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The heavy-lift vehicle that's lighter than air

David Cherry reports on breakthroughs in dirigible technology that will make it possible to "move mountains" and rapidly develop the Third World.

A program for rapid world economic development will have the urgent task of solving the problem of transporting capital equipment to Third World countries, where roads, ports, and other infrastructure are often nonexistent. This will require an airship that can carry high tonnages at low cost per ton-mile. It will have to have the vertical takeoff and landing (VTOL) and precision hover capability of the helicopter, but it will have to far exceed the payload tonnage of the most powerful helicopter, while outstripping the helicopter in cost per ton-mile. To meet those requirements, it must be a lighter-than-air (LTA) craft.

Consider, for example, the daunting prospect of hydroelectric development in Central Africa or the Lower Himalayas. Cable, transmission towers, transformers, concrete, and reinforcing steel must all be transported at a snail's pace over hundreds of miles of winding dirt road—road that may have to be constructed for the purpose. Unless, of course, a heavy-lift LTA vehicle is perfected. Over the past decade, design and experimentation for this kind of craft has been under way.

The history of the airship goes back to a parallel development with the early airplane. Ferdinand Zeppelin launched his first dirigible in 1900. It used lightweight metal girders to keep the body rigid, was controlled by two 15-horsepower engines driving propellers, and could fly at 50 miles per hour.

During World War I, the German Navy used Zeppelin dirigibles to scout the North Sea for surface vessels and submarines. After the war, the U.S. Navy took an interest and developed a helium-filled dirigible for long-range scouting over the Pacific Ocean. Two versions of it were built, the *Akron* and the *Macon*.

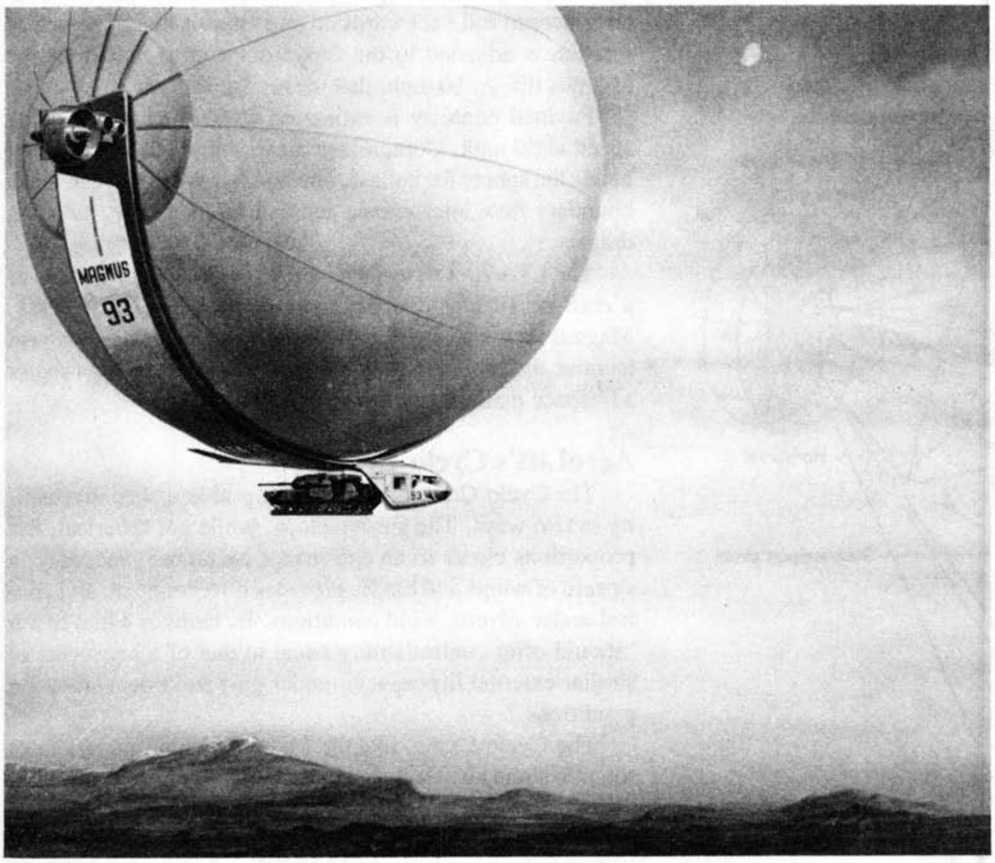
Both were destroyed in storms at sea, the *Akron* in 1933, the *Macon* in 1935. Then in 1937, the famous hydrogen-filled Zeppelin dirigible *Hindenburg*, which had made 36 transatlantic flights, crashed and burned in a storm at Lakehurst, New Jersey. This spelled the end of the huge rigid airships. During World War II, blimps were used for coastal convoys, but the blimp is a smaller, nonrigid craft with very limited maneuverability.

