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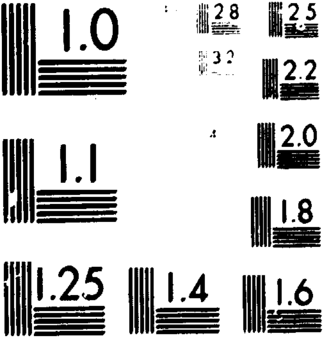

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CURRENT AND POSSIBLE FUTURE DEVELOPMENTS IN LIGHTER-THAN-AIR (LTA) SYSTEMS TECHNOLOGY

1983

Prepared by

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for the

United Nations Industrial Development Organization (UNIDO)

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1. INTRODUCTION

Interest in airships is today greater than at any time since the Second World War and there are those who believe that they are poised to make a comeback. Since the mid 1970s, governments in several countries, notably the U.S., France and Japan, have put money into studies of their feasibility and have even supported technology development programmes. The past few years have seen the emergence of a nascent airship industry and the first orders for new airships in more than three decades have recently been placed.

To many this renewed interest is something of a puzzle. The word 'airship' remains coloured by past perceptions and by the spectacular disasters that brought the development of large rigid airships to a close in the 1930s. Airships, many still believe, have more chance of coming to grief than anything else that moves. There are others who feel that airships belong more to the pages of comic books than to the world of serious aviation. And still others who associate the airship with the romantic era of luxury travel and the days when giant craft glided gently through the air to the sound of an orchestra and the expensive tinkle of porcelain, crystal and silver. These days are gone forever, replaced by Jumbo class travel with its plastic trays.

Such perceptions have not only hampered the objective assessment of the airship's past performance; they also stand in the way of a real appraisal of the airship's future potential. This potential has been documented in numerous books and studies which have appeared in recent years. Some of these have indicated that the airship's potential appears particularly great in developing countries. By and large, however, there appears little awareness in the Third World of the possible applications of airships and thus the danger that a vehicle which may be well suited to its needs and objectives will fail to receive the attention that it may justly deserve.

For this reason, the United Nations Industrial Development Organization (UNIDO) decided to convene a meeting during which representatives of the airship industry and sponsors of airship research could exchange views with representatives of developing countries and development specialists on the potentialities and limitations of airship applications in the developing world. The meeting took place in Vienna on 19-22 October 1981 and was attended by some 40 persons. The names of the meeting's participants and observers are given in Annex 1.

UNIDO has an ongoing programme on the implications of emerging technological breakthroughs for developing countries in selected areas. The aim of this programme is to sensitize policy-makers, senior officials and, where appropriate, scientists and technicians in the Third World to the possible implications of the technological advances that are emerging or are in the offing. Such a sensitization, based on an in-depth examination of the possibilities and limitations of the technologies from the viewpoint of the developing countries, enables, UNIDO believes, more conscious and rational choices to be made concerning the technologies. The informal meeting of experts was held within this framework and with this intention.

The meeting resulted in a number of interesting papers and a lively debate. It was unanimous in its view that developing countries should both monitor and participate in airship development programmes and identify as precisely as possible the situations in which airships and related vehicles could fill a perceived need. At the same time, the meeting acknowledged that many misunderstandings continue to surround airship applications and operations in both developed and developing countries, in part the consequence of a lack of 'hard' data and of an inadequate information base.

This, the meeting concluded, hampers both informed debate and sensible decision-making on airships and related craft in both the industrialized and developing world.

The meeting urged UNIDO to support demonstration projects of airship applications in developing countries and to monitor, analyze and disseminate the results of such projects to interested countries and groups, especially in the Third World.

As a first step in responding to this recommendation, UNIDO decided to commission a report which brings together the papers prepared for and the results of the discussions held in Vienna. These form the basis of this report. It has been prepared as a contribution to further understanding of the possibilities and limitations of airships and related vehicles.

2. TYPES OF LTA CRAFT

2.1 Definitions

The subject of this report is lighter-than-air (LTA) systems. LTA is a generic term used to distinguish aircraft that derive all or part of their performance from aerostatic principles from heavier-than-air (HTA) craft which do not. The traditional distinction used in discussing LTA craft is between balloons and airships. The conventional airship familiar to most people consists of a cigar-shaped streamlined hull or envelope enclosing a lifting gas or lifting system with propulsive power, stabilizing surfaces and altitude and directional control. A balloon makes use of similar aerostatic characteristics but has no propulsion or steering system. Airships, then, are controllable, balloons are the victims of winds and air currents. Airships are sometimes referred to as dirigible balloons, or simply dirigibles (from the French 'directable' or 'steerable').

The basic distinction between airship and balloon is no longer adequate to discuss all the forms that airships have taken and, more especially, are taking. A more comprehensive classification is given in Table 2.1. The main characteristics of each type can be summarized as follows:

(1) *Balloons.* Free floating unpowered balloons are the oldest type of LTA vehicle and were man's first successful attempt to achieve flight. The first lifting gas was hot air, but natural gas, hydrogen and helium have since been used. The two main types of balloons in use today are scientific balloons and sport balloons. *Scientific balloons* constructed of light-weight plastic materials have been in use since the early [illegible].

Table 2.1 : Classification of LTA Platforms

- Balloons
  - Scientific balloons
  - Sports balloons
- Conventional airships
  - Non-pressure or rigid airships
  - Pressure airships
    - Non-rigid airships
    - Semi-rigid airships
    - Metalclad airships
- Hybrid airships
  - Semi-buoyant airships
  - Heavy-lift airships
- Aerostats
  - Tethered aerostats
    - Fixed systems
    - Traversing systems
  - Remotely piloted aerostats
  - High altitude platforms
- Hot air airships

Balloons as large as 1.49 million cu m have been launched with scientific equipment to altitudes in excess of 45 km (150,000 ft) and space agencies and research institutions have found them to be a relatively inexpensive means of conducting high altitude investigation. The use of *sports balloons* has grown enormously in the past decade and some 3,000 hot air balloons are believed to be in use around the world. Their performance capabilities were amply demonstrated by the recent trans-Atlantic flight of the helium filled *Double Eagle II* and around the world trips are now being attempted. In September 1981, the *Solar Challenger* became the first solar powered balloon to cross the English Channel.

(ii) *Conventional airships*, or dirigibles, are of two main types: *pressure airships* that maintain their shape by the pressure of the lifting gas contained in their hull; and *rigid airships* which maintain their shape through a rigid metal girder structure independently of gas pressure, the lifting gas being contained in multiple cells placed along the ship's length in an arrangement similar to the watertight compartmentation of water-borne vessels. In pressure airships the envelope is generally a single gas cell that also contains one or more variable volume ballonets for the purpose of compensating for changes in pressure and temperature. Pressure airships are of three main types:

(a) *Non-rigid airships* - or 'blimps' - which comprise a fabric envelope and have no rigid structure other than the gondola (or control car), nose cone and empennage. The loads are supported by catenary curtains attached to the rigid elements by suspension cables. This arrangement is shown in Figure 2.1.

(b) *Semi-rigid airships* which similarly depend upon internal gas and air pressure to maintain their shape but have, in addition, a supporting structural keel extending longitudinally along the bottom of the envelope linking the gondola and empennage. In this

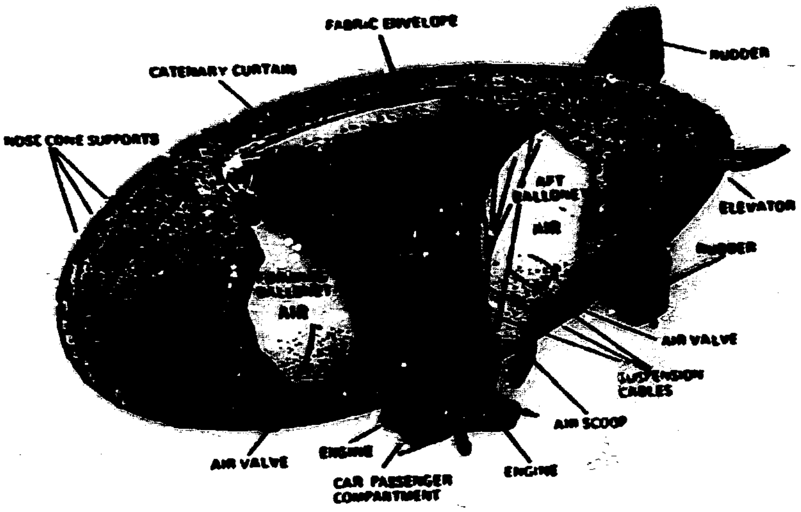


Figure 2.1: Internal Arrangement of Conventional Non-Rigid Airship

Courtesy of Goodyear Aerospace

type of vehicle the keel supports the primary loads and the catenary suspension system plays a less important role. The rigid keel makes it possible to operate semi-rigids with lower gas pressures.

(c) *Metalclad airships* which utilize a very thin aluminium skin in construction of the envelope rather than fabric material, although internal air pressure is still required to maintain the envelope's shape. The metal skin supports part of the primary loads.

Most of the 600 airships built have been non-rigids, and the seven airships flying today are of this type. The largest pressure airships ever built were the ZPG-3Ws of 41,500 cu m (1,465,000 cu ft) operated by the U.S. Navy in the late 1950s and early '60s. Far fewer semi-rigids have been built, the Italian airships *Norge* and *Italia* being the best known examples. The U.S. Navy's *ZMC-2* which operated for 7 years in the 1930s is the only metalclad airship that has so far flown, although a new interest in this type has recently emerged. Because rigid airships need to be large in volume in order to achieve flight efficiency, they were always the giants of their day. The more than 100 airships built by the Zeppelin Company were rigids and other well known examples include the *R-100*, *R-101*, *U.S.S. Los Angeles*, *U.S.S. Macon*, *U.S.S. Akron*, the *Graf Zeppelin* and the *Hindenburg*. The *Hindenburg*, with a gas volume of nearly 200,000 cu m,was the largest airship ever built, being five times the size of the largest non-rigid.

(iii) *Hybrid Airships* have made their appearance in the past decade and can be conveniently divided into two main types:

(a) *Semi-buoyant airships* in which airship performance is improved by increasing aerodynamic lift through modifications to the hull plan form, for example through multiple, deltoid, lenticular or ellipisoidal hulls; and

(b) *Heavy lift airships* which seek to combine the aerostatic characteristics of pressurized airships with the aerodynamic properties, especially controlability and maneuverability, of rotor craft. In heavy lifters the buoyant lift provided by the lifting gas is typically used to lift the weight of the airship, with the power provided by multiple rotors to lift the payload.

Examples of semi-buoyant airships include the U.S. designed *Aereon III* which flew in the 1970s, the *Thermo-Skyship* until recently under development in the U.K.,and several designs of the French engineer M. Balascovic (*Pegase*, *Titan*, *Vespa*, *Flipper*). Examples of heavy lift hybrids include the Piasecki *Helistat*, the *Aerocrane*, the *Cyclocrane*, and the *Heliostat*.

(iv) *Aerostats*. Aerostats are unmanned, usually small non-rigid airships or balloons that receive their instructions and sometimes their power from the ground and can be used for a variety of purposes, including communications and relay, surveillance,and lifting. Aerostat systems are of two main kinds, those that are tethered to the ground and a control station, and those operated from a station by remote control. *Tethered aerostats* may be fixed to one point (*fixed systems*) or to a track that allows them to move over a predetermined course (*traversing systems*). Fixed aerostats have been constructed in sizes up to 11,300 cu m (400,000 cu ft) with an altitude capability of up to 6 km (20,000 ft). They are used for communications and surveillance, several systems having been partially installed in developing countries (Nigeria, Iran). Traversing systems operate at very low altitudes and are designed to haul heavy loads over very short distances. Both the aerostat and its payload are winched back and forth over distances generally less than 2 km. These systems have found an application in logging operations. Whereas high altitude systems make use of streamlined balloons, the low altitude systems currently in use in North America all employ the 'natural shape' balloon.

Several small *remotely piloted aerostats* have also been built and tested for specialized missions,mainly of a military or law enforcement nature. These have been designed as non-rigid airships with control functions - patrol and loiter - activated by telemetry command from a ground station. Those tested have been able to carry 25 kg payloads, typically low light level TV and video cameras for law enforcement missions, and have proven easy to fly. Much larger remotely piloted aerostats have been proposed, capable of high altitude flight. The main examples are Project HI-SPOT employing an aerostat with a volume of 85,000 cu m and an operational altitude of about 21 km (70,000 ft), and project HAPP (High Altitude Powered Platform),a similar proposal, but with a novel source of power - microwave energy beamed up to the aerostat from the ground control station.

(v) *Hot air airships*. Finally, reference should be made to hot air airships. These are small balloons filled with hot air from propane burners, powered by small motors. The envelopes may be pressurized or unpressurized. With up to two seats they are used for sport, advertising and aerial photography.

The main types of LTA craft described above are shown schematically in Figure 2.2.

2.2 Some Principles of Aerostatic Flight

Instead of using power, and the required energy, to generate lift, an airship takes advantage of the natural buoyancy of the lifting gas. As can be seen from Table 2.2, hydrogen has the greatest lifting capacity and it has found widespread application in airship design, especially in Europe. As a number of tragic accidents testify, however, it is highly flamable and has now been abandoned

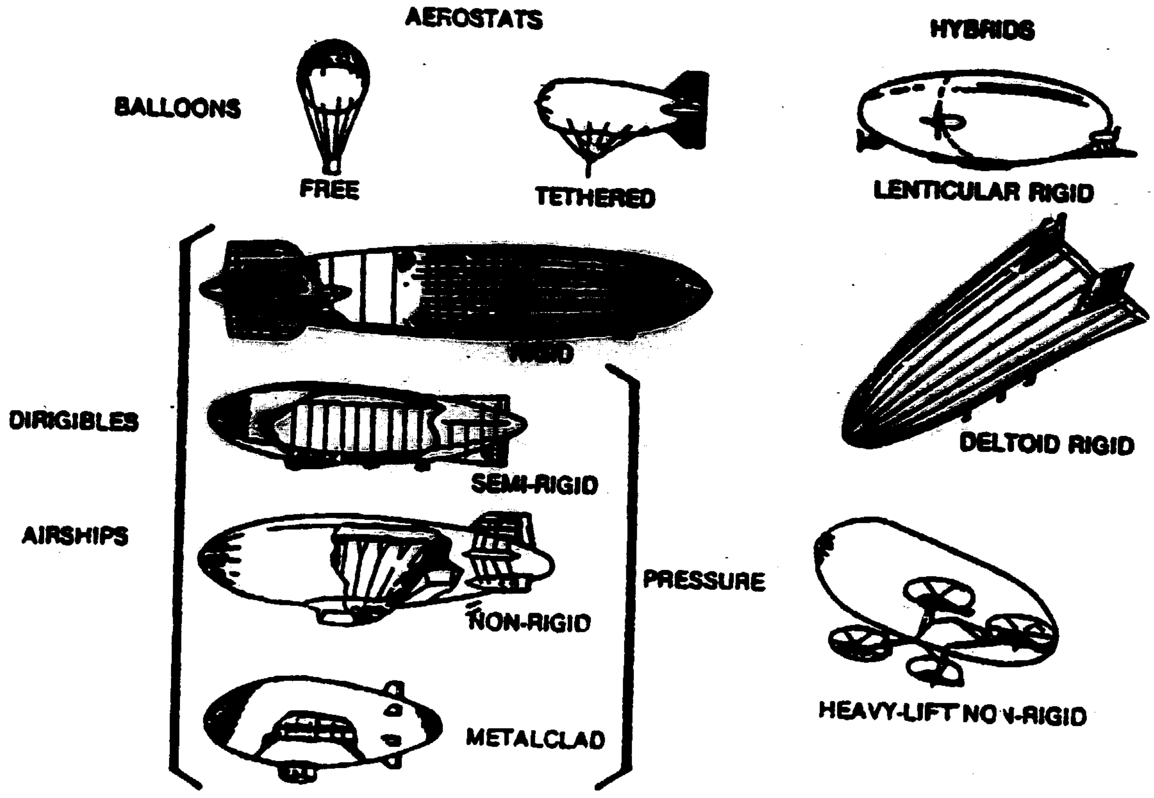


Figure 2.2: Main types of LTA Craft

Source: N.J. Mayer, 'Current Development Lighter than Air Systems', UNIDO 453/26 LTA-9, October 1981, p. 2

Table 2.2 : Lifting Capacity of Different Gases

Hydrogen[x] : 71 lbs lift per 1000 cu ft

Helium : 66

Steam at 100°C : 39

Methane[x] : 34

Ammonia[+] : 32

Natural gas[x] : 27

Air at 120°C : 20

x Flamable + corrosive

in favour of the inert but heavier helium. The lift derived from the natural buoyancy of the lifting gas is known as *static lift*. When an airship is buoyant, it is said to be light. When its weight and static lift are equal, it is in equilibrium. It is heavy when its weight exceeds its static lift.

LTA craft are potentially able to make use of two other types of lift: dynamic lift and powered lift. *Dynamic lift* is derived from the flow of air over a curved surface. The resultant differences in air pressure above and below the surface creates lift - the principle under which airplanes operate. The airship uses dynamic lift to meet either a heavy or a light condition in flight, a heavy ship flying in a nose up attitude and a light one flying nose down. *Powered lift* is created by vectoring the direction of force from the craft's propellers or rotors. Traditionally, airships have used static and dynamic lift. Modern conventional airships and notably hybrids also incorporate powered lift.

Most of the lift in airships is provided by static lift. Because of this, fuel is not required to get the craft off the ground and little is required to keep it afloat. The buoyancy of even heavy lift hybrid airships is usually sufficient to lift the craft's empty structure, enabling available power to be used exclusively for lifting a payload. In heavy lift helicopters, of course, the vehicle's power is required to lift both the helicopter and its payload.

Normal altitude control is maintained by setting the elevators (movable surfaces attached to the horizontal fins) in either their up or down positions. Horizontal steering is accomplished in the same way. The same principles are employed in submarines.

A pressure airship flies in an equilibrated state. This equilibrium is maintained by the ballonets within the airship's envelope. On the ground, the ballonets, are filled with air usually accounting for about 30% of the hull's volume. As altitude increases, the helium expands and air from the ballonets is expelled through air valves so as to maintain hull shape. At design altitude (or pressure height), typically 3000 m or 10,000 ft, the ballonets are empty and the helium will have expanded to fill the envelope to its full size. A further increase in altitude would require the wasteful process of venting helium to maintain pressure equilibrium. To return to the ground the process is reversed. Air is scooped from the engine exhaust, sometimes aided by auxiliary blowers, and forced into the ballonets. Pressurized airships typically have two ballonets, one forward and one aft, so that they can also be used for trimming purposes (altitude control), as shown in Figure 2.1.

In a non-rigid and semi-rigid airship the pressure control system is very much the 'nerve centre' of the whole craft. Vent valve design is obviously of great importance since this determines the efficiency of the pressurization system and the vehicle's rate of climb and descent.

In practice, pressure airships have traditionally been operated slightly heavy to provide better aerodynamic control. They were thus usually operated as short take-off and landing (VTOL) or zero take-off and landing (ZTOL) vehicles. To replace the weight lost in the consumption of fuel, or to compensate for cargo unloaded, the airship takes on ballast. The conventional way of doing this is to take on water. Late U.S. Navy non-rigids obtained ballast by condensing water out of the engine exhaust to compensate for fuel losses. The condensers did, however, add weight to the airships, traditionally the anethema of airship designers. The need for ballast and the ease of using water for ballasting meant that conventional airships were best suited for over the water operations.

Modern conventional airships which incorporate powered lift and control could be operated as vertical take-off and landing (VTOL) vehicles and without the need for ballasting. As yet, however, such vehicles can only be found on drawing boards and have still to be proven in practice.

3. A SHORT HISTORY OF LTA FLIGHT

3.1 THE FIRST MANNED FLIGHTS

The origins of lighter-than-air flight can be traced to the work of Roger Bacon who, in his *Secrets of Art and Nature* published about 1250, outlined the basic principles of human flight. At that time the idea of 'taking to the air' was considered contrary to 'the laws of nature' and stood in sharp contradiction to Catholic doctrine. Some four centuries were required before Bacon's principles could be put to the test. It was Francesco de Lana, a Jesuit priest born in Brescia in 1637, who was able to convince the church that manned flight was not necessarily incompatible with its teachings. It was another priest, the Brazilian born Father Bartolomeu de Gusmao who, in 1709, first demonstrated the feasibility of lighter-than-air flight and prepared a number of designs showing how this could be accomplished. His work enjoyed the patronage of King John V of Portugal.

In 1766 Sir Alfred Cavendish isolated free hydrogen (which he called Phlogiston), a step that advanced the feasibility of manned flight. His contemporary, Antoine Lavoisier, examined the properties of air and published his findings in *Different Kinds of Air*. This book aroused the curiosity of Joseph Montgolfier who began lengthy experimentation with a hot air balloon. On 25 April 1783, some 70 years after Father de Gusmao had demonstrated the feasibility of lighter-than-air flight to the court of King John V, Joseph Montgolfier and his brother Etienne first successfully tested a hot air balloon at Annonay near Lyons in France. A second test followed two months later, their *Montgolfière* rising to about 300m.

Their success resulted in a summons to Paris where King Louis XVI could see the Montgolfiers' invention for himself. On 19 September 1783 the first living creatures ever to take to the air - a sheep, a duck, and a cock - were loaded into the balloon's basket and, under the royal gaze, launched into the wind. They climbed to approximately 550m and travelled some 3 km in 8 minutes. History does not record the reactions of the first air travellers, although the cock reportedly looked distinctly the worse for wear, possibly the result of having been trampled on by the sheep.

The Montgolfier Brothers constructed another balloon, redolent with the royal cipher. In this vehicle François Pilâtre de Rozier made a tethered flight of 26 m on 15 October 1783, remaining airborne for about 4½ minutes. A month later, on 21 November, the young Rozier and the Marquis d'Arlandes became the first men to be carried by free flight in a balloon. They rose from the Bois de Bologne and were airborne for 25 minutes. Reaching a height of 450 m, they covered a distance of 8.5 km. Rozier also has the distinction of becoming the first man to be killed in balloon flight when the vehicle that was carrying him and a companion burst into flames while attempting to cross the English Channel in June 1785.

While the Montgolfier brothers persisted with hot air balloons, others devoted their attention to hydrogen. Seventeen years after the gas was first isolated, Prof. Jacques Charles demonstrated the feasibility of hydrogen flight. Launched from Paris, his trial balloon came to rest 25 km away in Gonese where panicstricken villagers used their pitchforks to tear it to shreds in the belief that the strange device was the work of the devil. Charles built another balloon. Just ten days after Rozier and the Marquis d'Arlandes had made their untethered flight, he and Marie-Noel Robert, one of two brothers who had helped Charles to build the balloon, took off from the Tuileries Gardens before a crowd of 400,000. His craft, the *Charlière*, covered 44 km and became the first hydrogen filled balloon to carry man aloft.

The success of people like the Montogolfiers and Charles generated an enormous interest in the balloon for sport and amusement. It also served to demonstrate its military applications. The French Republican Army became the first to use the balloon for this purpose when it employed tethered balloons conaissance duties during the battle of Fleurus in Belgium in 1794. During the 19th century, a period which saw the widespread use and rapid development of balloons, they were used by the Austrians (the first to use the vehicle for bombardment), by Federal forces during the U.S. Civil War, by the Brazilians in the Paraguyan War, and by the British in the Boer War and in the Sudan. They were to play a special role in the Siege of Paris during the Franco-German War of 1870-1871. Cut off from the rest of France, the nation's beleagured leadership used balloons to communicate with the outside world. When the siege started, Paris had only five balloons. Steps were quickly taken to mass produce them. By the end of the siege the mass produced balloons, piloted by circus acrobats and sailors selected by virtue of their head for heights, had made 66 flights and carried 155 passengers and crew and some 2.5-3 million letters. Infuriated by the success of the balloons, the Prussians went on the develop the first anti-aircraft gun.

3.2 The First Airships

As useful as the balloons were, they remained victims of the wind. Between 1783 and 1850 numerous unsuccessful attempts were made to steer and propel balloons using primitive forms of manual power. The breakthrough came in 1851 when Henri Giffard, the French inventor of the steam engine, developed a 3 hp engine which could drive a propeller. The following year he mounted it on a 43 m long envelope. He succeeded in travelling 27 km at 8 kph in what was to be the first true airship flight.

Developments followed fast. In 1872 Austrian Paul Haenlein made the first flight in an airship powered by an internal combustion engine. The four cylinder Lenoir gas engine he used drew its fuel from the craft's envelope. In 1883 Albert and Gaston Tissander built and flew the first electrically powered airship. Charles Renard and Arthur Krebs followed a year later. They attached an 8 hp electric motor to a 50 m bamboo trelliswork envelope of 1870 cu.m covered in Chinese silk and completed a circular course of 8 km at 23 kph. The flight of their craft, called *La France*, is regarded as the first fully controlled powered flight in airship history.

A few years later, in 1897, David Schwarz built the first rigid airship, consisting of an aluminium frame covered by aluminium sheeting. His was also the first airship to be powered by a gasoline engine. A year later Karl Wolfert built and flew another gasoline powered airship, making use of a Daimler motorcycle engine.

France and Germany became the leaders in airship design and construction. In 1898, Alberto Santos-Dumont, a Brazilian who lived in Paris, completed the first of 14 non-rigid, gasoline powered airships. These he used to make a number of records breaking and unusual flights - he was the first to pilot a craft around the Eiffel Tower - which gained him international acclaim.

At about the same time, Ferdinand von Zeppelin, perhaps the most legendary name in the history of airships, started to build rigid airships in a floating hanger on Lake Constance, near Friedrichshafen. Zeppelin, a Württemburg cavalry officer, had served as a balloon observer with Union forces in the American Civil War. Impressed by this experience and the success of especially Renard and Krebs, he saw it as his duty to provide Germany with a fleet of military airships. Awarded the first patent for an airship in 1895, he began construction of his first rigid vessel, the *LZ-1*. It was the giant of its day. Measuring 128 m long, it consisted of 24 longitudinal girders, extending from nose to tail, set within 16 transverse frames or rings and braced by diagonal wiring, the entire framework covered with cotton cloth. Its 11,300 cu.m of gas was contained in 17 separate cells of rubberized cloth. Its engines, by comparison, were anything but large: two Daimlers together producing 32 hp for a weight of 770 kg. When it made its first 20 minute flight in July 1900 it was obvious that the vessel was hopelessly underpowered. It was scrapped a year later after several flights and Count von Zeppelin went back to the drawing board. Four years later he began construction of the *LZ-2*.

The early 1900s had, however, witnessed the emergence of the first practical airships. In 1903 the Lebaudy Brothers in France made the first ever journey in a fully controlled airship, travelling a predetermined distance of 61 km. The ship, a steel tube structure carrying a basket gondola containing the 35 hp powerplant and crew, was handed over to the French government. Others were built for the French Army, and Britain, Russia and Austria, aware of its military applications, each acquired one.

The early 1900s was a period of considerable airship activity, the U.S., Britain and Italy initiating programmes which were already well underway in Germany and France. Thomas Baldwin built the first practical U.S. airship, the *California Arrow*, which flew for the first time in 1904. He was later commissioned to build an airship, designated *Dirigible No. 1*, for the U.S. Army which was to see three years of service. In 1906, the wealthy and eccentric journalist Walter Wellman hired Melvin Vaniman and Louis Godard to build an airship capable of reaching the North Pole. The resulting *America* was 70 m long and had a volume of 9900 cu. m. Two attempts were made to reach the pole, in 1907 and 1909, both of which ended in failure. Underterred, Wellman planned a trans-Atlantic crossing. This was attempted on 15 October 1910. Three days later the *America's* five man crew was rescued off the coast of New England. In 1912 another trans-Atlantic crossing was attempted by Melville Vaniman in the *Akron*, but within five minutes of taking off from Atlantic City it burst into flames with the loss of its entire crew of five.

In Britain, Ernest Willows constructed five small non-rigid airships between 1905 and 1910. The third of these became the first airship to successfully cross the English Channel. Willows' ships were notable for their swivelling engines, employed for increased controllability and maneuverability, a design which he patented. Britain's first military airship, a 1560 cu.m non-rigid known as *Nulli Secundas*, made its maiden flight in 1907. It was redesigned the following year, a triangular section keel being added, turning the ship into Britain's first semi-rigid. It was followed by the smaller *Beta*, the first practical airship to serve with the British armed forces. Between 1907 and the outbreak of hostilities in 1914, 8 pressure airships were constructed, while an additional five were purchased from France and Germany.

During the same period, Italy was building a number of non-rigid and semi-rigid airships for military purposes. The most important of these was the Forlanini semi-rigid of 3,700 cu.m, which first flew in 1909. Although airships of this type served with the Italian Army for several years, they did not prove particularly successful.

It was in Germany, however, that developments were most rapid. Concerned about what France was doing west of the Rhine, Germany launched a miniature 'crash programme' in airship development. The designers of rigid and non-rigid airships competed for official recognition and keen rivalry existed between the proponents of both types. The advocates of rigid systems, notably Johan Schutte, Heinrich Lanz and Ferdinand von Zeppelin, argued that their ships had speed and range, while the advocates of non-rigids, notably August von Parseval, argued that rigids were clumsy and dangerous to handle. The impulse given to airship developments, however, made it possible for Germany to introduce the first regular passenger airship service in 1910. Five airships, built by Zeppelin for the Delag company (Deutsche Luftschiffahrts-Aktien-Gessellschaft), were used to connect a network of towns. When they were taken out of service in 1914 they had made nearly 1600 flights and carried 34,000 passengers without a single accident.

2.3 The First World War

By the outbreak of the First World War Britain, France, Italy and the U.S. as well as Germany all had airship development programmes. The Great War gave an enormous impetus to their further development, when great strides were made in disposable weight, speed and range. Nowhere was this more so than in Germany, where the airship was seen as the most destructive weapon ever invented. During World War 1, the German government decided to standardize on airship design. Work on non-rigids was progressing slowly. Although Parseval had built 26 non-rigids for the German Army, further development was being handicapped by the lack of a suitable envelope material. The German government decided on the rigid airship and selected the Zeppelin in preference to the designs of its competitors. The Scütte-Lanz company, which had built 20 rigids, some of them wooden framed, became part of Luftschiffbau Zeppelin.

At four plants 88 Zeppelins were built, at a production rate of one vessel every two weeks. The ships were operated by the German Army and Navy for both bombardment and naval patrol. During this time, the Zeppelins were intensively developed. The German Navy started the war with the *L-3* and ended it with the *L-71*. The *L-3* was 158 m long, had a volume of 22,500 cu.m, and a top speed of 75 kph. The *L-70* was 211 m long, had a volume of 62,000 cu.m and its 1715 hp engines gave it a top speed of 130 kph. The last of the wartime Zeppelins had a useful lift of 50 tons and their ceiling had been increased to over 6,000 m to keep them out of range of enemy anti-aircraft fire. The ships developed a fearsome reputation in England with their bombing raids, although they in fact inflicted little damage. Equipped with machine guns in the cars and on top of the hull to protect them against enemy aircraft, they also had a car, or 'spy basket', which could be lowered beneath the clouds to permit the observer in his car to navigate or direct bombing while the airship remained hidden above. The longest flight during the war was made by Naval Zeppelin *L-59* which flew 6700 km, much of it in a tropical climate, and remained in the air for 95 hours.

Whereas Italy also developed new types of airships for bombing missions, Britain, France and the U.S. saw and used the airship as a maritime patrol vessel rather than a war-winning weapon. In this role it performed extremely well. The French Navy had 60 airships, mainly non-rigids, during the last years of the war which were mainly used for patrols over the Mediterranean Sea.

They performed more than 3,300 flights, attacking about 60 U-boats and sighting about 100 mines. Most of the non-rigids were of the Astra-Torres type, designed by the Spaniard Torres Queredo, which had internal rigging to reduce drag. Other were built by Clement-Bayard to designs derived from the Lebaudy type.

The British began the war with 3 airships: a Parseval, an Astra Torres, and a Lebaudy. An experimental craft was quickly built from the spare envelope of a Willows airship for coastal antisubmarine patrols. It proved so successful that it was to result in a family of related non-rigid airships - the Sea Scout (SS) Coastal (C) and North Sea(NS) being the main variations. The most successful of all was the N.S. class which, similar to the Astra Torres design, was 80 m long and had a volume of 10,000 cu. m. Its enclosed gondola could accommodate a crew of ten. With a maximum speed of over 90 kph it proved very effective in tracking U-boats and calling up surface vessels to harass or destroy them. Altogether, more than 9000 patrol and 2200 escort missions were flown by British airships during the First World War, operating from 17 airship stations and 12 mooring out sites. During the war Britain also built a number of rigid airships, including the wooden framed *R-31* and *R-32*, modelled on Zeppelin lines, none of which proved very successful.

The U.S. Navy moved to develop non-rigid vessels for anti-submarine and coastal patrol. Its first ship, the 53 m long, 3250 cu. m *DN-1* (later redesignated the *A-1*) was ordered in 1915 and completed in 1917. It was abandoned, however, after 3 flights due to excessive gas leakage. In 1917 it ordered 15 B-types (2180-2380 cu.m) which were completed in 1918 by three companies, including the Goodyear Tyre and Rubber Company which went on to play a prominent role in airship development. The B-class was followed by orders for 30 5160 cu. m C-class ships (reduced to 10 after the Armistice), the first of which was completed in 1918. During U.S. participation in the First World War, U.S. Navy non-rigids were based at 7 stations along the Atlantic coast, while other blimps, acquired from the French, were operated from a base at Paimboeuf over the Bay of Biscay.

The only other country to make significant use of airships during the war was Italy, which employed a small number of non-rigids and semi-rigids on naval duties, although new types were developed to increase altitude performance on bombing missions. The largest of Italy's airships were the three 71 m, 11,300 cu. m semi-rigids built by Forlanini.

3.4 The Inter-War Years

After the First World War airship developments continued apace. The limitations of the airship as a strategic weapon had been clearly demonstrated during the hostilities and attention turned to their potential role as commercial vehicles, at that time superior in every way to the aeroplane, and to further developing their usefulness for surveillance and monitoring missions.

The further development of the airship was stimulated by the spread of Zeppelin know-how. Under the terms of the Armistice, captured Zeppelins - some had been destroyed by their crews rather than surrendered - were delivered to France, Italy, Britain, Belgium and also Japan. Germany itself entered the post-war period with virtually no operational airships. The Delag Company, which had operated airships so successfully before the war, lost no time, however, in commissioning the Zeppelin company to build it a small commercial rigid, the *Bodensee*, which it operated between Friedrichshafen and Berlin. So successful was this service that it acquired a second vessel, the *Nordstern*. The allies soon put a stop to this operation since, under the Treaty of Versailles, Germany was prevented from undertaking further airship activity. The *Bodensee* was surrendered to Italy, the *Nordstern* to France. While operated by Delag, the vessels made 103 flights and carried 2320 passengers, all in safety.

The British used a captured Zeppelin, the *L-33*, as a basis for the *R-33* and *R-34* airships constructed in the immediate post war period. In 1919 the 200 m long *R-34* became the first airship to cross the Atlantic, only 3 weeks after Alcock and Brown's historic flight.

With a crew of 30, it made the westward journey in 108 hours, and the return flight in 75 hours. The British went on to build several other rigid airships, including the 2100 hp, 212 m long *R-38*, which was to be purchased by the U.S. Navy. On its fourth flight in 1921 it broke in two in severe weather conditions and fell into the Humber, killing 44 British and U.S. officers and men. This disaster put a temporary stop to British airship efforts.

Following the FIRST Second World War, the U.S. continued its airship development programme. The Navy ordered five 5350 cu.m D-type non-rigids and 2 small, single engined non-rigids, designated the *E-1* and *F-1*, were also built. An 11,330 cu.m G-type was completed in 1919 but not put into production. In the same year it acquired a semi-rigid from Italy but it saw only three months of service before being scrapped. The 1220 cu.m single-engined *K-1*, which could be used for towing operations, was acquired in 1921, and in 1922 the Navy took delivery of the first of its J-class airships. During the same period, the U.S. Army, which had flown non-rigids in Europe during World War 1, was also involved in the development of non-rigid and semi-rigid airships. To investigate the semi-rigid design the Army purchased the 124 m, 35,130 cu.m *Roma* from Italy. Reassembled in the U.S., it crashed during a test flight in 1922 with the loss of 34 lives.

During this period airship development in Germany had been forced into a dormant state. Count von Zeppelin had died in 1917. By the end of the Great War the enterprise that he had created had built a total of 115 airships. When taken over by Hugo Eckner, the Count's close associate, its financial fortunes were at a low ebb. Convinced that the airship was unsurpassed as a long-distance passenger carrier, Eckner suggested to the U.S. that it build it a new airship to replace the vessel it should have received as reparations but which had been destroyed. The U.S. agreed and this decision helped ensure that the Zeppelin company reestablish its position at the forefront of rigid airship development.

The resulting *LZ-126* began flight tests in early 1924 and, in October of that year, it was flown to the U.S. Navy's base at Lakehurst, New Jersey, becoming the first German airship to cross the Atlantic. Designated *ZR-3* by the Navy and christened the *USS Los Angeles*, it went on to accumulate 5,368 flight hours in 330 flights before being retired in 1932. Although occasionally recommissioned, it was finally scrapped in 1939.

Italy had also continued airship development. The best known of its post-war airships were the N-type semi-rigids developed by Umberto Nobile, which until 1926 were built under government sponsorship. In 1926, the *N1*, later named *Norge*, became the first airship to fly over the North Pole, the 4800 km flight from Spitzbergen to Teller, Alaska taking more than 70 hours. Although his semi-rigid design was criticized for being too small and fragile for use in polar regions, it was with a similar ship, the *N4 Italia*, that Nobile undertook a new series of Arctic flights some 2 years later. On the third flight he succeeded in again crossing the pole only to crash a day later some 300 km northeast of Spitzbergen, with the loss of 7 lives. A vast international rescue operation was mounted and, although Nobile and 7 of his colleagues were rescued, 10 others died in the rescue operation, including Roald Amundsen, the distinguished Norwegian Polar explorer, who had been on the flight of the *Norge*. In an official inquiry, Nobile was held responsible for the disaster. He left Italy to continue airship development work in the Soviet Union.

France acquired three Zeppelins from Germany in 1920-21 : the *L-72*, *LZ-113* and the small commercial *Nordstern*. The last two saw little active service prior to dismantlement, but the 70,000 cu. m L-72, renamed the *Dixmude*, established an endurance record of 118 hours in 1923. In the same year the ship was lost over the Mediterranean with its entire complement. This ended all rigid development in France, although the country did continue naval non-rigid and semi-rigid development until 1937 when all airship activity was stopped by government decree.

All the French Navy airships, 6 non-rigids and 4 semi-rigids, were built by Zodiac, the sole remaining French airship manufacturer. Up to 1937, the French Navy operated an average 2 ships from its main base at Rochefort.

The loss of the *Dixmude* did not prevent a resurgence of interest in Britain in the rigid airship. In 1924 work commenced on two ships - the *R-100* and *R-101* - to serve as forerunners for regular services to the Dominions, the first to be built by private enterprise, the second by the government. The crash of the *R-38* led to a greater emphasis being placed on safety factors and consequently to heavier airships, a decision that proved to be fraught with grave consequences. Spurred on by an imperial mission - the determination to keep empire intact - and, more mundanely, by the development of the mooring mast which was held by the British to be the solution to the intractable problem of handling large aircraft on the ground, the two vessels were completed in 1929. The *R-100*, designed by the distinguished inventor Barnes Wallis, was built to a modified Zeppelin design, an unconventional geodetic construction replacing unbraced transverse frames. With accommodation for 100 passengers, its 6 gasoline engines gave it a top speed of 130 kph. In July 1930 it flew from England to Canada in 78 hours, returning in in 58 hours. Though long journeys were not undertaken without hazard, its two year life was relatively uneventful.

A different fate awaited the *R-101*. Able to accommodate 50 passengers in a cabin 'as big as a small country house', it deviated more from conventional Zeppelin practice. Political pressures had led to a curtailment of the trials of both the *R-100* and the *R-101* and, with the unreadiness of the vehicle no secret, the *R-101* left England on a proving flight to India, via Egypt. As a new biography of the ship by Sir Peter Masefield makes all too clear, the *R-101* was a disaster waiting to happen.(2) It was three years late, 50% over cost, and, lengthened after construction to improve its poor lifting capability, more than 23 tons overweight. The vessel's gas bags rubbed against its girders and leaked as much as 4250 cu.m of gas a day. Certified without one overseas test or one full speed trial, it had travelled only a few hundred kilometers when the disaster occurred.

Crabbing 40° into a 40 knot wind at 2.00 in the morning, the nose, according to Masefield, suddenly dipped as 3 tons of rainwater, probably coinciding with a down gust, split the forward outer cover and burst the gas bags. Power and speed were cut, the nose dipped again, and the vessel crashed sideways at a speed of perhaps no more than 10 knots into a hill near Beauvais in northern France. The calcium water flares in the crushed control car caught fire immediately and the *R-101* was soon engulfed in hydrogen and oil flame. 48 of its 54 passengers and crew were killed. Ironically, for all its technical imperfections, had the captain ordered full power, the *R-101* might have flown out of its dive and, tattered and torn, limped back to England. But he did not.

The crash of the *R-101* shocked Britain. In the wake of the disaster and the deepening economic recession, the British government scrapped the *R-100* and abandoned all further airship activity.

While the British were building the *R-100* and *R-101*, the Zeppelin company was building perhaps the most famous of all airships, the *LZ-127*, known as the *Graf Zeppelin*. Some 240 m long, the *LZ-127* had a volume of 93,700 cu.m, of which nearly a third was filled with blaugas fuel, a petroleum vapour some 20% heavier than air, and the remainder with hydrogen, the lifting gas. Powered by five engines capable of developing 2650 h.p. it provided luxury accommodation for 20 passengers and could carry 12 tons of mail and cargo. First flown in September 1928, the *Graf Zeppelin* made a much publicized round the world flight in 21 days in 1929. One of the most luxurious flights ever made by any aircraft, the 20 passengers, some of whom had paid up to $9,000 for the voyage, complained of being overfed as a result of having to advance the ship's clocks one hour in every seven. Though undersize, the *Graf Zeppelin* saw nine years of continuous and successful service. When decommissioned in 1937, it had made 590 flights, including more than 140 trans Atlantic crossings, carried 13,000 passengers and more than 100 tons of mail and freight, engaged in scientific research over the Arctic travelled a total of 1.7 million km.

