, buffers for water supply and demand dynamics, and receivers for condensate created by the burning of hydrogen gas for heating and power. Runoff traps on the AeroCarrier's outer surface are used to direct rain water runoff through the shell to the tank reservoirs. When there is any shortage of water, the ship need only be driven through a rain squall to replenish its supplies.

Propulsion. Because it is supported aloft without power, an airship is in the unique position of needing its propulsion system only to move or hold its place. This gives it the flexibility to direct its power generation facilities to other purposes besides simply staying aloft—an enviable advantage it holds over winged aircraft. Of special value for passenger cruising, it is possible for an airship to loiter, stop, and, in general, match speed directly to the time desired for a trip, since no power (or minimum air speed) is required to stay aloft.

The extraordinary size of the AeroCarrier, however, sets extraordinary propulsion requirements when travel at higher speeds is necessary. Because power required is directly related to the square of the ship's velocity, even such relatively low subsonic speeds as 160 kph demand large amounts of power. The essential equation is: the thrust to attain a given speed must equal drag at that speed. For a maximum speed of 160 km/hour at an altitude of 1,500 meters the AeroCarrier's drag is approximately 21,744,000 newtons. Using electric propulsion motors now under development by NASA and expected to be capable of 135,000 newtons thrust, the AeroCarrier requires 160 engines.

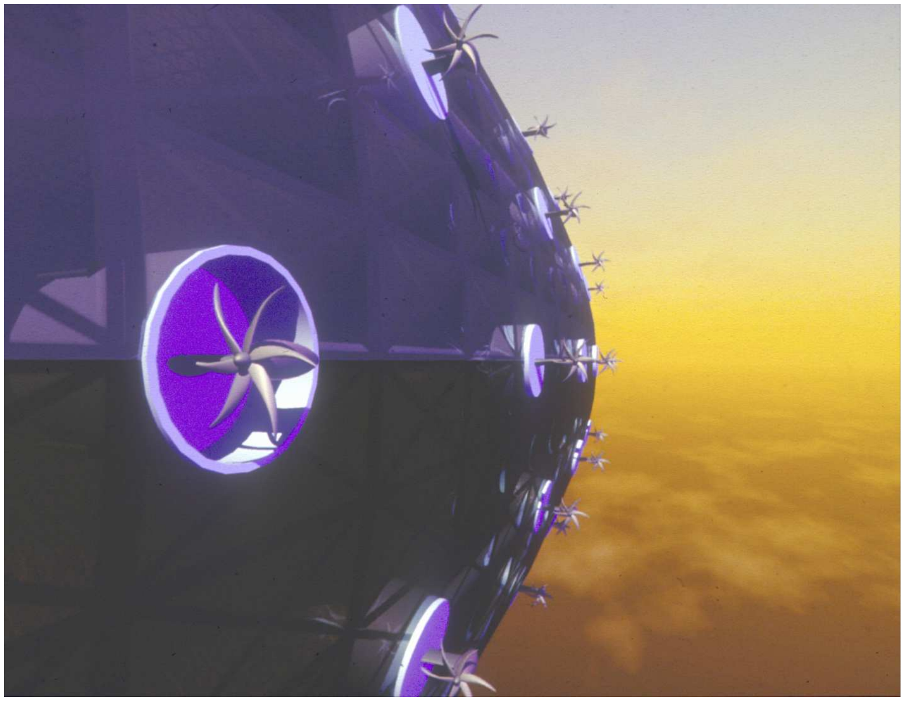


Figure 4 **Engines**
Banks of electric, retractable engines line the hull of the AeroCarrier. Used only as necessary, they can power the ship to a maximum speed of 160 kph.

At lesser speeds, the number of engines required to be on line drops dramatically. For speeds up to 30 km/hour, the equivalent power of only three of the high-powered engines is necessary. At 80 km/ hour, the power of 40 engines is sufficient. Only 114 engines are required to equal the maximum speed of the Hindenburg (135 km/hour). For many missions, an AeroCarrier will not need its higher speeds. For those involving competitive cargo carrying, however, speed in the range of three times that available by sea is very attractive, and when detours around storms are necessary or opportunities appear to make up lost time, reserve speed is highly desirable.

Engine Power

δ = Density of air @1,500 m altitude: *1.058 kg/m³*
v = Velocity in m/sec
S = Surface area of the moving body in m^2: 5,142,802 m^2 (for the AeroCarrier)
k = Constant: *.004*
D = Drag in newtons
T = Thrust of an engine in newtons: 135,000 newtons (for the AeroCarrier)

N = Number of engines necessary

g = $(.5)(\delta)(v^2)$
D = (g)(S)(k)
N = D/T = D/135,000

km/hr	v	g	D	N
5	1.39	1.02	21,003	1
10	2.78	4.08	83,971	1
20	5.56	16.33	335,927	3
40	11.11	65.32	1,343,691	10
60	16,67	146.77	3,023,309	23
80	22.22	261.28	5,374,463	40
100	27.78	408.24	8,398,072	63
120	33.34	587.87	12,093,237	90
140	38.89	800.16	16,460,237	122
160	44.45	1045.10	21,499,072	160

Table 3 **Engine Power**
Total thrust required for any velocity equals the drag at that velocity. The number of engines necessary increases dramatically as the required velocity increases. Top speed is 160 km/hr, about 100 miles per hour.