Why did so many dirigibles crash, and why was the dirigible idea abandoned? The flammability of hydrogen gas was not the problem. In fact, the American airships always used helium gas, which does not burn. What doomed the dirigible was the vulnerability of its large, lightweight frame to sudden stresses in stormy weather.

During the 1920s, the future of the dirigible looked rosy, since the airplane was then a flimsy and very dangerous craft. Dirigibles were ahead of airplanes in transatlantic flight. But during the 1930s, the design of airplanes advanced by leaps and bounds.

Airplanes began to be built of metal instead of cloth stretched over wood frames. Radio was installed in the cockpit to enable the pilot to stay on course while flying at night or in bad weather. Meanwhile, the best engineering efforts

FIGURE 1



The LTA 20-1 designed by Magnus Aerospace Corporation of Ottawa. The sphere rotates backward on the horizontal axis to produce Magnus lift as the craft moves forward. Hover is controlled by the thrust of turboprop engines mounted on either end of the axle. The engines can rotate to provide forward-backward and upward-downward thrust.

Magnus Aerospace

did not produce a dirigible that could stand the strain of storms and compete with the airplane in speed.

Because of the revolutionary advances in airplane technology, the dirigible offered no competition in most of its applications. The subsequent development of the helicopter met the need for heavy lift, where VTOL and precision hover were required.

The 1970s and '80s are witnessing a revival of the dirigible for tonnages no helicopter can be designed to carry. Two companies at work on these vehicles are featured here. Both got their initial impetus from the needs of the North American logging industry. While Third World needs are not shaping the market at present—quite the contrary—the other uses for heavy-lift LTA have led to significant interest in both companies' efforts.

AeroLift of Tillamook, Oregon is the company in the lead in actual development. Its Cyclo-Crane has undergone manned flight testing in a small version capable of two tons net payload. Its competitor is Magnus Aerospace of Ottawa, Canada, with an interesting and completely different design. Magnus has flight-tested a model of its LTA 20-1 too small to lift a significant payload or carry a pilot. A third design, Piasecki Aircraft's Heli-Stat, now in the flight testing stage, is also of interest.