The development of rigid airships was also well underway in the U.S. in the same period. Before it received the *LZ-126* from Germany, the U.S. Navy had already acquired a rigid airship, the *LZ-1*, christened the *USS Shenandoah*, a copy of the German Zeppelin *L-49*, modified mainly for helium and mooring mast operation. First flown in 1923 it went on to make a number of noteworthy flights, including a 14,000 km transcontinental roundtrip in 1924. The ship was, however, destroyed in a thunderstorm in September 1925 when it failed structurally. Being inflated with helium it did not catch fire, although 14 members of its crew of 43 were killed. The disaster has been attributed to crew inexperience as much as to faults in construction.

Further development of rigid airships in the U.S. was prompted by the arrival from Germany in 1924 of the *LZ-126* and the acquisition by Goodyear, also in 1924, of Zeppelin patents and processes as well as a small group of expert Zeppelin engineers who had been persuaded to emigrate to the U.S. Goodyear formed a subsidiary, the Goodyear-Zeppelin Corporation, in Akron, Ohio, which remains the home of the Goodyear Airship Co. In 1928 it began construction of two giant rigid airships - the *ZRS-4*, christened the *USS Akron*, and the *ZRS-5*, christened the *USS Macon* - for the U.S. Navy. Both were 240 m long and had a volume of 185,000 cu.m. Built for long-range reconnaissance missions, the vessels had a cruising range of more than 10,000 km and a maximum speed of 72 knots. They could operate unrefuelled for up to 160 hours. They were in many respects ingenious designs. They departed from the traditional Zeppelin design, being based upon a light weight wire bracing construction rather than heavy unbraced transverse frames. The power plant installation consisted of eight 560 hp Maybach engines mounted in separate engine rooms within the hull driving outboard propellors which could be swivelled to produce vertical lift. Each had an internal hangar for five scouting planes which could be launched and landed from a special trapeze. Despite all the innovation, however, neither were able to carry out all the naval exercises for which they were intended.

The *Akron* was completed in 1931 but, after about 1700 hours of service, crashed with the loss of 73 lives, in a storm off the New Jersey coast in 1933. The *Macon* was launched at the same time. In 1935, after 1800 hours of service, the upper fin structure failed and the ship fell into the sea and sank off the coast of California with the loss of two lives.

The loss of the *Akron* and *Macon* was, like the *Shenandoah*, probably due more to crew inexperience than to defects in their lightweight construction. The loss, however, left the U.S. Navy without a rigid airship. The increasingly threatening international situation led both the Navy and Army to concentrate on heavier-than-air craft, and further airship activity was limited to non-rigid designs.

The Navy's main non-rigids were the 5950 cu.m *J-4*, the 9070 cu.m *K-1*, and the 5720 cu.m *ZMC-2*. The *J-4*, an open gondola ship, had been completed in 1924, and the experimental *K-1* in 1931. The *ZMC-2*, the first successful all metal airship, was built, not by Goodyear as all other important Navy airships had been, but by the Metalclad Airship Corporation of Detroit. First flown in 1929, its hull consisted of 24 longitudinal girders and 12 circular frames to which an alumimum alloy outer cover was rivited. Although the *ZMC-2* had a long and successful life prior to dismantlement, it was not particularly popular with the Navy crews and no other metalclad airships were built.

Goodyear began the commercial operation of its own non-rigid airships in 1925. These were used to pioneer many airship flight and ground handling improvements. The company operated as many as 6 airships, ranging in size from 1440-5180 cu.m. The capacity was later standardized at 3480 cu.m, a size which can carry 6 passengers. This design forms the basis of the 4 airships operated today by Goodyear.

Airship activity started in earnest in the Soviet Union in 1931, the year that the *Akron* and *Macon* made their maiden flights. In that year, a public subscription of 15 million rubles towards an airship programme was announced.

The Second Five Year Plan provided for the operation of airships on civil air routes within the country. Spurred on by the arrival of Umberto Nobile, who had attained considerable fame with the *Norge* and was later compelled to leave Fascist Italy, the programme made rapid strides. Several small non-rigids and semi-rigids were built and plans were announced to construct larger commercial airships. Tsiolkovski, one of the leading Soviet designers, believed that there was an important future for the metalclad airship. He designed such a vehicle - larger than the U.S. Navy's *ZMC-2* - but it was never built. In 1936 Dirigiblestroi (Dirigible Construction Trust) began construction of the *DP-9*, a 106 m 25,000 cu.m semi-rigid. The following year the Soviet Union expressed an interest in purchasing the German built *USS Los Angeles*. By the outbreak of the Second World War the Soviet Union reportedly had a fleet of 15 non-rigid and semi-rigid airships and was operating a scheduled service using semi-rigids between Moscow and Sverdlovsk.

It was in the 1930s that the Zeppelin company built their two largest rigid airships, the *LZ-129*, known as the *Hindenburg* and the *LZ-130*, known as the *Graf Zeppelin II*. Both were to be bigger and better than the *Graf Zeppelin* who had impressed all who had seen her. Both were designed for helium instead of hydrogen operation to prevent an occurrence of the *R-101* disaster. The United States, however, then as today the only large-scale producer of helium, refused to sell the gas to Germany, fearing that it would find an application in military airships, and in protest against Nazi policies.

Failure to acquire helium did not stop the Deutsche Zeppelin Reederei. In 1936 it launched the *Hindenburg*, a vessel of conventional Zeppelin design with 36 longitudinal girders and 15 wire-braced main transverse frames. With a length of 245 m and a volume of 200,000 cu.m, it was powered by 4 Mercedes Benz diesel engines, each developing 1000 h.p., giving the ship a top speed of 130 kph. It could accommodate 75 passengers in unsurpassed luxury and a crew of 25, and had a range of nearly 14,000 km. It entered service in the summer of 1936 and made a total of 63 flights and carried over 3000 passengers, including 1000 passengers on 10 trans Atlantic flights. On May 6 1937, the hydrogen inflated craft burst into flames in front of newsreel cameras while landing at Lakehurst, New Jersey. 36 of the 97 persons on board lost their lives, the first passenger fatalities in the history of commercial airship operations. While the fire was officially attributed to a discharge of atmospheric electricity in the vicinity of a hydrogen leak, the Hindenberg's operators had received numerous threats from anti-Nazi groups and the possibility of sabotage has never been ruled out.

The *Graf Zeppelin II* was commissioned and tested in 1938. It too was inflated with hydrogen. It went on to make 30 exhibition and test flights but saw no commercial or war service. At the outbreak of the Second World War the German government directed the Zeppelin company to discontinue all lighter-than-air manufacture. The *LZ-127* and *LZ-130* were dismantled for duralumin and aluminium for use in warplane production. This marked the end of German attempts to build a world-wide fleet of commercial transport airships. With the cancellation of a U.S. design for a rigid airship for the U.S. Navy in 1939, the development of the rigid airship finally came to an end.

3.5 The Second World War

The Second World War did not, however, witness the end of all airship development. On the contrary, it gave it a new impetus. Britain designed and built hundreds of tethered aerostats - the barrage balloon - streamlined gas bags designed to lift a steel cable more than 1000 m to deter low flying enemy planes. In the U.S., new non-rigid and semi-rigid airships were designed and built for the role they had performed so well in the First World War - coastal patrol and surveillance. Only Japan persevered with lighter-than-air craft as a weapon of war. In the early 1940s it despatched about 9000 ingeniously constructed unmanned bomb-carrying balloons across the Pacific aimed at the not inconsiderable target of the United States. About 11-12% survived the crossing, killing 6 persons upon reaching their destination.

The U.S. Navy, which had continued semi-rigid and especially non-rigid development throughout the 1920s and '30s, was operating 4 K-type patrol airships and 3 small L-type trainers as well as a few ex-Army craft at the time of Pearl Harbour. It rapidly expanded its fleet as an airship building programme was initiated and accelerated. During the war years, 4 18,200 cu.m M-types, 22 3,500 cu.m L-types (for training) and 8 5,570 cu.m G-types (training/utility) non-rigids were built. The Navy's work horse was, however, the 12,000 cu.m K-type, 134 of which were built. First flown in 1931, the K-type carried its own mooring mast. Between 1942 and 1945, the Navy operated 15 airship squadrons totalling 164 non-rigids from more than 50 bases in four continents (North America, Latin America and the Caribbean, Europe and North Africa).(3)

Navy 'blimps' performed anti-submarine and patrol and escort operations in a 3 million sq. mile area along the Atlantic, Gulf of Mexico and Pacific coasts, in the Caribbean, along the South American coast from Panama to Rio, and in the Mediterranean. They flew a total of 55,900 flights, logging 550,000 hours, and escorted 89,000 ships without the loss of a single ship to enemy action. Of the blimps assigned to fleet units, 87% were in operational readiness at all time , thereby establishing a World War II record for the availability of military aircraft. It was a U.S. Navy blimp that became the first non-rigid airship to cross the Atlantic in 1944.

In addition to anti-submarine, escort and patrol missions, the ships successfully performed a number of other tasks, including shipping control, torpedo recovery, aerial photography, observation, special equipment calibration, search and rescue operations, as well as other operations requiring a low-speed and low-altitude capability. In the Mediterranean they fulfilled a valuable role in minesweeping operations by spotting and marking undetected minefields. This undoubtedly prevented a number of minesweepers from being destroyed.

3.6 The Post War Period

The airship's pre-War and war time performance convinced some that the vehicle would have a valuable role to play as a passenger carrier in the post-war period. Attention turned again to large rigid airships. No sooner had World War II ended, Goodyear advocated the construction of a rigid ship of 280,000 cu.m capacity, with accommodation for 112 passengers who were to travel in standards comparable to an ocean liner. By eliminating a dining room designed to seat 60 passengers and converting the whole interior to Pullman-type compartments, the Goodyear vessel was capable of carrying 232 passengers. The use of reclining chairs similar to those used in civil aeroplanes gave the airship a capacity of 288 passengers. Designed to compete with aeroplanes which in the early post war years were Spartan in their standards of comfort, the airship was to cruise at 120 kph, although Goodyear believed that, with stern propulsion and other developments, cruising speeds of over 150 kph would be possible.

In the 1950s other designers optimistically turned their attention to the possibility of nuclear powered airships. Francis Moore of Boston University designed a nuclear powered airship to be used either as a cargo carrier or a passenger vehicle with accommodation for 400 passengers. His ship, 300 m long, was to have a useful lift of 140 tons and a payload capacity of nearly 90 tons. The nuclear power plant was to drive three rear mounted engines - a 4000 hp gas-turbine driving 20 m long dual-rotation propellers, and two 1600 hp turbofans designed to help overcome the problem of drag. The airship was to be equipped with a hotel containing a dining room for 200 persons as well as a cinema and promenades. Like the *Akron* and *Macon*, the vessel was to have its own aeroplane: an 18 seat shuttle plane was to ferry passengers to and from the ship while in flight.

In Austria, Erich von Veress designed an even larger nuclear powered airship. Known as the *ALV-1*, it was to have a volume of some 400,000 cu.m, carry 500 passengers and 100 crew, and handle 100 tons of freight.

The vessel was to be propelled by a nuclear powered turbine with two propellers placed in tandem inside the hull near the bow. To be furnished to high levels of passenger comfort, the vessel's planned speed would have enabled it to make a westerly crossing of the Atlantic in [illegible] hours, the return trip to take 18 hours.

The post-war preoccupation with large rigid airships proved to be relatively short lived and the designs that emerged were more drawing board concepts than practical propositions. Much more practical, and hardly less interesting, were the rapid strides made in the post-war period in the development of non-rigid airships by the U.S. Navy. The emergence of new man-made fibres for envelopes made it possible to increase size. Various configurations of the successful K-type were evolved, with volumes of up to 19,000 cu.m. In 1953, the first N-type non-rigid subsequently designated the *ZPG-2*, entered service. This 28,000 cu.m ship had considerably improved lifting performance. The *ZPG-2W* was developed for airborne early warning at sea, and entering service in 1957, rapidly demonstrated its all weather reliability, economy, and high technical efficiency.

In 1957, a *ZPG-2* airship completed an unrefuelled flight of over 15,000 km over the North Atlantic and Caribbean, beating the one set up in 1929 by the rigid *Graf Zeppelin* when it flew 11,000 km non-stop from Friedrichshafen to Tokyo. In 1958, the first of the Navy's 42,000 cu.m *ZPG-3W* type, the largest non-rigid ever built, entered service. Equipped with a large radar antenna within its envelope it proved a very useful early warning device and served as a stable platform for the development of many present day AEW sensor systems.(4)

By the late 1950s it had become increasingly clear that the days of the U.S. Navy's non-rigid airships were numbered. Shifts in Soviet strategic forces from manned bombers to intercontinental strategic missiles eventually cancelled the requirement for an early warning system that could provide surveillance in seaward approaches.

Similarly, in the ASW role new sonorbuoys were developed for fixed wing aircraft that permitted them to close the gap in performance that the airship had previously enjoyed. The increasing cost of operations and the need for the Navy to reduce its ASW force levels led to the decision to decommission ASW airship squadrons.(5)

In 1961 the U.S. Navy terminated its airship operations, effectively bringing to a close a period of airship development which stretched over more than a century. Between 1917 and 1958 it had taken delivery of some 250 airships, some 40% of all the airships ever built.

3.7 The Performance of the Airship

In this short sketch we have attempted to outline the long history of the airship, its evolution from small to big, from primitive to sophisticated, from toy to tool. This history is shown schematically in Figure 3.1. The history of the airship is essentially one of performance and safety. It is somewhat strange, therefore, that the appelation 'airship' should today be so coloured by the handful of spectacular disasters which brought the development of rigid vehicles to a close in the 1930s. They seem to have left an indelible inprint in our collective subconscious and this has prevented a full appreciation of the performance of the airship.

As we have seen, there was no single reason for these disasters. In some respects they were the consequence of the fact that the airship was ahead of its time, demanding technologies and techniques which only later became or are only today becoming available. They were conceptualized, built and flown before there was the know how required to make and fly them. Even so, some accidents were almost unnecessary. The *R-101* and *Hindenberg* were lost to fire because they were inflated with highly inflammable hydrogen, unlike U.S. ships which used the inert, but heavier, helium. The Germans, as we saw, designed their ships in the 1930s for helium operation but were unable to attain it from the United States in the tense political climate that then prevailed.

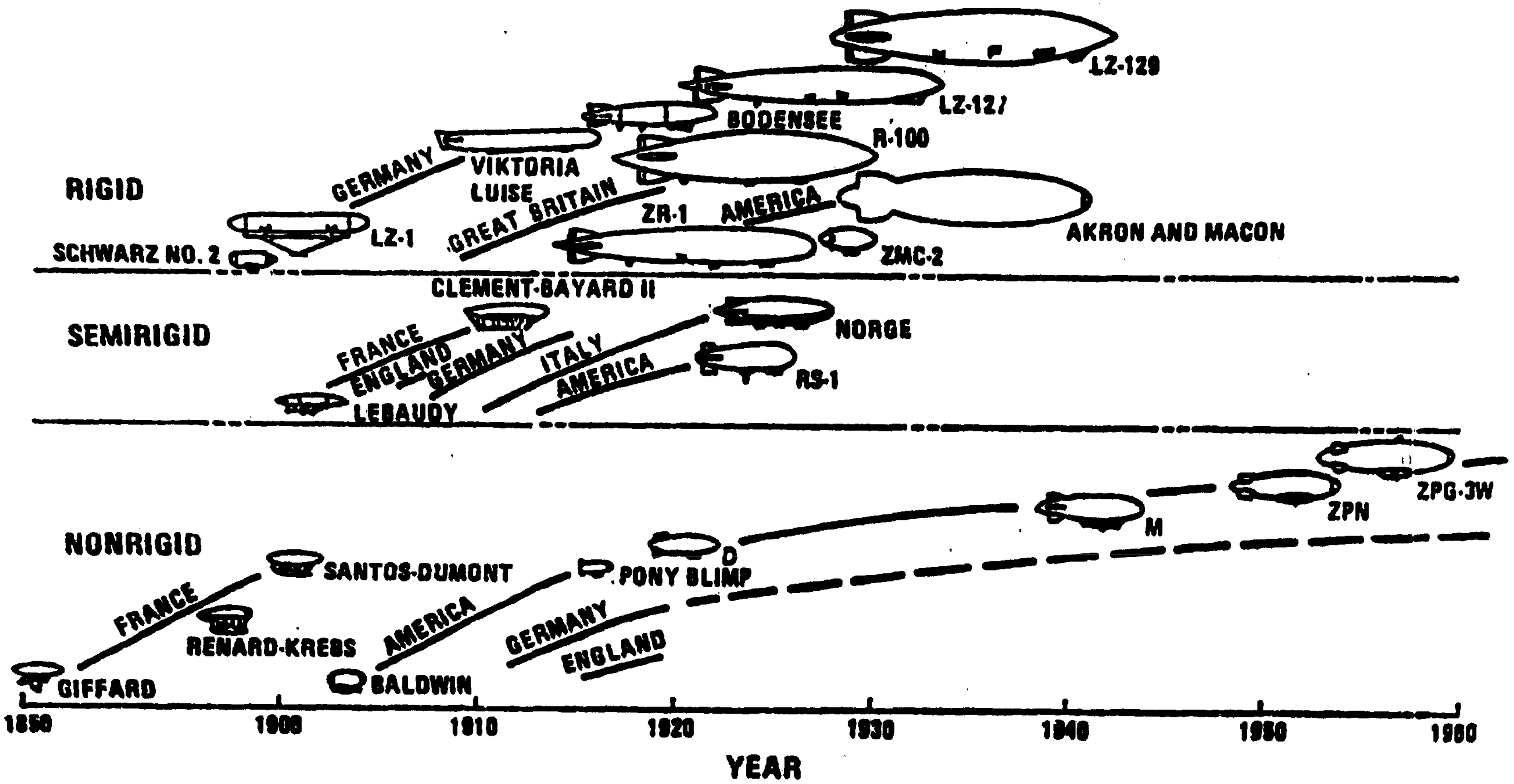


Figure 3.1: Genealogy of Airship Development

Source: *Maritime Patrol Airship Study*, 1980, p. III-3

Other disasters were due to defects in structural design and, often, as in the case of the *Akron* and *Macon*, to crew inexperience. Some ships, like the *R-101*, were forced by political pressure to take to the air long before they were ready to do so. It should also be noted that the giants of the past, never the most maneuverable of craft, were often underpowered and compelled to fly with the most primitive of navigation aids.

The essential point is, however, that for every rigid giant that crashed among front pages headlines, there were scores of non-rigid airships leading useful and uneventful lives, engaged in a wide range of military and civilian work. Consider the record of the Delag airships in pre World War 1 Germany, the performance of British and French airships in the First World War, and those of the U.S. Navy in the Second World War. The U.S. Navy flew 30 million km with more than 160 non-rigid ships with only one fatality and that was due to enemy action. By 1960, the airships built by Goodyear - one half of the 600 ever built - had carried nearly half a million passengers and made 180,000 flights without a single passenger injury.

The passengers who perished on the *Hindenburg* in 1937 were the first ever to be killed on a commercial airship service. Even here, more than half of those on board were able to walk away. There is little doubt that the safety record of the airship is at least as good if not considerably better than that of heavier-than-air craft in the same period.

Throughout their development airships served as a laboratory for technological innovation. Propulsion systems and construction techniques were pioneered that were subsequently put to good use in other fields and other aircraft. The geodetic construction method developed by Barnes Wallis for the *R-100*, for example, was later successfully used in the Vickers Wellesley and Wellington bombers, Britain's most successful bombers in the early years of the Second World War. Late U.S. Navy non-rigids were used to develop ASW and AEW systems.

The existence of new technologies and materials make it possible for the full potential of the airship to be realized as well as to virtually rule out the kinds of disasters associated - often unfairly - with airships. These have brought about a renewed interest in lighter-than-air craft for use in a wide range of fields. The development of the airship has always taken place around a theme. Count Ferdinand von Zeppelin was determined, for example, to build Germany a fleet of warwinning machines. Eckner used the airship to restore Germany prestige after the First World War. The British sought to develop airships for purposes of keeping their empire intact. The U.S.used airships to protect its coasts and cities.

Today, there is no shortage of new themes to which the new technologies and materials can be applied. The search for fuel-efficient forms of transportation, the need to develop suitable craft for patrolling the exclusive economic zones afforded coastal states by the new Law of the Sea, and the need to find cost effective means of opening up the remote areas of many developing and some industrialized countries are all examples of such themes. These have given a new impluse to lighter-than-air developments in the past decade. It is to such developments that we will now turn.

Notes and References

(1) This chapter draws upon a number of published sources, notably Robert Jackson, *Airships*, doubleday, London/New York, 1973; Guy Hartcup, *The Achievement of the Airship*, David and Charles, London, 1974; David Morley (editor), *Aviation: The Complete Book of Aircraft and Flight*, Octopus Books, London, 1980, pp. 290-317; and appropriate sections of *Encyclopaedia Britanica*, 1967 edition.

(2) Sir Peter Masefield, *To Ride the Storm: The Story of the Airship R-101*, William Kimber and Co., London, 1982.

(3) The 'classic' evaluations of the performance of U.S. Navy airships in the Second World War are: U.S. Navy, *They were Dependable - Airship Operation in World War II* (Second Edition), Naval Air Station, Lakehurst, N.J., 1946; D.F. Smith, *World War II Operations of Fleet Air Wings, Fleet Airship Wings, Respective Headquarters Squadrons and Supporting Units*, U.S. Navy (office of CNO), May 1, 1951.

(4) See B.B. Levitt, *Summary of Airship Missions Since World War II*, Summit Research Corporation Technical Memorandum ONR4C-1 for Naval Air Development Center, March 13, 1978.

(5) The reasons why the U.S. Navy chose to decommission its non-rigid fleet are discussed at length in Levitt, op. cit.

4. CURRENT LTA DEVELOPMENTS

Recent, current and planned LTA developments are the subject of this chapter. While the review cannot hope to be complete, it should nevertheless serve to convey an idea of the 'state of the art'. We will first review LTA activity on a country-by-country basis, go on to discuss developments in technologies and materials with the aim of identifying the main areas in which additional R & D work appears to be required, and then draw conclusions with respect to the status of non-rigid, rigid and hybrid airships.

4.1 United States

LTA activity in the United States in the 1960s and early 70s was in a dormant state, generally limited to small-scale experimentation by private companies. In the mid 1970s, following the oil 'crisis', things changed when the U.S.government entered the picture. NASA, the U.S. Navy, and the U.S.Coast Guard all initiated LTA programmes which continue today in various forms. The second half of the 1970s also witnessed the growth and acceleration of private LTA activities. By the early '80s, 27 companies had expressed a strong interest in building airships and a few of them were actually flying prototypes and scale models.(1)

In 1975, NASA sponsored a major LTA investigation known as 'the feasibility study of the modern airship'. As part of this study, Goodyear Aerospace and Boeing Vertol were commissioned to make examinations of modern LTA vehicles and to identify the main areas for possible civilian applications. These investigations resulted in three parametric studies of civilian role LTA craft and the recommendation that possible military applications be studied. In 1976, NASA, together with the U.S.Navy, initiated the second phase of the feasibility study. Goodyear Aerospace was contracted to develop point designs for a heavy lift airship and an airport feedliner. The second phase resulted in conceptual designs for 2 civilian and 2 Navy airships, all prepared by Goodyear. The feasibility study of the modern airship resulted in 15 volumes of published material (6 under phase I, 9 under phase II), two of which are classified. (2)

The U.S.Navy committed $4 million to LTA investigations as part of its Advanced Navy Vehicle Concepts Evaluation (ANVCE) study initiated in 1976 and aimed at specifying advanced air and sea vehicles for the medium and long term. This ongoing programme has included technical studies in aerodynamics, materials, structures, survivability, vulnerability, as well as life-cycle cost studies, undertaken in cooperation with NASA. Parametric studies of rigid and non-rigid naval airships for use in the 1980s and 1990s were undertaken by Goodyear Aerospace and Martin Marietta (3) (see boxes for two of the concepts) and Turbomachines was contracted to make a hull study of the metal clad airship. By 1980, the U.S.Navy's LTA programme had also resulted in 15 volumes of research and design findings.(4).

The U.S.Navy has shown a special interest in the heavy lift hybrid which was seen as a possible solution to the military problem of off-loading cargo vessels in ports where facilities are virtually non-existent or have been destroyed. This interest focused around the concepts developed by Frank Piasecki, a pioneer of helicopter design, aimed at combining the properties of both the aerostat and the rotorcraft. The Piasecki Aircraft Corporation has participated in several NASA and Navy sponsored studies designed to evaluate the feasibility of the concept. A similar concept has been used by Goodyear Aerospace in the development of its heavy lift hybrid under NASA sponsorship and, more recently, for the Alberta Ministry of Transportation (see under Canada below).(5)

Although the Navy specified an 'operational requirement' for a heavy lift hybrid (6) no development programme was authorized and

The Goodyear ZPG-X

The U.S.Navy specified that the airship should be capable of a 90 kt top speed, a 5000 ft normal cruising altitude, and a 4000 n.mile ferry range. To meet these requirements Goodyear proposed the *ZPG-X*, a VTOL/hover derivative of the ZPG-3W it had built for the Navy in the late 1950s. The craft could, Goodyear concluded, be operational by 1985 given prevailing technology levels.

The *ZPG-X* is a 1,490,000 cu.ft non-rigid, with a length of 405 ft, and a diameter of 86 ft. It could accommodate an 18 man crew, would have a useful lift of 45,400 lbs and be capable of carrying a military payload of 20,300 lbs. The *ZPG-X* has two propulsion systems: two forward engines and a single unit mounted at the stern. The forward engines, each mounted on a tilting wing with a 90° rotation capacity, are 1500 shp Lycoming T53 turboprops, each driving a 3 bladed 15.5 ft diamater propeller. The wing is an aluminium alloy stressed skin structure with internal fuel tanks, which provides the structural support for the engine. The main engines and their cross shafting configuration are based on the Canadair CL-84 tilt-wing V/STOL, first flown in 1970. The stern propulsion unit, for low speed control, is a twin turbine installation incorporating 2 Allison 250-C20B 420 hp turboshaft engines mounted in a 'V' tail. Both engines drive a 20ft 3 blade constant speed propeller with a 90° rotation capability.

The *ZPG-X* is designed for naval task force and shipping convoy protection. Operating as a forward screening platform, it would have an on station capability of up to 2 days.

ZPG-X MAIN CHARACTERISTICS

Dimensions

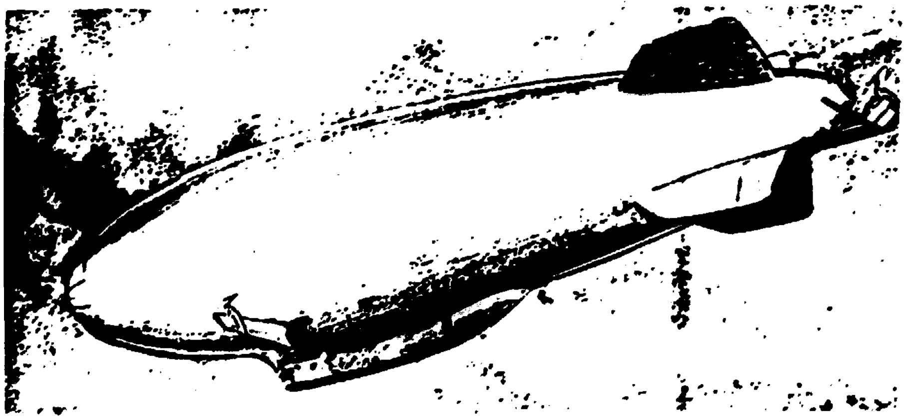
Length	405.0 ft
Width	85.7 ft
Height	104.5 ft
Surface area	9432 sq.ft.
Total air displacement	1,490,000 cu.ft
Max. lifting gas volume	1,490,000 cu.ft.
Fineness ratio	4.55
Buoyancy ratio	0.86
Lifting gas	Helium: 1,307,000 cu.ft, 83,000 lbs. static lift.

Weights

Gross lift	96,500 lbs
Deadweight empty vehicle	51,100 lbs
Useful lift	45,400 lbs
Payload	20,300 lbs

Power plant

Main	2 AVCO Lycoming T53 turboprops of 1500 shp
Auxiliary	Allison 250-C20B of 400 shp



ZPG-X General Configuration

Martin Marietta Model 836

The U.S.Navy specified that this airship for the 1990s should be capable of carrying some 50 tons of surveillance, attack and defence equipment to an area some 3000 km distant and patrolling the area for 8 days at an altitude of 3000 m. It was also required to be able to land, moor and launch without external aid.

The *Model 836*, designed to meet the Navy's specification, is of advanced rigid design. The structure is a conventional arrangement of wire-braced transverse frames, longitudinal girders, and diagonal sheer wires enclosed in a fabric hull. The lift system proposed by Martin Marietta is, however, unconventional, being based on a system of ballonets rather than separate gas cells. The system of 11 ballonets divides the airship into 14 compartments containing airship and payload equipment. The ballonet system expands to 28% of the lift volume, giving the *836* a theoretical pressure height of 3140m.

This semi-buoyant rigid airship is 239m long and has a maximum diameter of 50m. Displacing 263,900 cu.m, it weighs 188 metric tons, of which 106 tonnes would be useful load. It would carry a payload of 34 tons. Another special feature of the design is a large flat area along the lower surface of the hull aimed at improving operations on and near the ground. It is equipped with four-point landing gear to increase resistance to rolling and pitching movements when on the ground in gusty conditions.

Propulsion is provided by 4 rotatable gas turbine engines of 4280 mhp mounted fore and aft on horizontal pylons, driving large diameter reversible propellers, and a pivoted stern propeller driven by a 932 mhp diesel engine. The gas turbines are used for control and lift during take off and landing and the rotatable pylons function as thrust vector controls during hovering.

Three large tail fins and forward and aft horizontal stabilizers provide 3 independent pitch and 2 independent yaw controls, with a third yaw control provided by the stern propeller. This propulsion and control system would enable the *836* to take off and land without ground support.

Conceived as an ocean surveillance and patrol vehicle, the *836* would be able to remain on station for 12 days. It would have fully automated fly-by-wire controls and provide for remote monitoring of most subsystems. According to the ship's designers, a low altitude cargo carrying *836* would be able to carry a payload of 44 tonnes around the world in 45 days.

MODEL 836 MAIN CHARACTERISTICS

Length	239 m
Diameter	50 m
Total air displacement	263,900 cu m
Operating weight empty	106 metric tons
Gross operating weight	188 metric tons
Military payload	34 metric tons
Power plant: main	4 gas turbines of 4280 mhp
auxiliary	1 diesel of 932 mhp

?

the requirement has since been cancelled. NASA has continued to explore the dynamics and control characteristics of the hybrid concept, however, and a study was commissioned to explore the potential market for heavy lift hybrids of different types and sizes.(7) This study indicated that the market is considerable, with aerial logging as the main area of application.

The U.S.Coast Guard entered the LTA picture in 1975 when it initiated a programme aimed at identifying fuel efficient platforms for its many maritime patrol and surveillance duties, enlarged by the provisions of the new Law of the Sea and the creation of 200 nautical mile exclusive economic zones. Between 1975 and 1978, the Center for Naval Analyses examined on the Coast Guard's behalf, the feasibility of using LTA craft for maritime patrol and surveillance missions. A number of potential LTA vehicles were conceptualized and their operational costs compared with those of current and projected Coast Guard platforms. These analyses were continued in a study made by the Summit Research Corporation for the Naval Air Development Center (NADC).(8) This study, known as the Maritime Patrol Airship Study (MPAS), included a detailed analysis of Coast Guard missions and resulted in point designs for 3 non-rigid patrol vehicles, prepared by Summit/NADC (the *ZP-X)*, Goodyear Aerospace *(*the *ZP3 G)*, and Bell Aerospace (the *MPA*), all with a large mission capability. The study and the 3 patrol craft are described in Chapter 6.

The studies conducted for the Coast Guard show that airships could be compatible with Coast Guard operations and that the modern conventional airship would be a more effective performer for many missions than fixed wing aircraft and surface vessels. The MPAS shows that airships could undertake from 80-100% of the Coast Guard's missions at costs comparable to those of the HC-130 and at 50-60% of the costs of cutters.

The studies convinced the Coast Guard that it should go ahead with a LTA R & D programme and in 1980 it entered into a joint agreement with NASA aimed at developing the required technology. The Coast Guard's plans envisaged the building of a sub-scale demonstration maritime partol vehicle for testing in the period 1983-84. The trial programme would include both operations with and independent of surface craft to demonstrate hovering, detection and surveillance, air-sea rescue and other capabilities. Sucessful trials were to result in a full-scale prototype being flown in 1987-88(9). Recent budget cut-backs enacted by the U.S.government have, however, compelled the Coast Guard to shelve its plans.

Official support for LTA development has also come from the U.S. Forest Service. In 1980 it awarded a contract, to be administered by the Navy, to the Piasecki Aircraft Corporation for the development and operation of the Piasecki heavy-lift hybrid, called the *Heli-Stat*, for a demonstration of aerial logging of Federal forests in the U.S. Northwest. The demonstration is very much a 'cut-price' one, the *Heli-Stat* to make use of Navy surplus equipment. The major components are four H-34 helicopters and a 27,613 cu.m. ZPG-2 Navy airship envelope. The helicopters are modified to accommodate forward and reverse thrust propellers. The hybrid is designed to lift a nominal 25 ton payload at a forward speed of 60 knots. The *Heli-Stat* has made its first flight and is due for delivery in 1982.

A large number of private companies in the U.S. have airship designs on their drawing boards. Many of these are for experimental craft conceived to overcome some of the traditional limitations of conventional airships, such as poor maneuverability at low speeds and slowness. The California company Airships International, for example, has designed a vehicle equipped with rotating thrusters on its bow, stern and underside which should be capable of speeds of up to 300 kph. The streamlined hull of the ship would be made of aluminium alloy.

Some airships have, however, left the drawing boards. John Fitzpatrick, an ex-U.S.Navy airship officer, designed and built a buoyant wing comprising a catamaran structure with 3 hulls. With a volume of 10,000 cu.m. and a length of 25m, the airship, known as *Aereon III*, was propelled by a two-bladed helicopter type rotor. The craft had an ingenious controlled lift system and carried its own mooring mast in the form of a 6m retractable strut which carried the front landing wheel. Developed at the request of religious authorities to help bring assistance to the poor in developing countries, the *Aereon III* was destroyed by wind while being handled outside its shed.

Other privately sponsored airships which have flown in the U.S. include the Tucker Airship Company's *TX-1*, a 28m semi-rigid, Development Sciences' remotely piloted mini-blimp, a 12.5m, 3947 cu.ft. craft, capable of carrying a 25 kg. payload of TV and video cameras for use in surveillance and law enforcement,(10) and the hot air airships built and sold by Raven Industries. Reference should also be made to Goodyear Aerospace which launched its 303rd airship, the non-rigid *Mayflower*, in 1978 for advertising and television work.

A potentially important development in the U.S. is the ambitious plans recently announced by American Skyship Industries Inc., to build metal clad rigid airships at a special facility at Landsdowne Airport, Youngstown, Ohio.(11) American Skyship Industries is the U.S.subsidiary of Wren Skyships Ltd., a British company, founded in 1982 by Malcolm Wren. Prior to founding the company, Wren was a Director of Airship Industries (see under United Kingdom) mainly responsible for the development of a metal clad rigid airship, known as the *RS 150*. Disagreements within Airship Industries about the feasibility of the large rigid airship and, more especially, the possibility of the company being able to secure the funds to finance its very high R & D costs, led Malcolm Wren to leave Airship Industries and to set up his own company. Wren has no doubts about the feasibility of the large rigid airship and is convinced that a market exists for it as a maritime patrol, passenger carrying, and long haul cargo vehicle.

Youngstown was selected by virtue of the inducements it offered American Skyship Industries and its location close to Akron, the 'home' of U.S. airships. The company is now seeking the $22 million it considers necessary to launch the *R 30*, and to construct a factory which will eventually be capable of producing one airship every nine weeks. The company has begun selling stock and believes it can secure come $3.5 million from the sale of shares by the end of 1983. It hopes to obtain $4 million in loans from the U.S.Department of Housing and Urban Development, with most of the remaining capital required coming from loans from European banks.

The *R 30* (see box) is derived from the *RS 150* developed at the rigid division of Airship Industries. Its targetted sales price is $8 million - $12.5 million depending upon type. It is currently being marketed and several expressions of interest have reportedly come from South America.

4.2 Canada

A great deal of private and public interest in LTA development has been shown in Canada in recent years. Most of this attention has focused on the development of heavy lift vehicles for exploiting the natural resources of the country's western region where existing transport infrastructure is as yet poorly developed. A study conducted by Goodyear Aerospace for the Alberta Ministry of Transportation identified several types of modern airships for different heavy lift missions.(12) It was conservatively estimated that the western region could support 8 modern conventional non-rigids, 2 modern conventional rigids, and 6 heavy lift hybrids.(13) The use of this fleet could, the study argued, result in enormous savings from the elimination of the need to construct and maintain roads, the elimination of various time delays, the direct delivery of men and equipment to development projects, and the extension of the

The Wren Skyships R 30

The *R 30* is a scaled down version of the *RS 150* developed by Wren and the design staff at Airship Industries. Wren Skyships has specified two versions of the *R 30* for cargo/utility and passenger carrying rôles. The hull is common to both. It is aluminium clad with a length of 100m, a diameter of 23m, and a height of 25m. The ship's empennage has 4 fins set in a cruciform.

The cargo/utility airship is to be powered by 2 Garret Airesearch TPE 331-15s each driving 5m three-bladed feathering and reversing propellers. Maximum speed would be 195 kph, maximum cruising speed 185 kph. It would have a disposal load of some 16 tons and be equipped for low density cargos. The passenger carrying *R 30* is powered by 4 TPE 331-15s, giving it a cruising speed of 240 kph. Its disposal load would be 14 tons, giving it a passenger capacity of 100-120, depending upon seating arrangements. The company believes that the *R 30* will be competitive with most types of commuter travel over distances of up to 400 km.

With 10,000 lbs of fuel, no reserves, and still air conditions, the *R 30* will have a range of 800 nautical miles and an endurance of 7-8 hours. With special fuel tanks and ballast arrangements, the airship's still air range could be increased to up to 3,500 nautical miles.

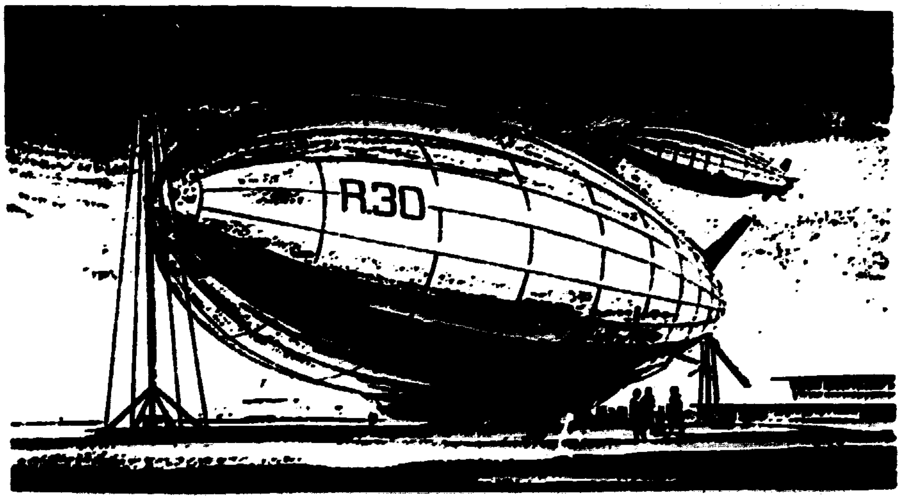
R 30 MAIN CHARACTERISTICS

Hull

Overall Length	102 m
Max. Diameter	23 m
Max. Width	33 m
Max. Weight	

Power Plant	**Cargo/Utility**		**Passenger**
Type	Garrett Airesearch		TPE 331-15
Number	2		4
Propeller RPM		900	
Propeller Diameter		5	
No. of Blades		5	

Performance			
Max. Speed	197 kph		248 kph
Max. Cruising Speed	187 kph		240 kph
Disposable Load	16 tons		14 tons
Range		770 n.miles	
Endurance		7.7 hours	



R 30 General Configuration

working season. The study resulted in the design by Goodyear of a hybrid vehicle with a 75 ton payload capacity. It is described in Chapter 7.

Several hybrid airships are under development for use in logging operations. One particularly interesting type is the *Cyclocrane* being developed by Aerolift, Inc. after a concept patented by the Delaware based D.C.Associates. It is an unusual combination of aerostat and rotorcraft. It consists of an ellipsoidal non-rigid aerostat hull supporting 4 rotor wings radially from points along its maximum diameter. The entire wing system and hull rotate, driven by the propellers, such that control and propulsion forces are developed by the wing system regardless of forward speed. A 1.8 tonne 9487 cu.m. demonstration model is being purchased by a consortium of four logging companies. It will be tested in Oregon and later operated in British Colombia. Flight tests were due to begin in 1982. The *Cyclocrane* is described more fully in Chapter 7.

The Aerostat Corporation, based in Montreal, also has a number of airships on the drawing board. These include the *A-7*, a 83m airship capable of transporting a 7 ton load over 3,800 km at speeds of up to 135 kph, and the larger *A-25*, a 135m craft able to carry 25 tons over 8,700 km at up to 145 kph. The company has also expressed an interest in developing long range passenger derivatives of the ships under development.