Engines are individually driven by the high-thrust electric motors. Fitted with six-bladed propellers, the engines are mounted on struts extending from the AeroCarrier's hull. Each strut, with its engine, can be retracted through a hatch for service inside the ship. To provide the best possible support for maneuvering, engines can be rotated 360 degrees around the axis of their struts.

The main banks of engines are on the flanks of the AeroCarrier. 60 engines each are mounted along the port and starboard sides. An additional 20 engines at the bow and 20 engines at the stern can be used either for forward motion or for trim and turning maneuvers at low speed. At medium and high speeds, 24 fins at the stern in two circles of 12 provide rudder and elevator functions.

Power Systems. Power to run the AeroCarrier's propulsion system and internal operations is electric. Three sources of power are employed.

Solar power. The AeroCarrier's elliptical cross section provides a broad "back" upon which fields of solar-cell panels can be mounted. Roughly 38.5 percent of its 5,108,000 square meters of surface area is covered with fields of photovoltaic solar cells.

The Earth receives approximately 1,353 watts of solar energy per square meter of exposed surface at its average distance from the Sun. About 70 percent of that energy reaches the surface of the Earth, either as direct or diffuse radiation; the rest is dissipated by the reflecting, absorbing and scattering effects of clouds and atmospheric gases. Assuming 25 percent efficiency for solar cells (efficiencies of 30 percent have been achieved in the laboratory) and an average of 12 hours of daylight per day with an efficiency factor of .67 to reflect the sun-up to sun-down intensity variation, the power produced by the photovoltaic system is 156 megawatts.

Solar Power

P_1 = Average solar power reaching the Earth's orbit: *1,353 w/m^2*

f_1 = Penetration factor (percent of energy penetrating the atmosphere): *70 percent*

A = Area of solar cell arrays: *1,966,000 m^2 (for the AeroCarrier)*

f_2 = Efficiency factor for solar cells: *25 percent*

d = Average fraction of daylight per 24-hour day: *.50*

f_3 = Intensity reduction factor for changing Sun elevation: *67 percent*

P_2 Average Power Generated Each Day

$P_2 = (P_1)(f_1)(A)(f_2)(d)(f_3)$

$P_2 = (1{,}353\ \text{w/m}^2)(.70)(1{,}966{,}000\ \text{m}^2)(.25)(.5)(.67)$

$\mathbf{P_2 = 155{,}942{,}000\ watts = 156\ megawatts}$

Table 4 **Solar Power**

Fields of photovoltaic cells on the AeroCarrier's upper hull contribute significantly to needs for electrical power for engines, displays and operations. Unused power is stored in SMES systems or electrolized hydrogen.

Gas turbine system. The principal power system for the AeroCarrier is a gas turbine power plant. Turbine-generator sets in this plant are driven by hot air, compressed and heated to working temperature in combustors burning compressed hydrogen gas. During the day, the compressed input air is additionally preheated by thermal-electric heat transfer processes.

Thermal-electric power. The Sun's radiation striking the AeroCarrier produces heat as well as photovoltaic electricity. To utilize that heat energy, a thermal electric co-generation system is integrated with the solar panels and gas turbine system. A maze of channels built into the shell passes air just below the fields of solar cell arrays. The air, as a heat transport fluid, circulates through the channels absorbing the radiant heat produced by the infrared portion of the Sun's radiation, but unused by the photovoltaic processes. At its hottest, it flows to the gas turbine system to pre-heat the working fluid.

The electric power produced by the gas turbine plant, solar photovoltaic system and thermal electric heat transfer processes is used directly. When power is produced in excess of requirements, it is stored in superconducting magnetic energy storage (SMES) systems or used to electrolyze water to oxygen and hydrogen that can be burned in the power plant combustors. At full speed, the AeroCarrier requires the great majority of its available power for propulsion. At lower speeds power can be distributed to other functions or stored for later requirements.

Working and Living Facilities. The AeroCarrier's extensive living, working and cargo handling facilities are located in the bottom sixth of the ship in an elliptical area 1,600 meters long, 650 meters wide and 120 meters high. Living and working quarters occupy three segments of a central keel area 1,200 meters long and, at minimum, 130 meters wide, but extending partially around each of six landing ports for the Shuttle Pods. Each of the three segments have Shuttle Pod ports located on their port and starboard sides.

Covering the entire 817,000 square meter area is an extensive space frame structure. This structure, 50 meters thick, supports the facilities below and provides storage and transfer capabilities for cargo. Cabling from the gas cells and the shell above suspend it. It, in turn, supports living and working facilities below with cables. Through the extensive cabling systems, some of the weight of the facilities is supported directly by the gas lifting cells and the remaining majority is supported by the upper portions of the hull.

Standard cargo containers brought up from the ground by Shuttle Pods are unloaded by traveling cranes rolling on tracks on the underside of the space frame. With access to all points below, the cranes transfer cargo between storage yards within the frame and ports and facilities throughout the operating area.

Despite the fact that a large portion of the AeroCarrier's working space is devoted to Shuttle Pod ports and cargo storage, there is considerable room aboard for research facilities and extensive passenger services. In her heyday, the luxury liner Queen Mary carried 2,200 passengers and a crew of 1,159 in a variety of spaces and working areas that occupied approximately 110,000 square meters on 12 decks. The AeroCarrier's passengers and crew have over 13 times that amount of space for themselves and their equipment (1,500,000 square meters on 12 decks spaced 4 meters apart). The Queen Mary's gross displacement weight of less than 100,000 metric tons is easily absorbed in the difference between the AeroCarrier's total lift and the weight of its shell, lifting gas structures and cargo.