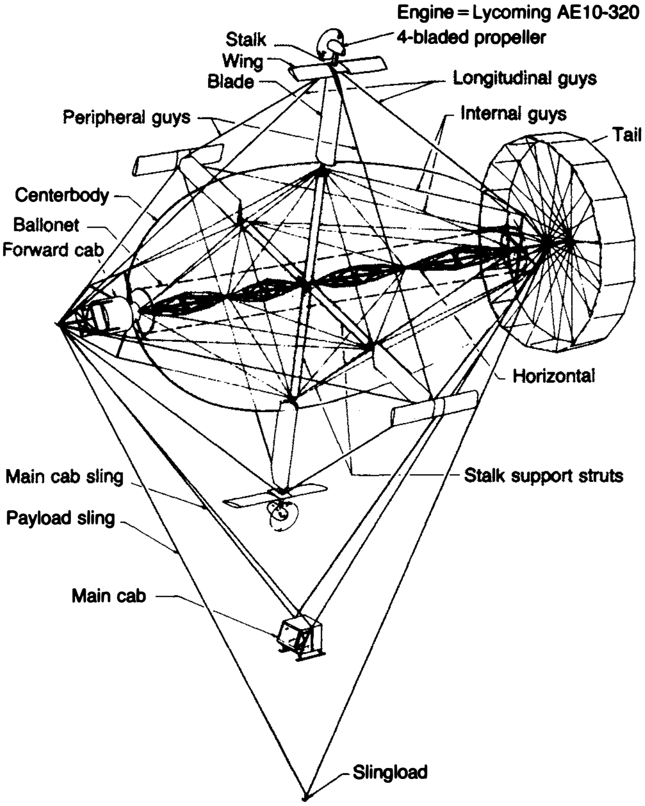
Both Cyclo-Crane and LTA 20-1 depart from all previous designs by combining aerostatic lift—provided by helium—with aerodynamic lift. Both consider that their designs could be scaled up to at least 100 tons of net payload (the most powerful helicopter can lift 15 tons).

In sum, because of the VTOL and hover requirements associated with many heavy-lift tasks, the airplane does not qualify. Because of the sheer weight of the cargo, the helicopter is ruled out. Because of metal fatigue, there is a limit to the size at which helicopters and airplanes can be built. But to exploit the dirigible for heavy lift, it has been necessary to address the unsolved problem that spelled the end for dirigibles in the 1930s—the problem of structural integrity under conditions of stress—and to develop more powerful control over the vehicle in flight.

The Magnus LTA 20-1

The Magnus design is based on a spherical gas envelope, on the grounds that the sphere provides the structural soundness lacking in the dirigibles of the 1930s (**Figure 1**). The

FIGURE 2



Schematic of the Cyclo-Crane. The entire gas envelope rotates on a longitudinal axis--the easiest means to rotate the blades and winglets. For vertical lift, no forward motion, the blades and winglets are positioned for this rotation, as shown here. The pitch of the winglets changes in the course of each full rotation, such that lift results. Going into forward flight, body rotation ceases and the winglets rotate through 90° on their stalks to face forward. These positions are shown in Figure 3.

AeroLift Inc.

sphere is geometrically the ideal shape from that standpoint. An axle passes through the sphere, and an aerodynamically shaped gondola is suspended from its ends. Also attached to the ends of the axle are the turboprop engines for maneuver and liftoff of the craft. They can rotate to shift the direction of thrust.

The employment of Magnus lift is the unique feature of the LTA 20-1. Magnus lift—named after the 19th-century German physicist Heinrich Magnus who observed the phenomenon—is the lift generated when a backspin is imparted to a flying sphere. It is why a baseball or golfball may "pop up." Eighty percent of the craft's lift derives from helium, and 20% is generated by causing the giant, 61-meter-diameter sphere to roll backwards on its axis as it flies. The rate of rotation is adjusted to the forward speed to maximize the Magnus lift. At 60 mph, that means 3.5 rpm.

Payload capacity is estimated at 60 tons and cruising speed at 50 mph. Compressed air is pumped into a ballonet inside the sphere for ballast. The gondola is designed to mask boundary flow interference and control side flow, reducing drag.

The LTA 20-1 described here is the projected scale-up of a craft of 19-foot diameter first built and flown in 1981. Magnus Aerospace will issue stock in Canada later this year to raise the money to scale up, and is looking for a major aerospace manufacturer to go in with.

AeroLift's Cyclo-Crane

The Cyclo-Crane adddresses the problem of controllability in two ways. The gas envelope, while not spherical, has proportions closer to an egg than a cucumber. Secondly, a system of wings and blades provides hover control, and control under adverse wind conditions. Its builders claim that it "should offer controllability equal to that of a helicopter of similar external lift capacity under gust and direct sidewind conditions."