More recently, the Van Dusen Commercial Development Corporation, an Ottawa based high technology development firm, proposed a very unconventional airship design: a revolving sphere. Based upon the aerodynamic principle known as the 'Magnus effect', the large sphere would rotate on a horizontal axis, the differences in pressure at the top and bottom of the sphere providing lift, the same principle that causes a spinning golf or tennis ball to rise. The vehicle, which would be powered by twin turboprop engines located at the ends of the horizontal axis, is conceived as a heavy lifter. Various sizes are being investigated. A 48m revolving sphere is expected to be able to lift 45 tons and travel at more than 50 knots. A 27m diameter model has been proposed as a surveillance platform. Van Dusen has reportedly spent 3½ years and $1.5 million in developing the design and has successfully tested a 6m diameter model. A full size prototype is reportedly under construction and is expected to fly in 1983. The company has begun marketing its 27m diameter model and commercial interest is believed to be encouraging.

Canada is becoming an 'airship minded' country. A number of airship companies have established Canadian subsidiaries to market their designs. The Piasecki Aircraft Corporation, which is developing the *Heli-Stat*, is an example; a number of Canadian oil and pipeline construction companies have reportedly expressed an interest in the heavy lift hybrid. There are plans to invite Goodyear Aerospace to cooperate in the setting up of an airship manufacturing plant in Alberta.(14) The British Airship Industries has also recently set up a Canadian subsidiary to market its Skyship range of airships, the Royal Bank of Canada having recently purchased an equity in the company.

4.3 United Kingdom(15)

Interest in LTA in Great Britain has never ceased, although government sponsorship of any R & D work very largely has. The LTA tradition was until the middle 1970s kept alive by a small group of enthusiasts who worked on projects in their free time with very little in the way of government recognition or financial support. A.W.L.Nayler of the Royal Aeronautical Society has suggested that it was probably L.P. Richards, now a Director of Airfloat Transport, one of Britain's several airship companies, who was the first to draw serious attention to the potential of large airships in a paper published in 1967.(16) Interest in LTA certainly grew and in 1970 some 150 persons founded the Airship Association, an organization dedicated to promoting LTA activities. It has since held regular meetings on LTA developments.

The first serious studies began to be undertaken in the early 1970s. In 1971 Airfloat Transport developed proposals for a rigid airship designed to carry a payload of 400 tons in different weather conditions. The airship was to have a length of 390m - 100m longer than the QEII - and a volume of over 1.1 million cu.m., nearly 6 times that of the *Hinderberg*. Power was to be provided by 6 Proteus gas turbines driving 7m propellers . All the engines were to be self-reversing and 4 were designed to provide thrust in any direction. All operations were to be automatic, with sensors supplying information to a computer which would control, among other things, lift-and-trim operations and gust evasion.

At about the same time, Aerospace Developments Ltd. began investigating, at the request of Shell International Gas Ltd., the feasibility of using airships for transporting natural gas. Aerospace Developments proposed huge vehicles more than half a kilometer long and 91 m in diameter, with a volume of 2.75 cu.m, 13 times that of the *Hindenberg*. The hull was to be of a semi-monocoque construction of stressed metal/skin honeycomb sandwich materials. This aerial tanker was to be powered by 6 or 8 fanjet gas turbines, each developing 4000 hp, driving 9m reversible propellers hung in pods from the horizontal tail fins mounted on either side of the hull, giving it a top speed of up to 190 kph. After research expenditures of some £250,000 the design was shelved.

Universities and technical colleges began taking an interest in LTA, this interest, like that of the designers, focusing upon the freight carrying potential of large rigid airships.(17) By the mid 1970s, various ambitious proposals for vehicles of this type had been drawn up, although none were specified in any detail.

The first airships to fly in Britain in the post war period were inevitably very modest ones. In 1974, Anthony Smith flew a hydrogen inflated 935 cu.m. non-rigid airship, the *Santos Dumas*. This simple design, powered by two 20 hp Wankel engines, had an open car capable of carrying 3 people. It flew for the second time, inflated with helium, in 1975 and received its Certificate of Airworthiness in the same year.

In mid 1976 air inflation tests were made of *Skyship I*, a 27m 708 cu.m. airship powered by 4 small Wolf-Hirth engines designed for use as an archeological research platform.(18) Work on this ship ceased before it flew due to a lack of funds. The company created to build and fly the craft has not, however, officially wound up and parts of *Skyship I* - engines, mast and car - are still in storage.

From 1977 Aerospace Developments worked on a 'new generation' non-rigid airship, the *AD 500*, made possible by a Venezuelan company, Aerovision, that wished to use the vehicle for aerial advertising. The *AD 500*, with a volume of 5131 cu.m. made use of various advanced materials and incorporated vectored thrust propulsors. It made its maiden flight in February 1979.(19) One month later, while moored at its mast in a force 9 gale, the ship's nose cone failed. The decision was taken to deflate the envelope and, in the course of deflation, it suffered considerable damage. Following the accident, Aerovision withdrew its support and Aerospace Developments went into voluntary liquidation. At the time of the accident both the Royal Navy and the Ministry of Agriculture, Fisheries and Food had announced plans to test the ship, after which it was to be shipped to the U.S. for trials by the U.S.Navy. The *AD 500* was not, however, scrapped. It was, as we shall see later, subsequently rebuilt and improved by Airship Industries.

By the late 1970s attention in Britain had shifted away from large heavy lift rigids. Designers turned their attention to small non-rigids able to lift up to 10 tons and to the big problem of finding the money required to build and test prototypes.

Airship activity in the United Kingdom is today spearheaded by two companies, Airfloat Transport and Airship industries, and it is to their work that we shall now turn. Whereas Airfloat Transport has probably conducted the largest number of LTA studies, Airship Industries was the first to fly a prototype craft and is now in the business of building and selling airships.

Since its formation in 1970, Airfloat Transport has examined, at the request of potential users or operators, 7 types of airship:

- A Heavy Lift (HL) airloading airship capable of carrying loads of up to 50 tonnes over distances of up to 2000 km.
- The Gas Ferry (GF) system, using small 'tug boat' airships to tow non-rigid vessels, each holding up to 55,000 cu.m. of natural gas, for transport in areas where a gas pipeline is not feasible.
- The Continuous Link (CL) system, for the transport of up to 100 tonnes of loaded containers over medium distances, the system envisaged particularly for the clearance of harbour bottlenecks.
- The Base Loading Module (BLM) system for the transport of general freight cargos of up to 100 tons in modular form, the study initiated by a South American agency.
- The Air Loading Module (ALM) system, similar to the BLM system but making use of an air loading airship to reduce the need for ground installations.
- A General Purpose (GP) base loading airship to carry a gross payload of 40 tonnes, or 30 tonnes with 10 tonne modules. A ferry version of the GP was also designed to carry 250 passengers, or 20 cars and 80 passengers.
- The Minimum Freight (MF) airship, a non-rigid craft capable of transporting 10 ton payloads, or 7 ton loads in modular form.

The 7 airship systems are compared in Table 4.1 and Figure 4.1.

All Airfloat Transport's designs have sought to make use of current technology and conventional airship configurations and all include variants running on natural gas or dual fuel as alternatives to oil.

		HL	CL	MTB	MTA	GP	MF
STRUCTURAL CATEGORY		RIGID	RIGID	RIGID	RIGID	RIGID	NON-RIGID
LENGTH	M	400	200	270	285	140	80
MAX. DIAMETER	M	85	50	60	65	38	23
VOLUME	000 CU.M	1,342	250	520	600	89	22
PAYLOAD: GROSS	TONNES	500	100	125	125	40	10
NET (in module)	TONNES	400	-	100	100	30	7
CRUISING SPEED	KPH	145	140	145	145	145	140
CRUISING RANGE	KM	2,000	1,000	1,000	1,000	600	400
MIN. SYSTEM COST	$ MILLIONS	50	20	18	18	4	15
OVERALL OPERATING COST	$ CENTS TONNE/KM	4	8	7	8	13	25

TABLE 4.1 : MAIN CHARACTERISTICS OF AIRFLOAT TRANSPORT STUDIES

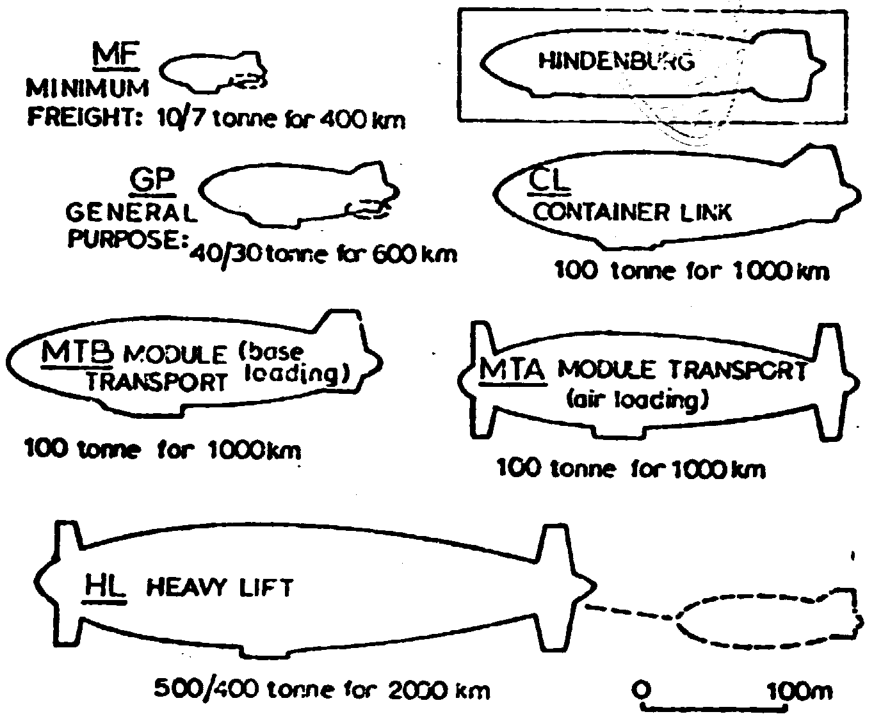


Figure 4.1: Airfloat Transport LTA Systems

Source: A.W.L. Nayler, 'British Lighter-than-Air Activity: A Review', AIAA Paper 79-1583

In some designs, the gas was to be carried in detachable pods or towed blimps, as indicated by the broken lines in Figure 4.1

The company has devoted most of its attention in recent years to the development of the MF airship (see box).(20) This has followed commercial interest in a 70 passenger airship with a STOL and loiter capability, low noise levels, and a cruising speed of 140 kph. The airship would operate from a disused area of London Docks for sight seeing flights over London and South East England. Both the CAA and London Air Traffic Control have cleared potential operations and the Greater London Council, recognizing the airship's tourist potential, has decided to draw up guidelines for its operation.(21)

The total cost of the MF in 1980 was in the order of £1.5 million. Operating costs were estimated at £206 per flight hour. Revenue calculations indicated that the MF would be a profit making proposition. The possibility of using the airship on flights from its east London terminal to cities in N.W.Europe was being investigated in 1981.

Airship Industries was formed in June 1980 with the merger of Airship Developments Ltd., and Thermo-Skyships Ltd. Airship Developments was built around the experience and design team of Aerospace Developments that built and flew the *AD 500* before going into receivership in 1979. Following the merger, Airship Developments, London based, operated as the company's non-rigid division, and Thermo-Skyships, based in the Isle of Man, as the company's rigid division. This arrangement lasted until 1982 when work on rigid airships stopped. Following differences of opinion in the company, some of those responsible for the design of rigid airships, led by Malcolm Wren, left Airship Industries and set up a new company, Wren Skyships Ltd., which is now attempting to raise the money required to build rigid airships on a large scale in the U.S. (See section on the U.S.).

Airfloat Transport's MF Airship

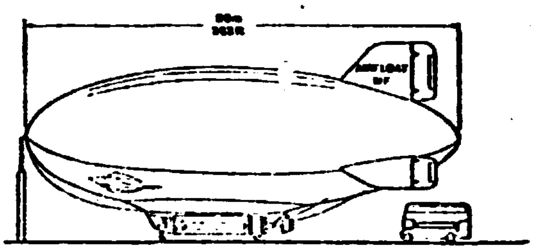
The *MF* is a non-rigid airship 80m long with a hull diameter of 23m. It has a volume of 22,000 cu.m, with two ballonets, each of 2500 cu.m. Main power comes from two 840 shp gas turbines each of which drives a 2.15m constant speed reversible pitch ducted propeller at 1590 rpm. A third engine, a 200 bhp piston engine driving a 1.5m fixed pitch propeller, is used for low speed loitering. Take off and landing are effectuated with the assistance of deflected thrust.

MF AIRSHIP MAIN CHARACTERISTICS

Dimensions	
Length	80.0m
Hull diameter	23.0m
Overall height	32.0m
Volume	22,000 cu.m.
Air ballonet volume	5,000 cu.m.each
Power Plant	
Main engines	2 Garrett TPE 331-3 gas turbines of 840 shp
Auxiliary engines	1 Lycoming piston engine of 200 bhp
Performance	
Max. cruising speed	136 kph
Economy cruise	108 kph
Loiter	65 kph
Max. cruise range	370 km
Economy cruise range	590 km
Loiter range	220 km

Weights

Empty weight	8,850 kg
Disposable load	13,150 kg
Loaded weight	22,000 kg



General Configuration MF Airship

Airship Industries today devotes most of its attention to further developing the original *AD 500*. Rather than simply rebuilding the damaged ship, the company chose to introduce a number of major improvements, notably with respect to bow stiffening, gas valves, envelope design, and flight controls. Support for some of the work undertaken has come from the U.K.Department of Industry.

The improved vehicle, called the *Skyship 500* (see Figure 4.2) made its maiden flight in September 1981. It has now accumulated several hundred hours of flying time and in September 1982 was awarded Special Category of Airworthiness certification from the U.K.Civil Aviation Authority, which allows military evaluations to be made. Once it receives Aerial Work Category status, which requires several months of additional flights, it can be hired out to operators.

The *Skyship 500* is a 5131 cu.m. non-rigid airship with a length of 50m, about the size of a 737. It is not an improved U.S.Navy airship, like the other 6 non-rigids currently flying, but a new design and, as such, incorporates a number of technological advances. Honeycomb sandwich materials, for example, are used for the tail fin structure, gondola bulkheads and flooring. The gondola is produced from Kevlar 49, a plastic developed by Du Pont which offers a 2:1 improvement in strength over traditional materials. The envelope is also of unusual construction, making use of gores (the panels of fabrics) which run longitudinally rather than transversely, thereby reducing the number of panels required to one-fortieth of conventional designs. This reduces both seam weight and costs. The envelope material, produced in France, is of advanced design and is of very high impermeability.

The *Skyship 500* has a maximum speed of 64 knots, a pressure altitude of 8000 ft and can carry up to 12 passengers or a 2 ton payload, the biggest payload carried by any non-rigid presently flying. A 'stretched' and uprated version of the 500 is under development. Called the *Skyship 600* it contains a 6m parallel middle body

Skyship 500

The *Skyship 500* is a non-rigid airship with a displacement of 5131 cu.m. (181,200 cu.ft). With a length of 50m, a diameter of 14m and a height of 19m, it is approximately the size of a Boeing 737.

The envelope material has a polyester load carrier spray coated externally with titanium oxide impregnated polyurethene and is sealed internally with a polyurethene bonded gas retention film. This provides a double barrier to helium leakage and a high level of impermeability - one litre per sq.m. per 24 hours - is achieved. The 500 has 2 ballonets which occupy 26% of the hull volume when filled. Considerable attention has been devoted to gas valve design. These can vent air up to the maximum required without a significant increase of differential pressure, and use only one third of the components of the valves used by the other non-rigids now flying.

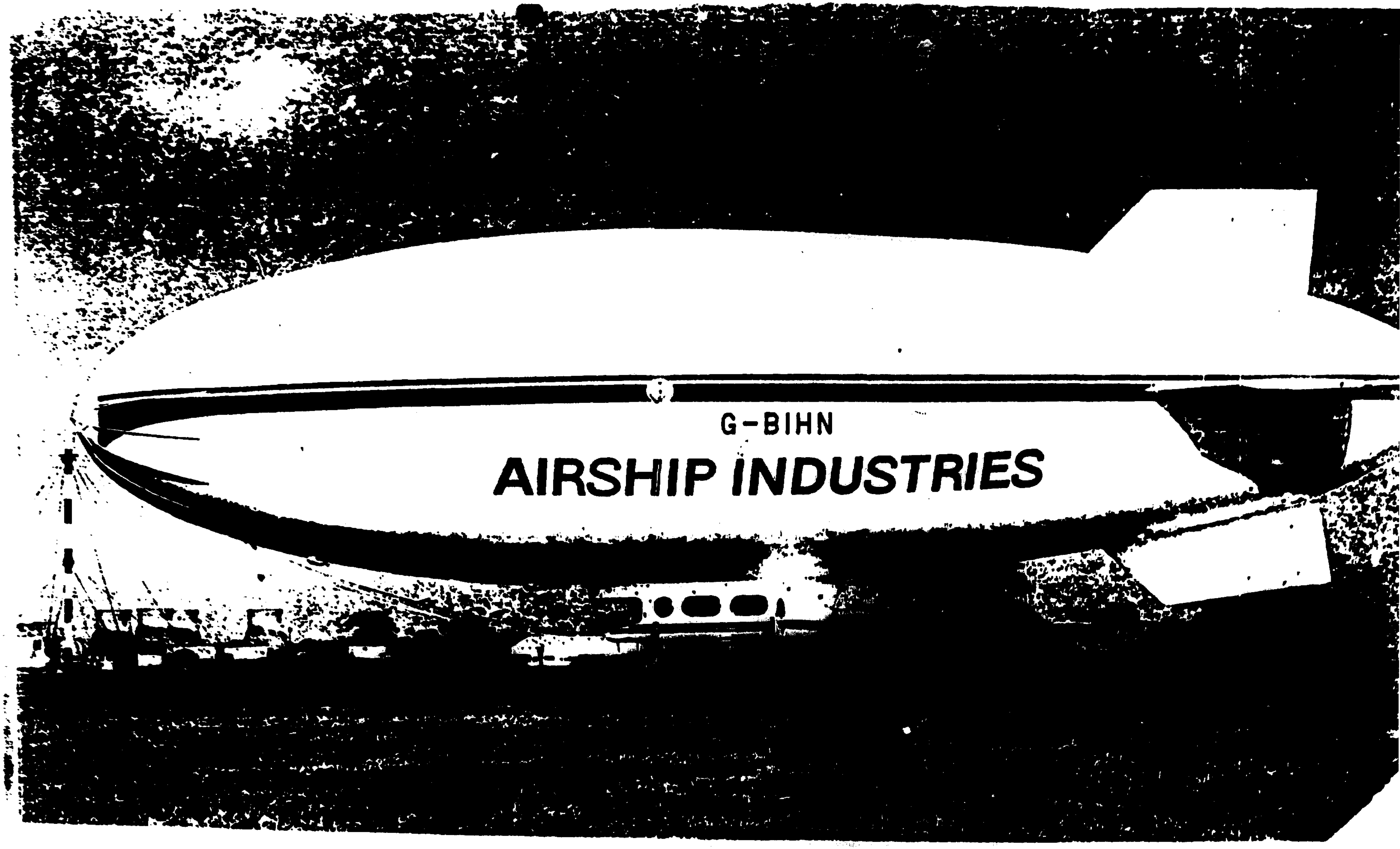
The four tail fins are made from honeycomb cored materials and are mechanically interlocked with the aid of high performance expoxy adhesive. Leading edges are Kevlar mouldings. The fins are therefore both light and strong and are designed to be virtually maintenance free.

The gondola is suspended against the hull by a system of 12 Kevlar cables. Nine metres long, it is manufactured as a two-piece Kevlar epoxy moulding, which makes it the largest Kevlar aircraft structure. The floor, ceiling and bulkheads are made from Fibrelam panels bonded to the Kevlar structure. The only metal used in the gondola is in the titanium-faced fire-proof bulkhead which separates the rear engine compartment from the cabin and the welded steel propulsor outriggers. The only metal used in the airship above the gondola are the pulleys that secure the cabin's suspension cables. All this reduces weight and gives the *Skyship 500* a very low radar profile.

Power is provided by two 6 cylinder air cooled Porsche piston engines, each of 204 bhp. Each drives a five bladed variable pitch ducted propulsor via modified Westland helicopter transmission shafts and tail rotor gearbox. Thrust vectoring is achieved by rotating the propulsors, 90° up and 120° down, using a ¼ hp motor. The propulsors have four pitch conditions (for course pitch, flight fine, zero pitch and reverse pitch). Whereas VTOL can be achieved, the favoured procedure for taking-off heavy using the vectoral thrust is ZTOL - a zero ground roll with a steep angle (45°) of climb out. This allows a quick build up of forward speed, and thus rudder control, and permits dynamic lift to be used by trimming the craft bow up in the event of a single engine failure. Fly-by-wire control systems are under consideration.

The *Skyship 500* has a maximum speed of 64 kts, a pressure altitude of of 8000 ft. and a normal range of 300 n.miles. It can carry up to 12 passengers or a 2 ton payload.

Skyship 500 General Configuration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AIRSHIP INDUSTRIES

providing an additional 0.9 tons of lift. The gondola is stretched by 2.5m enabling the 600 to carry up to 20 passengers. It has uprated engines and a larger envelope. With four times the fuel capacity of the 500, the 600 has considerably extended range, a requirement for patrol and surveillance missions.

The roles envisaged for the 500 and 600 are civilian and military. At the end of 1981 the company was negotiating eleven 'credible inquiries', all for marine patrol applications, ranging from fisheries protection in the North Sea to the detection of illegal immigrants in Australia. Orders for three airships (one 500 and two 600s) were placed in 1982 by Interport Marine, a shipping and charter company, for delivery in 1983 subject to full U.K.airworthiness certification. Other orders were expected to be announced in 1982, one of the deals involving the U.S.Navy.

The sales price of the craft are £1.2 million for the 500 and £1.45 million for the 600, exclusive of special role equipment. The figures are based on very low production levels and could be reduced substantially with increased production. Non-recurring tooling and R & D costs are put at £1 million, with the breakeven point at ships 3-4. In principle both the 500 and 600 are tooled up for large scale production.

Airship Industries has prepared concept designs for two much larger non-rigids, the *Skyship 2000* and the *Skyship 5000*, of 20,000 and 50,000 cu.m. Both are conceived for long endurance maritime patrol and advanced early warning. The *Skyship 5000* will be 108m long and 30m in diameter and able to lift a disposable load of 28 tons. It would be capable of carrying a three shift crew of 19 on week long missions. The *Skyship 2000*, designated Coastguarder, is a vessel 80m long with a 10 ton lift capability. Although conceived for maritime patrol and AEW, both the 2000 and 5000 could be configured for the transport of passengers. The 2000 could carry up to 80 passengers while the 5000 could accommodate up to 200.

Airship Industries has also announced plans for a small non-rigid of 1000 cu.m. and a length of 30m capable of carrying a 320 kg. payload, and a remotely piloted vehicle, the *RPV-15*, a 145 cu.m. craft capable of carrying a 22 kg payload for up to 10 hours at 40 knots. Neither the *Skyship 100* nor the *RPV-15* are at present being actively pursued. The company's current product range - the 500, 600, 2000, 5000 - are compared in Table 4.2.

Before work came to a halt in 1982, the rigid division of Airship Industries was involved in studies of advanced passenger and freight airships. Most advanced wer the designs for the *Thermo-Skyship* and the metal clad *RS 150*.

The *Thermo-Skyship* was conceived as a new concept for LTA. It was elaborated over a five-year period by Mercantile Airship Transportation Ltd., which was acquired by Thermo-Skyships prior to its merger with Airship Developments. The *Thermo-Skyship* is a rigid of lenticular shape which makes use of aerostatic, aerodynamic and powered lift. The circular plan form presents the same cross section to the wind in any direction and also permits the craft to be tethered by mooring cables rather than mooring mast. It would not require hangars at its operating base. The *Thermo-Skyship* has passive control surfaces to assist in cruise but makes use of thrust and control jet nozzles to give it a real VTOL capability.

The *Thermo-Skyship* is designed for all weather operations from small city centre sites of less than one hectare. The concept was seen to possess both passenger and freight carrying potentials. Work on the passenger version was, however, much more advanced due largely to the interest of European Ferries. This company, that operates services across the English Channel, made a 15% equity purchase in Airship Industries and made loans for the vehicle's further development. European Ferries had expressed an interest in operating 6 *Thermo-Skyships* for a passenger service between city centre sites in London and Amsterdam at speeds of up to 170 kph and at fares similar to those paid on hovercraft services across the English

			500	600	2000	5000
DIMENSIONS	VOLUME	CU.M	5,131	6,572	20,000	50,000
	LENGTH	M	50	59	81	108
	DIAMETER	M	14	15	-	30
	HEIGHT	M	18.7	19.5	-	41
	BALLONET VOL.	%	26	26	-	32
POWER PLANT	ENGINES	HP	2 x 200	2 x 270	2 x 1200	2 x 1600
WEIGHTS	GROSS(pass version)	KG	3,185	6,020	-	-
	GROSS(patrol ")	KG	-	5,924	-	20,172
[illegible]RFORMANCE	MAX SPEED	KTS.	60	62	90	100
	CRUISE SPEED		50	52	-	65
	NORMAL RANGE	NM	300	2,124	-	2,000
	FERRY RANGE	NM	1,400	-	-	10,000
	PATROL RANGE	NM	600	2,700	-	4,000
	ENDURANCE a 40 KTS		-	52 hrs.	-	4 DAYS
	OPERATING CEILING	FT	8,000	8,000	8,000	8,000
	DISPOSABLE LOAD	TONS	2	3	10	28
	PASSENGER SEATS		12	20	80	196
SALES PRICE		£ M	1.25	1.5	4	6
PROJECT STATUS			In flight trials	Maiden flight Spring '83	Design definition	Design definition

TABLE 4.2: MAIN CHARACTERISTICS SKYSHIP PRODUCT RANGE

Channel. The *Thermo-Skyship* was progressively scaled up during the course of its development. Originally conceived to carry 60 passengers and a 6 ton payload, it was sized to carry 200 passengers and a 20 ton payload when design work was stopped.

The decision to drop the *Thermo-Skyship* was motivated by its very high R & D costs, estimated by Airship Industries to be in the order of £100 million, and by its relatively poor performance in wind tunnel tests. European Ferries retains its requirement for passenger carrying airships but believes that it can be met at much less cost through the progressive development of the non-rigid Skyship.

The second advanced design, the *RS 150*, was a large rigid developed for both civilian and military applications. Work on this design was initiated by Red Coat Airlines, a small cargo carrier, which believes that its operations with fixed wing aircraft are becoming untenable in the face of ever rising fuel costs. Redcoat's requirement specified that the airship should be able to carry a payload of up to 75 tons over 1000 nautical miles or 46 tons over 4000 nautical miles for services to West Africa, the Middle East and Central America. The cruising speed should be variable between 63-85 knots - twice as fast as the fastest ocean freighters - depending on range and application. The cargo to be carried was to range from machine parts to day-old chicks and low density cargos. The requirement also specified that the airship should be able to operate from relatively simple landing sites.

The *RS 150* was conceived to meet these requirements. It is a ellipsoidal helium filled airship of conventional shape with a displacement of 5.4 million cu.ft. (see box). With a length of 570 ft, it would still be 70m shorter than the largest rigids built 50 years ago. After reviewing different alternatives, the design team selected a metal clad construction. The cargo area was to be 200 ft long and 18 ft wide, giving the *RS 150* 56% more cargo space than a 747.

The Skyship RS 150

The *RS 150* is a metalclad rigid of conventional ellipsoidal shape with a length of 570 ft, a diameter of 134 ft and a hull volume of 5.4 million cu.ft. The sheet metal skin of the envelope is the main load bearing member which, with the assistance of internal gas pressure, carries the bending and sheer loads. Frames retain the circular shape and diffuse concentrated loads, namely cargo and the ship's engines. Small longerons retain structural integrity at zero internal pressure and local secondary structures support the cargo hold, nose mooring and landing loads. The empannage has 6 fins, each 1.1 times the diameter of the hull.

The propulsion system is provided by 4 gas turbine engines of 1645 shp mounted on stub wings driving 18 ft diameter feathering and reversing propellers that can be vectored. A 500 hp turboshaft engine serves as the power source for bow and stern thrusters for positive control at air speeds from 20 knots down to hover. This engine is coupled to a ducting system with 5 outlets, providing for thrust up, down, port, starboard, and along the ship's longitudinal axis. The outlets supplement the control provided by the elevators and rudders at low speed.

RS 150 MAIN CHARACTERISTICS

Dimensions	
Length	570.35 ft
Diameter	134.20 ft
Surface area	188,437 sq.ft
Hull volume	5,397,215 cu.ft
Gas volume	5,316,526 cu.ft
Ballonet volume	750,000 cu.ft

Power Plant

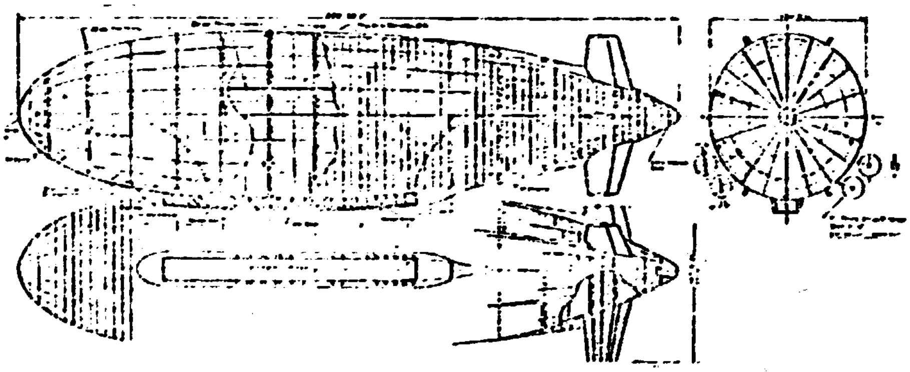
Main Engines	4 Garrett TPE 331-5 gas turbines of 1645 shp
Auxiliary	Allison 250-B28 of 500 hp

Weights

Empty	124,136 lbs
Disposable load	188,000 lbs
Max. take-off	312,736 lbs

Performance

Max. speed	92.3 kts.
Cruise speed	88.5 kts
Max. range	13,529 miles
Payload	98,000 lbs.



RS 150 General Configuration

A natural gas option has also been considered, the gas carried in 2 cells within the hull envelope. While fuel costs fall, extra weight reduces the *RS 150s* payload with maximum fuel from 75 to 63 tons.

Very provisional calculations suggested that the direct operating costs of the *RS 150* would be in the region of $1100 per hour, the yearly total fixed costs about $2 million. Redcoat Airlines' estimates suggested that the ship could cut its fuel costs by about one third. Several other airlines, including the freight carrier Federal Express, reportedly expressed an interest in the design.

While conceptualized for civilian applications, the *RS 150* was seen to possess a potential for military uses, such as ASW, surveillance and patrol, and strategic air lift. At 48 knots the ship would have a range of 11,740 nautical miles and be able to stay on mission for 245 hours. Airship Industries was examining the feasibility of a rigid with a payload capability of 150 tons when the rigid division was disbanded and several the company's directors and design staff left to form Wren Skyships Ltd. As noted in the description of LTA activities in the U.S., Wren Skyships has plans to build the *R 30* metal clad rigid, a smaller version of the *RS 150*, at a plant to be constructed at Youngstown in Ohio.

Airship Industries, which has an accumulated debt of £5 million, has recently received a number of cash injections. The Royal Bank of Canada has invested in the company and Economic Regionale Wallone (ERW), a Belgian regional development agency, has acquired 4% of the equity capital.(22) Negotiations with ERW on a major £3 million investment, worth 39% of the present equity capital, are in progress,(23) as are discussions with a number of other First World governments. In July 1982, the European Energy Commission awarded the company a grant of £313,000 for the demonstration of the fuel efficiency of the *Skyship 500*.

Since 1977 parametric studies of a solar powered airship - the *Sunship* - have been undertaken in England by Solar Airship Ltd. The Sunship's designers believe that improvements in solar cell technologies and their falling costs will bring solar energy, in favourable climates, on economic parity with fossil fuels by the mid 1980s. The *Sunship* is a conventional non-rigid helium airship equipped with an array of solar cells over the greater part of the envelope (see Figure 4.3).(24) The cells generate electrical power which is collected and fed through a grid and control system to DC motors that drive propellers. A part of the energy generated would be stored on board. The energy required for flight services, such as lighting and instrumentation, would be obtained directly from the grid or from the storage unit. A typical prototype for validation and demonstration purposes would be some 80m long and capable of carrying a working load of 3 - 5 tons with two 100 Kw DC engines.

The design problems are formidable. Ways have to be found, for example, of achieving acceptable performance with the weight penalties imposed by the cells and power storage unit, of reducing solar power losses to acceptable levels, of fixing the cell arrays to the flexible envelope, and of protecting the cells from damage caused by ultra-violet rays and general wear and tear. The Sunship's designers are confident that such problems can be overcome, and are now able to point to the successful crossing made in 1981 by the solar powered balloon, the *Solar Challenger*.

The Sunship's operational requirement would be for clear skies, low seasonal variations in incident solar energy, relatively low wind velocities, and terrain that permits flying at no more than 1000m above sea level. When this requirement is met, speeds in excess of 100 kph are considered possible. The required conditions are most likely to be found in the area lying between 15° and 30° north and south of the equator, which includes large parts of Africa, South America and Australia. This suggests that the *Sunship* would be most suitable for operation in the developing world and an

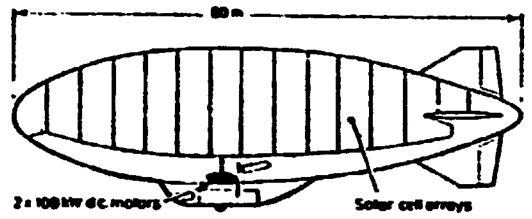


Figure 4.3: Sunship General Configuration

Source: A.W.L. Nayler, op. cit.

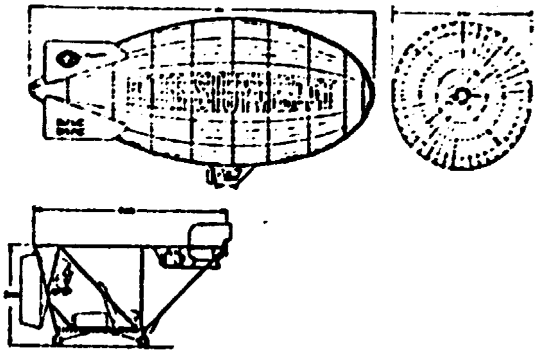


Figure 4.4: Thunder Balloons AS-80 Hot Air Airship

Source: A.W.L. Nayler, 'LTA Developments in Great Britain, AIAA Paper 81-1321 industrialized country with internal transport difficulties.

The cost of solar cells has fallen 100 fold in the past decade and, according to some estimates, could reach the competitive price of less than $1.00 per peak watt by the mid 1980s. At these prices, the Sunship's designers believe, the prototype solar propulsion system could cost less than $200,000, with an annual replacement and maintenance cost of about $4000. At these costs, the designers maintain, the initial difference in price between gas turbine and solar power airships could be recovered in about 3 years.

To complete the picture of LTA developments in the U.K., reference should be made to 2 companies - Cameron Balloons, Ltd., and Thunder Balloons Ltd., - that manufacture and sell small hot air airships. These are hot air filled balloons propelled by small engines for use in sport, advertising, and aerial photography.(25)

The *Cameron Balloons' D-96* first flew in 1973 and some 10 have so far been sold. The model has been progressively improved and today consists of a 31m long, 14m diameter envelope of 103,000 cu.ft. with an inflated tail unit. Hot air at 100°C is provided by a pylon mounted propane burner, propane also powering a VW engine for forward travel. The car contains 2 seats. The *D-96* has a maximum speed of 15 knots and sold in 1981 for £20,200.

In 1980 Cameron Balloons first flew a smaller hot airship. Designated the *D-38* it has an envelope 23m long with a volume of 38,000 cu.ft. Power is provided by a light-weight 2-stroke engine which gives the *D-38* a top speed of 12 - 15 knots. Priced in 1981 at £9,600, several models have so far been sold.

Thunder Balloons produces the *AS-80*. Similar in size to the *D-96*, it is 30m long, 13m in diameter and has a volume of 2250 cu.m. (See Figure 4.4), It also has 4 tail fins and derives its lift from hot air provided by a propane burner. Power is provided by a watercooled Honda CX500 engine which drives a 1.2m diameter ducted wooden propeller. Unlike the *D-96*, the *AS-80* has a pressurized envelope. A secondary 5 hp Honda engine is used to achieve this and to steer air flow control via movable flaps.

The ship's gondola is 4.1m long, 1.8m high and 1.8m wide, providing space for 2 seats with the joystick control located between them. The gondola has a plexiglass covered roof and front. Four rubber spring wheels serve as the undercarriage. The maximum speed of the *AS-80* is 25 kts, cruise speed 15-20 kts. With a crew of 2 it can stay aloft for 2.5 hours, for 4 hours with the pilot only.

4.4 France

Various government and private organizations in France have sponsored studies of airship concepts and applications. Two agencies in particular, ONERA and SNIAS, have investigated hybrid airships, some of which are similar in concept to the helicopter-aerostat combinations under development in the U.S. One of these, called the *Heliostat*, featured a tri-lobed non-rigid envelope and 2 Turbomeca Arriel turbines driving AS 350 Ecureil rotors to provide forward and reverse thrust. Designed to demonstrate the feasibility of aerial logging, the vehicle never left the drawing board.(26)

The same envelope concept was used in an experimental remotely piloted vehicle called the *Dinosaure*. In this 40 cu.m. mini-airship, 2 envelopes were joined together to form a single wing with lift capabilities. Other features included blown controls and an air cushion landing system. The craft was used for atmospheric research and made a total of 70 flights.

The work of Pierre Balascovic has attracted considerable attention. He has experimented with lenticular shaped hulls and prepared designs for 3 craft, named *Pegase*, *Titan*, and *Vespa*. A 'proof of concept' vehicle, *Flipper*, was constructed in 1978 to provide early data.(27) Unfortunately, it was damaged beyond repair prior to its first flight. Present plans by Balascovic and his company, SEAB, include development of a 6,200 cu.m. airship, called *Alcyon*. Intended as a low altitude VTOL vehicle, vertical thrust is obtained from 3 rotor systems located at 120° points on the hull perimeter. Forward thrust is provided by 3 propulsive units mounted on the tail support structure. Although the vehicle has a large horizontal tail, it was judged to be inherently stable (in pitch) without this appendage on the basis of an analysis made by CERT, the Toulouse branch of ONERA. Wind tunnel tests to measure drag were also made by ONERA. A full-scale vehicle is planned for completion in 1982.

4.5 West Germany

As in the U.K., activities in West Germany are mainly privately sponsored. The most active company is the West Deutsche Lufterwerbung GmbH (WDL). WDL built two non-rigid airships, designated the *WDL-1*, in the early 1970s, one of which is operated by the company in the Federal Republic for advertising purposes (it is equipped with a specially designed array of 10,000 lamps), the other was sold to Japan initially for shipping control and communications relay, although it was used, like its sister ship, mainly for aerial advertising.

The *WDL-1* is essentially a modified version of the Goodyear L type, built for the U.S.Navy before the Second World War. Several improvements have, however, been made. These include fuel tanks suspended by the internal car suspension cables within a centre ballonet, an improved pressurization system, a slightly larger envelope and a new envelope fabric (rubberized Trevira), and tractor propellers. The craft has a length of 60m, a diameter of 14.5m and a volume of 6000 cu.m. Gross weight is 6300 kg. Its two 250 hp engines give it a top speed of 100 kph and its range is 1800 km. It can carry a payload of 1500 kg. The *WDL-1* carries its own mooring mast. In low wind conditions it can take-off vertically, otherwise it requires a grass strip some three times the length of the craft for safe operation.

WDL has acquired 20,000 flying hours experience, 6,000 of them at night, with the two craft. In addition to Europe and Japan, the ship has been operated in Ghana and Upper Volta in trials supported by the German Ministry of Technical Cooperation. The craft was shipped to Ghana where it was assembled in the open. There are plans to ship the German craft to Peru for fisheries and oceanographic research and maritime surveillance trials. No major problems have been encountered with the *WDL-1* in the 20,000 hours.

The company has made studies of two large airships, the *WDL-II* and *WDL-III*. The *WDL-II* is a 20,000 cu.m. airship with a length of 80m and a maximum diameter of 20m. It would be powered by two 400 hp engines which could be rotated though 180° to provide for greater controllability at take-off and landing. It would have a top speed of 140 kph, a range of 2400 km and be able to carry a 10 tonne payload. The *WDL-III* is a non-rigid of 60,000 cu.m, 120m long and a diameter of 28m. Power would be provided by two 700 hp diesel engines located within the envelope, giving the craft a top speed of 140 kph. It would also have vectoring turbines for maneuvering control. The ship would be able to carry a 30 tonne payload over 8000 km or more and would be equipped with removable cargo and passenger modules. At present, the company has no plans to build either the *WDL-II* or *WDL-III*.

The name of Luftschiffbau Zeppelin has been restored as an active part of Zeppelin Metalwerke GmbH in order to respond to the continuing interest in historical materials and information and to keep abreast of current LTA developments. More recently the company has joined hands with Lightspeed U.S.A. Inc. to outline a heavy lift airship, drawing on current and advanced technology, called the *Helitruck*. The German Agency for Technical Cooperation is assisting in potential user and marketing studies. The *Helitruck* is described in Chapter 7.

4.6 Soviet Union

Developments in the Soviet Union are not widely publicized and are not known with any certainty. Despite apparent opposition from the Ministry of Aviation it appears that a number of semi-rigid airships were built in the post-war period for a variety of uses, including mineral resource surveys in Siberia and other developing regions.(28)

The Soviet Union does have airship designers and airship design offices. Occasionally, they unveil plans for various ambitious projects. In 1970, for example, a proposal was made for a 18 million cu.ft. 'superairship' capable of carrying 500 passengers, mail and freight at speeds of up to 240 kph.(28a) More recently, it has been suggested that some designers are thinking in terms of very heavy lift airships - up to 500 tons - using multiple hulls.