The AeroCarrier contains all the luxury appointments and services of the great cruising fleets of the early twentieth century, but extended dramatically in area to take advantage of the plentiful space. Staterooms can be suites, even apartments; work spaces are spacious, not cramped. Open spaces for gathering are possible, in fact, desirable because they use space well at low cost in weight. Cruising on the AeroCarrier is more like visiting an elegant moving city than traveling on a ship.

Exhibit and Communication. An important mission for the AeroCarrier is the communication of information across cultures and continents. Its massive presence cannot be ignored by villager or city dweller; when it is in sight, it creates its own special event.

For its role as conveyor of information, it incorporates ultra-large, lighted information displays on both its lower flanks. Extending from just under the engine banks to the central spine of the working quarters, and covering a distance of 1600 meters fore to aft, the displays each have 720,000 square meters of surface.

Displays are created with "pixels" .7 meters in diameter that are lighted with three high-power LED's (red, blue and green) and covered with a fresnel lens that distributes the light evenly over the face of the pixel. 1,870,130 pixels are used in each display to achieve a resolution equivalent to high-quality computer monitors. The total power required for both displays at 1.5 watts for each LED is 16.84 megawatts.

Viewed squarely from the ground with the ship at 1,000 meters altitude and 45 degrees elevation, each display subtends an angle of 29.5 degrees for an observer, the same angle produced by a medium-sized (19 inch) television screen just 34 centimeters from the eye. Observers farther away from the ship, at locations where it appears about slightly less than 15 degrees above the horizon, see it as if it were a television or computer screen only one meter away. Images and type at this scale are still highly readable, just as they are on the television or computer screen. In this situation, however, the observers are over 4 kilometers from where the AeroCarrier is hovering, allowing communications to made with precision over a 12.5 square kilometer area.

In conjunction with the displays, the AeroCarrier can further engage a city or region with conferences and exhibits on-board and exhibitions landed in the Shuttle Pods. Conferees can be ferried from nearby cities to the AeroCarrier's landing strip by local helicopters and small aircraft. Large numbers of people can visit exhibitions built on the 60-meter diameter main decks of one or more of the Shuttle Pods, and Shuttle Pods can be landed together or in several locations around a region.

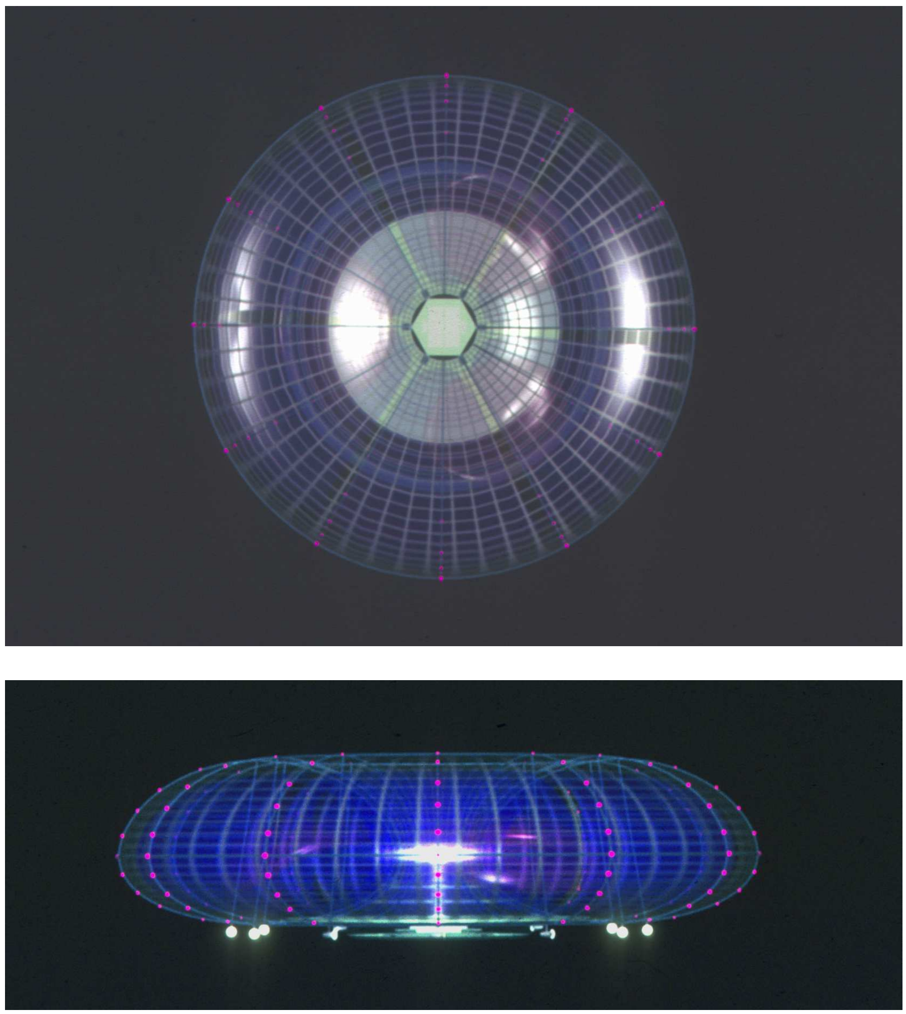
Shuttle Pod: Air to Ground Vertical Transfer Vehicle

Six Shuttle Pods transfer materials and people between the ground and the AeroCarrier. Each is an airship in its own right with its own lift, propulsion and control systems.