The Cyclo-Crane, like the Magnus design, incorporates rotatio through its center—but in a completely different approach (**Figures 2** and **3**). The axle runs the long dimension—along the line of flight instead of across it. The entire craft rotates to achieve rotation of winglets oriented parallel to the axle and mounted on four pods extending from the gas envelope at 90° intervals around the craft. Rotation (up to 13 rpm) is used to produce lift in the absence of forward motion, and is not employed once forward motion is well underway. Forward motion generates sufficient lift in itself.

How does this work? The winglets are subject to "cyclic control," that is, the angle of attack of each winglet is varied in a repeating cycle in each full rotation. When one winglet is at the top, the one opposite is at the bottom. Their angles of attack at that moment are such that they complement each other in producing lift. This principle of cyclic control is borrowed from the helicopter.

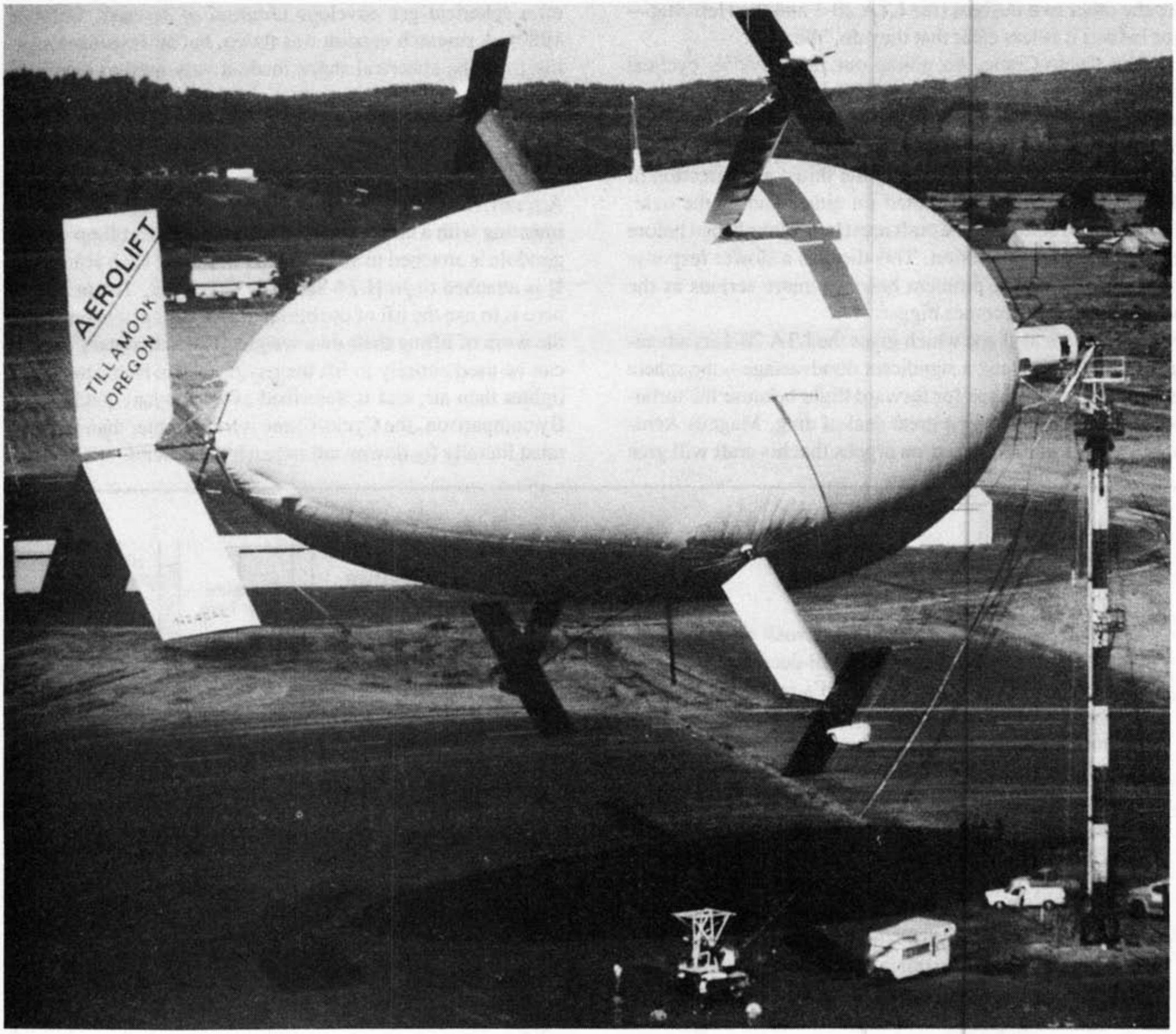
As the vehicle goes into forward motion, rotation ceases, the winglets are rotated on their pods by 90° to face into the line of flight, and a separate "collective control" system takes over to adjust their angles of attack for achieving lift in that configuration. Also included in the collective control system is control over the airfoils on the pods (called blades in the diagram), for the same end of achieving lift in forward flight.