Airships have been studied for specific missions. Investigations were, for example, undertaken into the design of an airship for use in modular housing construction.(29) The requirement was specified by the S. Lazo Polytechnical Institute in Kishinev and an airship was designed to meet the requirement by the K.E.Tsiolkovsky Dirigible Design Office in Leningrad. The ship, designated the *TS.M-100*, is an unballasted metal clad craft 245m long with a diameter of 37m, making use of engine exhaust heat for aerostatic control. The gondola is 60m long, 5m wide and 5m high and the craft would be capable of carrying a useful load of 100 tonnes at a cruising speed of 170 kph. The investigation concluded that such a vehicle would have great potential for modular housing construction, especially over distances of 50 km or more.

Pravda of 19 September 1981 describes one project currently in progress. The aim of the project is to develop a vehicle for the transportation and installation of power transmission towers. It is being carried out for the Ministry of Energy and Electrification by a team of 20 engineers led by Prof. O.E.Chembrovsky of the Research Institute for Energy Projects in Ozgenezgostroy. According to the *Pravda* report, Prof. Chembrovsky and his team studied 100 airship variants before deciding upon a conventional design: a non-rigid, 50m in length, 20m in diameter, powered by 2 aircraft engines. The vehicle is designed to have a speed of approximately 100 kph, a range of 250 km and a useful lift of 6 - 8 tons. It is to be 'state of the art', only 5-10% of the vehicle will have new technologies.

The first experimental flight of the ship is scheduled for 1982-83. If trials prove successful, a 30 ton heavy lift vehicle may be developed, possibly with twin hulls, and additional engines. Other ministries are reportedly watching developments with a keen interest and the possibility of developing LTA vehicles for other missions, such as logging operations, has already been raised. According to the *Pravda* report, studies indicate that there is a potential demand for 'several hundred' airships of different types in the Soviet Union.

4.7 Japan

LTA development recommenced in Japan in the mid 1970s. At that time Fuji began flight trials with a small research ship called the *500*. More recently, the Ministry of International Trade and Industry (MITI), whose many responsibilities include aircraft development and production, has sponsored studies aimed at identifying missions in which modern airships could play a useful role. These studies indicated that two types of vehicle would be particularly useful: a heavy lift airship able to transport cargos in the 20 - 100 ton range; and a short haul passenger carrying airship linking medium-sized cities no more than 300 km apart. Design studies on each of these types are underway.(30)

The heavy lift airship is configured for the special problems involved in the construction of inland hydroelectric and geothermal power stations. According to calculations made by the Toshiba Electric Co., a hybrid heavy lifter capable of transporting a 20 - 100 ton payload over distances of 50 km at a speed of 50 kph could result in savings of up to $75 million per year. Japan is currently investing $65 million a year in the construction of inland power stations, a level of investment to be continued throughout the 1980s. Toshiba's calculations suggest that in the power industry alone, there is a potential demand for 5000 hours of flying time.

The passenger carrying airships are designed to serve Japan's so-called rib routes. Japan stretches over 2000 km along a backbone of mountain ridges. The main trunk lines, running north from Tokyo to Sapporo, and west from Tokyo to Osaka, are well developed, making use of high speed trains and aircraft. These modes have limitations, however, when it comes to serving routes across Honshu, the main island, and many of the country's 420 inhabited islands. Rib routes are seldom longer than 300 km and, where islands are involved, frequently involve the need to cross straights and to change mode. These distances are generally too short for the use of fixed wing aircraft. The costs of building railways, currently in the order of $20 million per km, are also considered prohibitive.

Kawasaki Heavy Industries has been commissioned to prepare preliminary designs for an LTA craft that could serve the rib routes and islands. Its proposal is for a hybrid vehicle, called the *KHI-Helistat*, capable of carrying 120 passengers at 150 kph. (Figure 4.5) The craft is 80m long, has a diameter of 52m, a height of 30m, and a volume of 21,500 cu.m. Power comes from eight 600 hp engines driving four 11m diameter 4 bladed rotors. It has an operational ceiling of some 3000m and a range of about 700 km.

KHI estimates that its *Helistat* could sell for $7.5 million if 10 craft were produced. Its possible operating costs have been

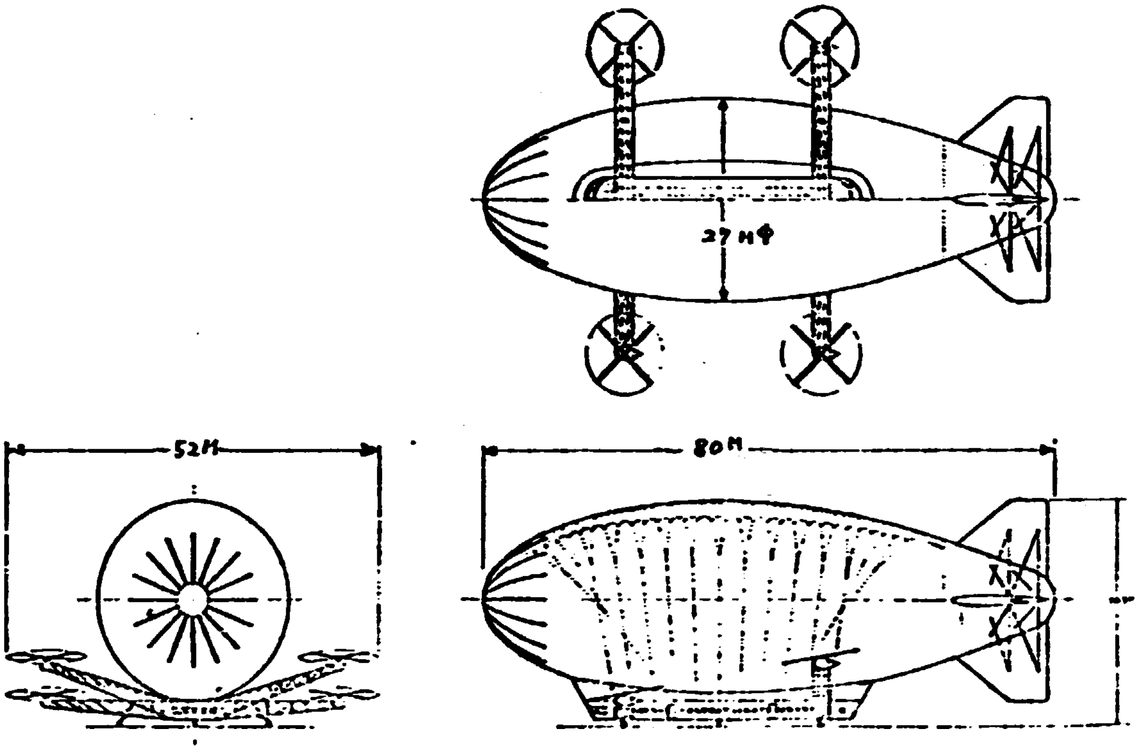


Figure 4.5: Kawasaki Helistat

Source: K. Iinuma, 'Japanese Lighter-than-Air Mission Studies', AIAA Paper 79-1587 compared with those of the YS-11, currently flown on rib routes, production of which has ceased. The comparison suggests that the *Helistat* could compete favourably with the YS-11 over block distances of 300 km, the Helistat's 28.6 yen/seat/km being 5 cents higher than the YS-11's 23.6 yen. This difference is almost exclusively due to higher depreciation costs, and the calculations do not take into account the higher ground costs associated with an expansion of fixed wing operations.

MITI has declared its attention to develop a limited number of heavy lift hybrids for use where there is no alternative mode, and to develop the passenger carrying vehicle with the intention of gradually introducing it into Japan's domestic air network. In 1980 it announced a $75 million R & D programme but as of early 1982 it was still to be implemented.

4.8 Latin America

Several countries and groups in Latin America have demonstrated an interest in LTA development, in some cases extending financial support for R & D work. The best known example of this is the backing given by Aerovision, a Venezuelan company, to the development of the *AD 500*. This support was withdrawn when the airship came to grief in 1979. More recently, operators in Argentina, Colombia and Peru have reportedly shown an interest in craft under development by the Canadian Aerostat Airship Company.

The government of Brazil has conducted various studies of LTA transport, being particularly interested in the role that the airship could play in colonizing the Amazon basin. In terms of airship operations, Brazil has the advantage of having a very large hangar, a product of the trans-Atlantic crossings made by the *Graf Zeppelin* in the 1930s. Few results of the government sponsored studies have, however, been published.

Brazil also has a small group of LTA enthusiasts led by Gilberto Riega. Riega has designed and started to build a hot air airship, 44m long, 15m in diameter, with a volume of 5,950 cu.m. (245,000 cu.ft). It is to be powered by two 4 cylinder 60 hp engines driving wooden propellers of 1.5m diameter. Large by hot air airship standards, the craft is designed to carry up to 8 passengers.(31)

4.9 Technology Development

Some of the main recent and ongoing LTA developments in different parts of the world have been described above. We have seen that there has been a flurry of activity in the past decade which has produced a large number of LTA studies and a small number of LTA craft. In some countries, notably the U.S., France and Japan, governments have sponsored investigations, in others, notably West Germany and the U.K., private companies have invested their own limited resources in designing and building vehicles.

Most interest has centered around non-rigid and hybrid airships, although the potential of the large rigid airship has also been studied. It is the future of the rigid which is the most debatable. Due to the heaviness of the rigid structure, they must be very large to provide enough lift for the structure and the payload. The larger the structure, the greater the lift for payload. The ratio of total lift to payload in rigids has traditionally been very unfavourable: in the giants that flew in the 1930s it was approximately 20-30% of the total volume. By comparison, the payload of a non-rigid airship of 60-70,000 cu.m. would be about 50% or more of total lift.

Tomorrow's rigids would be more efficient than those of yesterday. But they would still need to be very large since they are likely to display structural deficiencies when smaller than about 85,000 cu.m. The largest rigid ever built, the LZ-139 *Hindenberg*, had more than twice this volume. Theoretically at least, there is no maximum size for a rigid. The limit is imposed by the practicalities of fabrication and ground facilities, not by theory.

The age of the rigid airship ended in 1940 with the scrapping of the *USS Los Angeles*. Views on whether a new age could dawn are mixed. Most would probably argue that their fabrication and ground support costs and their slow speed make them poor competitors with commercial aircraft as long distance freight carriers. Others, however, believe that they could have a future, could be cost competitive and are inherently superior to non-rigids. Malcolm Wren who, as we have seen, left Airship Industries to build the metal clad *R 30* believes that 'people are wasting their time with blimps... They aren't as fast, as maneuverable or as strong as rigid airships'.(32) U.S.Navy sponsored studies have suggested that the large rigid could serve as a very useful long-range patrol and surveillance platform for the 1990s.(33) To build large rigids today would, however, be an act of faith and of daring. It would also be very expensive. One of the main obstacles to the development of rigids is their extremely high R & D costs. The true costs of building a 200,000 cu.m. craft today are simply not known but are likely to be in excess of $100 million. The possibility of a private airship company finding such an amount for an essentially speculative venture remains an open question.

Much more modest are the costs of building and progressively improving non-rigid airships. Because they have much less weight and thus have greater buoyancy, economically interesting payloads can be obtained with much smaller airships. The biggest payload currently being carried by a non-rigid is only 2 tons. That this can be increased dramatically is beyond doubt. The maximum size for a non-rigid is limited by envelope (seaming) technology and aerodynamic efficiency. The upper limit within current technology is considered to be about 85,000 cu.m, which is a very large airship, twice the size of the largest non-rigid so far built. For practical purposes, the upper limit is likely to be closer to 55-60,000 cu.m.

With current technology and proven materials, such a craft could lift up to 30 tons. With new materials, (especially fabrics) and advanced technologies (bonding, jointing, propulsion systems), its payload capacity could be increased to perhaps 55 tons.

This brings the non-rigid into the heavy lift category and makes it a rival to the hybrid. The hybrid, because it uses the dynamic lift provided by the rotor propulsion, would, however, be a much smaller vehicle. Current technology hybrids will be able to lift up to about 75 tons. For payloads in excess of 100 tons it will be necessary to go to beyond the state-of-the-art hybrids - Goodyear has looked at a hybrid able to lift 160 tons, almost the weight of a fully-loaded 707 - or to rigids.

As we have seen, proposals for non-rigids range in size from several thousand cu.m. to as large as 50-60,000 cu.m, the latter for long endurance maritime patrol and surveillance. It should be no surprise that airship designers are trying to break into this new and expanding market. Airships have in the past demonstrated a very real capability in this area, where their inherent qualities - fuel-efficiency, endurance, reliability - can be put to good use. Studies conducted for the U.S.Coast Guard focused on the use of airships of 20,000 cu.m. for patrol missions of up to 30 hours (see Chapter 6).

The Coast Guard and other concepts incorporate vectored propulsion systems for significantly improved low-speed control, precision hover and a real VTOL capability. Trimotors with 2 engines mounted adjacent to the hull and a propulsion unit at the stern, and quad-rotors with 4 tiltable engines mounted adjacent to the hull, have all been proposed. The quadrotor designs provide for reverse thrust, allowing the airship to operate light and eliminating the need for ballasting. Such airships bear little resemblance to the non-rigids which have so far flown. But if airships do 'take off' this is the route they will most likely follow.

The new conventional airships and the hybrids, while offering promising possibilities, remain unproven designs. Work is in progress to test some of the new concepts and to expand the empirical data base. It is to some of this work that we will now turn.(34).

Configurations

Hull forms that depart from the traditional ellipsoids and cylinders are being studied in several countries. The new forms are being investigated for a number of reasons, such as the desire for increased dynamic lift in flight, reduced resistance to ground winds while moored, and the need for a special hull form because of payload or mission requirements. The new configurations include, as we have seen, delta planforms, lenticular shapes, and ellipsoidal cross sections.

Comparisons of the new configurations with conventional forms have proven difficult due to the lack of an inadequate data base for the new concepts. One evaluation recently made of the specific productivity(35) of deltoid hybrids and conventional equilibrium shapes show that hull forms of very low aspect ratio (~0.5) have slightly higher specific productivity values than conventional shapes. These tests point to the usefulness of hulls which combine ellipsoidal fore bodies with flattened (deltashaped) after bodies. This appear to have been confirmed in another study which compared very large VTOL hybrids with equilibrium types for military airlift missions involving very long range flights.(36) The results of these investigations are shown in Figure 4.6.

It should be noted that whereas the productivity values are low compared to heavier-than-air craft at their best ranges, the advantages of LTA craft, such as their VTOL capability, large single volume and payload capacity, and their potential for very long range flight, could make some LTA vehicles an attractive proposition for future development.

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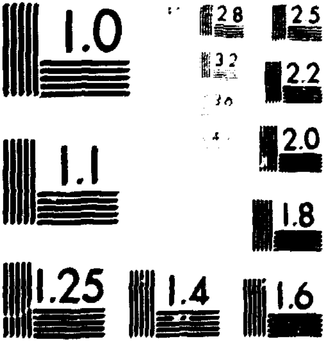

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

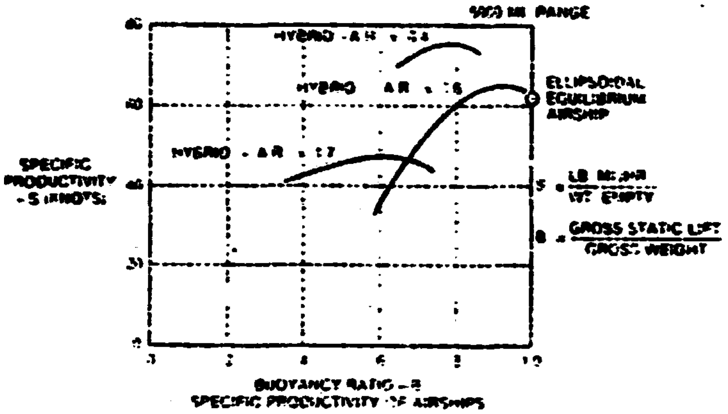

Figure 4.6: Productivity of Different Hull Forms

Source: N.J. Mayer, 'Current Development Lighter than Air Systems', UNIDO 453/26 LTA-9, p. 8

Dynamics and Control

Conventional equilibrium airships are generally designed to be aerodynamically controllable through the use of hull and empennage forces above some minimum flight speed. Below this point, only static forces are available for control. The new hybrid concepts which combine large rotors with aerostatic hulls are, by design, intended to overcome this problem through the availability of large thrust forces at all airspeeds, and to achieve near helicopter-like hover capability. Some non-rigid airships, such as those intended for maritime patrol and surveillance, will also require high levels of controllability at or near zero airspeeds. These requirements establish needs for design criteria beyond the present data base. For this reason, the bulk of research effort in recent years has been devoted to the development of flight analysis and simulation techniques.

One example of such effort is the simulation programme developed by Goodyear for examining the behaviour of non-rigid heavy lift hybrids.(37) The programme models flight path and dynamic stability and incorporates control concepts for a range of flight mission profiles. The vehicle's motions, velocity changes, power requirements, and suspended payload dynamics are recorded on strip charts and also displayed visually.

A similar but more comprehensive programme has been developed by Systems Technology, Inc., for NASA.(38) This programme is intended to be developed in 3 sequences or versions. The first incorporates the basic major elements of vehicle dynamics in steady flight with simplified rotor models. The second version contains the effects of hull-rotor interference, and atmospheric turbulence. Version three will include the simulation of payload effects, ground effects and vehicle stability. The complete programme was scheduled for completion in 1981. It is to be used in NASA's Ames Computer facility and will be made available to other organizations.

The programme can be used for simulating different vehicle configurations, including those with control and thrust units that differ in number and location from the basic heavy-lift rotor concepts. The flight simulator at the NASA Ames Research Center is also utilized for airship flight simulation.

Another approach to the study of flight characteristics is being employed by NADC. This involves the construction and trial of a 1/10 scale model of the airship under consideration by the U.S. Coast Guard. The model, 9.75m in length with a volume of 24.5 cu.m, will be remotely controlled and incorporate a tilting bi-rotor propulsion and control system.

Dynamics and control studies of conventional airships have also been conducted in Canada by DeLaurier(39) and in France by ONERA. The French studies include analyses of sling-load dynamics undertaken in connection with heavy-lift airship certification.(40)

A number of other analyses related to the development of specific vehicles have also been made in France, the U.K., and U.S.

As noted earlier, the fundamental problem with most of the new programmes is the lack of an empirical data base. Some new LTA configurations have strained theoretical knowledge to the limits and have yet to be proven in wind tunnel tests or substantiated with 'hard' flight data. An early indication of the problems involved was revealed in discrepancies observed between wind tunnel tests and analyses of hybrid designs with large rotor systems.(41) Force vectors did not agree in either magnitude or direction. Larger scale and higher Reynold's number tests are scheduled to be undertaken by NASA in 1982 to further investigate the differenc .

Structures and Materials

Two developments in recent years have had a major impact on airship structures. These are new methods of analysis and new materials.

The analysis of airship structures has in the past been severely hampered by the very complexity of the structures. In rigids, for example, simplifications and approximations were made based upon little more than rules of thumb and experience. In non-rigids, it was assumed that the strength and elasticity of large parts of the envelope and suspension system were relatively uniform.

Finite element methods using digital computing equipment now provide a basis for more exact and more detailed computations. It is now possible to model the dynamic behaviour of systems taking into account non-linear characteristics and coupling effects. Large computers are no longer to be found only in government research centres: all self-respecting airship design offices have one of their own.

Structural weight continues to be one of the most important considerations in sizing airships, and hence determining their efficiencies. Weight reductions can be achieved through the use of composite materials, and new synthetic filaments and films for inflated components.

The envelope assembly is the heaviest part of any non-rigid airship. New materials make it possible to build airships today with assemblies only half the weight of their predecessors - a saving commensurate with a 15% reduction in envelope volume and 13% in propulsive power. Such savings are possible by combining composites for the hard structural components with new synthetic filaments such as Kevlar and Graphite. As we saw earlier, such new materials have been used extensively in the *Skyship 500* built by Airship Industries. The gondola, empennage, and nose mooring and stiffening units have been built using combinations of Kevlar and fibreglass composites.

Much remains to be done in the development of structural design criteria for new configurations and materials. Some studies were undertaken as part of the NASA sponsored investigations into heavy-lift hybrids, but this is only a beginning. Design criteria relating to gusts and turbulence are in particular need of development. The criteria used for past airships may not be very applicable for determining loads for heavy-lift hybrids with their much higher thrust and, in some cases, suspended payloads.

Propulsion

It is unlikely that engines designed specifically for airship applications will ever become available: the 'airship market' just does not seem to be big enough to justify the development costs involved. It seems likely that future airship designers will be compelled to continue the practice of adapting engines produced for other types of vehicles. The process of adaptation will in the future, however, be more complex than in the past. The new emphasis on low-speed control and precision hover establishes requirements for more thrust in some cases and for thrust vectoring through the use of tilting propellers and cyclic and collective pitch variation. It should be noted, however, that, with the exception of cyclic pitch, all of these systems have been incorporated in past airships, albeit to a lesser degree.

Response time for counteracting disturbances is crucial if any thrust system is to be effective. Even though inertial characteristics of airships favour longer periods, these would be shorter than the time required for tilting thrust axes. Thrust units already mounted in the proper direction is a practical way out of this dilemma, a solution tested in the experimental *HX-1*. An experiment conducted by ONERA in France involving two intermeshing propellers with axes at 90° to each other appears to be another suitable approach. The experiment showed that both thrust and efficiency were enhanced by the configuration tested.

Certification

Considerable work remains to be done in formulating rules for airworthiness certification, the regulation of airship operations, and pilot licensing. Most work in this area has been done in the United Kingdom where the British CAA was compelled to develop a complete requirement during the design and development of Airship Industries *Skyship 500* (formerly the *AD 500*). The CAA's 'BCAR Section Q - Non-Rigid Airships' is the first set of airship requirements which has reached the status of a detailed and comprehensive national code of airworthiness for airships.(42) The CAA is considering the further development of requirements to cover rigid airships, the use of gas turbine power units, and sophisticated control systems, although the need for such requirements is no longer as urgent as it was now that Airship Industries has terminated its rigid airship development programme.

In the U.S., Goodyear's activities are regulated on the basis of the requirements prepared for the Navy's 'L' type airships flown during the Second World War. A detailed certification of any type has never been developed. If airship development work in the U.S. continues and prototype ships are built, the FAA will need to prepare detailed requirements. Canada, France and Japan are also considering establishing airworthiness certification requirements.(43)

Helium Supply(44)

It has been suggested that LTA developments, should they proceed on a significant scale, could eventually be constrained by a shortage of helium. Helium is a comparatively 'new' gas. It was first isolated in 1903 and first liquified in 1908. It was first produced on a large scale by the U.S.Bureau of Mines during the First World War for use in airships. Since then, the U.S. has enjoyed a virtual monopoly position as producer and supplier of helium, although, more recently, Poland has begun extracting and exporting helium as a by-product of methane gas production.

Most of the helium in use in the world is extracted as a by-product from a natural gas field that runs from Northern Texas through Oklahoma to Southern Kansas. Two extraction plants on this field account for 86% of total U.S.helium production. The total demand for helium is about 30 million cu.m. a year. About 70% of all helium consumed is used in cryogenics, welding and purging and pressurization. About 4% is used for lifting.

Today, helium can only be economically extracted from natural gas when its helium content is more than 0.3%. There are several other potential sources, such as extraction of helium from the air in special separation plants and its separation from nitrogen gas fields, but none of these are at present considered economic.(45)

At present, the production of helium exceeds demand by about 40%. Demands for U.S. helium are, however, increasing by about 10% a year, with demand outside the U.S. increasing more rapidly than domestic demand. Given present production and demand patterns, demands for U.S.produced helium could begin to exceed supply by about 1990. This has given rise to the concern that helium could be in short supply when airships are likely to be most in need of it.(46)

This concern does not, however, appear completely justified. There are natural gas fields both within and outside the U.S. which have a potential for helium extraction. Such fields exist in Algeria and Alberta north of 49° latitude, and, within the U.S., in Wyoming (the 'Tip Top' field). According to some estimates, these and existing fields provide several hundred years of helium supply.

Even if these fields are not developed, a significant increase in helium prices would not significantly affect airship development and operation. A ten fold increase in the price of helium would probably add no more than 5% to the cost of an airship. Maintenance costs would probably increase by no more than 1%.

4.10 Concluding Note

The main characteristics of some of the LTA craft described in this chapter are summarized in Table 4.3. The table suggests that a good deal of LTA activity is currently taking place and that more vehicles will soon by flying than at any time since the 1950s.

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LTA systems appear to stand at something of a threshold. Whether they are able to cross it and realize their undoubted potential remains to be seen. The requirement for heavy-lift and maritime patrol vehicles would seem to suggest that it is now or never. It is important that the airship, in its conventional or one of its new forms, establish itself in these areas while there is still time. The odds are stacked against the airship. The cancellation of the U.S.Navy and Coast Guard airship requirements were severe blows and the largest LTA project currently underway - the Piasecki Helistat - has reportedly run into difficulties. Against this is the progress being made by Airship Industries in turning enquiries and interest into orders.

When seen against the backcloth of aeronautical research and development, LTA activity is miniscule and extremely vulnerable. The viability of LTA transport is conditioned by the critical need for a true industrial base. That base is today embryonic at best.

Norman Mayer, Program Manager on LTA systems for NASA, has suggested that the world of LTA developments today is comparable to the world of aeronautical endeavour that existed in the period following the First World War - 'much enthusiasm, limited financing, and inadequate engineering in many cases'.(47)

If real progress is to be made then research and development will need to be intensified and the money found that will make this possible. Among the areas currently in need of urgent investigation perhaps the most important are:

Table 4.3: Main Characteristics of Some Current LTA Vehicles

LTA Vehicle	Volume m3	Length m	Max. Diameter m	Gross Weight kg	Gross Lift kg	Max. Speed knots	Useful Load kg	Engines hp	Status
Goodyear Heavy-Lift Airship	75,050	138	33	131,885	63,858 (1)	80	68,027	8760	Under study
Goodyear GZ-20A	5741	59	14	5587	5587 (2)	43	1488	420	Operational
Piasecki Heli-Stat	27,613	105	23	5109	27,021 (2)	60-70	25,569	5100	Undergoing flight trials
Skyship 500	5132	50	14	5703	5068 (3)	62	1883	300	Operational
Skyship 600	6055	56	14	6256	5707 (3)	65	2883	500	Under construction
Skyship 5000	50,000	108	30	50,000	-	-	30,000	-	Under study
WDL I	6000	60	15	6286	6286 (4)	61	1497	500	Operational
WDL III	60,000	122	30	62,239	58,716 (2)	76	39,909	2600	Under study
Cyclocrane	9487	55	20	10,884	9070 (2)	60	1814	360	Under construction
Heli-Costat	3400	37	15	6540	3447 (2)	49	3447	1200	Under study
Dinosaure RPV	47	8	1	46	46 (4)	-	-	7	Operational
Alcyon	6200	44	9 (5)	-	5627 (2)	60	998	885	Under development
Development Sciences RPV	-	13	4	-	50	45	25	20	Has undergone flight trials

Notes

(1) at 1524 m altitude
(2) at 305 m altitude
(3) at 610 m altitude
(4) at sea level
(5) Height

- Aerodynamic drag and the effects of various configuration changes;
- the design and location of propulsion units for maximum efficiency, performance, and the control of aerostatic lift and hovering, especially when loading or discharging heavy loads;
- the development of structural design criteria, including the formulation of realistic requirements for flight turbulence and gusts for various airship concepts;
- envelope materials so as to improve long-term permeability, durability, and to achieve lower weight fractions;
- improved methods of groundhandling, maintenance and determination of all-weather flight maintenance;
- the realistic assessment of design, construction, and operational costs for specific missions and types.

Other problems requiring attention include the development of equipment for monitoring the state of structures and sub-systems, and the development of cost effective means of fabricating and assembling large hull structures.(48)

In the final analysis it will not be technology that proves the biggest hurdle to future LTA development. It will be money. We will take up this issue in Chapter 9.

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40. See M. Bercovi, 'Etude du Couplage Pilotage Trouillage d'un Dirigible de Transport', SERA Paper No. 1/7127, January 1977

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5. LTA APPLICATIONS AND OPERATIONS

5.1 Introduction

In the previous chapter we documented airship activity around the world in an attempt to describe the current state-of-the-art. We looked at some of the important studies made of LTA craft in recent years and reviewed some of the prototypes which are either flying or on the drawing board. In this chapter we will examine more closely the potential of the airship and its operational requirements.

We will first list the main attributes of the airship and go on to discuss the potential areas in which these can be put to good use. We will then review the airship's main operational requirements with the intention of both indicating the difficulties involved in airship utilization and dispelling some of the myths which continue to surround this subject. In the final section, we will discuss airship applications and operations in developing countries.

5.2 The Main Attributes of the Airship

The history of the airship and the studies conducted in recent years point very clearly to the main attributes of the airship. They include:

- *Fuel Efficiency* Airships require little fuel to become airborne and have a low power-to-weight ratio. They are able to carry an indivisible load and, as a general rule, require one third of the fuel of a C-130 to carry the same payload. For certain types of missions, the C-130 requires up to 8 times the fuel of a modern conventional airship (cf Chapter 6), an important consideration in a world in which the price of jet fuel has increased tenfold in the past eight years. The possibility of using solar energy to propel airships may enable them to become even more fuel-efficient.

- *Endurance.* An airship can remain in active service for days or even weeks on end compared with the few hours of conventional airplanes and helicopters. A modern conventional airship of around 20,000 cu.m. could be expected to remain aloft for 30 hours or more without refuelling. (Some U.S. Navy rigids of World War II could operate for up to 85 hours without refuelling). When required, refuelling could take place from surface vessels or ground stations with the airship remaining in the air.
- *Low environmental impacts.* Airships have extremely low vibration, noise and pollution levels.
- *Payload capability.* An airship has a large load and space capability. The U.S.Navy's 40,000 cu.m. non-rigids could carry payloads of 25-30 tons. Modern conventional non-rigids, drawing upon new technologies and materials, may be able to lift 50-55 tons. Hybrid airships capable of lifting 25 tons are being tested and those with a 400 ton payload capability have been conceptualized. Modern rigid airships able to transport loads well in excess of 100 tons could be constructed. The large space available in airships makes it possible to economically transport such low-density cargos as tea, cotton, fruit and vegetables.
- *Limited ground requirements.* Airships do not require - indeed should avoid - large, space-consuming airports, and can operate successfully from relatively unprepared sites. Modern conventional airships with a VTOL/ZTOL capability could operate from city centre skyports (in parks, decks on railway stations, etc.) with a diameter of 100 metres.
- *Safety.* Should their engines fail, airships, unlike HTA craft, do not fall out of the sky. They have a safety record which is at least as good as commercial airplanes.
- *Reliability.* Airships have a record of reliable performance. Of the non-rigids operated by the U.S.Navy in the Second World War, 87% were in operational readiness at all times, a

World War II record for military aircraft.

- *Serviceability*. Airships offer possibilities for inflight maintenance and the repair of equipment.

5.3 Airship Applications

This impressive list of attributes suggests a wide-range of potential civilian and military applications for airships and aerostats, manned and unmanned LTA craft. The potential applications are indeed both varied and numerous, as indicated in Table 5.1.

Tables of this kind, however, carry an inherent danger: they convey the impression - sometimes deliberately cultivated by LTA enthusiasts and hobbyists - that airships especially are a panacea for virtually all transport problems and a mode with a universal application. This is far from being the case. Airships should be seen as a complement to existing modes of air and ground transportation. They are mission dependent vehicles: they are suitable for specific uses, under well-defined conditions, and according to a particular set of requirements. If the airship does make a come-back, it will be because it can perform certain operations more effectively and cheaply than can other modes.

As a general rule, the airship is 100% competitive where there is no infrastructure and serious alternatives to it do not exist. Evidence shows only too clearly however, that in situations where alternatives do exist, they will be used, even when it can be shown, in theory at least, that airships are a more attractive proposition. In cases where choices have to be made about alternatives, the airship is often an unknown, a drawing board design rather than operational hardware. Its 'competitors' - truck, airplane, helicopter - are proven technologies that can be bought 'off the shelf'. A robust non-rigid airship capable of carrying 20-25 ton loads over tropical jungles and swamps would be a splendid vehicle. But that vehicle does not yet exist. Until such time as it does, the

Type of LTA Operation	Application Areas				
	Transport	Monitoring & Surveillance	Research & Study	Communications	Military
General	• Transport heavy equipment - Pipeline construction - Power stations & transmission lines - Petro-chemical plant constn. - Bridge construction - Modular housing constn. - Repositioning crawler coal shovels • Transport bulk commodities - Low density cargos • Transport volatile commodities - Cryogenics - Natural gas • Transport passengers - Long haul - Short haul • Emergency & disaster relief	• Enforcement of laws & treaties • Environmental protection • Narcotics control • Illegal entry	• Meteorological studies & weather forecasting • Aerial photography	• Radio broadcasting • TV broadcasting • Radio relay • Telephone microwave relay - National telephone system - Rural telephone system - Mobile telephone system • Telemedicine	• Command/control • Strategic air lift • Airborne early warning • Electronic warfare • Military preparedness
Over Land Operations	• Aerial logging • Outpost supply • Forest fire-fighting • Remote construction projects	• Forest fire detection • Urban law enforcement • Urban traffic control • Industrial security	• Remote sensing • Prospecting • Cartography • Hydrographic studies • Geophysical survey • Animal migration studies		
Over Water Operations	• Inter-island transport - Supplies - Passengers • Ship offloading and port decongestion • Offshore platforms (supply & construction)	• Maritime patrol • Fishing grounds protection • Pollution control • Smuggling detection • Shipping control • Ice operations • Aids to navigation • Search & rescue • Port safety and security	• Marine scientific research • Fish migration studies	• Aids to navigation	• Anti-submarine warfare • Sea control escort • Mine counter measures

Table 5.1: Potential LTA Operations

transport operator will continue to use 10 ton trucks, which become unusable in monsoon rains on jungle roads, or STOL aircraft and helicopters, which are expensive to operate. He has experience with these modes, whatever their imperfections. He has neither the patience nor the money to wait three or more years until an airship which could do the job more efficiently and cost-effectively for him has been designed, tested and certified. And even if he is prepared to wait, he has to learn to operate the airship, and learning, experience tells him, often costs money. This situation is, however, beginning to change as operational airships are becoming available.

Even so, there are other resistances that need to be overcome. There are the widespread beliefs, [illegible] albeit unfounded, that airships are 'old hat', something that belong to the pages of history books, that they are inherently unsafe, fair weather vehicles that require impossibly large hangars when they are not flying. Whatever the evidence to the contrary, such beliefs still need to be dispelled.

Despite such obstacles and resistances, there are areas in which the airship and other LTA craft do have an undoubted potential:

- There is the world-wide need for cost-effective platforms for patrolling the 200 nautical mile Exclusive Economic Zones acquired by coastal states under the new Law of the Sea. The airship is uniquely equipped to fulfil this role and the unmanned remotely piloted mini-blimp may also have a contribution to make (cf. Chapter 6).
- There is the need, in both developed and developing countries, for vehicles capable of transporting heavy loads. This capability may be required to transport bulky cargos that are too large to move over normal highways and rail rights-of-way and too heavy for existing bridges. A heavy lift capability is required in the construction of pipelines and offshore platforms, the transport and emplacement of power transmission lines, and in logging operations. It may be required

to transport loads over innospitable or vulnerable environments such as swamps and permafrost, and in connection with construction and development projects in remote areas where existing ground infrastructure is virtually non-existent. The modern airship - non-rigid, hybrid, perhaps even rigid - has a potential in all these areas. (cf Chapter 7).

- There is the need, especially in developing countries, for cost-effective broadcasting and telephone systems at national and regional levels. The tethered aerostat is designed to provide such services at a cost comparable or below that of the alternatives (cf. Chapter 8).

Maritime patrol, heavy lift transport, and low-cost communication appear the most promising areas for LTA applications. The airship's potential is undoubtedly greatest in over-the-water operations, the airship's traditional 'home'. There are no impediments to low altitude flight. There is the water that may be required for ballasting. And there being less thermic movement in the air column, the air is more stable. 'Seas' other than blue may also offer a high potential for airship operations: 'white seas' (tundra and permafrost regions), 'green seas' (forests, jungle and swamp), and 'brown seas' (deserts) may be almost as suitable, although in the case of deserts, air currents are sometimes treacherous. Least suitable of all are mountainous regions. The pressure altitude of the conventional airship is seldom more than 10,000 ft, its cruising altitude considerably less (5,000 - 7,000 ft). In addition, air conditions in mountainous regions tend to be very unstable and unpredictable.

Whether airships can ever return as passenger carriers in anything other than sightseeing flights is an open question. As we saw in Chapter 4, a range of studies suggest that airships could be competitive over distances of 300 - 400 km and some airship development, such as the work being done by Airship Industries for European Ferries and Kawasaki's work for MITI, is taking place around this theme. There are also those who believe that the airship could recapture the prestige and status it enjoyed in the 1930s as a luxury intercontinental passenger vessel. One such person is Claude Bélanger, President of the Canadian Aerostat Corporation. "There is no reason", he has suggested, "why an aerostat or airship can't take a few hundred people across the Atlantic in 30 hours. They would fly 300 ft. above the ocean, occasionally glance at whales, and relax in superlative style. It wouldn't be expensive. No, it won't replace the passenger jet, but it would satisfy a certain group of travellers who like to take their time".(1) There is indeed no technical reason to prevent the construction of an airship for such a discerning group of travellers. The question is whether the group is large enough to justify the enormous costs of building the airship. All the evidence suggests that it is not.

5.4 Airship Operations

Before discussing operational procedures, it is necessary to refer to commonly held misconceptions mentioned above concerning airships: (i) airships are unsafe; (ii) they have poor performance in bad weather; (iii) they require extensive ground handling equipment; and (iv) they need to be hangared when not in use.

(i) *Safety*. The safety record of airships has been demonstrated in numerous studies.(2) Modern conventional airships are in fact among the safest of all aircraft. Because they are inflated with the inert helium and require modest fuel tanks, the risk of fire is very small, much smaller than in HTA craft. They have a very low landing speed and are equipped with multiple engines to permit normal landings in the event of engine failure.

When the airship's envelope is punctured - by bullets or accident - it does not burst like a toy balloon. The internal pressure of the envelope is only slightly above the ambient air pressure. Leaks and holes cause a gradual seepage, not catastrophic failure.(3)

Holes of many square meters, which could only be caused by very modern missiles, would be required to bring the airship down rapidly. Even here, the ship would descend gradually, rather than fall like a stone as in the case of HTA craft. And, if the worst were to come to the worst, an airship would crash land at no more than 50 kph not the 500 or more kph of airplanes. With little risk of a major fire, airship accidents would be 'survivable accidents'.

(ii) *Weather Capability.* The modern conventional airship should be no more vulnerable to adverse weather than other modern aircraft. Historical evidence shows that airships can maintain station in extremely severe weather. It has a proven performance capability in icing conditions, snow, sleet, rain, fog and winds as high as 60 knots.

All aircraft are, of course, affected by extremes in their operational environment and airships are no exception. Under some conditions they are less severely affected, under others more so. In general, airships have a superior performance to HTA craft in poor visibility/ceiling conditions, but are more affected, both on the ground and in the air, by high winds. The airship's performance in thunderstorms, the nemisis of all aircraft, is comparable to that of propeller driven or rotary wing aircraft.(4)

Wind is the most important weather factor in airship operations. While high winds in themselves are no threat to the structural safety of an airship in flight, they do reduce the airship's flight performance and delay ground operations, particularly when the winds are turbulent. The airship can, however, remain aloft with minimal fuel consumption postponing its landing until winds have dropped. Should fuel supply become low, fuel in containers can be picked up in flight while the airship hovers or flies at low ground speed. Modern airships and mooring masts have been designed to allow the ships to remain on the mast in winds of up to 90 knots and to dock and undock in winds of up to 40 knots. When the wind direction approaches 90° to the axis of the hangar, the maximum speeds for docking operations is about 20 knots. While an airship is riding out strong winds at its mast, there is a danger that it could be struck by wind blown objects. WDL for example, lost an airship in 1972 when it was struck by flying debris from its own hangar.

Severe thunderstorms and hurricanes are typically avoided. The standard procedure with all aircraft, not only airships, is to fly them out of the danger area. Unlike airplanes, the airship cannot fly over a thunderstorm. They are usually avoided by flying around them. When they cannot be avoided, the usual procedure is to penetrate the storm at the lowest possible altitude consistent with safe operations, usually between 4000 and 6000 ft. The long endurance of the airship, however, provides it with a large margin of safety, usually more than sufficient for appropriate storm avoidance. Modern weather forecasting, communications along with onboard radar provide sufficient warning to initiate avoidance.

Lightning is not a cause of great concern with helium-inflated airships, although it can be a problem with tethered aerostats. All aircraft attempt to avoid areas of lightning because of the turbulence that usually accompanies it. There have, however, been cases of lightning striking airship cars, fins and topside radomes. In none of these cases was damage to non-rigid airships reported. There have been reports of small holes in the outer coverings of rigid airships where charges struck the metal framework underneath, but the structure was not damaged.

Flight operations are not affected by snow or ice, but snow needs to be removed from the envelope when the airship is moored. The procedure employed by the U.S.Navy was to throw a rope over the airship and to walk it the length of the envelope. More sophisticated methods were considered, such as heating the helium, but were rejected as being unnecessary.

Testimony to the airship's all weather performance comes from rigorous evaluations made by the U.S.Navy between 1954 and 1959.(5) During the first two years, 9 flights were made in weather conducive to icing, snow, and other winter conditions. Although ice accumulation was recorded on two of these flights, at no time were the control or flight characteristics subject to change. In tests conducted from 14-25 January 1956 a station was manned continuously for 240 hours by 5 airships in icing, fog, sleet, snow, rain and gale force wind conditions. Operations during this period were conducted from a mobile mooring mast.(6) On 25 January, the Assistant Secretary of the Navy for Air announced:

> "On the 14th January - 11 days ago - we placed one of our latest airships - a ZPG - on patrol in the North Atlantic, about 200 miles off the East Coast. Twenty-four hours later a sister ship relieved her on station. This turnover was repeated at long intervals. The watch was maintained continuously through some of the worst weather the East Coast has experienced in 35 years. These airships flew through extremes of snow, freezing rain, winds of 60 miles per hour, and extreme turbulence - conditions which at times kept all planes grounded. One airship flew in icing conditions for 32 hours on a 40 hour flight. Another was airborne for over 56 hours. At 9.20 this morning the last flight landed... successfully completing an all weather evaluation which provided a continuous airborne alert of over 10 days".