The form of the Shuttle Pod is derived from its primary mission: vertical transfer of cargo. It is a toroid, 240 meters in diameter, with a 30-meter central opening and an elliptical cross section 60 meters in axial dimension, 105 meters in radial dimension. Shuttle Pods operate in light or no winds, travel slowly with precise movement control, and confine their major movements almost exclusively to vertical travel.

Propulsion for the Pods is electric. Eight engines, each capable of 27,000 newtons thrust, surround the Pod. Like the engines on the AeroCarrier, the Pod's engines are mounted on struts and can swivel through 360 degrees. Unlike the AeroCarrier's engines, these engines can also swivel 45 degrees relative to the axis of their struts. This enables a Pod to move horizontally using any two engines on opposing sides as port and starboard engines and the two engines directly behind them as secondary engines. The thrust of four engines is sufficient to drive the Pod horizontally at speeds up to 50 kilometers per hour. To minimize any potential for damage to the engines when the Shuttle Pod is moved into berth in the AeroCarrier, engines are shut off as soon as hoisting lines are in place, and both struts and engines are swung down within the profile of the Pod's "doughnut" shape.

The working decks of the Pod are at the bottom of the ship surrounding the interior opening. A large main deck, 60 meters in diameter, holds cargo for transfer or can be configured for large-scale passenger transfer and exhibitions or other special uses. At the center of this deck is a loading aperture, 15 meters in diameter, able to accept standard shipping containers 2.5 meters high, 2.5 meters wide and 6 to 12 meters long. The aperture also acts as the entrance to the Pod for passengers or exhibition attendees. Around the periphery of the main deck and in ring-shaped decks above, are working spaces for the crew, ship control and engineering compartments, hoisting machinery, general purpose spaces that can be custom-fitted for research or other purposes, and living quarters for short-term activities (typically taking no longer than a week). Riding around a ring above the turn of the toroid’s center space is a folding bridge crane that loads and unloads the Pod when it is away from the AeroCarrier. Semi-circular in form, it folds down along the circumference of the Pod’s 30-meter opening when not in use. In use, it swings up to an erect position and rolls around its track to position its lifting tackle anywhere within the opening.



Figures 5 and 6 **The Shuttle Pod**
Views of the Shuttle Pod from from above and the side. The hull is rendered translucent to reveal the Shuttle’s doughnut form and internal structures.

Maximum lift for a Shuttle Pod is 4,537 metric tons, created by over four million cubic meters of helium. Its .5-meter-thick shell (constructed of the same stressed-skin composite used for the AeroCarrier) and eight gas cells weigh 3,298 metric tons. The 1,239 remaining tons of lift are distributed to permanent structure (decks, compartments, engines and engineering equipment), ballast and payload. A Shuttle Pod can be configured to transfer up to 750 metric tons of cargo (approximately 20 fully-loaded containers) or outfitted with special facilities for research, exhibition or passenger-carrying functions.

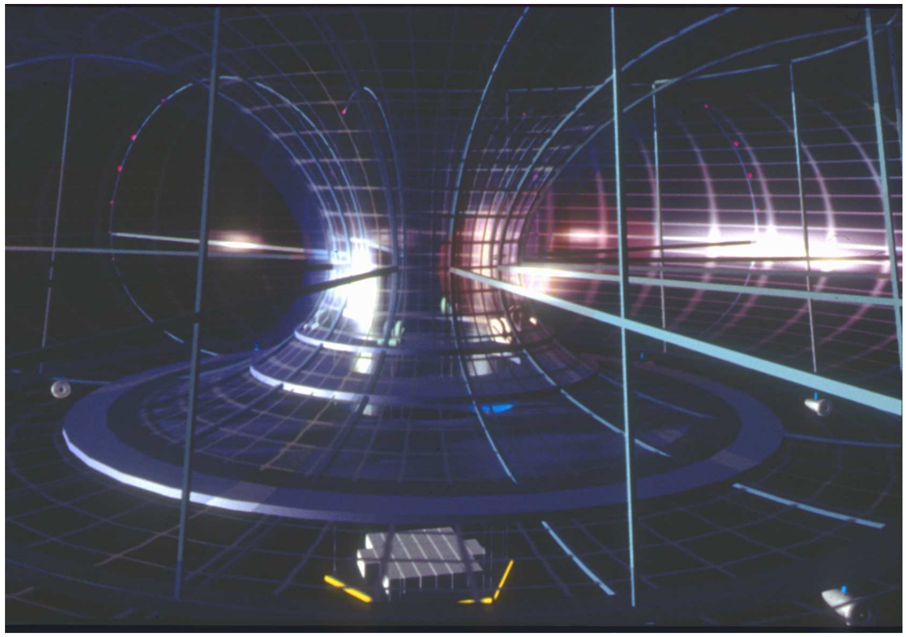


Figure 7 **X-ray View of the Shuttle Pod**
A semi-diagrammatic, translucent close view showing the toroidal form. Gas bags are removed to show internal structures. Engine positions can be seen and a pre-loaded cargo skid is visible in position to be raised into the cargo bay.

Hangar: Facility for Construction and Repair
The size of the AeroCarrier overwhelmingly influences almost everything associated with it. This is nowhere more evident than in the facility necessary to build it and provide maintenance and repair for it after it has been launched.