The designs compared

Comparing the two designs is difficult, since they are not at the same stage of development, and projections do not happen to have been premised on comparable payloads. The

FIGURE 3

AeroLift's Cycle-Crane at its mast in Tillamook, Oregon. The stabilizer tail design has been replaced by the one shown in Figure. 2.



AeroLift Inc.

Magnus LTA 20-1 is to employ four engines totaling 14,000 horsepower, and its projected payload is 60 tons. The flight-tested model of the Cyclo-Crane with a payload capacity of two tons, uses two tractor propellers with 300 horsepower combined.

Prof. H. C. Curtiss, of Princeton University's Department of Mechanical and Aerospace Engineering, points out that the two designs are roughly comparable in engine power once the difference in scale is allowed for.

Curtiss says that gas volume scales up proportionally to payload, but that engine power scales up at more than the cube of the volume or payload (about a power of 3.5). The calculation necessarily ignores any redesign for scale-up. Curtiss is an authority on helicopter technology, and developed the mathematical model for the control of the Cyclo-Crane.

Curtiss urges that cheapness and efficiency are subordinate issues relative to controllability of the craft in hover and when faced with winds. "After all, all of these designs are *relatively* efficient in that they get so much lift 'for free,' so to speak. The Cyclo-Crane has strong positive control, and for the other two designs [the LTA 20-1 and the Heli-Stat—see below] it is less clear that they do," he says.

The Cyclo-Crane, he points out, employs its cyclical control system to maintain hover. In other words, it uses variations in the angle of attack of the winglets, and gets instant response from the craft. By comparison, the LTA 20-1 accomplishes hover by varying the thrust and direction of the turboprop engines mounted on either end of the axle. Hence some rotation of the craft must be accomplished before each desired lateral motion. This dictates a slower response of the craft, and the problem becomes more serious as the scale of the craft becomes bigger.

The spherical shape which gives the LTA 20-1 its advantages also brings along a significant disadvantage—the sphere is not a preferred shape for forward flight because the turbulence in its wake causes a great deal of drag. Magnus Aerospace President Fred Ferguson argues that his craft will give a superior performance in cost per ton-mile. That may be true below a certain speed. His design has indeed undergone wind-tunnel tests at the Institute for Aerospace Studies of the University of Toronto. But Curtiss recalls a predecessor of the Cyclo-Crane in the late 1970s called the Aerocrane, based on a spherical gas envelope (*Journal of Aircraft,* October 1980). A research version was flown, but air resistance arising from the spherical shape made it very hard to drive, he says.