The conclusions of the official report of this evaluation were:

- Airship ground handling operations can be accomplished in virtually all weather conditions;
- Routine ground maintenance can be accomplished under extremely adverse weather conditions;
- Rime ice accretion at normal airship operating altitudes is not considered a deterrent to proper station-keeping for protracted periods;

- Maintaining a continuous barrier station over the Atlantic Ocean appears to be feasible under all weather conditions.

Still further weather evaluations were made. Between March 1957 and June 1959 the performance of an AEW airship squadron based at Lakehurst, N.J., was monitored.(7) During this period there was one hurricane and a severe winter that included a record snow storm that closed the runways for five days. Despite the adverse conditions, no operations, with the exception of the 5 day period when runways were closed, were cancelled, not even during the hurricane period. The flight schedule objective of 288 sensor hours on station per month was achieved during the whole period. A VTOL capable airship would not have lost the five days of operation due to snow on the runway.

(iii) *Ground handling requirements.* As airships have become more controllable and ground handling equipment improved, so ground handling requirements have been reduced. Early airships - rigid and non-rigid - were never very controllable at low speeds and required large numbers of rope handlers in landing operations. Some 50 handlers were employed to dock British non-rigids during the First World War and as many as 100 were required for the larger airships of the 1930s. During the Second World War the size of ground handling parties had been reduced to about 50. The advent of mechanical ground handling equipment, notably mobile winches, in the early '50s further reduced the ground party to less than 30, while the airships themselves had tripled in size. When the U.S. Navy terminated its LTA operations in 1961, a ground crew of less than 20, using mobile and short masts, was able under normal conditions to handle the largest non-rigids ever built.(8)

Ground handling operations for a modern conventional airship with a hover capability could probably be performed by a ground crew of less than 10. Advances in variable and vectored thrust will make it possible to reduce the size still further. As we saw in Chapter 4, airships are being designed which can take-off, land and moor without external assistance.

(iv) Hangarage requirements. The deployment of U.S.Navy airship squadrons in remote areas during World War II demonstrated that airships could perform their duties entirely without the aid of hangars except for periodic overhaul and depot-level maintenance.(9) Today's materials and weather forecasting make this even more feasible.

A modern conventional airship could be expected to spend almost all of its working life outdoors. When not flying, it would be moored in the open. Hangarage would be required when the airship is assembled or disassembled, although small non-rigids have been put together and taken apart in the open (as with WDL's operations in Ghana). Hangars are also required for major maintenance and when still air conditions are needed, as in the case of work on the nose cone (the ship being off the mast), the alignment of electronic equipment, and the fitting of specialist electronic devices.

Airship operations can thus be conducted from open sites with little more than mooring masts and power supplies. Such sites require the support of a service base with hangarage facilities for major repair and maintenance. The pattern is thus more or less the same as other aircraft operations.

The small non-rigids now flying can be accommodated in inflatable and semi-inflatable hangars. Larger airships will require custom-built sheds.(10)

Operational Procedures

Let is now review some of the operational procedures involved in airship operations. We will group these under ground procedures and flight procedures and limit the discussion to small non-rigid airships of the type currently flying.(11)

(i) *Ground Procedures*. Ground procedures begin with the *assembly and inflation* of the airship. This should be carried out inside a suitably sized hangar. The hangar floor and roof should be in a reasonable condition to ensure that no debris can damage the fabric of the envelope. When all the airship's components have been assembled at the hangar, a protective plastic ground sheet is rolled out over the inflation area. The hull envelope is unpacked, lifted onto the ground sheet and unrolled, an operation that takes an hour or so. The envelope is partially inflated with air and checked for pinholes or signs of transit damage. The internal catenary gondola suspension system is fastened to the load curtains. Once the air valves, ballonet trunks, inspection dome and other minor items have been fitted, the envelope is covered by an inflation net which is used to hold it down when inflation with helium takes place. Sandbags are arranged around the periphery of the net and emergency restraint lines are attached to strong points on the hull. The envelope is now ready for inflation.

In order to ensure that no air is trapped inside the envelope, a vacuum pump is connected to a fitting on the envelope and run for several hours. The helium supply is then coupled up to a non-return valve on the underside of the envelope and inflation commenced. Helium is available in most parts of the world in banks of cylinders under high pressure, either in the form of a 'Kelley' (a bank of large cylinders 12m long containing a total of 5000 cu.m) or in racks of cylinders of 9 cu.m, (the racks containing multiples of 16 cylinders). Most of the worl'd helium comes from the U.S. An idea of freight costs and delivery times is given in Table 5.2.

The envelope gradually rises from the floor. The sandbags on the inflation net are rearranged as the envelope fills. Inflation is a straight forward operation and for a small non-rigid can be completed in about 12 hours. When the envelope is inflated, the gondola, engines and empennage are fitted. The ship is then ballasted and the net removed. The nose cone and nose battens are

ONE WAY OCEAN FREIGHT

11,000 GALLON HELIUM CONTAINERS

FROM	TO	COST	APPROX. DAYS
NEW YORK	ENGLAND	$ 3,200	10
NEW YORK	EUROPE	$ 2,600	10
NEW YORK	FRENCH GUIANA	$10,700	12
NEW YORK	BRAZIL	$13,000	14
LOS ANGELES	JAPAN	$ 6,000	16
LOS ANGELES	SINGAPORE	$16,000	20
LOS ANGELES	SYDNEY	$10,000	22

Table 5.2: Helium Freight Rates

Source: H.A. Grieco, 'Helium: Rarer than Thought', UNIDO 453/26 LTA-8, October 1981, p. 8

then attached. Final fittings are made to the gondola. After a full inspection, the ship is ready for roll out.

An experienced assembly crew can complete the above operation within 20 days.

The airship will require *periodic topping up* with helium. Helium in an airship loses purity by becoming contaminated with air in spite of the fact that the gas is always maintained at a slightly positive pressure. The air permeates through the envelope's skin at a rate of about one quarter of that at which helium permeates out. If the helium loss is 20% per annum, replaced by a periodic topping-up process, then there will be a 5% air contamination resulting in a 5% loss of lift. Purification is normally required when purity levels in the envelope drop below 94-95%. This means that purification will usually need to be carried out once per year.

The purification process is straight forward. The gas is extracted from the lowest part of the envelope, passed through a purifier, and fed back in, usually at the front of the envelope. In due course, most of the impurities are removed.

Two main types of purifiers are available commercially, both primarily designed for the recovery of diving gases. The first employs cryopurification, a refrigeration process that relies on the fact that a gas cooled below its critical temperature will liquify when the pressure is above a minimum value. Helium has an extremely low critical temperature and remains a gas while oxygen, nitrogen, carbon monoxide, methane, etc., are liquified and can be decanted from a suitable separator. Liquid nitrogen is used as a refrigerant. Water and carbon dioxide are extracted before the low temperature purification stage.

The second purification process is based on a series of absorption, filter columns which remove water, carbon dioxide and air respectively.

An oxidizer bed converts carbon monoxide to carbon dioxide prior to the gas being passed through the carbon dioxide column.

There is an unavoidable loss of helium during the purification cycle. In the cryogenic process the discharged liquid impurities contain a certain amount of dissolved helium, and the filter columns of the absorption/filter process require periodic purging, thus losing the helium they contain at the time. The airship will need therefore, to be topped up at the end of the purification process.

Once a non-rigid airship has been inflated it is necessary to maintain a positive pressure inside the envelope at all times, both to maintain the shape and to prevent the lifting gas from being contaminated by air. In flight, the necessary pressure is obtained by air scoops, with appropriate ducts and control valves leading to the ballonets. When the main engines are not running the pressure must be maintained by an auxiliary blower. When the ship is moored, therefore, a ground power supply must be available and a pressure watch maintained.

Mooring is one of the most important of all ground procedures. The normal method of mooring an airship in the open is to attach it by the nose to an appropriate mast in a way that allows the airship to swing such that it is always headed into the direction of the prevailing wind. The standard mooring procedure is to approach the mast into the wind with neutral buoyancy. A line from the mast head is attached to the nose cone, and the airship is winched the short remaining distance. The ship is then ballasted to a slightly heavy condition so that the castoring wheel under the car remains in contact with the ground as the airship weathercocks into the wind.

A probe on the nose of the airship engages a socket on the mast-head where it is retained by spring loaded catches, operated by a lever, so that they can be set in the 'locked', 'free', or 'release' position.

Once the probe has engaged the catches the lever is moved to the locked position and secured to prevent inadvertent movement.

A variety of mast systems can be used. For a permanent base a fixed mast is desirable, secured to suitable foundations and with ground power supplies led to the base of the structure. For operations away from a base a portable pole mast can be used. This is anchored to the ground and cable-braced. A mobile mast is most often used for maneuvering the airship into and out of the hangar. The mast is either mounted on a heavy prime mover or operates as a wide-base, ballasted, towed structure. Such a mast can also be used operationally, tied down to strong points if high winds are expected.

It is possible to secure an airship without the use of a mast. One method is the three wire system where wires from the nose of the ship are attached to anchor points on the ground. The ship is then made 'light' to tauten the wires and it then flies attached to the apex of a triangular pyramid. Simplest of all is to attach lines to all the handling points which are located along the side of the ship, and literally tie the airship down. This scheme was used prior to the development of the mast system, and can be used where short-term landings are required on unprepared sites.

(ii) *Flight Procedures.* Prior to *take-off*, the fully loaded airship must be 'weighed off' to determine whether and to what extent the ship is 'light' or 'heavy'. On a modern airship like the *Skyship 500* this is carried out by simply reading a cockpit instrument which indicates the ship's heaviness. At take-off, with full fuel, the ship will normally be substantially heavy. The water ballast carried can be dumped by the pilot to achieve the required take-off heaviness.

The engines are then started up (in a modern ship from its own batteries) and the ship released from its mast. In the case of a fixed mast the vessel must be backed away downwind; a mobile mast can be driven away from the ship. The airship is trimmed to level condition by adjusting the air in the ballonets, the ground crew instructed to let go and stand clear, and the ship takes off.

In airships with vectored thrust, a vertical take off is possible. The usual procedure, however, is to use the ZTOL technique. The airship builds up speed during a steeply angled climb out (in the order of 45°) from a stationary position. This provides early directional control and the possibility of supporting static heaviness with dynamic lift in the event of an engine failure shortly after take-off.

In flight, a slightly heavy ship will fly with its nose up, a light ship with its nose down. Prior to *landing*, the ship is trimmed to level condition by adjusting the air in the forward and aft ballonets. This is done either by slowing down and performing the operation directly, or by maintaining cruising speed and adjusting the ballonets until the ship flies in level attitude with the elevator control in mid position. A normal aircraft type approach can then be flown.

Airships with vectored thrust can use this capability to control their descent and to check forward speed. As the ship comes to rest it is caught by the ground crew, ballast is put aboard if the ship is light, and it is then guided to the mast. Engines are not stopped until the ship is safely secured to the mast. In strong winds, an airship with vectored thrust can make a so-called 'high landing': it is brought to a stop about 7m above the ground and the vectored thrust is used to bring it down vertically.

5.5 Airship Applications and Operations in Developing Countries

The airship has an undoubted potential in developing countries and this potential has been recognized by some Third World governments, notably in Latin America. Government organizations in Argentina, Brazil, Colombia, Peru, Venezuela and also Ghana and Upper Volta have examined the feasibility of introducing airships. Some Third World groups have actually sponsored airship development work, the best known example of this being the support given by the Venezuelan company 'Aerovision' to the development of the *AD-500*. This company at one time expressed an interest in acquiring no less than 22 small non-rigids for aerial communications and advertising work.(12) Aerostat telecommunications systems have been partially installed in Iran and Nigeria and the company that installed them hopes to sell some 20 systems to developing countries in the next five years or so. (cf. Chapter 9).

Many Third World governments, however, have given little serious thought to LTA systems. Some that have remain sceptical. They are unfamiliar with airships and have no experience of operating them. Like their counterparts in the industrialized countries, they are inclined to see airships as 'old' technologies which are both unsafe and limited in their applications. Some, with a more positive view, are not convinced that LTA systems are fully operational and can compete successfully with other modes. They also see that Western governments are not backing LTA development with public money. Experience tells them that if airships are the breakthrough they are sometimes claimed to be, then governments would be actively supporting their development.

The airship is pre-eminently a Third World vehicle, and this may help explain why Western governments have not rushed to support it. The fields of application in the Third World are basically the same as those in the industrialized countries but only more so: maritime patrol, freight and cargo heavy lift, and cost effective communications, perhaps even passenger travel. Many developing countries have acquired very large Exclusive Economic Zones under the new Law of the Sea and are now faced with the task of patrolling their extended national jurisdictions with little in the way of effective monitoring and surveillance platforms. Some evidence suggests that airships could perform maritime patrol 5-10 times more cheaply than

HTA craft. (cf.Chapter 6).

The airship's heavy lift and freight carrying applications in developing countries are particularly numerous. (cf.Chapter 7). It may have a special role to play, for example, in opening up remote and inaccessible areas. As noted above, airships are most competitive when other alternatives - on the ground and in the air - do not exist or are poorly developed, which is often the case in regional development projects. The cost of road construction for such projects typically varies from $100,000 per km to up to $1.5 million per km in badly drained areas, sometimes characteristic of tropical rain forests. Such roads are prone to periodic flooding and may be impassable for several months a year. Their maintenance costs are high. Moreover, the construction of roads in such areas can lead to soil erosion, other types of environmental damage, and to the destruction of wildlife habitats. The use of airships in such cases may not only prove cost effective but also environmentally and ecologically the most appropriate response

In other cases, the airship could prove a useful interim mode. It could be used to initiate regional development projects, to get things moving. When the project becomes established and is generating revenues, permanent ground infrastructure can be constructed. Should the project fail, little will have been lost. Where airports are used to open up remote areas, ancillary roads and secondary systems are required, unnecessary in the use of airships.

Airships may also be able to contribute to the solution of multimodal problems, typical for example, in the transport of goods and commodities to and from land-locked states and ports. They may also have a special role to play in ship off-loading in portless areas and in congested ports.

A study made of potential airship applications in Egypt, India, Indonesia, the Philippines, Brazil, Paraguay and Peru, suggests that the airship could be used, in addition to maritime patrol and regional development projects, for the transport of low density bulk cargos from areas of production to ports for export, the transport of perishable commodities, such as fish, fruit and vegetables from areas of production, such as lakes and oases, to centres of consumption, and for inter-island transport and communication in archipelagic states, such as Indonesia and the Philippines. Airships, the study also notes, would make it possible to effectively service outposts with medicines and health related equipment.(13) They could also be ideally suited to disaster relief and the provision of emergency supplies. Other studies have attempted to show that the airship can be cost competitive in Third World applications, able to compete with even trucks over difficult terrain.(14)

These applications remain theoretical ones. They have yet to be subjected to serious examination and compared with the alternative modes that are currently available. The fact is that the most suitable kind of airship for Third World missions and Third World environments is just not known. It may be wrong to assume that an airship developed for use in an industrialized country is necessarily appropriate to the needs and conditions of developing countries. Precision hover may be required for the U.S.Navy and U.S. Coast Guard, for example, but may not be required to transport low density cargos in developing countries. Precision hover only makes airships more expensive and delicate.

The limitations of airships would be more acutely experienced in Third World environments. These limitations stem from the laws of physics, the laws of economics, the laws of nature and, in the real world, as suggested in Figure 5.1, a complex mixture of all three. Payload capacity, for example, is reduced as temperature, humidity and altitude increases. This indicates reduced lifting performance in many developing countries. High winds and cyclonic storms will constitute major problems in some regions. U.S.Navy

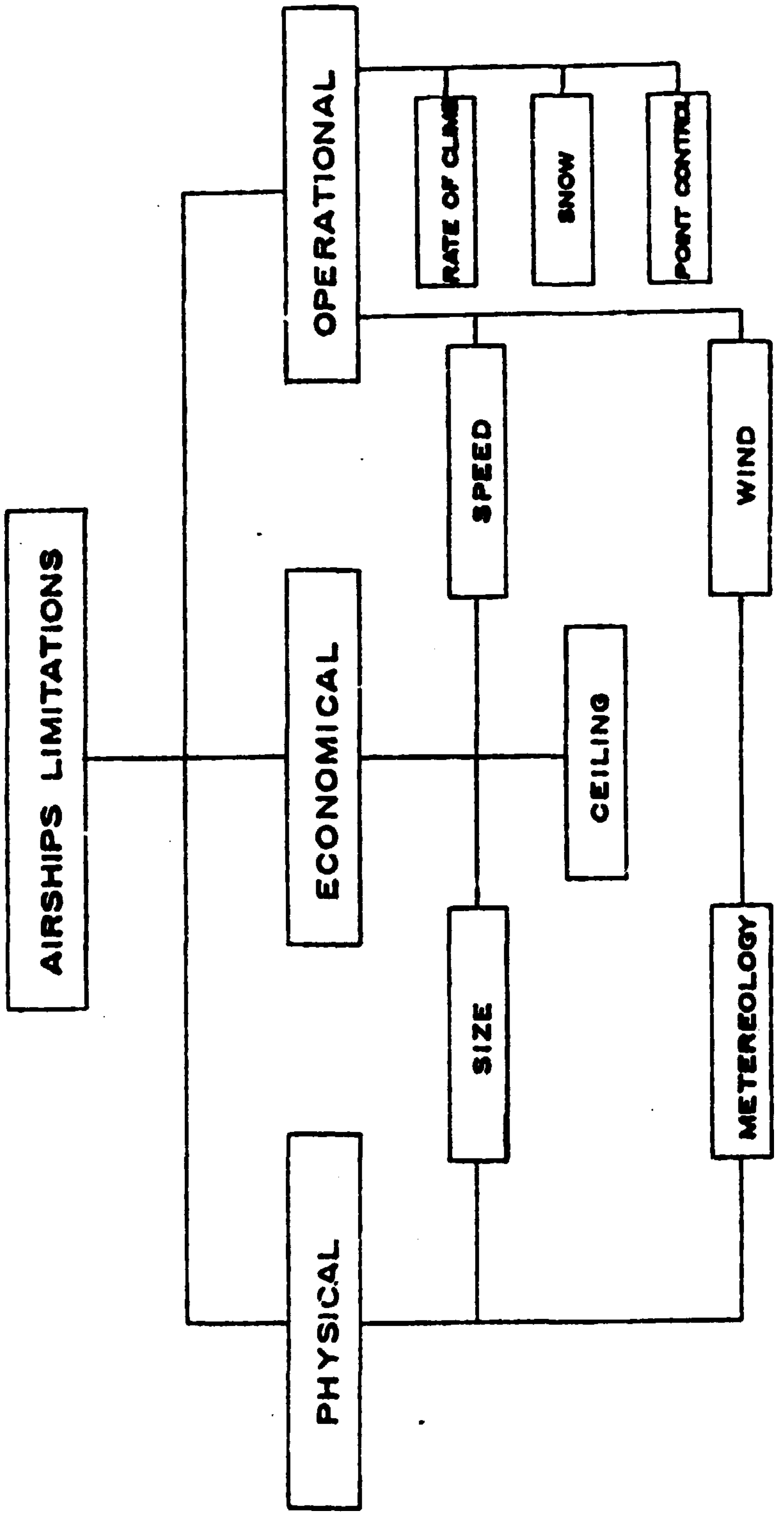

Figure 5.1: Main Limitations of Airships

Source: G. Cahn-Hidalgo, 'General Applications and Limitations of LTAs', UNIDO 453/26 LTA-4, October 1981, p. 9

pilots may have successfully landed large non-rigid airships in winds of nearly 50 knots (considered unsafe for airplanes), but as a general rule, non-rigids of the type flying today cannot be landed in complete safety in winds gusting over 25 knots. Third World airship crews would, by definition, be comparatively inexperienced crews. Similarly, a Third World operator in a region prone to cyclonic storms would need to be sure that he has sufficient time to either hangar his airships in a shed that will withstand the storm or to fly the ships out to a safe location equipped with mooring masts.

Decisions on the usefulness of airships in developing countries are seriously hampered, as they are in the industrialized world, by the general lack of 'hard data' on the costs of airship operations and on the difficulties that can be encountered. The only operational experience with airships in developing countries in recent times is the limited demonstration project conducted by WDL in West Africa. In 1976, the *WDL-1*, a small non-rigid based on a 1930s U.S.Navy design, flew for several months in Ghana and Upper Volta. The trial, supported by the German Agency for Technical Cooperation (GTZ), was considered 'very positive' but was not continued nor were the results published. The main reason given by GTZ for terminating the demonstration was the lack of management and organizational capacities in the developing countries. 'It is a question', GTZ has observed, 'whether these countries are prepared and in a position to establish this new transport system now, with all consequences, it being entirely new to them'.(15) In any event, there is a considerable need for more demonstrations supported by public monies, in different parts of the Third World. Such demonstrations should be carefully monitored and the results made available to developing country governments and aviation groups.

One potentially interesting demonstration is in preparation in Peru. The government of Peru intends to invite WDL to demonstrate the feasibility of using airships, in this case the *WDL-1*, for various maritime operations, including the enforcement of laws and treaties, oceanographic studies, and the collection of meteorological data. UNIDO has been requested to participate in the demonstration project and to disseminate the results to interested parties. Many more such demonstrations are required before data can be analyzed, compared and made available in ways that facilitate decision-making.

Market studies conducted by the airship industry in Africa suggest that an airship for internal transport should meet the following requirements:(16)

- have a payload capability of 30-50 tons;
- have a 250-500 km range;
- be able to operate in winds of 40-50 knots and land in winds of 30 knots;
- be suitable for day and night time operations;
- be able to operate in temperatures of 50-60°C;
- envelopes should be able to withstand temperatures of up to 80°C;
- have airfield lengths of 300-400m for safe operation;
- provide for fast and safe loading and unloading;
- have good controllability and maneuverability both on the ground and in the air;
- sand or water should be available for ballasting;
- hangar facilities for major maintenance should be available;
- ground crew requirements should be low.

There is no disguising the fact that such an airship would be large and sophisticated, far longer and sophisticated than any non-rigid now flying or, indeed, that has ever flown. A 30-50 ton payload capability means an airship of 40,000-60,000 cu.m, perhaps 120-130m long. High levels of controllability on the ground and in the air and the ability to land in 30 knot winds means vectored thrust and a VTOL capability. Such an airship could be built but it would be an advanced vessel wing on the most recent advances in construction and propulsion technologies and materials. Its operating environment is hostile and it may be mistaken to believe that it could operate trouble free without regular hangarage.

The cost of such an airship is more a matter of speculation than fact and hinges on production numbers. A 'one-off' vessel would conceivably cost $50 million. If produced in significant numbers the cost could possibly be reduced to as low as $5 million. For $5 million a developing country would have a very sophisticated aircraft that could outperform any competitor, which at present does not exist.

It is certainly appropriate for developing countries to examine the feasibility of using airships and other LTA craft for different purposes. Should they decide to go beyond feasibility studies into airship operations, then several 'rules' would need to be observed. Firstly, an airship is not a truck or a rail car and never will be. There will be few advantages in introducing a single airship for it is likely to be little more than an expensive toy. The effectiveness of an LTA system lies in the gradual introduction of a fleet of vehicles sufficiently large to justify initial investments in the provision of basic infrastructure, the development of required ground skills, and crew training. Secondly, the guiding principle should be to start small with proven technologies and over-the-water operations.An appropriate approach might be to use small maritime patrol and surveillance airships to gain experience and to develop skills. If the experience proves satisfactory move into larger airships and internal transport and, perhaps eventually, into passenger operations. It may be no exaggeration to suggest that in some developing countries people may need to see airships in operation for some time before they are prepared to travel in them.

There is, however, no reason why developing countries should be passive importers of airship technologies. Given the airship's fuel efficiency and its multi-role potential, there is a lot to be said for developing countries adopting a more active position. They might even consider moving into airship R & D and, eventually, construction. Some developing countries - Argentina, Brazil, India, Indonesia, for example - have aviation industries and a tradition of aeronautical research. A few, like Brazil, even have large airship hangars, remnants of the age of the giant rigid airship. The same countries are among those which have acquired the largest Exclusive Economic Zones under the new Law of the Sea. And some of them, again like Brazil, have ambitious programmes of regional development, while others, like Indonesia, have problems of inter-island transport.

Airships are labour intensive and have high labour costs. Developing countries could be competitive producers. A decision to move into airship manufacture could help to establish developing countries in a mainstream of technological advance and innovation. The search for appropriate technological solutions to some of the problems posed by LTA systems could, should it lead to the acquisition of knowledge and skills in advanced areas, serve to promote the process of technological innovation and the development of indigenous technological capabilities. If the airship is indeed a pre-eminently Third World vehicle, it is right and proper for developing countries to be at the forefront of its development.

There is no reason, however, why developing countries should seek to go it alone. To do so would be to deny the relevant LTA technologies, skills and experience accumulated over more than a century in the industrialized world. The field of LTA transport is large and it would be neither necessary nor desirable for developing countries interested in developing operational airships to isolate themselves from what has been learnt over a long period of time and, often, at considerable expense. The development of airships could prove to be an area in which it is possible to devise innovative programmes of technical cooperation involving both developed and developing countries. The essential context for such programmes would need to be the furtherance of mutual interest through the development of technologies from which both developed and developing countries could benefit. And because the interests would be shared interests, the programmes could be organized on a partnership basis.

Notes and References

(1) Quoted in 'Return of the Airship', *Kanata* (Magazine of C.P.Air), September - October 1981, P.30.

(2) See, for example, G.L.Faurote, *Feasibility Study of Modern Airship: Phase I, Volume III - Historical Overview*, NASA CR 137692, August 1975.

(3) Goodyear often has to patch up holes in its advertising/aerial photography non-rigids inflicted by those with the mistaken belief that they 'can bring down a blimp'.

(4) These conclusions are contained in D.B.Bailey and H.K.Rappoport, *Maritime Patrol Airship Study (MPAS)*, Naval Air Development Center (Report no. NADC - 80149-60), Warminister, Pennsylvannia, 19 March 1980, Appendix A.

(5) For a description of the U.S. Navy's weather evaluation programme, see NASA Report no. 2-8643, NASA Ames Research Center.

(6) See Naval Air Development Unit, *Second Partial Report on Project NDSW/ONR-46101, Evaluation of the All Weather Capabilities of Airships*, NADU, South Weymouth, Mass, 1 March 1957.

(7) See Goodyear Aircraft Corporation, *An Operational Evaluation of Airship Early Warning Squadron One (ZW-1)*, (Reports no. GER. 8438 S/I and GER 8439 S/2) Akron, Ohio.

(8) See W.A.Biering, *Ground Handling of Airships: Evaluation of Equipments and Development of Techniques*, U.S. Naval Air Station, Lakehurst, N.J. (Report no. 3-57),.14 June 1957; and S.Scheindlinger, *Survey of Flight Load Parameters in Model ZPG-2 Airships*, Naval Air Material Center (Report NAMATCEN-ASL-1017), 6 March 1959.

(9) See *They were Dependable - Airship Operation in World War II (Second Edition)*, U.S. Naval Air Station Lakehurst, N.J. 1946.

(10) The European Operation of Goodyear utilizes a purpose-built hangar at Copena, outside Rome. Airship Industries' operation makes use of the sheds constructed in the 1920s for the *R-100* and *R-101*. WDL has an inflatable hangar at Essen-Mulheim.

(11) The following ground and flight procedures are based on information published by Airship Industries, notably *General Airship Operations Data : Data Sheet 5, Issue 2.*

(12) Reported in G. Lamb, 'Airships Again', Earthscan, International Institute for Environment and Development, London, 1980 (mimeo)

(13) See G.Cahn-Hidalgo, 'Potential Cases for LTA Uses', UNIDO (Paper 453/26 LTA-5), Vienna, October 1981 (mimeo)

(14) See Cahn-Hidalgo, op.cit. Annex II, G. Cahn-Hidalgo, Developments of ighter Than Air Flights in Latin America', AIAA Paper 81-1318; W.V.Kirschbaum, 'Recommendations for Airship Use in Developing Countries, Technisch-Wirtschaftliche Beratung (TWB), Bensberg am Rittersteg (FRG), October 1981 (mimeo); and Helitrans Consulting, *The Helitruck VTOL Cargo Mover*, Burgbrohl bei Bonn (FRG)/New York, no date.

(15) Quoted in Helitrans Consulting, op. cit.

(16) The following requirements were presented by representatives of WDL to the UNIDO 'Expert Group Meeting on the Implications of Technological Advances in Lighter-than-Air Systems Technology for Developing Countries' held in Vienna, 19-22 October 1981. The requirements resulted from WDL's experience in operating its *WDL-1* in Ghana and Upper Volta during a limited demonstration project in 1976.

6. THE MARITIME PATROL AIRSHIP

6.1 Introduction

Under the new Law of the Sea, some eight years in the making, the national jurisdiction of coastal states is extended from a few miles to 200 nautical miles, with provisions for possible extentions beyond that. Within their greatly extended jurisdictions, coastal states have exclusive economic rights to the exploitation of living resources and the non-living resources of the sea-bed. The Exclusive Economic Zones (EEZs) acquired by some coastal states are truly immense. Those of the U.S. and Australia, for example, are in excess of 2 million sq. nautical miles, those of Indonesia, Canada and New Zealand are in the order of 1.5 million sq. nautical miles, while those of Brazil, Chile, India, Mexico and the Philippines vary between half a million and one million sq. nautical miles. Some scattered archipelagic states in the Indian and Pacific Oceans, such as the Maldives, the Seychelles, Kiribati and Tuvalu have acquired EEZs out of all proportion to their land area, so large that they defy delimitation.

Exclusive economic rights bring their own responsibilities, duties and obligations. If rights are to be 'exclusive', for example, then they need to be defended: there is the responsibility of ensuring that they are not contravened by the direct and indirect actions of others. Economic zones and the many activities that take place within them - shipping fishing, mining, navigation, as well as smuggling and pollution - thus require continuous observation. The very size of the zones, however, make monitoring and surveillance a very difficult and costly affair. It is not surprising, therefore, that the question of maritime patrol is receiving the detailed attention of developed and developing countries alike.

There is a new, expanding - and lucrative - market for maritime patrol vehicles. Certainly, fixed wing aircraft manufacturers have not been slow in developing maritime patrol variants of their basic business aircraft and small airliners. Virtually all the manufacturers of turboprops and business jets are developing vehicles for what they call the 'inshore maritime market'.(1) Some of their aircraft are fully operational and first sales have been recorded. Operational aircraft, prototypes and demonstration models are embarking on world-wide sales tours, with very frequent stops planned in Third World capitals.

Without any doubt, maritime patrol is the best attested of all past airship activities and it is in this role that the airship, with its special set of attributes, can compete with alternative modes. In a real sense, the airship has been waiting in the wings for the new Law of the Sea. If it is to make a reentry, it will be in the role it has performed so well in the past. The technology advances recorded in the past 30 years will ensure that, if given the opportunity, it will perform even better in the future.

Airship manufacturers are making special efforts to capture a share of the 'inshore maritime market'. Their share is potentially large. Goodyear Aerospace has, for example, projected a world-wide need for 100 maritime patrol airships.(2)

In this chapter we will review the maritime surveillance attributes of airships, examine studies made of the surveillance potential of airships, and look at the kind of airships required and on offer for maritime patrol duties.

6.2 The Search and Surveillance Attributes of Airships

The airship is literally a ship in the sky. It combines many of the attributes of the displacement vessel and the airplane. It has the ability to travel at higher speeds than ships, it is not affected by high sea state, and has the ability to survey the sea from high above it. At the same time, it has the ship-like characteristics of long endurance, the ability to travel at slow speed or to remain stationary, and it can deliver a substantial payload. More specifically, the airhsip's attributes include the following.

. They provide a stable platform conducive to visual observation and sensor operation. Even small non-rigids make stable platforms in moderate wind conditions.

. They have speed range. The speed range of a modern conventional airship would vary from the precision hover (using vectored thrust) required for certain missions, such as boarding, to speeds of up to 150 kph, faster than the fastest surface vessels and fast enough to sweep large areas in short time.

. They have a wide horizon, giving the observer a broad view from their operating altitude. At 2000 ft the line-of-sight radar range is 50 nautical miles, giving the airship a radar coverage of 100 nautical miles. At 7000 ft radar range would be sufficient to oversee a 200 n.m. EEZ. Since the pressure altitude of most modern non-rigid airships is in the order of 10,000 ft., radar coverage would extend well beyond the limits of EEZs. Even at 2000 ft, one 72 hour patrol at 38 knots gives a potential coverage of 274,000 sq. miles. A surface vessel with a radar range of 20 n.m. would require approximately 19 days to sweep the same area.

. They have long endurance. They can stay on station for days without requiring refuelling or back up services. A 20,000 cu.m non-rigid would be able to undertake 30 hour missions; a 50,000 cu.m. airship would be capable of week long missions. By way of comparison, converted business jets have an endurance of 3½-5 hours at 150 n.m. from base. Even large turboprops equipped with extra fuel tanks, like the F-27 Maritime and the BA 748 Coastguarder, have at best 9-10 hours duration at 150 n.m.

. They are able to descend rapidly to provide close observation and they can, if required, launch the surface vessels required to effectively fulfill certain types of missions, such as search and rescue.

. When operating at lower altitudes they have a significant 'deterrence presence'. When operating at higher altitudes they have high radar transparency and a low infra-red signature, both important where airships are used to monitor illegal operations, such as fishing violations, pollution discharges, and smuggling.

. They are fuel efficient, requiring hundreds not thousands of pounds of fuel per flight hour. As a general rule, an airship requires one quarter of the fuel required by a HTA craft to carry the same payload.

. They have low noise levels. Even in close to the water operations, little noise is transmitted into the water, important in ASW and some oceanographic missions.

. They offer an excellent crew environment. They have low noise, vibration and acceleration levels. In the airship's large car, there is space to stand and walk around.

These attributes are precisely those required for cost-effective and efficient monitoring and surveillance of large areas of ocean space at long distances from a 'home base'. At a minimum, a maritime patrol vehicle must be able to detect surface vessels, to positively identify them and to record their position and, where necessary, to initiate action by, for example, direct intervention or by summoning others to investigate the situation. Clearly, the modern conventional airship can do all of this and very much more besides.

6.3 The Airship as a Maritime Patrol Vehicle

The potential of the modern conventional airship for maritime patrol has been most extensively studied within the framework of investigations conducted for the U.S. Coast Guard (USCG). In 1975 the Coast Guard initiated a programme aimed at identifying cost-effective and fuel-efficient platforms required in connection with its greatly expanded monitoring and surveillance duties. This programme has included evaluations of the airship.

The predominant need within the Coast Guard is for a cost-effective aerial surveillance platform which is able to interact with the surface. It should be able, for example, to deploy and retrieve a small boat, to tow a small craft, to operate pollution sensors, and to deliver bulky and moderate weight payloads (in the range of 3,000-20,000 lbs) to the scene of pollution incidents. It was recognized by the USCG that the airship might be able to meet this requirement.

Between 1975 and 1978, the U.S. Navy's Center for Naval Analyses (CNA) examined, on the USCG's behalf, the feasibility of using airships for maritime patrol duties. The Coast Guard specified that the airship should meet the following requirements:

- Have an endurance of 1-4 days, depending on vehicle cruising speed;
- Have a 90 knot 'dash' capability;
- Provide for fuel-efficient operation at low to moderate speeds (20-50 knots);
- Be controllable to the extent required to operate all missions in winds gusting up to 45 knots;
- Be able to operate for extended periods in arctic weather conditions; and
- Be able to survive - both on the ground and in flight - the severe turbulence and gusting winds associated with local thunderstorm activity.

CNA's analysis confirmed that these requirements could be met. A number of potential LTA vehicles were conceptualized and their probable operational costs compared with those of current and projected USCG platforms.(3)

The Maritime Patrol Airship Study

These analyses were continued in an important study made by the Summit Research Corporation and the Naval Air Development Center (NADC) under contract to the U.S. Naval Air Systems Command and the USCG. This study, known as the Maritime Patrol Airship Study (MPAS), had the following main objectives: (i) to identify the missions that could be performed by LTA craft and to establish the rationale for using them for such missions; (ii) to evaluate the effectiveness with which the missions could be accomplished; (iii) to define the type of airship required to perform missions effectively, this to include appropriate LTA case studies; and (iv) to estimate the acquisition and operating costs of the airships described.(4)

It was assumed at the outset of the study that the main requirements of a maritime patrol airship should be:

- a real hover capability;
- a VTOL capability;
- a 90 knot top speed;
- the ability to tow sensors and vessels;
- the ability to operate in severe weather conditions; and
- low power requirements and high fuel efficiency.

It was further assumed that a modern helium inflated non-rigid airship could meet all of these requirements.

In the MPAS, USCG missions are first reviewed. Of the 13 programmes operated by the Coast Guard, 8 were identified as being suitable for airship applications. These programmes are listed in Table 6.1. 'Realistic missions" were then defined for each of the 8 programmes and a range of 'mission profiles' were developed which specified in detail the sequence of operations to be performed by the airship, the main performance parameters (speed, weight, payload, etc.), and mission duration. In total, 264 mission profiles were identified as being appropriate to airship operation.

USCG missions are currently being performed by medium and high endurance cutters, helicopters, and fixed wing aircraft. The mission analysis indicated that a moderate sized airship could fill a void in both the speed/payload and speed/endurance regimes provided by current platforms, as shown in Figures 6.1 and 6.2.

ENFORCEMENT OF LAWS AND TREATIES • Surveillance, Interdiction and Seizure of Illicit Fishing and Drug Traffic	(ELT)
SEARCH AND RESCUE • Search, Logistics and Aid	(SAR)
MARINE ENVIRONMENTAL PROTECTION • Search and Surveillance of the Marine Environment • Assist in the Logistics and Command, Communication, and Control of Clean Up Operations	(MEP)
PORT SAFETY AND SECURITY • Hazardous Cargo Traffic Control • Command, Control and Communications	(PSS)
MARINE SCIENCE ACTIVITIES • Ice Patrol • Oceanographic Survey • Locating Buoys	(MSA)
ICE OPERATIONS • Surveillance of Ice Conditions	(IO)
SHORT RANGE AIDS TO NAVIGATION • Monitor Buoys	(A/N)
MILITARY OPERATION/PREPAREDNESS • Surveillance for Enemy Forces • Antisubmarine Warfare (ASW) • Protection of Offshore Installations • Convoy Ships • Logistics Support • Inshore Undersea Warfare	(MO/MP)

Table 6.1: U.S. Coast Guard Programmes with Potential for Airship Utilization

Source: H.P. Rappoport, 'Analysis of Coast Guard Missions for a Maritime Patrol Airship', AIAA Paper 79-1571, p. 1

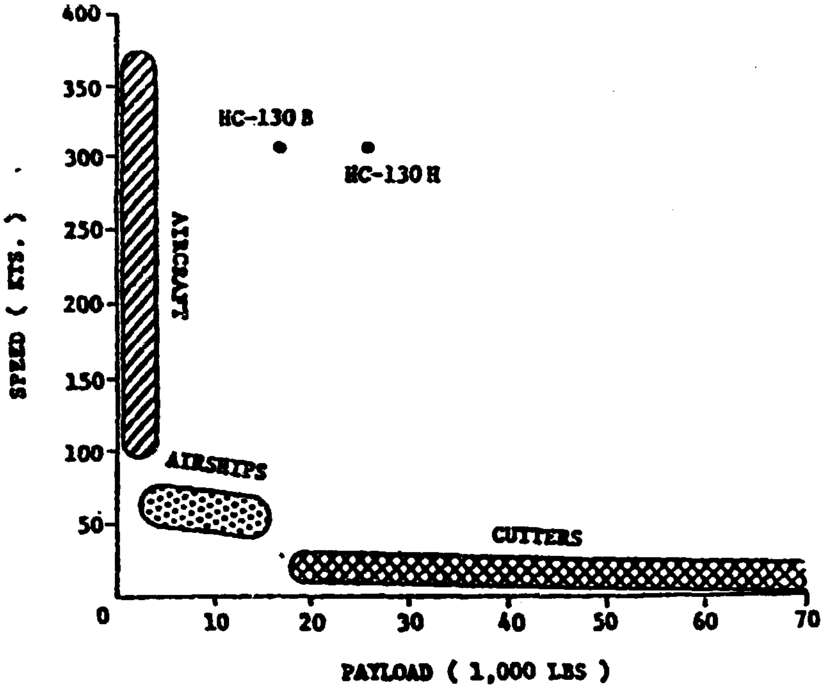

Figure 6.1: Speed/Payload Relationship Coast Guard Platforms

Source: H.F. Rappoport, 'Conventional Airships', UNIDO 453/26 LTA-7, October 1981, p. 14

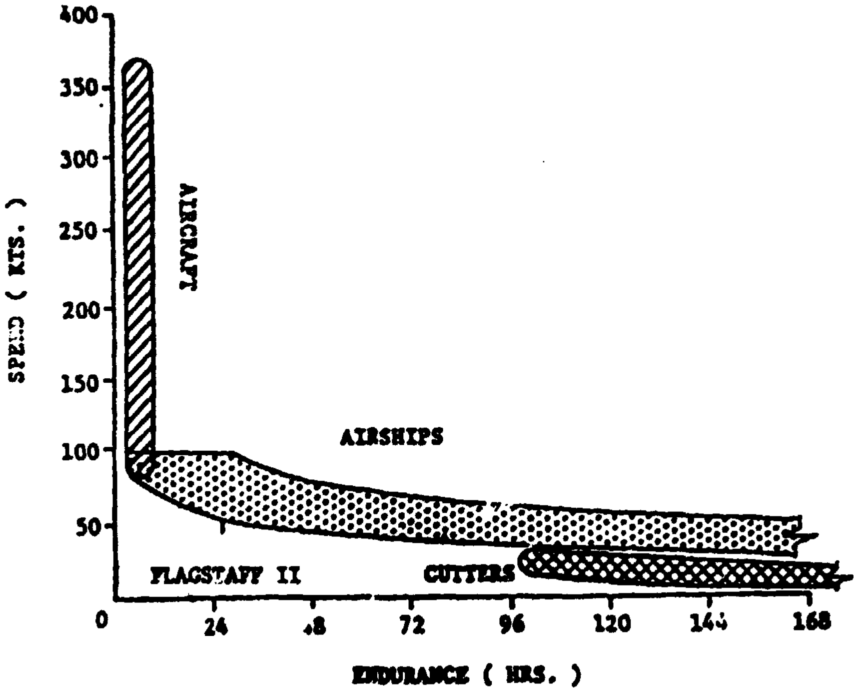

Figure 6.2: Endurance/Speed Relationship Coast Guard Platforms

Source: Ibid

The analysis of mission requirements for a maritime patrol airship also revealed that:

- Over 90% of all the operations analyzed utilized transit or patrol at 50-60 knots;
- Station-keeping/trailing at less than 20 knots is utilized in over 60% of missions;
- Only short-range A/N and PSS operations do not require a search capability;
- Hover capability for either boarding or logistics operations is only required in 33% of the missions. Most of the missions requiring a hover capability are for either SAR or ELT operations;
- 47% of all flight hours are for ELT operations, 30% with SAR. None of the other programmes accounted for more than 10% of the flight hour requirement;
- Shorter missions (less than 20 hours) tend to dominate in A/N, PSS, and SAR operations. Longer missions dominate in ELT, MEP, MSA and IO operations.