Two major factors underly all other decisions: first, the AeroCarrier dwarfs all single structures previously built; second, the AeroCarrier is expected to remain airborne almost continuously once it has been launched. Because of the first factor, the construction of a larger structure as a "hangar" to hold the AeroCarrier is difficult to conceive. Because of the second factor, such a hangar will have very infrequent use (perhaps, once every ten years) once the AeroCarrier is launched.

The solution is a construction and repair site that maximizes the use of already-existing natural structure. Such a site is a deep, dry canyon of the kind found in the American southwest. Grand Canyon is over 1,600 meters deep in some locations. Other canyons are shallower; some are narrow, others are wide. Choice exists for a section of a canyon slightly deeper than the AeroCarrier's height (640 meters), slightly wider than the AeroCarrier's width (1,000) meters, and with a straight run at least longer than twice the AeroCarrier's length (2,400 meters).

The Construction and Repair Hangar is a section of such a canyon. Suspension bridges at ground level cross over it to hold cranes and access structures for top-down work. At the floor of the canyon, leveling structures create a flat, artificial working floor, and along the sides of the canyon, scaffolding anchored to the the canyon walls provides the vertical structures necessary for side access.

An AeroCarrier is built in sections. Lateral cross-sections are constructed flat on the Hangar floor and tilted into proper vertical orientation. As they are completed, they are lined up with space between them for access. Gas cells are installed before work on the major interior structures is begun, and these are progressively inflated to support the AeroCarrier's interior space frame and lower living and working quarter as they are constructed. Only when all major interior structures have been completed are the shell sections moved together and sealed into the final integral shell.

Since gas cell inflation is a part of the construction process, the AeroCarrier's apparent weight is always under control. When construction is complete, the ship is towed into the open part of the canyon and, in a wider area, tested before being allowed to rise above ground level. Successfully tested, it will not return to the Hangar until it requires major overhaul or unexpected major repair.

Operations

Cargo Carrying: Intercontinental container shipping

Except for bulk goods, oil and large equipment, almost all commercial materials and finished goods today are shipped in containers. For transcontinental delivery, a shipment is containerized near its origin, transported to a sea port by truck, railroad or combination of the two, transferred to a container ship for the journey across the ocean, and then unloaded, reloaded and transported through another series of rail and truck cycles until it reaches its destination. No portion of the trip is fast, and the necessary transfers add substantial delays and cost.

An AeroCarrier with its Shuttle Pods makes possible point-to-point, one-carrier shipping at speeds many times faster than conventional transcontinental shipping. Even within continents and between port cities, the AeroCarrier has significant advantages of speed and directness over conventional transportation for long-distance container shipping.

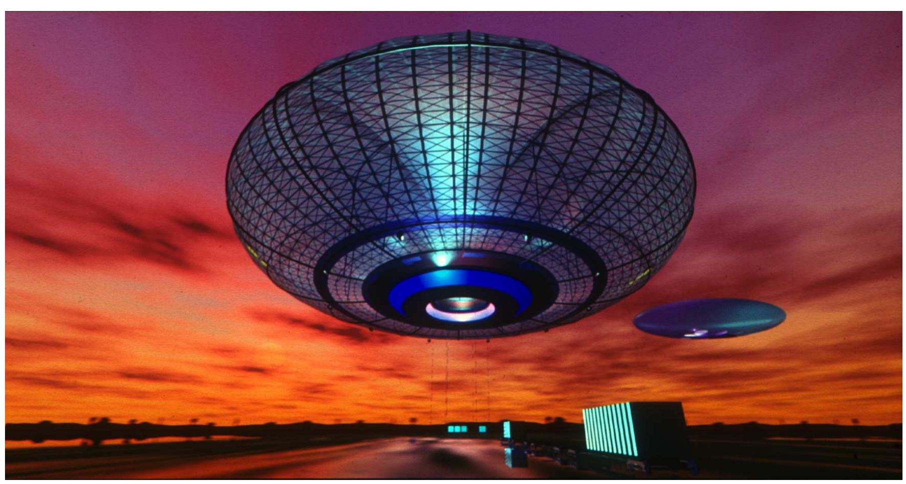


Figure 8 **Delivery and Pickup of Cargo**
Cargo loading and unloading is done by Shuttle Pod. Pre-loaded Shuttle Pods are launched and retrieved in minimal time by the AeroCarrier.

An AeroCarrier remains aloft. Its six Shuttle Pods move cargo between the ship and ground services. Cargo taken aboard is moved from the Pods to storage throughout the AeroCarrier's storage yards above the berthed pods and operating spaces. For each delivery, containers are retrieved and assembled in a Pod with others destined for the same site while the AeroCarrier is underway to the site. The AeroCarrier is detained only long enough to launch the Shuttle Pod. While the Pod is being unloaded and reloaded on the ground, the AeroCarrier moves on to make other cargo launches and retrievals, tour scenic surroundings for the benefit of its embarked passengers, and conduct large scale disembarking and re-embarking of passengers by Shuttle Pod for land tours of important ports of call.

The extraordinary size of the AeroCarrier allows it to carry a huge amount of cargo. After the weight of the ship and its structures are subtracted, and the weight of facilities for 2,000 passengers, 1,500 crew members and embarked professional and research staff, there is still capacity for over 32,000 metric tons of cargo. This is the weight of 870 fully loaded containers, more than four times the capacity of the largest container ships!