The Piasecki Heli-Stat

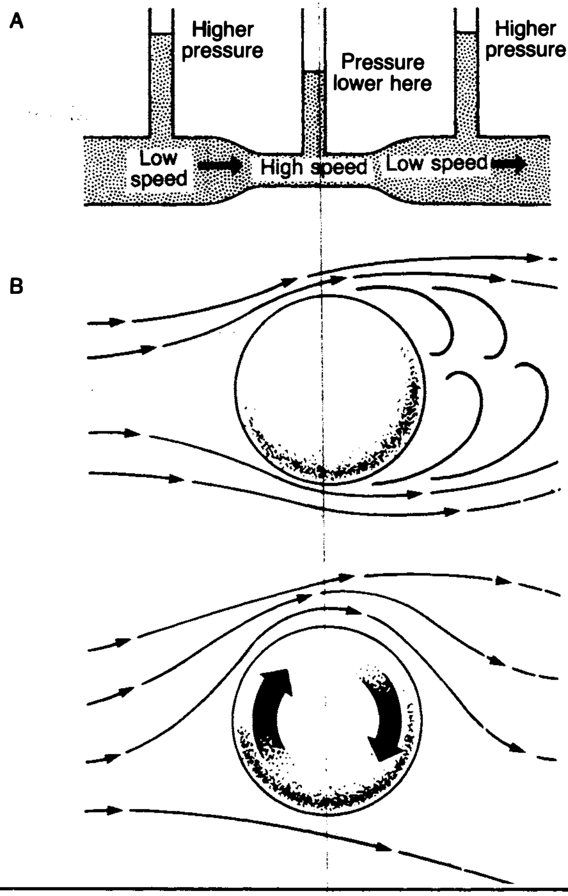
In addition to the two designs featured here, Piasecki Aircraft, headed by Frank Piasecki in Philadelphia, is experimenting with a craft called the Heli-Stat. It is a blimp whose gondola is attached to an H-shaped structure; each arm of the H is attached to an H-34 Sikorsky helicopter. The principle here is to use the lift of the blimp to relieve the helicopters of the work of lifting their own weight. The helicopters' power can be used entirely to lift the payload. The Heli-Stat is not lighter than air, and is described as a "buoyant quadrotor." By comparison, the Cyclo-Crane is truly lighter than air, and must literally fly downward to reach the ground.

The Magnus effect

When a liquid or a gas moves across a surface, the pressure it exerts on the surface will decrease if the fluid speeds up. This is called Bernoulli's principle. Diagram (a) shows a flowing liquid being forced to speed up when the tube narrows. The pressure columns show that the pressure is less where the speed is greater. This can be demonstrated using plastic or glass tubing from a scientific supply house.

The Magnus effect is a special case of the Bernoulli principle, applied to a rotating cylinder or sphere, which was first noticed by the German physicist Heinrich Magnus more than a hundred years ago. Here is how it works:

In the non-rotating sphere (b), airflow separates equally from the top and bottom near the midpoint of the sphere. In the rotating sphere, flow remains attached longer to the top side. The sphere's rotation speeds up the airflow. At the bottom side, the rotation goes against the direction of airflow. This causes earlier flow separation. The velocity difference and the downward deflection of the wake produce Magnus lift.



Flight-testing

The U.S. Forest Service is interested in both the Cyclo-Crane and the Heli-Stat as potentially useful for logging, and contracted the Aerospace Corporation in El Segundo, California to write the specifications for flight-testing both craft.

Forest Service interest in the Cyclo-Crane goes back to 1982, when it put $1 million into testing it. The original craft was destroyed in a gale that year, after tolerating winds of 70 knots for hours. After rebuilding on a much-reduced budget, the Cyclo-Crane in January 1985 achieved full forward flight at about 40 mph with a load of timber. Some flight data were accumulated before the Forest Service money ran out.

The Forest Service resumed flight testing with money from the Pentagon's DARPA, in tests which ran from June until mid-December 1985. The military interest in the Cyclo-Crane stems from a need for heavy lift and the need for a phased-array radar platform capable of remaining on station for days at a time. During these tests, the Cyclo-Crane hovered, maneuvered vertically and laterally, and made the transition to forward flight. It exercised all controls both tethered and untethered. A great deal of data was accumulated on magnetic tape, and data reduction is still continuing. The data goes into the continued development of the computer model simulating the performance of the craft, providing coefficients from actual flight.