These findings were seen to imply the need for two types of maritime patrol airships: a smaller one capable of performing missions of up to 15 hours; and a larger vessel with an endurance of about 40 hours. The smaller ship would be designed primarily for economical operation, while in the larger one the emphasis would be on multi-mission capability.

The analysis also indicated that a Coast Guard airship could be expected to be in 'ready' status or on mission for about 90% of its operational life (64% 'ready' and 26% in the air). By comparison, the USCG currently utilizes its aircraft on an average of less than 10% of the time.

A NADC computer programme was used to generate and evaluate conceptual LTA vehicles - so-called three point designs - capable of performing the missions described. Conceptual designs for 8 vehicles, one for each of the programmes, were outlined. The main characteristics of each of these airships are given in Table 6.2. The 8 designs were then examined and the smallest vehicle capable of fulfilling all mission profiles was selected. The choice fell on the vehicle generated for marine environmental protection (MEP) missions. Only marine science (MSA) missions required a larger airship but it was determined that the MEP vehicle could perform MSA missions at a lower altitude in a satisfactory manner.

The vehicle sized for MEP missions was designated the *ZP-X*. This was used as a basis for cost evaluations. The *ZP-X* is a modern conventional non-rigid airship with a length of 93 m, a diameter of 21 m, and a volume of 22,200 cu.m. It has 3 engines, 2 mounted forward and a propulsor mounted at the stern, which together develop nearly 2000 hp. The engines can be rotated through 90° and provide for precision hover. It would have a useful load of 12 tons, a maximum speed of 90 kts and a pressure altitude of 10,000 ft. Except for the placement of the propulsion system, the trimotor *ZP-X* is a fairly conventional airship which serves to facilitate cost calculations.

Two approaches to the calculation of airship costs were used: life cycle cost (LCC), reflecting total life-time build up; and standard rate cost (SRC), calculated on an hourly basis. For calculation purposes, the *ZP-X* was considered capable of performing missions of up to 40 hours, or 72% of all possible airship missions described. Using 40 hours duration as a cut-off point, the approximate annual mission requirement for airships was found to be in the order of 125,000 hours. It was further assumed that each airship would fly 2,400 hours/year, resulting in a total requirement of 45-52 airships. With nine airship bases each operating 5 ships, a total of 45 would be required. With an additional 5 ships acquired for training, R & D, and back-up, the total purchase would be 50 airships. It was calculated that each

Table 6.2: Main Characteristics of Eight Maritime Patrol Airships

MISSION	ELT	MEP
Volume, (ft^3)	586,494	783,696
Static Lift, (lbs)	32,092	46,917
Dynamic Lift, (lbs)	5,224	7,638
Length, (ft)	277	305
Diameter, (ft)	63	69.3
Fineness Ratio, (ℓ/d)	4.4	4.4
Buoyancy Ratio	.86	.86
Horsepower Required	1,471	1,927
Gross Weight, (lbs)	37,316	54,554
Empty Weight, (lbs)	20,850	27,674
Useful Load, (lbs)	16,466	26,880
Empty Weight Fraction	.559	.507
Fuel Weight, (lbs)	8,812	5,057

Source: *Maritime Patrol Airship Study*, 1980, p. V-4

MO/MP	PSS	SAR	A/N	MSA	IO
700,045	282,390	392,154	447,330	992,165	607,678
38,305	15,454	21,458	24,477	54,289	33,251
6,236	2,515	3,493	3,985	8,838	5,413
294	217	242	253	330	280
67	49	55	57.5	75	64
4.4	4.4	4.4	4.4	4.4	4.4
.86	.86	.86	.86	.86	.86
1,651	942	1,142	1,236	2,076	1,506
44,541	17,967	24,951	28,462	63,127	38,664
24,527	10,816	14,478	16,289	33,717	21,540
20,014	7,151	10,473	12,173	29,410	17,124
.551	.602	.580	.572	.534	.557
6,650	915	2,568	4,752	21,638	9,706

airship could expect to have an operational life of 12 years and that crew sizes would vary from 5-13 depending upon the particular mission.

Four different approaches were used to calculate unit acquisition costs. These approaches were based on speed and weight, weight, systems weight, and on estimates provided by Goodyear Aerospace. The different approaches resulted in unit prices varying from $ 3.9 million to $ 8.45 million for a purchase of 50 ships. A further analysis of the 4 approaches led to the conclusion that the unit price for 50 airships was likely to be in the order of $ 5 million, with the first unit costing between $ 15-20 million. The addition of costs for ground stations, maintenance and training increased the total investment cost to approximately $ 6.4 million per airship. A R & D programme valued at $ 35 million was included in the calculation of purchase price.

With a 12 year life-time and an annual utilization of 2,400 flying hours, an airship would have a total flying life of 28,800 hours. For a purchase of 50 ships, the investment cost on an hourly basis would be in the order of $ 175 per hour.

Life cycle costs prorated on a flight hour basis were found to lie between $ 900-$ 1350, the difference depending upon the type of mission. Long duration missions were the most expensive due to higher crew costs. Personnel costs were the largest single element in LCC calculations, varying between $ 235-$ 567 per flight hour depending upon crew size, which is mission dependent.(5) The longer the mission the larger the crew. Missions of less than 10 hours were considered to require a 5 man crew; missions of longer than 20 hours 13 men.

Standard rate costs for airships were found to vary from $ 446-$ 654 per hour. This compares favourably with current USCG platforms, as shown in Table 6.3. SRCs for helicopters and small fixed wing aircraft vary between $ 614-$ 910 per hour, while those of the HC-130 and high endurance cutters are well in excess of $ 1000 per hour.

PLATFORM TYPE	STANDARD RATE ($/HR)
LTA	450 - 600
HC-130B	1,365.16
HH-3F	910.20
MEC 210	448.30
HEC 378	1,109.24
MRS* (HU-25A)[32]	614.90

*Estimate also based on HU-16E operational experience

Table 6.3: Comparison of Standard Rate Costs for Selected Coast Guard Platforms

Source: *Maritime Patrol Airship Study*, 1980, p. VIII-25

A special analysis of fuel efficiency was also conducted. The most frequently occuring proposed airship missions were chosen for this analysis (4 ELT missions and 5 SAR missions). The airship's SRC and fuel requirements for these missions were compared with a broad range of Coast G rd cutters and aircraft. It was found that cutters are always more expensive to operate than airships. Small helicopters could be cheaper to operate. Larger ones would always be more expensive. Neither of the helicopters, especially the smaller ones, however, had the performance capability of the airship and were unable to undertake all the missions covered in the analysis.

A comparative analysis of fuel consumption for 13 selected missions (4 ELT and 9 SAR) indicated that the *ZP-X* would use 50% of the fuel required for helicopters, 20-50% of the fuel required for airplanes, and 15-16% of the fuel required for cutters. In some cases, the ubiquitous HC-130 was found to require 8 times the fuel needed for the airship to accomplish the same mission, while cutters sometimes required 10 times the airship's fuel.

The MPAS is also interesting for other airship design concepts that emerged from it. The need to compare the *ZP-X* vehicle analysis with independent thinking was acknowledged. Goodyear Aerospace and Bell Aerospace Textron were given the airship mission profiles prepared as part of the MPAS and invited to propose conceptual vehicles capable of performing them.

Goodyear proposed the *ZP3G*. Presented as a near-term low risk prototype, the vehicle is a derivative of the non-rigid *ZPN-1* developed by Goodyear for the U.S. Navy in the 1950s.(6) The main differences between the two airships reside in the envelope material, car configuration, and the propulsion system. The ZPN envelopes were cotton. The *ZP3G* would use Dacron, a polyester fabric. The ZPN's gondola is reconfigured to simplify design and to reduce production costs. The ZP3G's propulsion system is redesigned to provide significant improvements in low speed control and a VTOL capability. The propulsion system is made up to three engines, two mounted forward and one at the stern, each capable of developing 800 shp and driving propellers. The forward propellers and the stern propulsion system can be rotated through 90% for VTOL and low speed control. The forward engines are mounted externally on struts, not fixed to the car, so as to reduce noise and vibration levels.

The *ZP3G* is shown in Figure 6.3. It has a length of 98 m, a diameter of 22 m, and a volume of 24,800 cu.m. A ballonet volume of 6,100 cu.m. would permit the craft to fly missions at 5000 ft. Under standard atmospheric conditions its pressure altitude would be 9000 ft. Most of the rigid structure is state-of-the-art aluminium and steel alloys.

The *ZP3G* would have a top speed of 97 knots and a maximum ferry range, with a 2000 kg fixed onboard payload, a crew of 6, and provisions for 5 days, of 3400 nautical miles. The lift off weight of the vehicle less fuel would be around 20 tons. Maximum endurance with the same payload at 25 knots would be 101 hours. The vehicle's low speed control would allow it to tow an acoustic array for passive ASW screening operations, and a disabled ship with a 400 ton displacement at 6 knots (equivalent to a ship 35 m long with a 8 m beam).

Goodyead devoted considerable attention to the layout of the car. Shown in Figure 6.4, it is 21 m long and 2.3 m wide. With an area of nearly 50 sq.m. it provides generous space for crew facilities and a large radar/sensor capability. The car is equipped with a winch for towing and hoisting, and with a 4.5 m inflatable boat with a 70 hp outboard motor that can be raised and lowered with winches through trap doors in the cabin floor.

According to Goodyear, a prototype *ZP3G* could be flying within three years of the finalized design.

The craft proposed by Bell Aerospace Textron, the *MPA* (Maritime Patrol Airship), is shown in Figure 6.5. A non-rigid pressure airship 99 m. long, 22 m in diameter, its envelope, made of Dacrone-neoprene fabric aluminized on the outside, has a volume of 24,300 cu.m. Its conven-

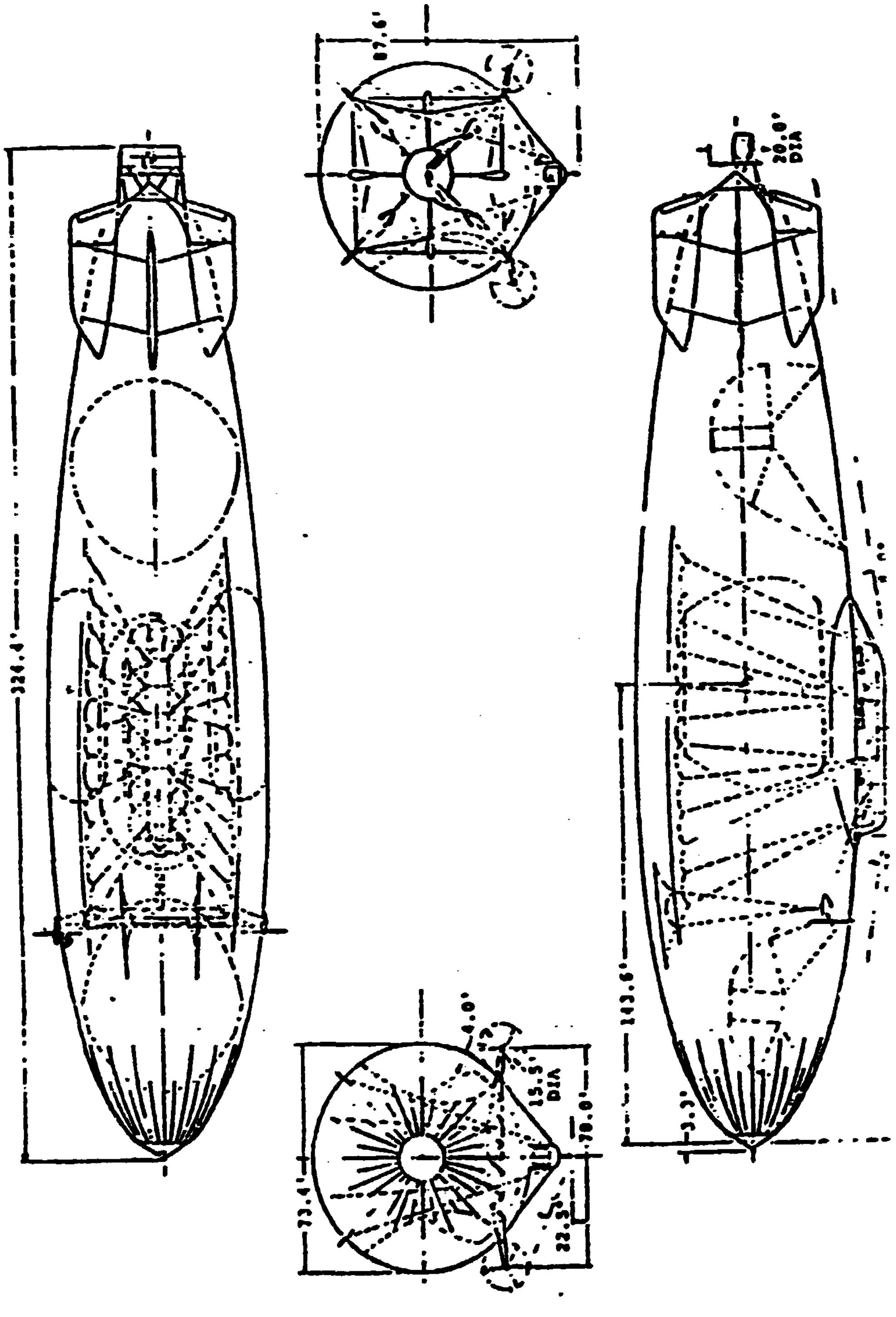

Figure 6.3: General Configuration. Goodyear ZP3G

Source: *Maritime Patrol Airship Study*, 1980, p. VIII-2

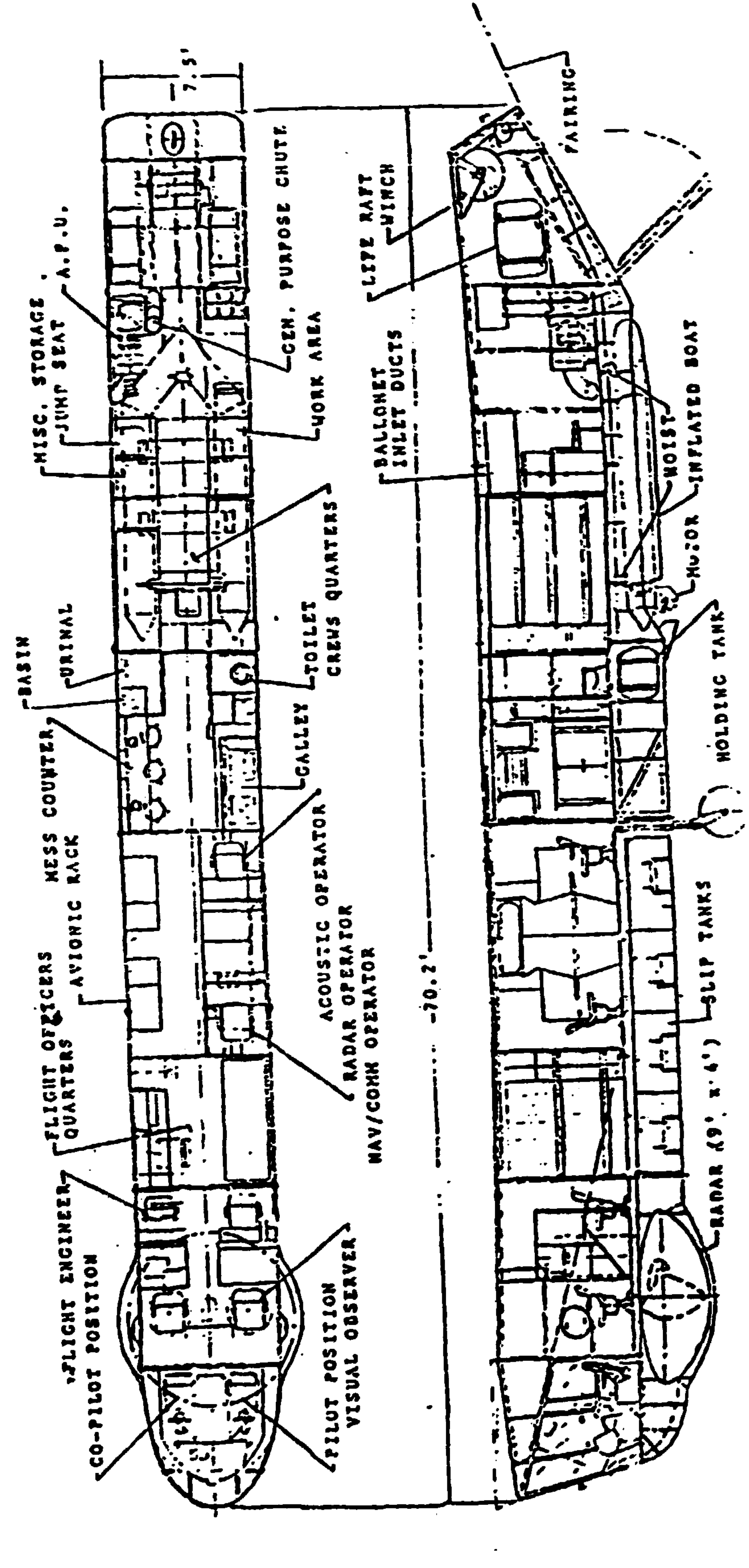

Figure 6.4: ZP3G Car for Maritime Patrol

Source: *Maritime Patrol Airship Study*, 1980, p. VIII-6

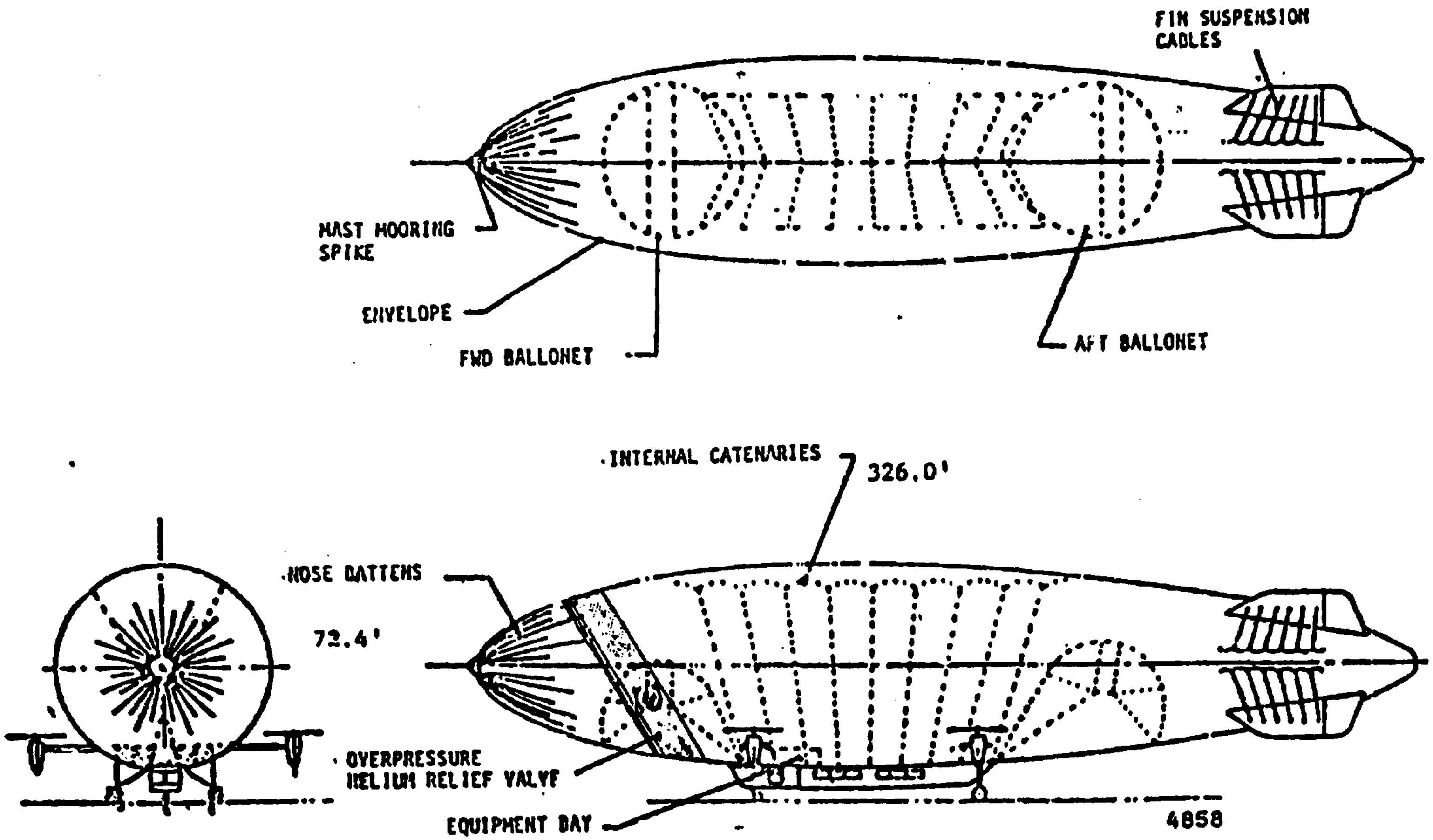

Figure 6.5: General Configuration Bell MPA

Source: *Maritime Patrol Airship Study*, 1980, p. VII-9

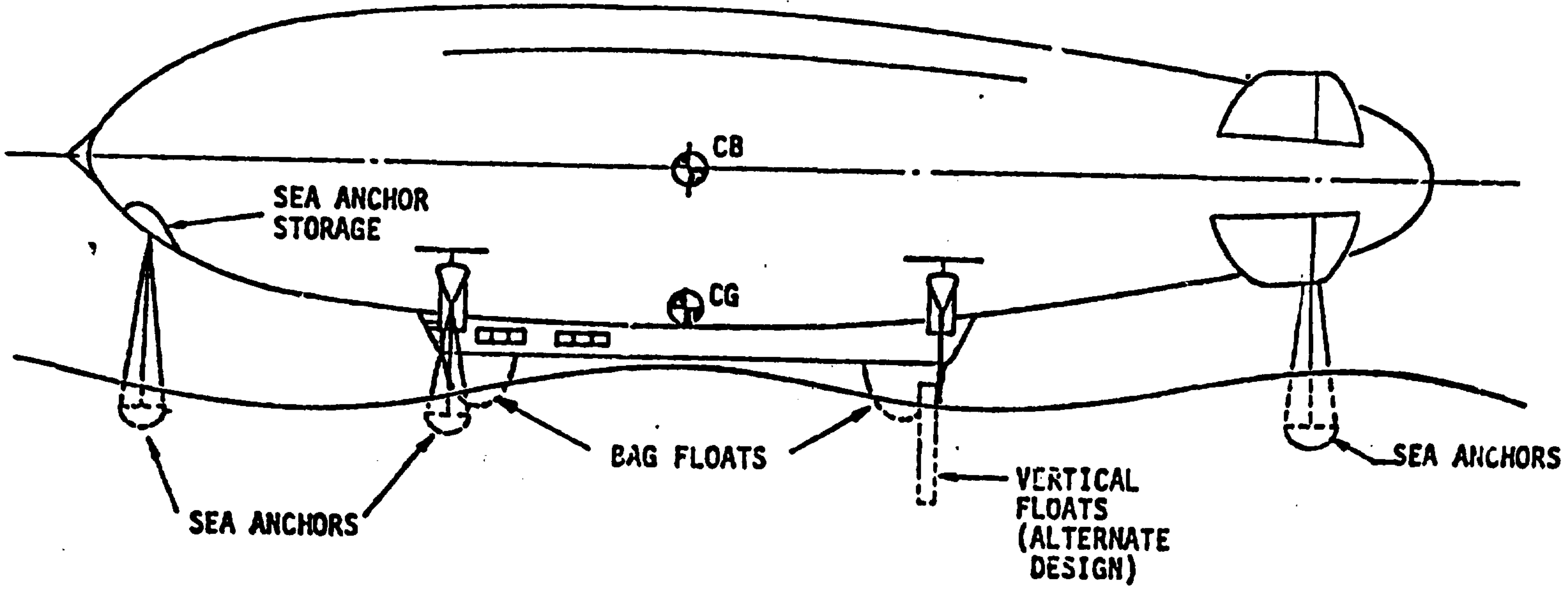

Figure 6.6: Bell MPA Flotation System

Source: *Maritime Patrol Airship Study*, 1980, P. VIII-13

tional features include fore and aft ballonets, internal suspension system, nose stiffening, and 'X'-tail empennage.

It has, however, a number of non-conventional features which make it a beyond the state-of-the-art airship. A complex propulsion system provides for rotation and reversible thrust, a ground taxi capability, and eliminates the need for ballast or ballast transfer. The propulsion system comprises 4 turbine engines with tilt rotors. The engines and rotors can be tilted from vertical to horizontal for forward flight, and from horizontal to vertical for hovering, taxiing and VTOL. To permit the tilting of the propulsion units, they are mounted outboard. A rigid structure links the propulsion units.

The *MPA* has a retractable tricycle landing gear, the single wheel being located fore, the two others aft. Using the propulsion system's downward and horizontal thrust components, the airship can be held stable on the ground and taxiied to a mooring mast or into a hangar in moderate cross winds. The large amounts of vertical thrust provided by the 4 tilt-rotors can be used to trim the vehicle and eliminate the need for ballast.

An advanced automatic mooring system is proposed. The ship's precision hover and taxi capability make it possible to guide the ship's nose into a mooring mast cone. The cone with the airship is free to turn 360°. An aft tie down line would emply a hook running on a circular track.

Another distinctive feature is the provision of a floatation system to permit landings at sea. As shown in Figure 6.6, floats are attached to both the nose and main gear, and sea anchors at nose and tail are used to provide for pitching stability in rough water conditions.

The main characteristics of the three vehicles developed as part of the MPAS - the *ZP-X*, the *ZP3G*, and *MPA* - are compared in Table 6.4 and their distinctive features in Table 6.5. Despite differences in vehicle configurations, essential airship characteristics are found

ITEM	GAC ZP3G	BAT MPA	NADC ZP-X
Envelope Volume	875,000	858,437	783,696
Length	324	326	305
Diameter	73.4	72.4	69.3
Static Lift @ 2,000 Ft.	52,164	44,658	44,243
Dynamic Lift	8,500	17,917	7,638
Horsepower Required	2,400	4,306	1,927
Gross Weight	60,644	65,274	54,554
Empty Weight	33,740	33,019	27,674
Useful Load	22,504	32,256	26,880
Buoyancy Ratio	.86	.73	.86
Max. Altitude	10,000	10,000	10,000
Max. Speed	97	104	90

Table 6.4: Comparison of ZP-X, ZP3G and MPA Airships

Source: *Maritime Patrol Airship Study*, 1980, p. VII-17

Table 6.5: Distinctive Features of ZP-X, ZP3G and MPA

ITEM	NADC ZP-X
Propulsion	Three gas turbine engines with propellers
Buoyancy	Typical of non-rigids, $\beta = .86$, must collect ballast
Thrust Management	VTOL capable, some reverse thrust on props for landing
Ground Handling	As in previous airship operation aided by precision hover capability
Miscellaneous	

Source: *Maritime Patrol Airship Study*, 1980, p. VII-18

GAC ZP3G	BELL MPA
Three gas turbine engines with propellers	Four gas turbine engines with prop/rotors
Typical of non-rigids, $\beta = .86$, must collect ballast	Less than typical, $\beta = .73$, no ballast collection
VTOL capable, some reverse thrust on props for landing	VTOL capable, high degree of reserve thrust on prop/rotors for "light" condition
As in previous airship operation aided by precision hover capability	Employs "space-type" ground docking system
Detailed layout of car was considered	Has water landing system

to be quite similar. The designs suggest that the multi-mission maritime patrol airship is a 22,000-25,000 cu.m. vehicle with a length of 90-100 m. and a diameter of about 22 m. Its empty weight will be 13-15 tons, its gross weight 25-27 tons, and it will have a useful load of 10-14 tons.

The main difference between the 3 designs prepared as part of the MPAS is the lesser buoyancy ratio of the Bell vehicle. This provides for a greater load carrying capacity but at the price of twice the installed power. While technically more ingenious than the *ZP-X* and the *ZP3G*, the Bell *MPA* would be a more expensive vehicle in terms of both its acquisition and operating costs and it would also have a higher 'lead time'.

The MPAS leaves little doubt that, with few exceptions, airships are both cost-effective and fuel efficient when compared with existing and projected USCG cutters and aircraft. An airship operating at moderate altitudes and airspeeds is an extremely attractive aerial surveillance platform. The study concludes:

- Airships appear to have a direct, cost-effective application to many maritime patrol missions. Their advantage lies not in a superior capacity to perform a single task but in their ability to perform a range of tasks, characteristic of Coast Gaurd operations.

- Airships appear both technically and operationally feasible in maritime patrol roles. They deserve special mention for their energy efficient operation.

The USCG appeared sufficiently impressed with the results of its LTA programme. It announced its intention to: (i) further refine the cost analysis of airship utilization in its operations; (ii) demonstrate the capabilities and limitations of airships in specific mission areas by testing a sub-scale demonstration vehicle in the period 1983-84; and (iii) if experience with the demonstration vehicle proves satisfactory, to develop, test and evaluate a full size prototype in the period 1987-88.(7)

The development of a sub-scale man-rated demonstration vehicle was seen by the Coast Gaurd as the least expensive route to an eventual operational platform. Its development was to be undertaken in co-operation with NADC, which would provide technical and administrative support, the USCG providing contract funding.

NASA was also involved in the USCG programme. In 1980, the Coast Guard and NASA signed a Memorandum of Understanding to jointly participate in the development of technologies relevant to airships. NASA agreed to expand the scope of its ongoing heavy lift airship project to include investigations into possible configurations and appropriate technologies for a maritime patrol airship. Areas to be covered included control system design, dynamic analysis of vehicle control characteristics, flight simulators, materials studies, airship structural analysis techniques, and model wind tunnel testing. Work on the dynamic analysis of vehicle controllability and on structural analysis techniques was underway in 1981.

The USCG's plans were, however, disrupted by the government spending cuts enacted by the U.S. administration. Its budget for 1982 was reduced by $ 168 million. Forced to make cuts of its own, it abandoned in October 1981 its plans to build the $ 8 million sub-scale demonstration vehicle. Despite this, it retains its interest in airships and has not abandoned all LTA activity. Whether the US Coast Guard will, however, 'go airships' remains today an open question.

6.4 Other Developments

Efforts to develop a maritime patrol airship are also being made outside the U.S. As we saw in chapter 4, the British company Airship Industries is currently marketing a small but modern airship, the *Skyship 600*, for the maritime patrol role. The vessel is expected to make its maiden flight in spring 1983.

The *Skyship 600* is a 6572 cu.m. non-rigid with a length of 59 m and diameter of 15 m. A 'stretched' version of the company's *Skyship 500* which is already flying, it is equipped with auxiliary fuel tanks which will give it an endurance of up to 40 hours at 30 knots. It is equipped for refuelling and revictualing at sea. The *600* has a VTOL/ZTOL capability, a 'dash' speed of 65 knots and a cruise speed of 40 knots. It has facilities for a crew of 7 and can carry a 3 ton payload. Its gondola, shown in Figure 6.7, is 12 m. long and 2.6 m. wide, the main cabin being 7 m. with 1.92 m. headroom, sufficiently spacious for a range of surveillance duties. The *600* would be equipped with a 4.5 m. inflatable dingy slung beneath the gondola and accessible through a floor hatch.

The maritime patrol 600, called the *Skyship 600 Sentinel*, will sell for £ 1.45, exclusive of special surveillance equipment. While it is undeniably a small airship for operations 200 nautical miles from its base, it could prove to be the smaller maritime patrol airship designed for economic operation identified by the MPAS. Both the U.S. Navy and the USCG have expressed an interest in the craft and Airship Industries is currently discussing trials and negotiating sales with different types of potential operators.

Airship Industries has two much larger vehicles under study for multipurpose maritime support: the *Skyship 2000 Coastguarder* and the *Skyship 5000*. The *2000* is a slightly smaller airship than the three vessels conceptualized as part of the MPAS. It would be 81 m. long, have a volume of 20,000 cu.m., and be capable of carrying 10 ton payloads at speeds of up to 90 knots.

The *5000* is a very large non-rigid of 50,000 cu.m. With a length of 108 m. and diameter of 30 m. it would have a disposable load of 28 tons. It would be able to go 4-7 days without refuelling and provide accommodation for a three-shift crew of 19. The *5000* is shown in Figure 6.8 and 6.9.

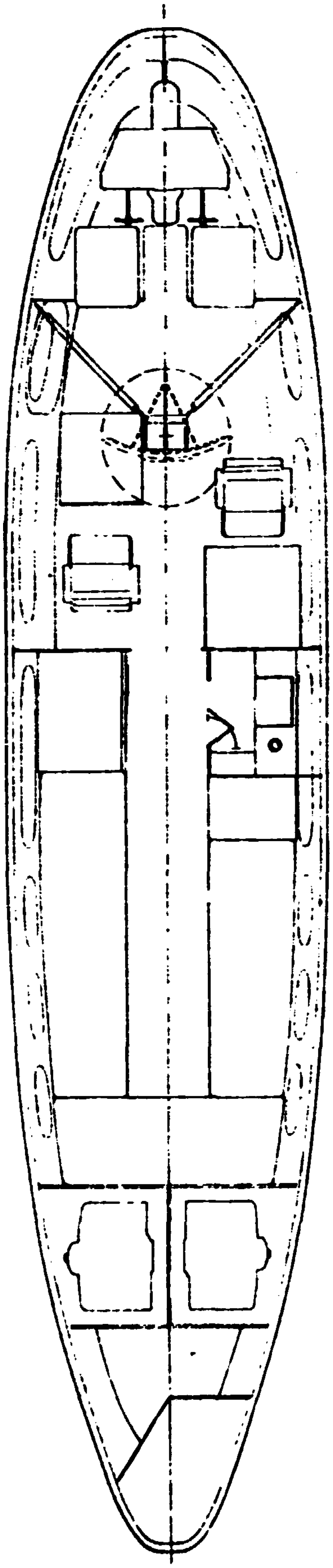

Figure 6.7: Gondola Skyship 600

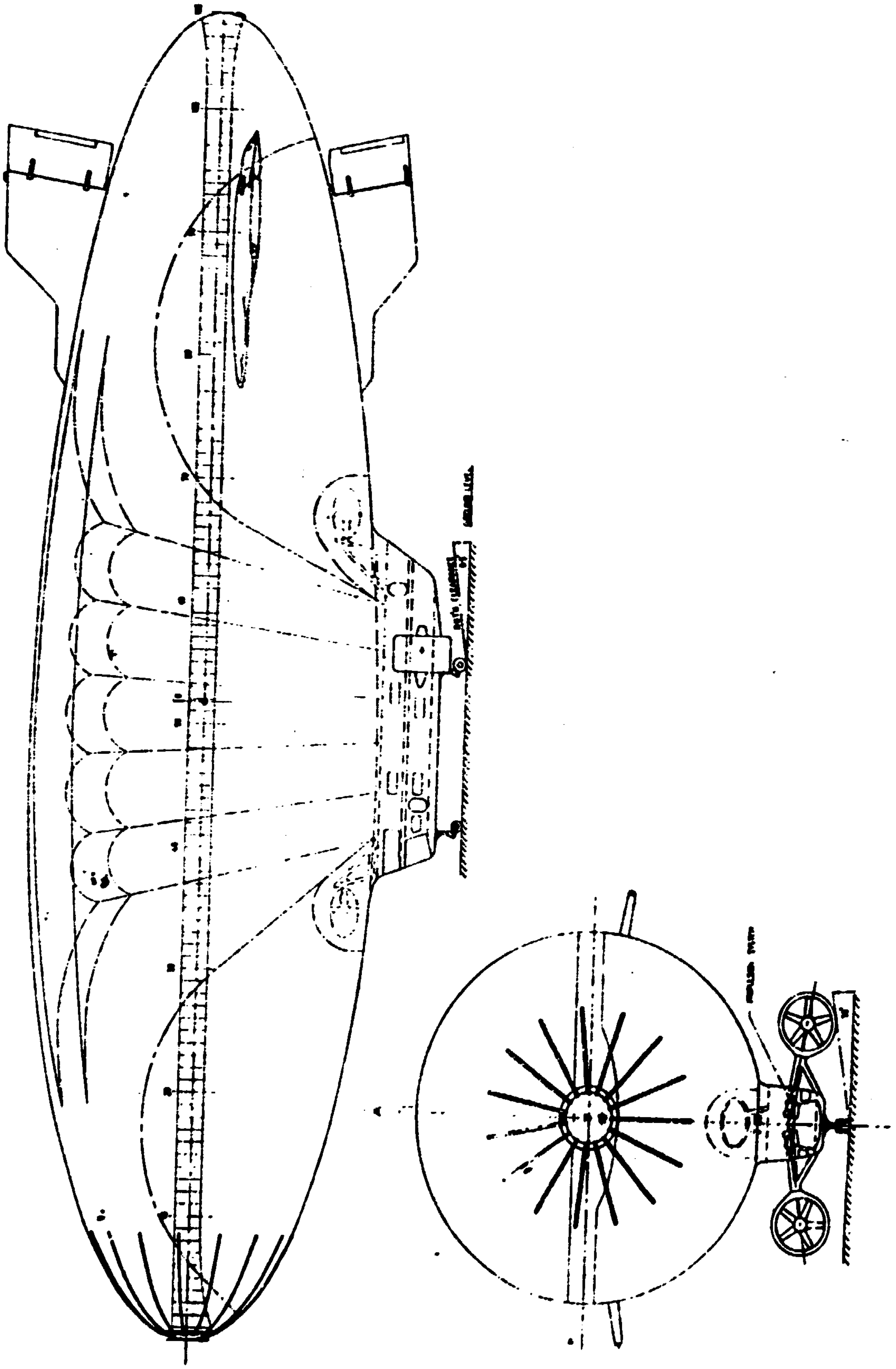

Figure 6.8: General Configuration Skyship 5000

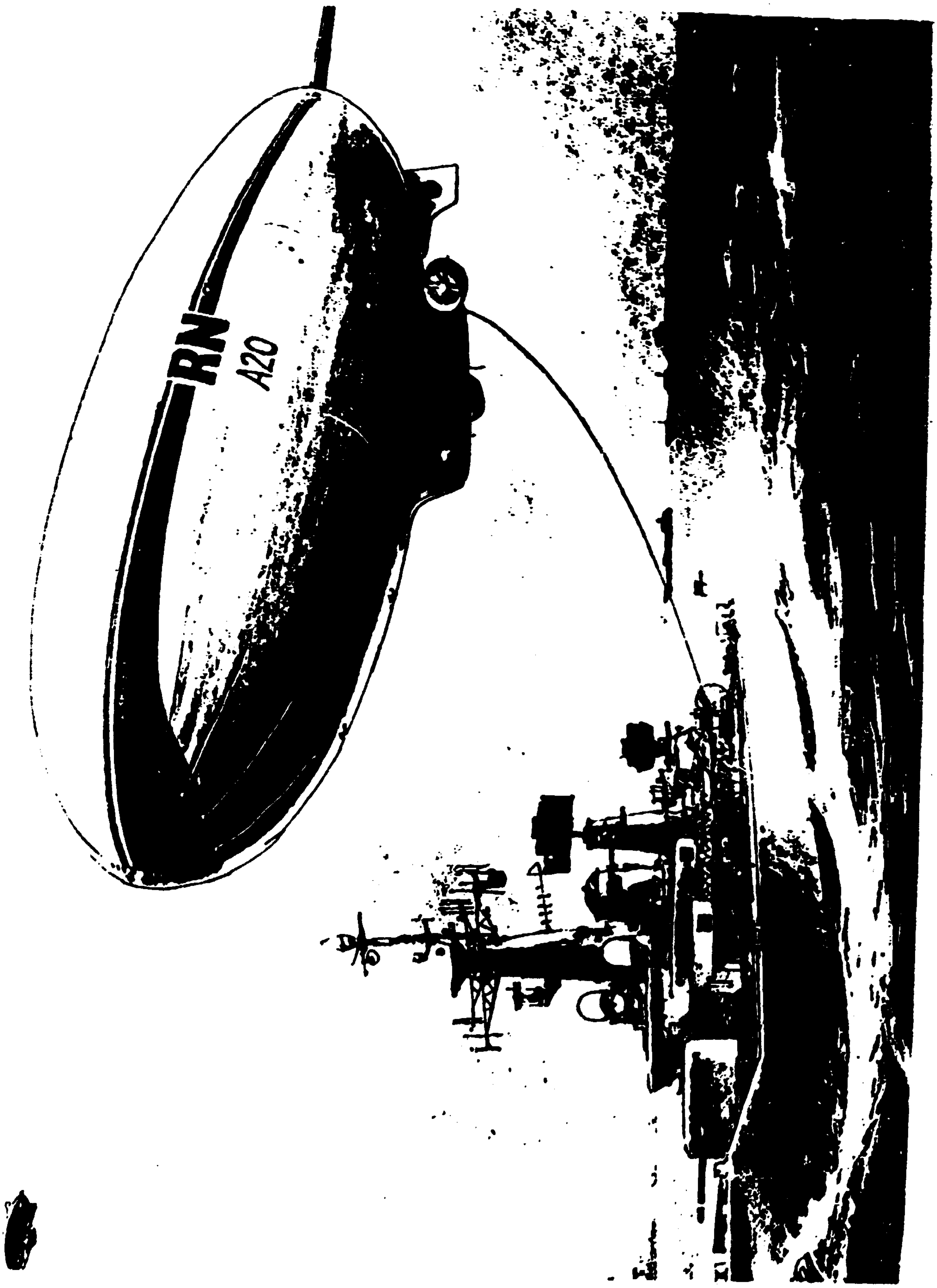

Figure 6.9: General Impression Skyship 5000

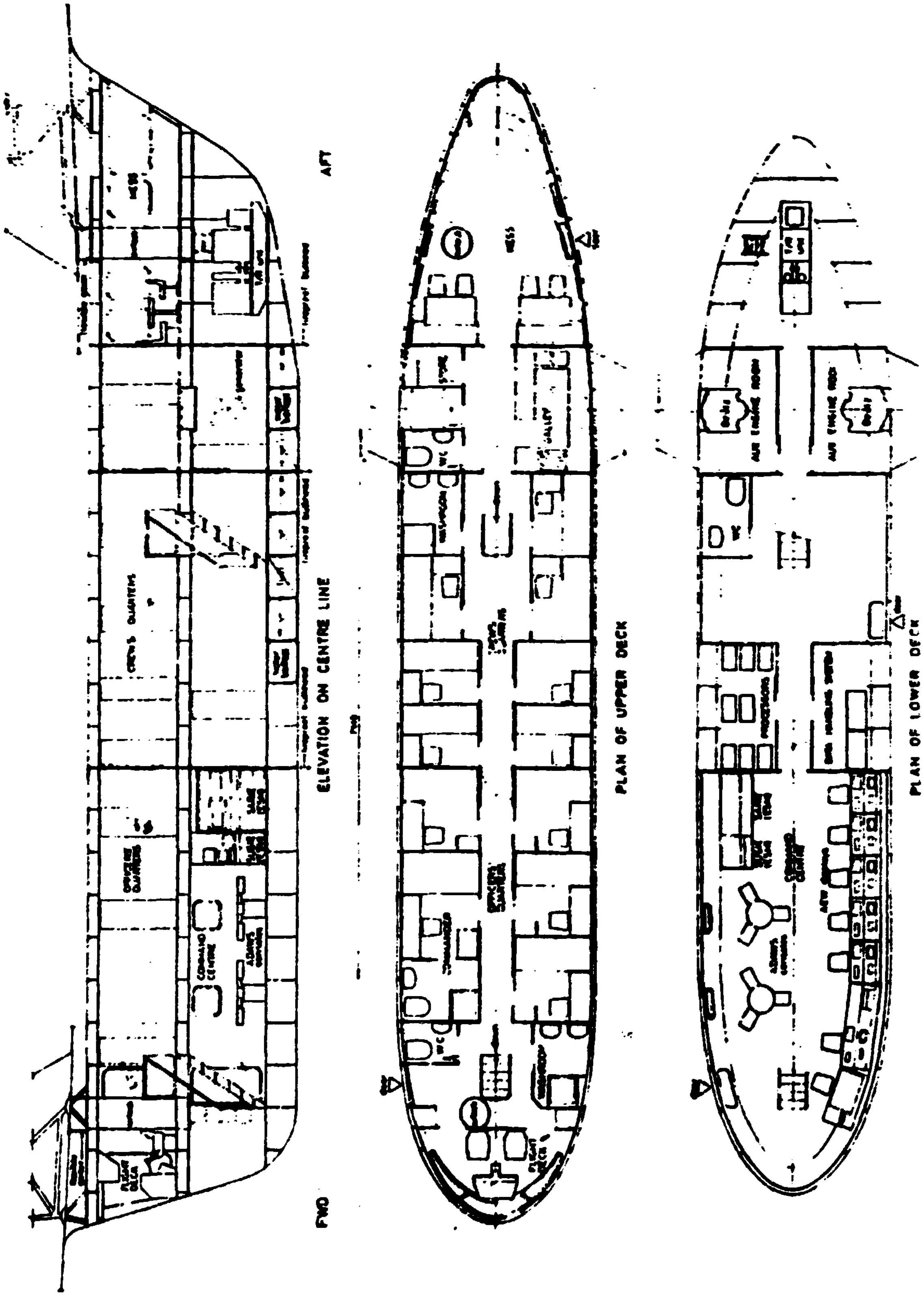

Figure 6.10: Skyship 5000 Gondola for Maritime Patrol

The *Skyship 5000*'s gondola for maritime patrol/AEW is shown in Figure 6.10. It resembles a small ship. It has two decks. The flight deck and crews quarters (12 beds, galley and mess) are housed on the upper deck, the command centre, data processing units, and engine room on the lower.