Scenario

In the industrial region north of Paris, containers brought to a collecting site from local factories are being loaded into a Shuttle Pod. The Pod's crew uses the ship's on-board crane to lift containers one at a time through the hatch of the tethered-down Pod. As they are taken aboard, the containers are positioned around the Pod's main cargo deck to balance the load.

The Pod was launched just before sun-up by the AeroCarrier when it arrived in the Paris vicinity. While the Pod is being unloaded and reloaded, the AeroCarrier has traveled on in the early morning to additional loading sites around Paris, launching other Pods. Now, in the afternoon, it is using the loading time for a tour of the Paris environs for its passengers. It visited Chartres earlier and now sails low over the magnificent chateaux country in the late afternoon sun. It then swings northeast to Fontainebleau and follows the Seine River back into Paris for sunset and early evening views. Some of the passengers leave the AeroCarrier by aircraft to spend a week in the city. Because they are not many in number, they fly down by chartered helicopter in the evening from the AeroCarrier's dorsal landing strip. Many will be picked up again next week again when they fly onto the ship during its scheduled flight over Brussels.

The next morning, the reloaded Shuttle Pod uses its engines to rise into position below the hovering AeroCarrier now returned for recovery. Dangling mooring lines from the AeroCarrier's port are taken aboard by line handlers on the Pod's crane deck and main deck below. With all lines fast, the engines are shut down and swung down along with their struts to be out of the way as the Pod is winched aboard. To provide resistance for the winch crew above, the Shuttle captain brings the Pod's lift to slightly negative. The Pod is raised into its berth and secured in position. Because it has its own lift, it adds no weight to the AeroCarrier's payload.

With the Shuttle Pod snuggly berthed, the AeroCarrier picks up speed on its way southwest on an arc that will pass over the Bay of Biscay and Bordeaux to Madrid and then to Europe's "silicon crescent", the technological corridor fast developing along the coast from Barcelona to Milan. On the way, the new cargo from Paris is distributed to storage. Traveling cranes riding under the elliptical space-frame structure remove containers from the Pods and relocate them to positions within the "storage yards" in the space frame.

At the same time, a Pod is being loaded with a shipment of 18 containers to be delivered to the industrial area southwest of Madrid. Computer-directed cranes find the containers in storage and move them off to the Pod along routes calculated to minimize disturbance to the ship's trim, as other cranes distribute the new containers similarly to storage locations designated by calculating the moments their weights will produce.

A storm, now tracked by the AeroCarrier's radar, but anticipated by the navigator, has reached position to be used by the AeroCarrier. Long range weather tracking and projection services received by satellite have allowed the navigator to adjust the AeroCarrier's schedule. It will be possible to use the edge of the slowly whirling storm to swing the ship on its way, increasing speed with a savings in fuel. Along the way, the ship will dip into the rain to refresh its water supply. Rain water rolling down its sides will be directed through gutters to the ship's water tanks.

Madrid will come into view right on schedule, and a trip along the northern Mediterranean coast will be enjoyable for the passengers as preparations begin for the next cargo transfer, over Milan.

Cruising: Passenger movement for business and pleasure

After a long period of decline, the ocean cruise has returned to popularity. Weekend newspapers fill entire travel sections with information about cruises, cruise ships and exotic destinations. Cruise ships are once again being built profitably, and passengers are traveling in numbers to their embarkation ports.

The best cruise of all, however, is in the air! Those who traveled in the Graf Zeppelin or the Hindenburg thrilled at the sights of cities and countryside as the great ships floated over them. Given a choice, almost everyone would prefer to cruise smoothly at ballooning heights over the endlessly varying landscape than pitch and roll relentlessly on endlessly empty seas. The AeroCarrier combines the wonder of cruising over land and sea with the splendor of the full-service cruise ship ***and*** the additional amenities of a working city—and it can embark and disembark passengers anywhere on its travels.

Supporting continuous passenger embarkation and disembarkation is the airstrip on the AeroCarrier's dorsal hull. Aircraft from helicopters and VTOL airplanes to STOL aircraft—literally any airplane that can land on a 1,600 meter runway—can fly passengers to the AeroCarrier. This means that traveling on the AeroCarrier is not constrained by ports of call as it is on a cruise ship. Tour groups, conference planners, travel chartering agents—even charter airlines—can contract flights to and from the AeroCarrier. Flights need not meet the ship over cities; rendezvous can be scheduled anywhere at almost any time over land or sea.

The huge size of the AeroCarrier necessary for the lift to carry large amounts of cargo, also extends dramatically the amount of space available for passengers and services. The 1,200 by 130 meter space with its 12 decks holds more space than is available in many small cities. Cabins can be spacious; specialty facilities can be numerous; gathering places can be more like plazas than compartments. Cruising in the AeroCarrier is much like visiting an interesting city, except that the city is moving and the views, rather than up, are down and out!