The design of a scaled-up Cyclo-Crane for the Army is now on the horizon, according to Virgil Binkley of the Forest Service's Bureau of Timber Management in Portland, Oregon. Binkley says that $900,000 is expected from the Army through Fort Eustis, Virginia for such a design, and the definition of the contract is now in process. McDonnell Douglas and Lockheed have expressed interest in manufacture of the Cyclo-Crane.

Flight testing for the Heli-Stat at Lakehurst, New Jersey has been supported by Forest Service money and Navy equipment and personnel. Testing is in the initial phase, and control evaluation and calibration has been carried out with the craft tethered to the mast. Two free flights in hover have been accomplished. A control difficulty was experienced in the second of these, on April 28, resulting in damage to two landing gears, but flight testing should resume before the last week of May. An error in calibration is held responsible. Testing should then continue through the summer.

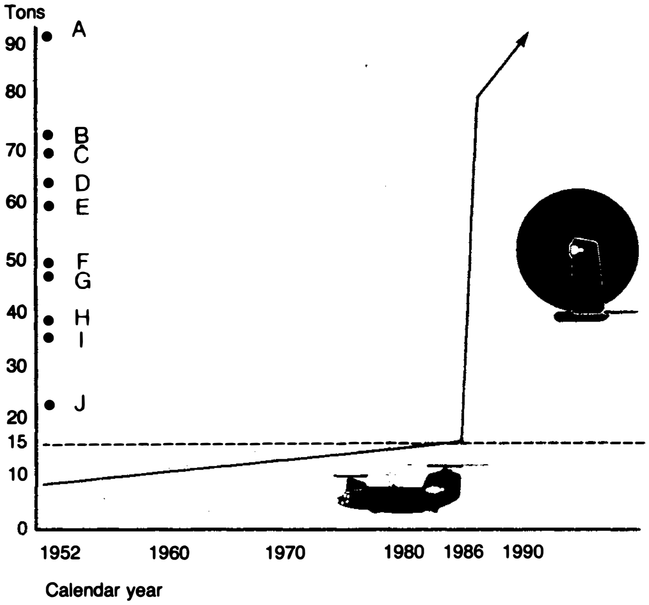
Foreign interest

Foreign countries, especially in the Third World, have expressed interest in LTA heavy-lift technology. Ray Trudeau, Magnus Aerospace vice president for sales, says that companies in Japan are interested in representing Magnus in the Pacific Rim, including C-Itoh and Nissho Iwai. Trudeau mentions Singapore, Indonesia, and Malaysia in connection with logging operations and the placement of transmission towers. China and India are energy-hungry, Trudeau says. India has plans to spend more than $40 billion chiefly for hydroelectric capacity according to World Bank information, and in China, one such energy project alone is priced at $26 billion.

FIGURE 4

Heavy-lift vehicle capability

Typical payloads



A: D-10 tractor

B: 5 pieces of pipe

C: 28 ft. × 8 ft. × 40 ft., 150 containers

D: Main battle tank (M102)

E: Pipe layer (D-9 with counter balances)

F: D-9 tractor

G: 2 mil vans

H: Pre-fab structures

I: 8 ft. × 8 ft. × 40 ft., 150 containers

J: Mil van (8 ft. × 8 ft. × 20 ft.)

The potential of heavy-lift LTA in relation to helicopter capacity, as conceived by Magnus Aerospace.

Magnus Aerospace

Inquiries to Magnus directly from Africa have not been forthcoming in the past two years, but Bechtel Engineering has been in touch concerning mining applications.

In earlier years, LTA heavy-lift technology was the subject of studies by the United Nations, for food relief and transport of goods to market. Such goods can take three to six weeks to travel 700 miles over existing rail lines—where they exist. The U.S. Agency for International Development studied the technology for such uses in the Sahel.