The *5000* would be equipped with two 'sets' of engines: main engines are two 1500 hp turboprops driving ducted fans, while two 525 hp turbocharged diesels serve as cruise engines. Top speed would be in excess of 90 knots, cruise speed 40-60 knots depending upon engine rating.

Like the *2000*, the *5000* could be deployed in ASW, AEW, MCM and EW roles. The envelope's large volume provide all the space required for very large sensors. The AEW version of the *5000* could, for example, be fitted with even larger 180° scanners than are found on the Nimrod.

If the airship is to reestablish its presence as a multi-purpose maritime patrol vehicle, it will most likely be in the form of the modern conventional non-rigid. Other types of LTA craft would, however, be well suited to maritime duties. Several studies, some conducted for the U.S. Navy (cf. chapter 4), have pointed to the potential of the large rigid airship. It has been suggested, for example, that a modern rigid the size of the *Hindenberg* would make an ideal sea control escort vehicle.(8) Its very large hull could be used to deploy a phased radar of unparalleled power and performance which could be used in a wide range of over-the-water roles.(9) As we saw in chapter 4, the Wren Skyship's *R 30*, a private venture yet to get off the ground, is to be developed with maritime patrol missions clearly in mind.

At the other end of the LTA spectrum are unmanned remotely piloted vehicles which can be used for a wide range of surveillance duties. These, together with their more exotic high altitude counterparts, are described in chapter 8.

Notes and References

(1) For a review of the aircraft currently available see H. Field and D. Richardson, 'The Inshore Maritime Market', *Flight International*, 7 July 1979, pp. 29-32 and p. 37. They note that "A distinct battle is .... developing among the turboprops and business jets. Virtually all the manufacturers in this class have laid out a brochure describing a maritime version, though not all have actually flown". (p. 30) The main competitors include, in the United States, Beech (Super King Air variant), Cessna (Citation III variant), Gates (Learjet variant), Rockwell (Sabreliner 65 variant) and Swearingen (Merlin IV variant); in Canada, De Havilland (Dash 7 Ranger); in Australia, GAF (Nomad Searchmaster); in France, Dassault Breguet (Falcon Guardian); in Italy, Partenavia (P68 variant); in the Netherlands, Fokker (F27 Maritime); Embraer (EMB 111 variant); and in the United Kingdom, Britten Norman (Islander Maritime Defender), Shorts (330 Seeker) and British Aerospace (Jetstream variant, HS 748 Coastguarder, HS 125 Protector). All these aircraft have been developed as a direct result of the UN Law of the Sea Conference, their principal task being one of patrolling EEZs. They are not long-range maritime patrol aircraft of the 'traditional' type, e.g. British Aerospace's Nimrod, Dassault Breguet's Atlantique, Lockheed's P-3C Orion and Ilyushin's IL-38.

(2) See Goodyear Aerospace Corporation, *Alberta Modern Airship Study, Final Report, June 1978*, Akron, Ohio, 1978, pp. 123-126, viz. Table XI.

(3) See R.A. Beatty, Jr., and R.D. Linnel, *Assessment of Selected Lighter-Than-Air Vehicles for Mission Tasks of the U.S. Coast Guard*, Center for Naval Analyses, (USCG Report CG-D-39-78), May 1978.

(4) D.B. Bailey (NADC) and H.K. Rappoport (Summit Research Corporation), *Maritime Patrol Airship Study (MPAS)*, NADC Report No. NADC-80149-60, 19 March 1980. See also H.K, Rappoport, 'Analysis of Coast Guard Missions for a Maritime Patrol Airship", AIAA Paper 79-1571.

(5) In the U.S., the FAA restricts flying hours to 800 a year. This can be considered low for airship operations, a point stressed in the MPAS.

(6) For a description of this vehicle, see N.D. Brown, 'Tri-Rotor Coast Gaurd Airship', AIAA Paper 79-1573.

(7) See L.J. Nivert and K.E. Williams, 'Coast Guard Airship Development', AIAA Paper 81-1311.

(8) See D.G. Kinney, 'Modern Rigid Airships as Sea Control Escort Platforms', AIAA Paper 79-1575.

(9) See B. Levitt, 'Military Applications of Rigid Airships', in J.F. Vittek, Jr. (editor), *Proceedings of the Interagency Workshop on Lighter than Air Vehicles*, Flight Transportation Laboratory, MIT, Cambridge, Mass., January 1975, pp. 509-515.

7. HEAVY LIFT AIRSHIPS

7.1 Introduction

The transport of heavy loads is an area in which LTA vehicles have an obvious potential and considerable efforts have been and are being made to design and develop heavy lift airships (HLAs) capable of transporting payloads in the range of 25-150 tons.

As noted in chapter 4, the largest payload which can be carried by any of the small non-rigid airships at present flying is the 2 tons of the *Skyship 500*. With current technology and proven materials non-rigids could be constructed to lift payloads of up to 25-30 tons. The possible payload capability of beyond the 'state-of-the-art' non-rigids is a matter of speculation. According to some, a 'top-of-the-range' non-rigid of 75-80,000 cu.m. which could draw upon advances in bonding, jointing, propulsion systems, and envelope materials could be expected to carry loads of up to 55 tons.

Such a HL non-rigid is a long way off and it is an open question whether a non-rigid of this size would possess the controllability and maneuverability required in many HL operations. Most of the efforts underway to develop HL vehicles are based upon hybrid concepts which seek to combine the aerostatic lift of the airship with the dynamic lift and controllability of the rotor craft. Hybrids based on current technology should be able to lift up to 75 tons. Beyond 100 tons it will be necessary to go to beyond the state-of-the-art.

Several studies have been done to identify the potential market for HLAs. Some of the industries that have expressed an interest in airship applications are listed in Table 7.1. Representatives of these industries have been interviewed in studies undertaken for NASA and by Goodyear. The transportation problems in each of the industries and their associated costs were examined in some detail and estimates of possible savings which could result from the use of HLAs were made. These estimates are given in Table 7.2. It can be seen that project-

- LOGGING (HARVESTING SAWTIMBER)
- FORESTRY (FIRE FIGHTING)
- SHIP OFF-LOADING (PORT CONGESTION)
- POWER GENERATION AND TRANSMISSION (CONSTRUCTION)
- PIPELINE (CONSTRUCTION AND MAINTENANCE)
- PREFABRICATED STRUCTURE (TRANSPORT AND EMPLACEMENT)
- REMOTE CONSTRUCTION PROJECTS
- GENERAL HEAVY LIFT TRANSPORTATION
- OFF-SHORE PLATFORM (SUPPORT AND CONSTRUCTION)
- PETRO-CHEMICAL (SITE CONSTRUCTION)
- HIGH RISE AND BRIDGE (CONSTRUCTION)
- MILITARY APPLICATIONS
- PEOPLE/CARGO SHUTTLE (DEVELOPING NATIONS)

Table 7.1: Industries Evaluated with High HLA Potential

Source: F.R. Nebiker, 'Heavy Lift Airships', UNIDO 453/26 LTA-7
October 1981, p. 27

Table 7.2: Economic Benefits from Use of HLA

HEAVY LIFT APPLICATION	TOTAL PROJECT COST ($ MILLIONS) WITHOUT HLA	TOTAL PROJECT COST ($ MILLIONS) WITH HLA	REDUCTION (PERCENT)
POWERLINE TOWER CONSTRUCTION	48	36.2	25
MOVEMENT OF HEAVY EQUIPMENT, (FIRE BREAKS)	8	0.05	99
LOGGING	18.65 (ANNUAL)	10.3 (ANNUAL)	45
PREFABRICATED STRUCTURES ACROSS RIVERS	10 (ANNUAL)	3.2 (ANNUAL)	68
PIPELINE REPAIR			
LOST COMPRESSOR STATION	0.3	0.1	66
LINE BREAK	12	6	50
EXTENSION TO WINTER SEASON (PIPELINE)			
CASE I – 48-INCH PIPE	143	138	3
CASE II – 56-INCH PIPE	167	139.5	16
OIL AND GAS DRILLING	0.56	0.15	73
MOVEMENT OF EQUIPMENT ACROSS RIVERS (PIPELINE)			
USE PUBLIC ROADS	3.7	2.6	30
CONSTRUCT TEMPORARY ROADS (10% OF DISTANCE)	5.2	2.6	50
EXTENSION OF WINTER SEASON (GENERAL)	200	190	5

Source: F.R. Nebiker, op cit., p. 28

related savings vary from as little as 3% (in the case of laying a 48 in pipeline in winter weather) to as much as 99% (in the case of transporting heavy fire breaks). The average saving for all cases is 45%.

Estimates of the potential market for HLAs vary considerably. Recent NASA and Goodyear estimates for the industries which have been examined in detail are given in Table 7.3, NASA's estimate of 118 HLAs comparing with Goodyear's 88. The estimates exclude possible applications in aerial logging. Another study conducted for NASA has suggested that this could be by far the most important area for HLA applications, projecting a potential market for more than 1000 HLAs with a 30 ton payload capability and a further 600 able to lift up to 75 tons.(1)

The market for the HLA thus appears to be there, although its size is a matter of opinion rather than fact. It will be greatest in areas of application where surface infrastructure does not exist or is poorly developed. The three areas that appear the most promising are aerial logging operations, and resource development and construction projects in remote areas.

Such applications should be of special interest to developing countries. Aerial logging, for example, would make it possible for Third World timber exporters to come to terms with the massive environmental degradation that has accompanied logging operations on the fragile soils of the tropics. Many of the tropical hardwoods most in demand on the world market are found in stands of only 1-2 trees per hectare. Aerial logging for such low-density stands could be accomplished without the clearance required in conventional logging operations. It would result in very important environmental benefits through the prevention of soil erosion as well as prove more cost effective. Similarly, finding the tools to exploit the resources of remote and inaccessible regions is typically a concern of Third World countries. The investments required in surface infrastructure to open up these regions often fall beyond the country's means. In such cases, the HLA may have a special role to play and be able to make a contribution to economic development unmatched by other modes.

Table 7.3: Estimates of World Market for HLAs

High Potential Industries*	Market Estimate	
	NASA	Goodyear
. Shuttle/General Transport	5	25
. Port Congestion	80	40
. Remote Construction	25	15
. Prefabricated Structures	5	5
. Power Distribution	3	3
Totals	118	88

* Other high potential industries for which estimates have not been made include the construction of off-shore platforms, bridges, high-rise structures, and gas and oil pipelines, and forestry.

Source: F.R. Nebiker, 'Heavy Lift Airships', UNIDO Paper 453/26 LTA-7, October 1981, p. 29.

Its 'competitor' in the industrialized countries is the heavy lift helicopter. The largest HL helicopter at present in commercial use is the Sikorsky *S-64* 'Flying Crane'.(2) It has a maximum sling load of 12 tons (with minimum fuel on board), but averages about 8 tons in logging type crane operations. The *S-64* is expensive. It sells for about $ 7 million and costs over $ 3000 per hour to operate (with a 1500 hrs/year utilization). Helicopters which can carry larger payloads are in military use and commercial versions may be produced. Given the present state-of-the art of helicopter technology it is unlikely that helicopters capable of lifting more than 35-40 tons will appear in the near future.

In this chapter we will look at four hybrid airships. Two are under development. (Piasecki *Heli-Stat* and the *Cyclocrane*), one is on the drawing board (Goodyear *HLA*), and the fourth is still at the ideas stage (the *Heli-truck*). The latter is included to indicate the kind of thinking which surrounds hybrid development and because it has been conceived especially for use in the developing world.

7.2 The Piasecki Heli-Stat(3)

The *Heli-Stat* is being developed by the Piasecki Aircraft Corporation (PAC) of Philadelphia. Frank Piasecki, a pioneer in helicopter development, can be credited as the first person to give serious thought to the idea of combining the aerostat and the rotor craft. Work on the *Heli-Stat* design started in 1974 but was hampered due to a lack of funds. In 1980, the U.S. Forest Service awarded Piasecki a $ 10 million contract to demonstrate the feasibility of the HL *Heli-Stat* for aerial logging of Federal forests in the U.S. Northwest. The demonstration project is designed to verify the technical, cost, and operational features of the HL system.

Provisional estimates made by PAC indicate that the *Heli-Stat* could increase reachable logging areas by 2000% at a 37% reduction in harvesting costs using helicopters. Road building costs, averaging $ 150,000 per mile in Federal forests, would be very largely saved.

The *Heli-Stat* would transport logging payloads to an unloading site where delimbing and length cutting would take place.

The U.S. Forest Service project is a low-cost demonstration. The *Heli-Stat* makes use of surplus Navy aircraft and supplies. The main components are a ZPG-2 27,613 cu.m. envelope and four H 34 helicopters each capable of developing 1525 hp. The 4 helicopters are interconnected with a platform structure, as indicated in Figure 7.1. The controls of the helicopters' rotors, which are being modified to incorporate forward and reverse thrust propellers, are interconnected and operated by one pilot seated in the rear port side helicopter. The controls of the remaining 3 helicopters are operated by flight engineers, giving the *Heli-Stat* a four man crew. The equipment being used is shown in Figure 7.2.

The *Heli-Stat* is 103 m. long, 45 m. wide, and 34 m. high. The 40,000 lb buoyant lift of the helium filled envelope brings the empty weight of the 4 helicopters to near zero, enabling the 6000 hp of the H 34s to be applied to lifting. The *Heli-Stat* is designed to carry loads of up to 24 tons at a forward speed of 60 knots. A larger version, designed to carry up to 75 tons at 73 knots, is under study. An artist's impression of a commercialized *Heli-Stat* is shown in Figure 7.3.

The envelope has been inflated and flight tests are taking place at the U.S. Navy's facility at Lakehurst, New Jersey. The *Heli-Stat* is due for delivery to the U.S. Forest Service in 1982. It is seen to possess a potential for a wide range of lifting operations, such as the emplacement of power transmission lines, the construction of oil rigs, and the transport of maritime cargo containers, especially in portless areas. PAC has recently established a Canadian subsidiary and a number of Canadian oil and pipeline construction companies have reportedly expressed an interest in the *Heli-Stat*.

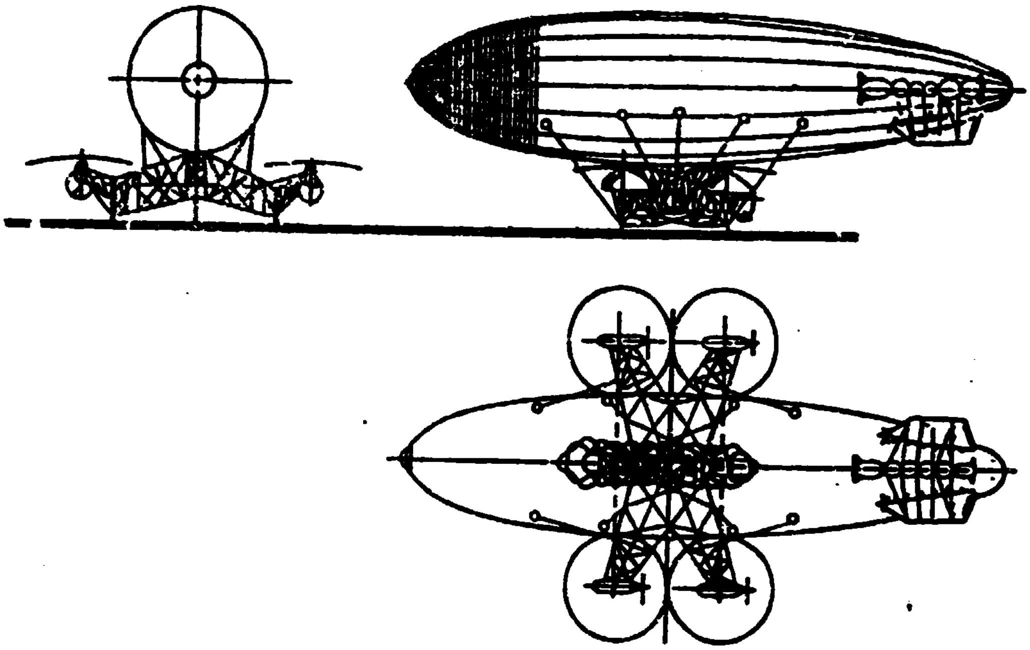

Figure 7.1: General Configuration Piasecki Heli-Stat

Source: N.J. Mayer, 'Current Development Lighter than Air Systems', UNIDO 453/26 LTA-9, Ocotber 1981, p. 4

Photograph

Figure 7.2: Heli-Stat Configuration Showing Use of Surplus Equipment

Courtesy of Piasecki Aircraft Corporation

Photograph

Figure 7.3: General Impression Commercialized Heli-Stat

Courtesy Piasecki Aircraft Corporation

7.3 The Cyclo-Crane(4)

The *Cyclo-Crane*, a concept patented by D.C. Associates and being developed and marketed by Aerolift, Inc. is an unusual combination of rotorcraft and aerostat. It consists of an ellipsoidal non-rigid aerostat hull supporting 4 rotor wings radially from points along its maximum diameter. The wings are equipped with tip airfoils and propellers. In hover, the wings are parallel to the horizontal axis of rotation. The blade airfoils are used to generate forces in line with the horizontal axis for either forward or reverse movement. This is accomplished by rotating the entire wing/blade system. The wing/blade airfoil assemblies continue to turn as the vehicle accelerates until the maximum forward speed is reached, at which point all airfoils and engines are directly aligned with the direction of flight and the vehicle has reached a non-rotation condition. Propellers have both cyclic and collective control systems. The wings provide lift through cyclic control. Airspeed over the wings is held at a constant value.

The pilot cabin is detached from the vehicle, slung below on bearing assemblies mounted fore and aft on the main horizontal structure. The slingload is attached to the pilot cabin. The pilot controls the thrust vectors of the airfoils using controls similar to those found in helicopters. Analytical studies supported by wind tunnel test indicate that the *Cyclo-Crane* will have the same controllability as a helicopter in gust conditions.

The aerostatic lift derived from the helium inflated centrebody is sufficient to support all structural weight plus 50% of the slingload specification.

Although appearing frail, the design reportedly uses a high safety factor and accepts weight penalties in return for a strong structure that can be fabricated from low-cost components using comparatively simple construction techniques. Maintenance costs should be lower than those of fixed wing aircraft due to the use of parts and systems more massive and durable than those normally used in airframe manufacture.

The *Cyclo-Crane* is currently being developed to transport 16 ton slingloads although the same concept can be applied to vehicles able to lift up to 75 tons. The 16 ton *Cyclo-Crane* is expected to sell for $ 2.5 million and operate for $ 747 per hour at a utilization of 1500 hrs/year, or about one quarter the costs of a S-64 for loads twice the size. A 50 ton slingload *Cyclo-Crane* would have a central body 85 m long and 43 m. in diameter and cost about $ 8 million. With a full sling load of fuel, the 16 ton *Cyclo-Crane* would be able to travel 5,000 km without refuelling. For normal operations it would have about 8 hours of fuel.

The *Cyclo-Crane* is seen to possess a future as a mass transit vehicle. A 50 ton slingload vehicle designed for this role would be able to carry 550 persons, more than current 747s,at 190 kph in dual two-tier cabins. According to provisional estimates made by Aerolift, Inc. such a vehicle,called the *Cyclo-Cruiser*, could be very cost competitive over short distances. It suggests that with a *Cyclo-Cruiser* service a return Los Angeles-Las Vegas could be offered for $ 31 (compared with the $ 61 for scheduled airlines) and New York-Atlantic City for $ 17 (compared with the present $ 44). With detachable passenger modules, the ground space requirements for passenger services would be very modest. In operation, the incoming *Cyclo-Cruiser* would release its passenger module at a special berth and reconnect with an outgoing module that has already been boarded with passengers. This would ensure quick turn-round times and high vehicle utilization.

The *Cyclo-Crane* is being actively marketed. A 1.8 tonne 9487 cu.m. demonstration model has been purchased by Canadian Forest Products Industries, a private group. It will be tested in Tillamook, Oregon (where Aerolift, Inc. has an office), and subsequently operated in the Canadian province of Vancouver. Flight tests were due to start in mid 1981.

A *Cyclo-Crane* for use in logging operations is shown in Figure 7.4. The *Cyclo-Cruiser* for passenger travel is shown in Figure 7.5. Figure 7.6. shows in more detail the passenger module.

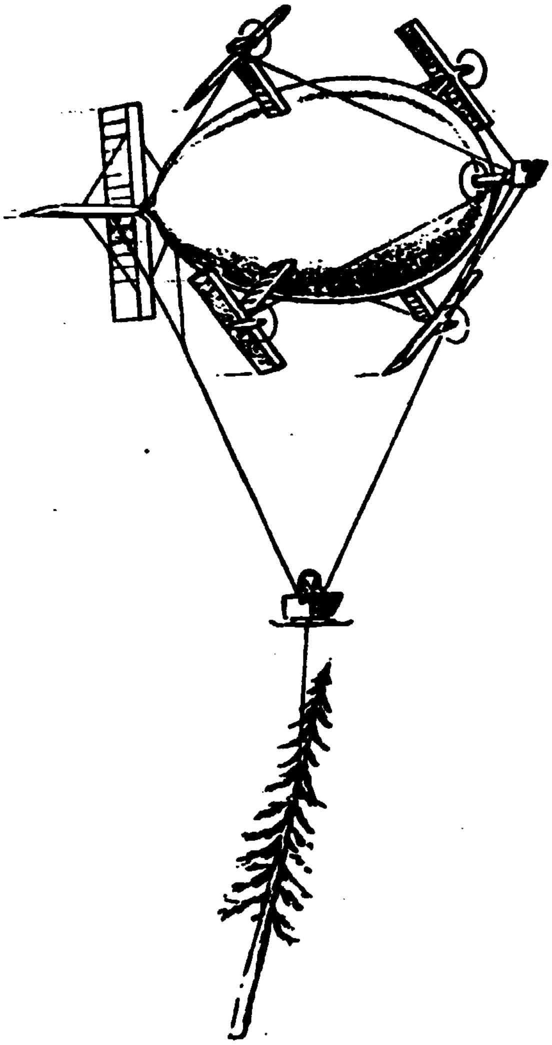

Figure 7.4: Cyclo-Crane in Logging Operations

Source: A.G. Crimmins, 'The Cyclo-Crane Concept', July 1981

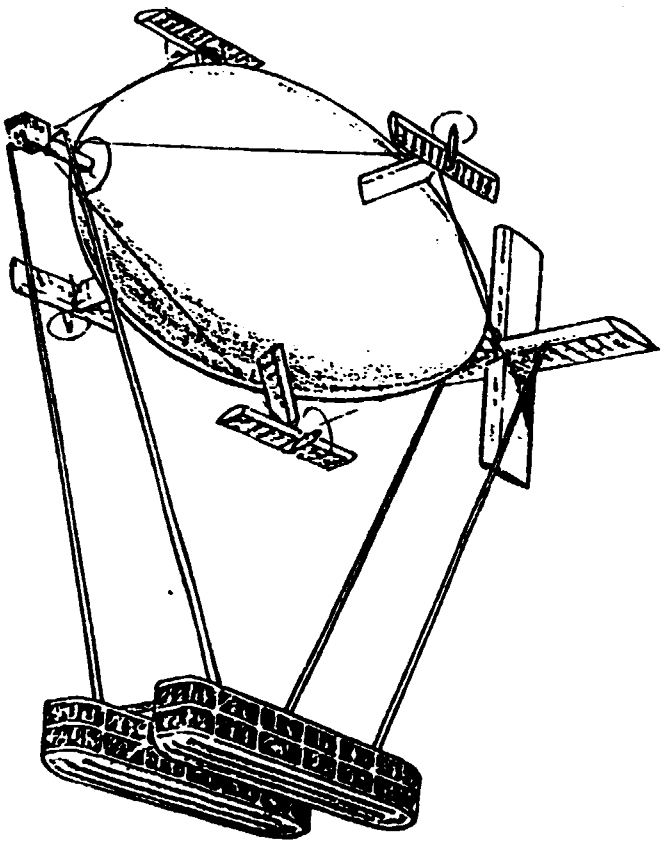

Figure 7.5: General Impression Cyclo-Cruiser

Source: A.G. Crimmins, op. cit.

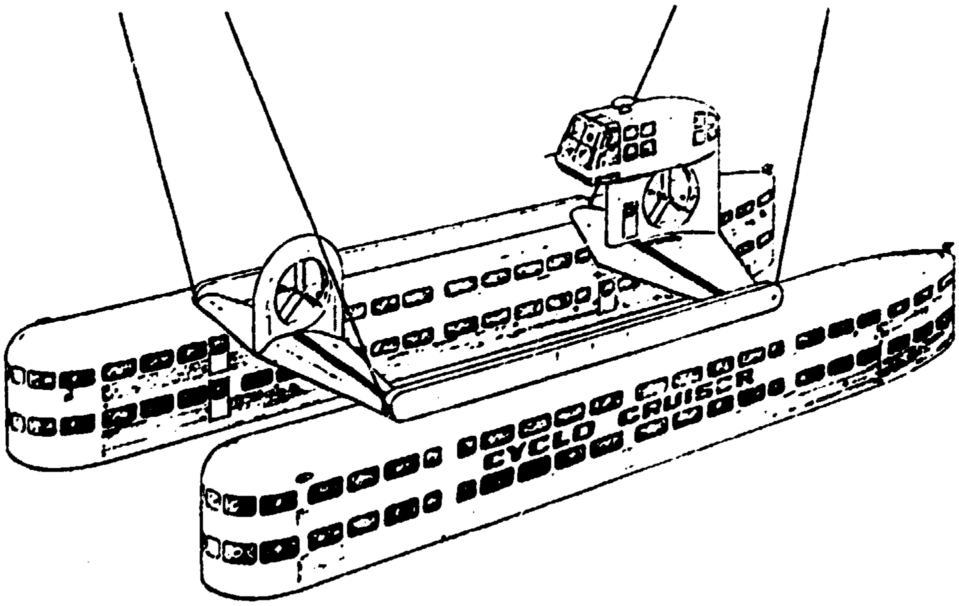

Figure 7.6: Cyclo-Cruiser Passenger Module

Source: Ibid

7.4 The Goodyear HLA(5)

Goodyear has examined many configurations for a HLA in a range of studies, including those for NASA(6) and, more recently, for the Alberta Department of Transportation.(7) These studies have led Goodyear to conclude that the most suitable configuration for the HL hybrid is as shown in Figure 7.7. This basic concept can be sized within available technology to carry payloads ranging from 50-150 tons.

Goodyear's recent work has focused on specifying the requirements for a 75 ton HL hybrid. This payload requires an envelope with a volume of 73,600 cu.m. with 4 rotor modules each capable of providing a maximum thrust of 24,000 kg. The vehicle would be 138 m. long, have a width of 70 m., and an overal height of 38 m. With the rotors folded, the width is reduced to 53 m. The length of the envelope would be 136 m. with a diameter of 33 m.

The general arrangement of the vehicle is shown in Figure 7.8. The envelope is of conventional airship construction. Four ballonets, with the two lateral centre ballonets interconnected to act as one, provide a total air volume of 18,400 cu.m. At the stern, three fins and their movable surfaces and mounted in an inverted 'Y' formation. The bow stiffening is of conventional design, consisting of a nose cone, mooring spindle, and batterns that extend to 10% of the envelopes length. A separate internal and external suspension system provides the support. Caternaries, starframe, and outrigger struts are positioned at the airship's centre of buoyancy.

The 4 rotor modules, which are interchangeable, house the engines, gearboxes, and shafting for the vertical thrust rotors and the horizontal thrust propellers. The rotors provide the lift, the propellers horizontal flight. The natural buoyancy of the craft is sufficient to lift the empty vehicle. This enables the rotors to lift twice as much payload for the same amount of fuel. The vehicle would make use of fly-by-wire controls with computerized control of the vehicle's many control mechanisms available from the combined systems.

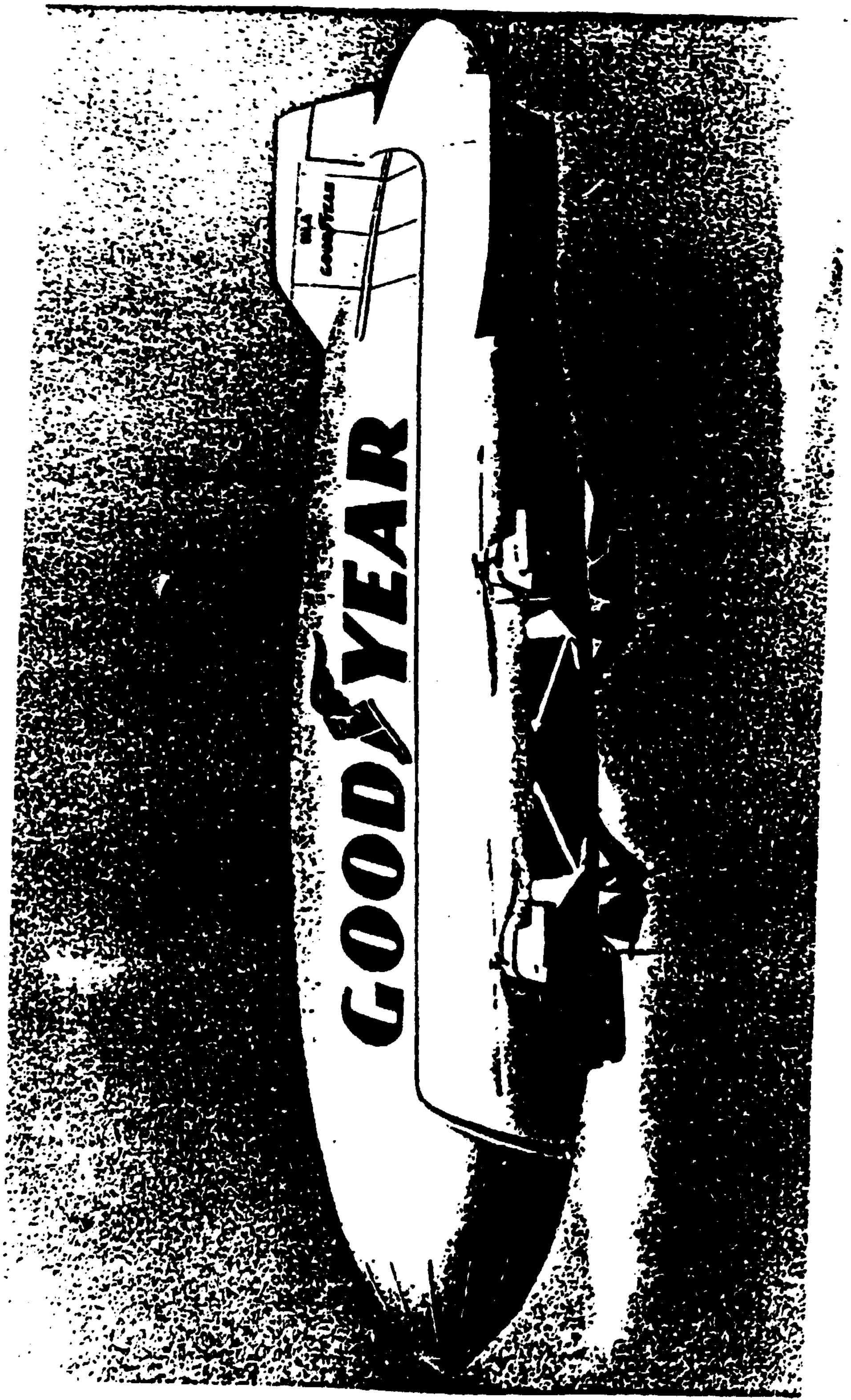

Figure 7.7: Most Suitable Configuration Goodyear HL Hybrid

Source: F.R. Nebiker, 'Heavy Lift Airships', UNIDO 453/26 LTA-7, October 1981, p. 21

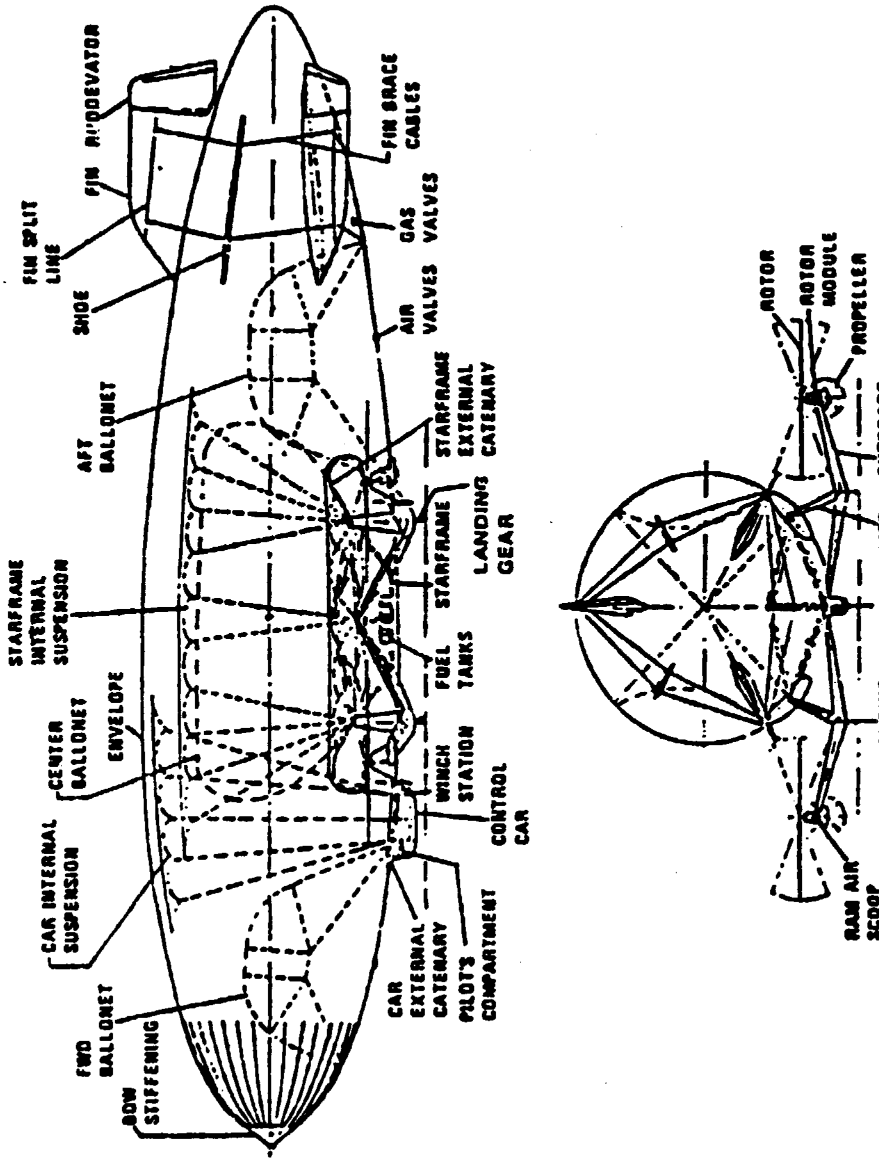

Figure 7.8: General Arrangement Goodyear HLA

Source: F.R. Nebiker, op. cit., p. 23

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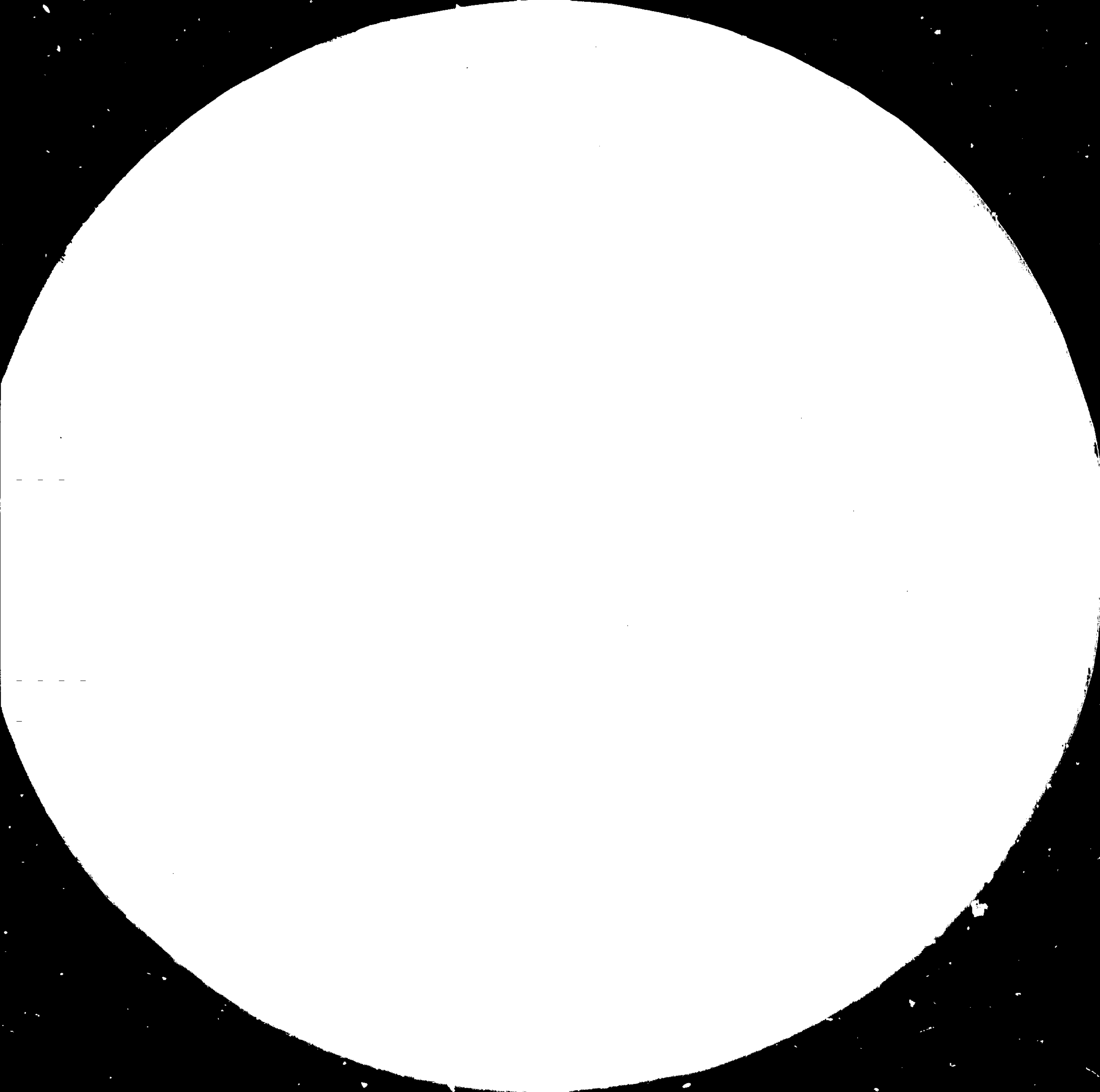
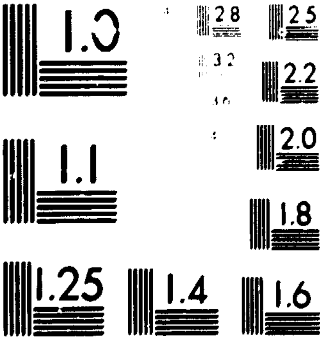




MICROCOPY RESOLUTION TEST CHART

[illegible]

Development costs for the 75 ton HLA are high. Goodyear believes that in excess of $ 150 million would be required to build the first vehicle. Included in this cost is a two year technology development/preliminary design phase valued at approximately $ 20 million. Whereas the true costs of the vehicle cannot be estimated with great accuracy, Goodyear would aim for a selling price of around $ 30 million. The sales price would be determined by the number of ships produced.