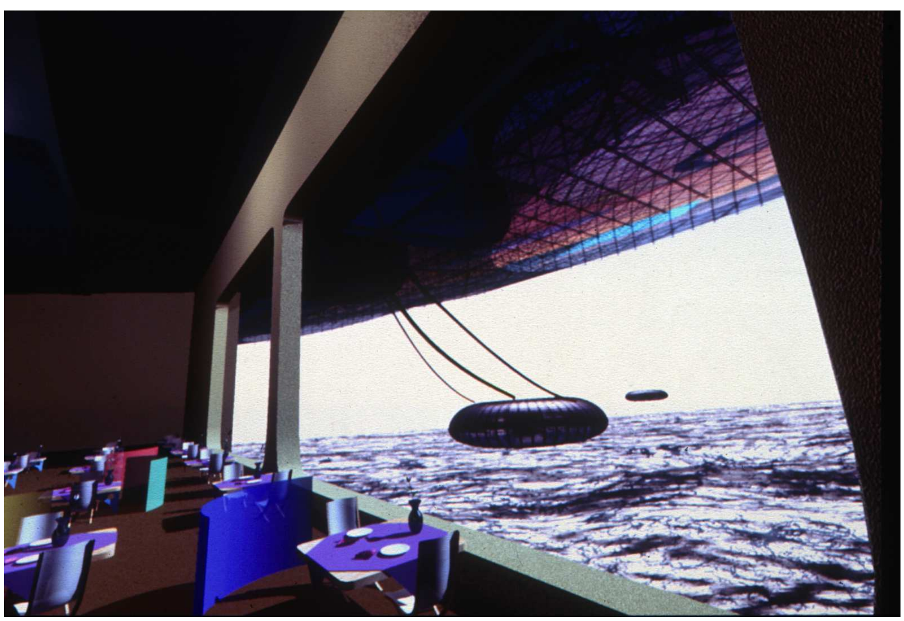


Figure 9 **Watching Shuttle Recovery**

Restaurants provide ideal locations for observation of the landscape below. Shuttle Pod launch and recovery operations are also exciting events.

Scenario

Chicago will soon come into sight. Its world-reknowned architecture will be instantly recognizable as it stands out against the flat Illinois landscape and the broad blue expanse of Lake Michigan beside it. It has been a productive and delightful week traveling from Osaka. The International Consumer Electronics Show will open in Chicago next week.

A week ago, as the AeroCarrier traveled over Japan on its way east from China, business groups from Sharp and Matsushita flew aboard, while containers carrying their exhibits joined the AeroCarrier by Shuttle Pod transfer. During the week of travel, business meetings have shared time with final training sessions for staff, and last-minute plans have been completed for the installation and operation of the exhibits. The best part of it was that there was much more time to work on the materials to be brought from Japan before they had to be shipped, and the past week's work was conducted in expansive, well-equipped facilities as well designed for pleasure as for productivity.

There is still time for lunch. Some of the businessmen join others on an elevator going down to one of the AeroCarrier's several "restaurants in the sky". It still seems a little odd to go down for the view, but many things are different when you are cruising in the sky. In the restaurant, this one operated by a masterful chef-owner from Italy's Piedmont region, a number of others are already dining at arrangements of tables artfully intermixed with table-high sky-light ridges.

From every table the sights below are visible. Just now, the rolling countryside of northeastern Iowa is in view with the classic contour-plowed fields of American midwestern farm country. The Mississippi river is already visible in the distance ahead. One of the wonderful differences between travel by airship and travel by jet is the nearness of the ground below. A farmer on a tractor below waves to the ship above—and he is seen by the diners!

Catching the attention of the diners from Matsushita, a diner from a nearby table waves a hello. He is a product design consultant and long-time friend from San Francisco traveling with his wife and twenty other designers and their wives. Although he flew onto the AeroCarrier two days ago as it passed through Washington state, he had not known that the group from Matsushita was aboard—when there are thousands of passengers, it is hard to know who they are or what they are doing.

The designers are on a combined conference and pleasure cruise. For a week they will share time between speakers and papers and the many activities available on the AeroCarrier. Besides the excellent restaurants and the always-interesting views below, there are all the expected pleasures of a cruise ship with the space to enjoy them in style. As part of their week they will disembark for a day at the Consumer Electronic Show. Afterward, they will take a chartered flight to meet the AeroCarrier over the east coast, finishing their conference in time to disembark finally in New Orleans for the jazz festival there.

The weather is predicted to be clear over the southeast United States for the last leg of their trip, but if the overcast now developing to the west confounds the weather forecasters, the AeroCarrier will detour south across Florida and the Gulf of Mexico. Either way, it will be a beautiful trip.

Environmental Research and Education:
U.N. sponsored research, conferences, presentations and exhibitions

Environmental research has taken on new urgency in recent years as global warming, the thinning of the ozone layer and the threat to biodiversity have been forcibly raised to public attention. Hampering policy making is the inadequacy of information about many of the factors involved in the complex physical and biological systems. All three of the problems are system problems requiring not only extensive knowledge of specific situations and processes, but integrative knowledge of systemic relationships among the variables.

Complementing the need for environmental research is a growing need for education. The results of research must be communicated to a world audience, along with the seriousness of problems detected and the value of policies to solve them.

The AeroCarrier and its Shuttle Pods are almost perfectly designed for study of some of the more elusive of these research problems. The AeroCarrier's extensive resources and ability to move directly at good speed to a site, and the ability of its Pods to hover motionless or move slowly with great control are major assets in this regard. Two of the most appropriate problems are study of the biology of rainforest canopies and study of the physico-chemical processes of coupled ocean air and water columns.

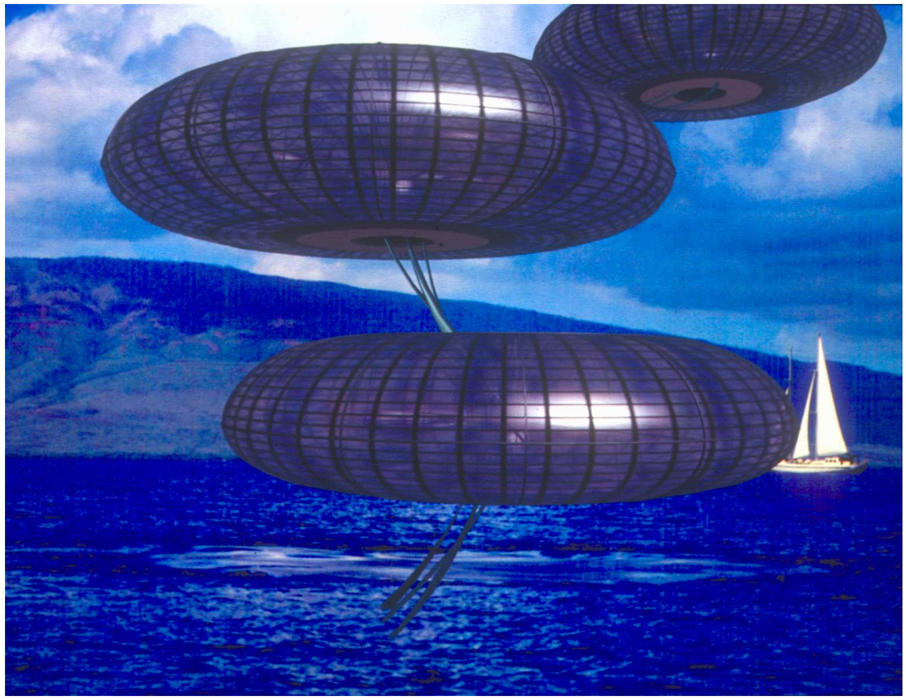


Figure 10 **Temperature Recording**
Shuttle Pods maneuver into vertically "stacked" position to record simultaneous air and water column conditions. Atmospheric and oceanic data are crucial to understanding global warming phenomena.

Over a rainforest, the AeroCarrier launches Shuttle Pods outfitted with research equipment to move down within 25 meters of the tree tops. Hovering in position over the rainforest canopy, the Pods lower "rafts" with research teams aboard. Using four winches controlling lines to four corners of the 240-meter diameter craft above, the researchers can raise or lower themselves or move laterally within the forest canopy. The stability created by the large Pod above enables a research team to carefully observe, record activities and collect specimens much more easily than can be done from the ground 60 meters below. Movement to another group of trees requires only that the Pod relocate itself and its raft laterally.

Over the ocean, the AeroCarrier's Shuttle Pods orient themselves in a vertical column with one Pod near the ocean surface, one high in the air above it and one or more equally spaced in between. Lines with a variety of sensors attached at preset intervals are lowered from the uppermost Pod to the next Pod, from the second Pod to the next, and so on to the Pod just above the ocean surface. From the lowest Pod a line with sensors and computer-controlled propulsion modules is lowered into the ocean. As the Pods move slowly through a planned spiral course, the propulsion units below the sea surface operate to keep the underwater line as much as possible in line vertically with the stack of Pods above. Readings taken with the array of sensors can correlate undersea, surface and air data for any area of interest.

Figure 11 **Aerial Visual Presentations**
As part of its communications program on global air quality, the AeroCarrier shows the movie "Blade Runner" on its displays. The movie is visible to all within a four kilometer radius—provided the atmosphere is clear enough.

Scenario

The AeroCarrier is on its way to Shanghai. Over the last three months a special U.N. research program has funded a series of visits to ocean and rainforest sites in Papua New Guinea in between cargo carrying flights and, of course, passenger cruising. The research activities have been special attractions for cruise passengers, and a number of people have joined the ship especially to see the research operations and share the excitement of the researchers' findings. Ongoing workshops and seminars have been held in the AeroCarrier during and between field operations.

As a part of its educational mission, the ship uses its elaborate side/bottom-mounted displays and capability for exhibition to communicate on environmental issues for the United Nations. For the visit to Shanghai, a special exhibition has been prepared on the effects of indiscriminate *logging on the ecology of land and sea. It will be tested on the city population as an example of a sophisticated East Asian audience.*

Materials for the visual display presentation and the exhibition include fresh information obtained in the studies over Papua New Guinea. Researchers on the AeroCarrier's teams discovered over 200 new species of insects, several previously unknown birds, mammals and reptiles and a number of new plants. Range studies showed that many of these occupy highly circumscribed habitats very sensitive to habitat destruction. Studies in the air and water columns near coastal areas under consideration for logging revealed patterns of water movement that, in some areas, would seriously contaminate large areas of offshore reef. In combination, the studies helped local officials to decide how and where to initiate an informed logging and forest management program. The incorporation of this new information in the presentations will add new credibility to the U.N. message for responsible stewardship of the environment.

As the AeroCarrier nears the China coast, its on-board television station cooperates with Shanghai broadcasting. Chinese language transmissions are picked up by the Shanghai stations to announce environmental seminars to be held for city and university officials on-board the AeroCarrier. Special shows are also transmitted for the general public telling about the Exhibition scheduled for a large open space near the outskirts of the city.

Preparation of the exhibit by the AeroCarrier design team is complete, and the Exhibition Pod is finally readied for launch. As the China coast comes into view, The ship's side display presentation is turned on. Its effect in the early evening is impressive; no one in Shanghai will fail to see it. The Pod will be launched in the early morning and will be operational on site within one half hour of landing.