Estimates of total operating costs are also necessarily provisional. In the Alberta Study they are projected to be in the order of $ 6,000/hr in the lift mode and $ 4,800/hr in ferry. Since neither helicopters nor fixed wing aircraft could accomplish the missions for which the HLA is designed, direct cost comparisons are very difficult to make. The HLA would, however, appear to offer extremely good operating economics, more favourable by far than the S-64, as indicated in Figure 7.9. The projected ton/mile costs of the HLA are compared with the heavy lift helicopter and fixed wing transports in Figure 7.10. HLA tariffs fall midway between those of the other two modes.

The curve marked 'MCA' in Figure 7.10 refers to the 'modern conventional airship'. The Alberta Study is particularly interesting for its discussion not only of the HLA but of other types of airships also. Two non-rigid designs with useful load capabilities of 8 and 24 tons and a large modern conventional rigid airship with a useful load of 167 tons were also examined. The non-rigids were designated the *ZPG-X-3W* and the *ZPG-X-5K*. The first of these is a derivative of the *ZPG-3W* built by Goodyear for the U.S. Navy in the late 1950s. The largest non-rigid ever built, it was operated for several years by the Navy for AEW. Conceived as a low-risk concept the *ZPG-X-3W* is essentially the same as the *ZPG-3W*, modified to incorporate technological advances. The major difference is in the propulsion system. The *ZPG-X-3W* is equipped with 2 main forward engines, mounted on a tilt wing with a rotational capability of 90°m and a stern propulsion system which uses a twin turbine engine installation mounted on an inverted 'VEE' tail which can also be rotated through 90°. In the *ZPG-X-3W* the stern area of the original *ZPG-3W* is modified to accommodate the stern propulsor structural attachment and tilt mechanism.

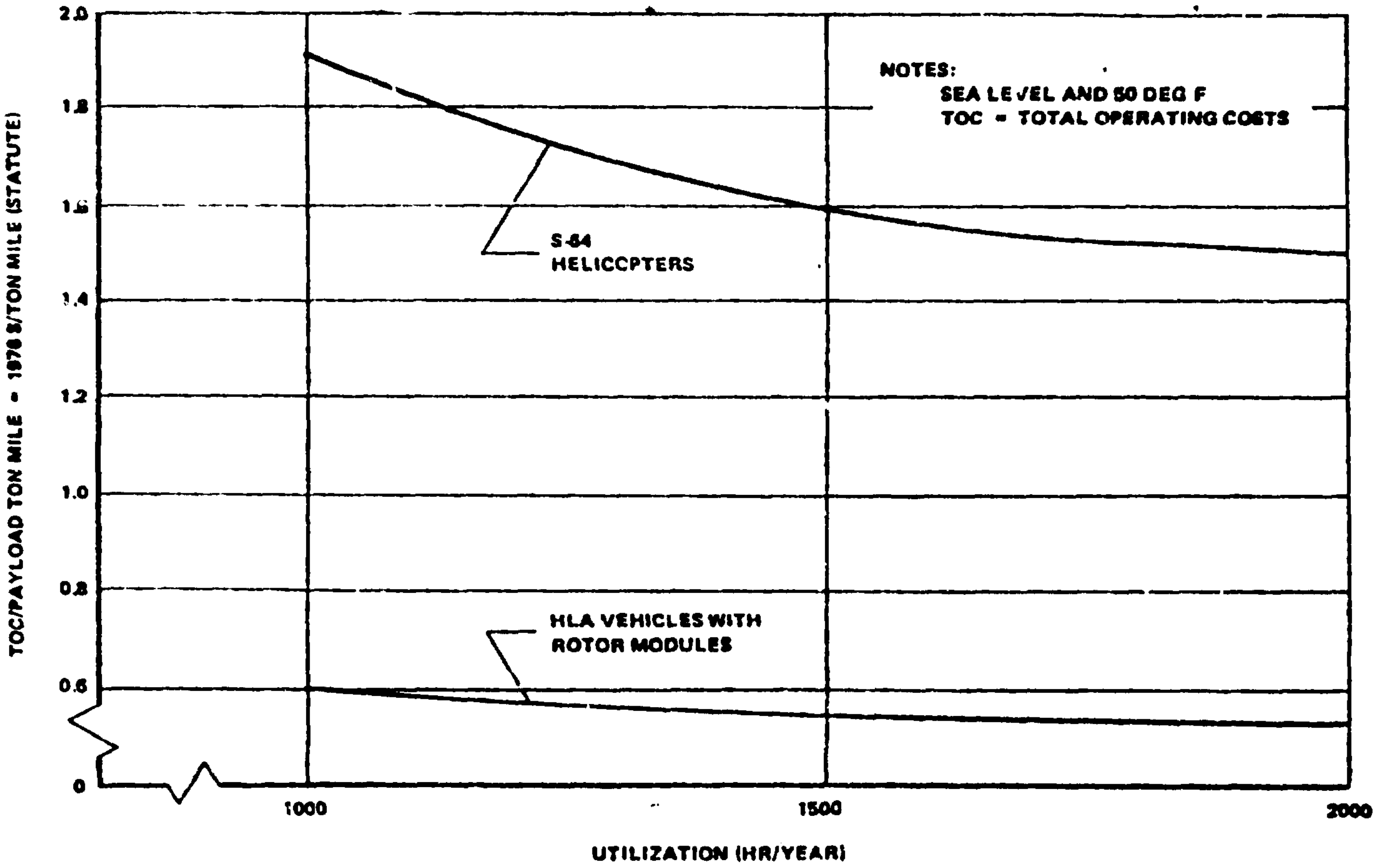


Figure 7.9: Comparision Operating Costs of HLA and S-64

Source: F.R. Nebiker, op. cit., p. 24

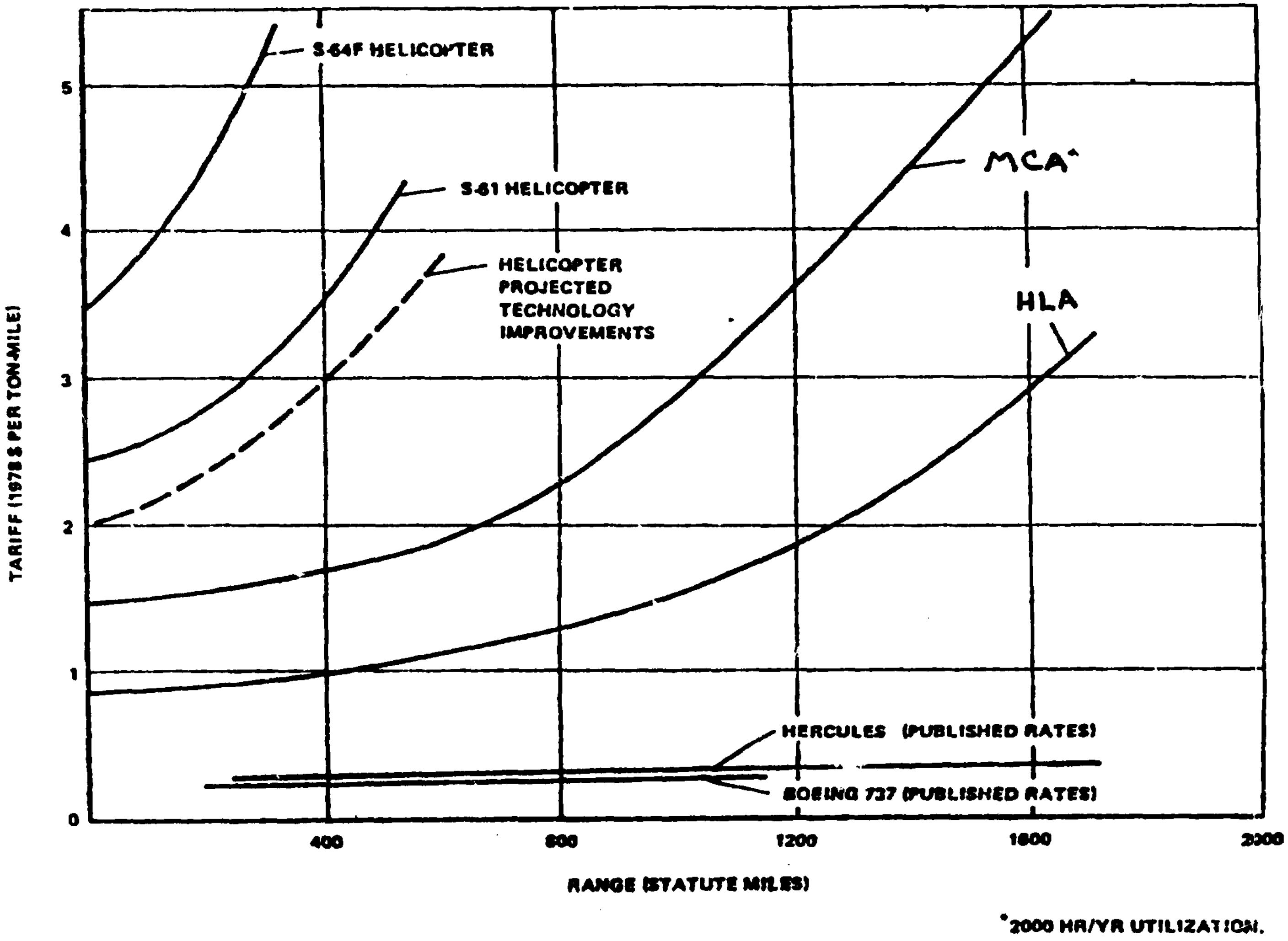


Figure 7.10: Comparison of Tariff.

Source: F.R. Nebiker, op. cit., p. 25

The car is also lengthened to provide the structural attachment and thrust balance requirements for the forward propulsors. These modifications give the *ZPG-X-3W* low speed flight control, a hover capability in heavy or light condition, and improved ground handling during take-off and landing. The ship is 123 m. long, has an overall width of 26 m., a height of 31 m., and a hull volume of 42,200 cu.m. It would have a useful lift of 24 tons.

The *ZPG-X-5K* is a derivative of the *ZPG-5K* built by Goodyear for the U.S. Navy in the late 1930s and used during the Second World War primarily for submarine patrol. Like the *ZPG-X-3W*, the *ZPG-X-5K* utilizes 2 main forward engines and a stern propulsion system to achieve the desired improvements in the low speed, hover, and ground handling characteristics of previous non-rigids. It would have a useful load of 8 tons.

Only the size of the modern rigid airship was considered in the Alberta study. The upper limit of the size range was based upon a four rotor configuration and assumptions concerning maximum rotor diameter, disc loading, and so on, reasonable for today's technology. This resulted in a rigid with a maximum useful load of around 150 tons.

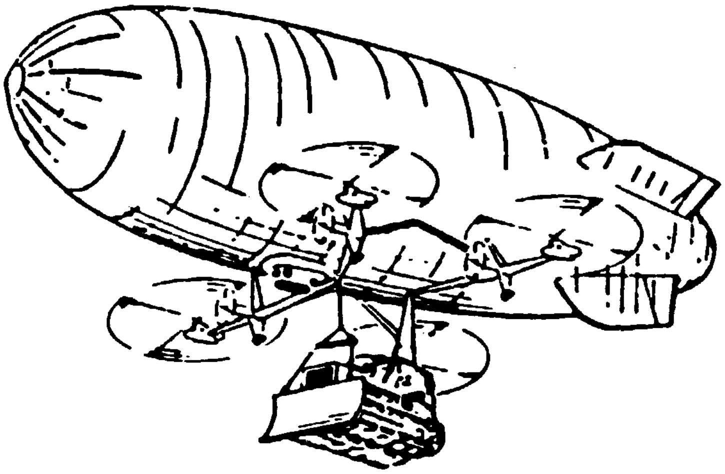
Table 7.4 gives a summary of the main characteristics of the 4 airships examined and indicates the possible operating parameters within *areas identified in user surveys as having a high potential for air*ship applications. Configurations are compared in Figure 7.11.

Detailed user and cost analyses indicated that all four airships examined in the study were economically viable in a wide variety of applications. HLAs were found to be most suited for the transport of construction equipment and project operating equipment. Other economically viable HLA applications were found to include the transport of prefabricated structures, the transport of oil and gas drilling equipment, and forest fire-fighting and logging operations. Modern conventional non-rigid airships were shown to have economically viable applications in the transport of both cargo and personnel. The larger

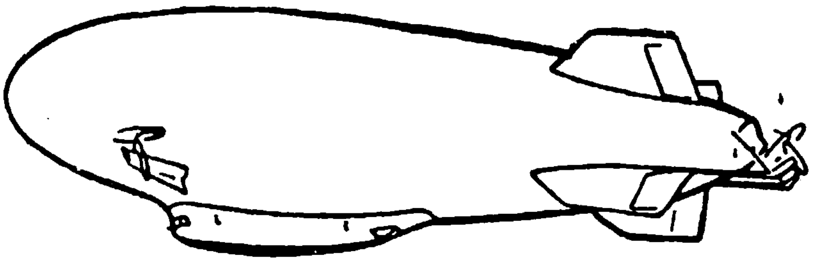
Type of Industry	Type of Construction	Payload (kg)	Endurance and/or Range (Unrefueled)	Ferry Range (Unrefueled) (km)	Maximum Useful Load (kg)	Cruise Speed (km/h)	Comments
General Construction	Heavy Lift Airship (HLA)	36,288 - 136,080 (VTOL)	4 hrs flight time at max payload	3704-5556	45,360 - 158,760 (VTOL)	148	Study results suggest current market could support two sizes: (1) Useful Load = 45,360 kg (2) Useful Load = 90,720-113,400 kg
		136,080 - 1,088,640 (VTOL)	Same as above	3704-5556	158,760 - 1,360,800 (VTOL)	148	Demand may eventually justify development of these large vehicles.
	Modern Conventional Airships Non-Rigid (ZPG-X-3W)	18,144 kg (VTOL) at 741 km	3700-5552 km Dependent upon payload and cruise speed	3704-5556 Dependent upon cruise speed	18,144 (VTOL) 22,680 (CTOL)	148	Primary market is movement of cargo to remote areas/projects where roads, airstrips, waterways do not exist.
	Rigid $V=3.11\times10^5 m^3$	133,358 kg at 1852 km 115,214 kg at 3704 km	Several thousand km dependent upon payload and cruise speed	Several thousand km dependent upon cruise speed	151,502 (VTOL)	185	Same as above
Oil & Gas	Heavy Lift Airships	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY (USEFUL LOAD = 90,720-113,400 kg)					
	Modern Conventional Airships Non-Rigid	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY					
	Rigid	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY					
Mining	Heavy Lift Airship	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY					
	Modern Conventional Airships Non-Rigid (ZPG-X-5K)	7,530 kg (VTOL) at 741 km	2778-4625 km Dependent upon payload and cruise speed	2778-7408 km Dependent upon cruise speed	9,618 (CTOL)		Primary application is movement of mine operating personnel.
	Rigid	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY					Application is transport of concentrate
Forestry	Heavy Lift Airship	38,102 kg (VTOL)	4 hrs flight time at max payload	3704-5556	45,360 (VTOL)	148	Applications are fire fighting and logging.
Surveying & Coastal Patrol	Modern Conventional Airship (ZPG-X-5K)	SAME AS FOR THE MINING INDUSTRY					Applications are: (1) Multi purpose surveying functions (2) Protection of 370 km economic limit
Prefabricated Structures	Heavy Lift Airship Modern Conventional Airship ZPG-X-3W Rigid	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY					Applications are for transport of structures.
General Transport	Modern Conventional Airship (Rigid)	SAME AS FOR THE GENERAL CONSTRUCTION INDUSTRY					Application is competition with other transport modes

Table 7.4: Summary of Main Characteristics Four Goodyear Airships

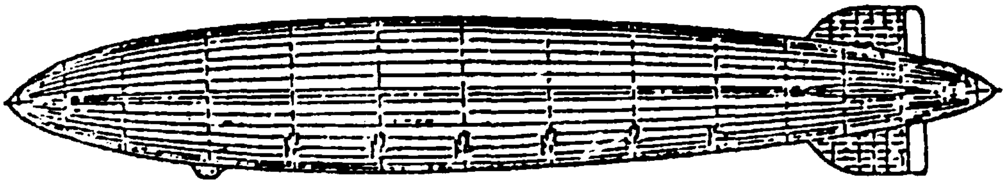
Source: Goodyear Aerospace, *Alberta Modern Airship Study*, 1978, p. 19



HEAVY LIFT AIRSHIP



MODERN CONVENTIONAL AIRSHIP (NON-RIGID)



MODERN CONVENTIONAL AIRSHIP (RIGID)

Figure 7.11: Comparison of Configurations Goodyear Airships

Source: Goodyear Aerospace, *Alberta Modern Airship Study*, 1978, p. 20

Industry	Application	Vehicle
General Construction Industry	Early Movement of Construction equipment to remote projects	HLA
Oil and Gas Industry	Movement of construction equipment across rivers (two cases)	HLA
	Extension of winter construction season (two cases)	HLA
	Emergency repair of pipeline (two cases)	HLA
	Modular construction of compressor stations	HLA
	Movement of construction equipment between Arctic Islands (two cases)	HLA
	Oil and gas drilling in remote areas	HLA
Power Generation Industry	Erection of power transmission line towers (two cases)	HLA
Mining Industry	Movement of personnel (two cases)	ZPG-X-3K
	Movement of Concentrate	Rigid airship
Forest Industry	Fire fighting	HLA
	Logging	HLA
Prefabricated Structures	Transport of structures (4 cases)	HLA ZPG-X-3W -Rigid
General Transport	Competition with trucks operating over winter and all-weather roads	HLA ZPG-X-3W
	Competition with various aircraft	Rigid

Table 7.5: Summary of Market Findings Alberta Modern Airship Study

Source: Goodyear Aerospace: *Alberta Modern Airship Study*, 1978, p. 17

ZPG-X-3W was most attractive with respect to the movement of prefabricated structures, goods and equipment in priority situations. The potential of the smaller *ZPG-X-5K* with its 8 ton payload capability was greatest as a multi-purpose survey platform. Large rigid airships were found to be competitive with trucks and other special purpose aircraft (e.g. helicopters, HC-130) in the transport of prefabricated structures, goods and equipment to remote areas. A summary of the main findings is given in Table 7.5.

The Alberta study concludes that the Canadian North West Territory could support 8 modern conventioanl non-rigids, 6 HLAs, and 2 modern conventional rigids. The 'lead times' for the 3 types are estimated by Goodyear at 3 years for the non-rigids, 5 years for the HLA, and 8 years for the rigid. The study also concludes that the establishment of an airship operating company (rental service) is essential for the introduction of the airship and that such a company would be a viable proposition for the private sector. As noted in chapter 4, steps have recently been taken by Canadian groups to establish a Canadian airship industry.

7.5 The Helitruck(8)

The *Helitruck* is a concept developed by Luftschifbau Zeppelin Gmbh, and Lightspeed U.S.A., Inc. in cooperation with the German Agency for Technical Cooperation (Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ)). Although only a concept it is included here by virtue of the claim that it has been conceived with developing countries in mind, hence the involvement of GTZ. It is also interesting for its combination of current and advanced technology.

The *Helitruck* is shown in Figure 7.12. It has a modular rigid frame structure with 4 side rotors for vertical lift and a ducted fan gas turbine motor mounted in the tail for forward flight. It would reportedly have VTOL performance and a precision hover capability in wind speeds of up to 50 kph. It is designed to operate from un-

Figure 7.12: General Configuration Helitruck

Source: Helitrans Consulting, op. cit., pp. 9-10 prepared sites. It makes no use of the mooring mast. It has a 4 wheel retractable landing gear and a centre anchor point. When standing unloaded in winds in excess of 20 kph it would swivel actively on its four point landing gear around its central anchor. The parking circle required is thus a little more than the length of the vehicle.

The *Helitruck* is conceived as a multi-purpose vehicle suitable for a wide range of missions. Four basic models are at present under review, the Helitrucks 5, 21, 36 and 75, with payload capabilities of 1.6 tons, 18.8 tons, 30 tons, and 57 tons respectively over ranges of 1000-2000 km. The main characteristics of the four models and compared in Table 7.6 and their payload/range profiles in Figure 7.13.

The *Helitruck* would have a spacious cargo hold located within the hull. The cargo bay of the *Helitruck 36* would be 30 m. long (twice the length of the H-130 or Transall C-160), 5.4 m. wide, and 3 m. high, giving it a volume of 486 cu.m. (compared with the H-130's 142 cu.m. and the C-160's 126 cu.m.). It would be suitable for low density cargos, such as fruit and cotton. As shown in Figure 7.14, the *Helitruck* would be equipped with front and rear cargo doors for quick and easy 'roll-on/roll-off' loading.

The *Helitruck* is designed to be cost-effective and fuel efficient. According to its designers, its fly away cost, in 1980 prices, would be in the order of $ 175 per lb, compared with the $ 200 per lb for helicopters and $ 120-160 per lb for conventional cargo aircraft. It would use one-half to one-third of the fuel of a helicopter and its total operating costs would be significantly less than rotor craft and competitive with fixed wing transports. If road investment is included, TOCs for some missions could be lower than those of a 12 ton truck.

The *Helitruck* is seen to possess considerable potential as a short-haul passenger vehicle. In a small vehicle designed for a 5-10 ton payload, the hull would be sufficiently spacious to provide cabin and floorspace for up to 100 seats. Estimates suggest that the passenger vehicle,

	Helicar 5	Helitruck 21	Helitruck 36	Helitruck 75
Gross weight kg				
Sea level to 5,000 feet, l	12.000	42,000	72,000	150,000
Empty weight kg	7,000	21,000	36,000	75,000
Helium volume	6,300	18,900	32,400	67,500
Useful load kg	5,000	21,000	36,000	75,000
At range of km	2,500	1,000	1,000 1,500	2,000
Payload kg	1,604	18,765	31,367 29,503	56,711
At cruising speed km/h	200	200	200	220

Table 7.6: Main Characteristics Helitruck Models

Source: Helitrans Consulting, *The Helitruck VTOL Cargo Mover*, n.d. p.6

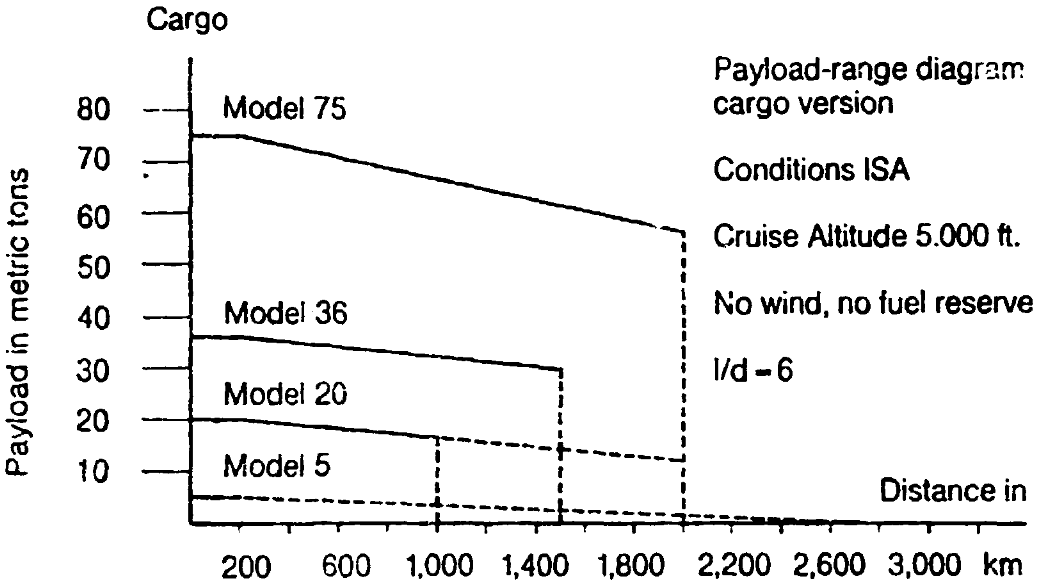


Figure 7.13: Payload/Range Capability of Helitruck Models

Source: Helitrans Consulting, op. cit., p. 7

Figure 7.14: Helitruck 36 Cargo Hold

Source: Ibid, p. 8

called the *Helibus*, could be competitive with the airplane over distances of up to 400 km. Passenger seat-mile costs comparable to those of fixed wing transports are believed to be possible.

Notes and References

(1) NASA contract NASZ-9826. Report No. CR 152202, December 1978.

(2)

(3) Information on the *Heli-Stat* is derived from company releases.

(4) Information on the *Cyclo-Crane* derived mainly from Arthur G. Crimmins, 'The Cyclo-Crane Concept', July 1981 (mimeo). Crimmins is President of Aerolift, Inc.

(5) Information on the Goodyear HLA is derived mainly from F.R. Nebiker, 'Heavy Lift Airships' in R.L. Ashford, B.B. Levitt, F.R. Nebiker, H.K. Rappoport, 'Application of Lighter-than-Air Technology in Developing Countries', UNIDO (Paper 453/26 LTA-7), October 1981, pp. 20-31 (mimeo).

(6) See especially Goodyear Aerospace Corporation, *Feasibility Study of Modern Airships (Phase II) - Volume 1, Book 1: Heavy Lift Vehicle* (NASA CR-151917, September 1976. Volume 1, Book III (NASA CR-151919) contains an analysis of the performance of the HL airship at low speeds.

(7) Goodyear Aerospace Corporation, *Alberta Modern Airship Study, Final Report, June 1978*, Akron, Ohio, 1978. For a summary of some of the study's main findings, see R.G.E. Browning, 'Canadian Interest in Modern LTA Transportation', AIAA Paper 79-1585.

(8) Information on the *Helitruck* is derived from GTZ and Helitrans Consulting, *The Helitruck VTOL Cargo Mover*, Eschborn/Burgbrohl/New York, (n.d.).

8. AEROSTAT SYSTEMS

8.1 Introduction

Aerostats are unmanned, usually non-rigid, airships or balloons that receive their instructions and sometimes their power from the ground. They are of two main types: tethered aerostats, which are fixed to either a single point or a short track on the ground and a control station; and remotely piloted aerostats which receive their instructions by telemetry command from a ground station. Although most of the remotely piloted vehicles (RPV's) which have been constructed are designed to be relatively fast and maneuverable, proposals have also been made for stationary high altitude aerostats.

Aerostat systems have a very wide range of applications. Tethered aerostats can be used, for example, for television and radio broadcasting, radio relay, rural and mobile telephone services, telemedicine, monitoring and surveillance, and hauling heavy loads over short distances, as in aerial logging. Small RPVs have been conceived for mainly civilian and military monitoring and surveillance duties but also have a potential in many other areas. High altitude RPVs display many of the qualities of satellite systems which again points to a very wide range of applications.

In this chapter we will describe more fully both types of aer systems.

8.2 Tethered Aerostats (1)

The tethered aerostat has the longest history of any LTA platform. As we saw in chapter 3, the first ever manned flight, that of François Pilâtre de Rozier in 1783, was made in a balloon that was tethered to the ground. We also saw that the tethered balloon enjoyed considerable popularity as a military observation platform in the nineteenth century and that thousands of them were produced by the British for use as anti-aircraft barrage balloons during the Second World War.

With the exception of parachute training in Britain, (2) little use was made of the tethered aerostat in the post war period. This situation changed, however, in 1968. In that year a research and development programme for tethered aerostats was initiated in the U.S. at the Range Measurement Laboratory (RML) at Cape Canaveral, Florida. The RML began to experiment with larger aerostats patterned after the old British barrage balloons. These balloons were designated the 'BJ' series after the names of their inventors, Bateman and Jones. The volume of the BJ series balloons ranged from 600 cu m (21,200 cu ft) to as large as 2,500 cu m (88,000 cu ft).

In the latter part of 1968, a $ 6 million research and development programme for the production of a 'family' of new generation aerostats was begun. This programme lasted until 1972 and resulted in the Family II series of aerostats. The first of these, a 5,600 cu m (19,750 cu ft) version, first flew successfully in December 1971. Since then, 35 Family II aerostat systems have been produced in the U.S., ranging in sizes from 5,600 cu m to nearly 12,000 cu m (424,000 cu ft). These aerostats have been used in a variety of civilian and military applications, including communication relay, long line telephone relay, community telephone services, mobile telephone services, radar surveillance, electronic surveillance, and in a variety of sensor demonstrations.

Goals were continuously raised toward larger aerostats able to carry larger payloads to higher altitudes. Recently, a new record was established when a tethered aerostat demonstrated the capability to operate successfully at 5,500 m (18,000 ft). Of greater importance, however, is the fact that more than $ 200 million has been invested in tethered aerostat systems, including aerostats, payloads, and ground handling systems for military and commercial purposes, over the past ten years. Perhaps another $ 200 million has been spent on civil works to accommodate the aerostat systems in various locations throughout the world.

A recent development in the world of tethered aerostats has been the application of a large natural shaped balloon which is held captive by a tether and used as a 'skyhook' in logging operations. Fifteen large balloons have been built in two sizes, 15,000 cu m (530,000 cu ft) and 17,500 cu m (618,000 cu ft), which are used in connection with yarding and winching equipment to move heavy logs from the forest, lifting them up over hills, across valleys and finally lowering them to an accessible area for transport. These balloons save millions of dollars in road construction and equipment costs which would normally be required to drag the heavy timber from relatively inaccessible logging areas. Of even more importance is the conservation of the topsoil, small timber and natural environment of the forest areas as the logs are transported up and over their surroundings instead of being dragged across the ground.

Technical Description

The construction of the tethered aerostat is similar to that of late model non-rigid airships. The aerostat hull is a single compartment aerodynamically shaped gas envelope with an empennage of three or four tail fins. It is inflated with helium for safe buoyant lift. As in a non-rigid, the shape of the envelope is maintained by keeping the gas pressure slightly above the ambient atmospheric pressure. The superpressure normally used is between 50 mm (1.91 in) and 75 mm (2.95 in) of water. A ballonet within the hull forms part of the pressurization system. As the aerostat ascends and atmospheric pressure falls, air is vented from the ballonet through values so as to allow the helium to expand within the hull while maintaining a constant superpressure. Unlike most non-rigid airships, which typically have two or more ballonets for pressure and trim control, all the tethered aerostats so far constructed have had a single ballonet. For high altitude operation, the ballonet must be large. At an altitude of 5,500 m (18,000 ft) where the atmospheric pressure is approximately one half that at sea level, for example, the size of the ballonet must be at least 50% of the total hull volume. The ballonet volume in modern aerostats has ranged from as little as 25% of the total hull volume to as much as 56%. The internal ballonet configuration is shown in Figure 8.1.

The ballonet in a tethered aerostat must be designed to permit longitudinal stability at any fullness. An airship with a 50% ballonet volume can experience big fore and aft excursions in the centre of buoyancy as the aerostat pitch changes and the large air bubble shifts fore and aft. The large movement of the centre of buoyancy is detrimental to aerostat stability and must be carefully considered in the overall design of the system. The ballonet is built out of lightweight synthetic material (dacron or nylon) which is coated with highly flexible substances such as polyester or polyether urethane which is also resistant to helium permeation.

The general configuration of the tethered aerostat is shown in Figure 8.2. All of the loads that are supported by the aerostat as well as the aerostat suspension system which tethers it to the ground are externally attached to the aerostat hull and do not make use of an internal suspension system similar to those used on manned airships. Another visible difference between the tethered aerostat and the manned airship is the use of air-inflated or helium-inflated fins. Characteristically, the fins on

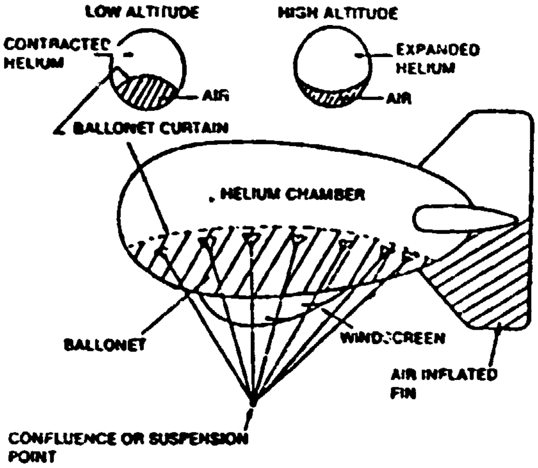


Figure 8.1: Internal Arrangement of Tethered Aerostat

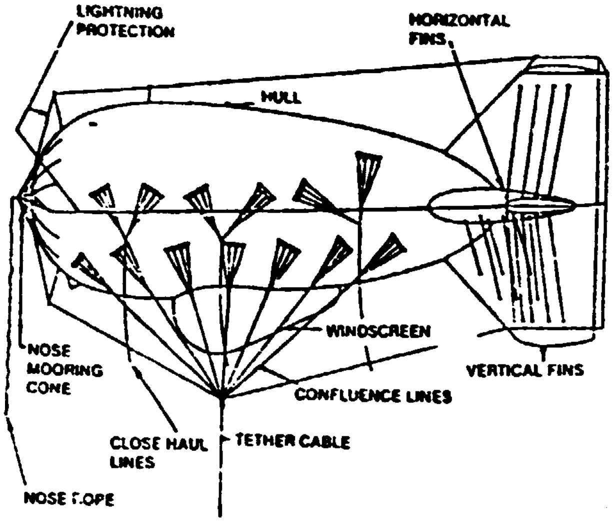


Figure 8.2: Aerostat General Configuration

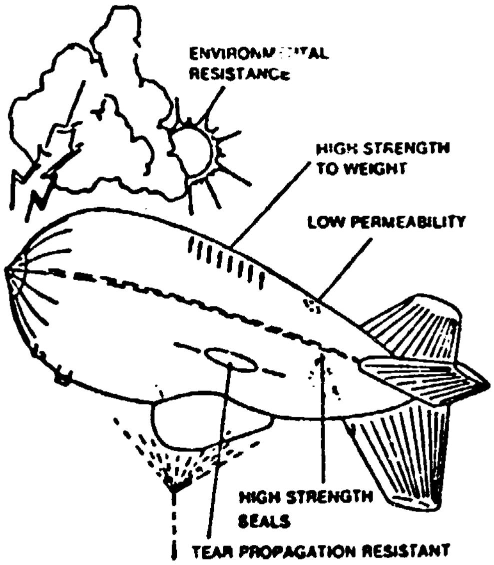


Figure 8.3: Main Hull Requirements of Tethered Aerostat

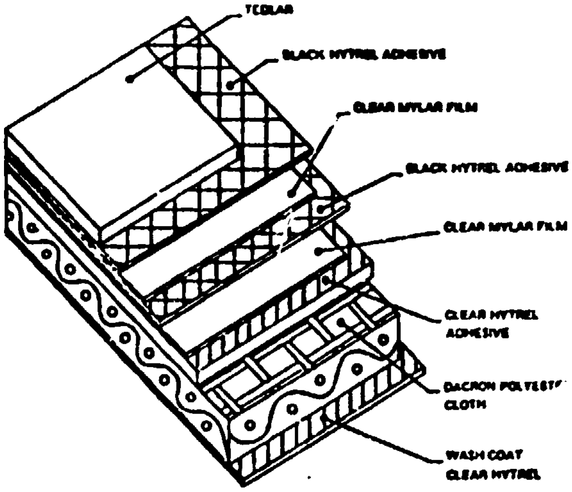


Figure 8.4: Envelope Construction

Source: J.P. Hirl, 'Tethered Telecommunications, Broadcast, and Monitoring Systems', AIAA Paper 79- 1609 tethered aerostats are many times larger in area that the fixed and movable control surfaces on manned airships.

The working payload (usually electronics) is normally housed within an inflated, streamlined windscreen which is attached to the belly of the aerostat. The windscreen is normally pressurized with air from the ballonet. Windscreen materials are traditionally similar to the ballonet fabrics, except that the outer surface is coated with a white pigmented polyester urethane which is resistant to the environment.

Because the tethered aerostat does not have a structurally reinforced nose like manned airships to withstand the dynamic pressure of high velocity winds, the internal pressure is referenced to the dynamic pressure as measured at the aerostat. This differs from the manner in which manned non-rigid airship pressure systems operate. Manned non-rigids maintain a superpressure above the ambient *static* pressure; tethered aerostats operate at a superpressure above the ambient *dynamic* pressure. In very high wind velocities (up to 105 knots at 3,000 m (9,800 ft)) the total superpressure within the aerostat hull may reach a value approaching 175 mm (6.9 in) of water in order to preclude dimpling of the nose by the wind forces.

The main hull requirements of a tethered aerostat are shown schematically in Figure 8.3. The hull envelope must possess high strength-to-weight and low permeability. The envelope will need to be resistant to attacks by weather and to repeated handling. Minor damage, such as a tear in the envelope, should not lead to catastrophic failure. The cost of the hull envelope, although secondary to most other requirements, must remain within reason. Lastly, high-strength sealing techniques must be used to weld panels. The hulls of tethered aerostats are constructed out of the most modern synthetic materials available today. All aerostat hulls use single or multiple ply dacron cloth that is either coated with a synthetic material such as polyurethane, or, as shown in Figure 8.4, is laminated to synthetic films such as mylar and tedlar. The strength of modern aerostat hull material is about equivalent to the strongest envelope material used in modern nonrigids but its weight is only about half that of the material used in traditional manned airships.

Although there are no active controls on a tethered aerostat in the form of rudders, elevators, thrustors, etc., the aerostat uses a telemetry system to relay to the ground the several parameters which accurately describe the status of the aerostat, particularly the operation of the pressurization system. Characteristically the helium hull pressure, ballonet pressure, empennage pressure and the windscreen pressure are transmitted to the ground as well as the status of all of the pressure relief valves (OPEN or CLOSED) and the blowers (ON or OFF). There is also a command telemetry system operated from the ground console that can be used to command blowers ON or OFF and cause valves to OPEN or CLOSE. The command system is used in emergency situations to override the normal automatic operation of the aerostat pressurization system.

In cases where the aerostat must operate in areas prone to thunderstorms, a lightning protection system is fitted. Heavy gauge aluminium wires are suspended above and below the aerostat and along each side with all parts of the system bonded together and to the outer conductive jacket of the tether. Thus a form of Faraday Cage encloses the aerostat and intercepts lightning strikes which might otherwise damage or destroy the aerostat system. The conductive jacket on the tether is designed to conduct the heavy lightning currents safely to the ground.

The only visible link between the aerostat and the ground is the tether. This has been the subject of much research and development in recent years. Since aerostat performance is dependent almost entirely on the buoyancy of the lifting gas countered by the weight of the system, a considerable effort has been directed toward the development of a high strength, low weight tether. Cables constructed of high tensile steel were used for many years and were particularly useful in barrage balloon applications. With the discovery of synthetic fibers with a greater strength to weight ratio than steel, new lightweight tethers with high elasticity have been made from polyester fibers held together in an unplaited, untwisted bundle by an outer plastic jacket. This no-lay-rope, made of Dacron fibers, has been in wide use in tethered aerostat applications for more than ten years. More recently, Kevlar, a synthetic aramid fiber, has been used in the construction of tethers.

Modern tethered aerostat systems carry sophisticated payloads and require a considerable quantity of electrical power to operate the aerostat pressurization system and the payload. System operational safety is derived from a large number of blowers that can be used in emergency conditions to permit high recovery (descent) rates for storm avoidance. The large blower capacity places additional demands on the power subsystem. Two forms of power systems have been developed and are in operation today. The older of the two types employs an airborne lightweight internal combustion engine-generator combination. This device has been used successfully for many years with gasoline driven reciprocating engines, rotary drive gasoline engines (the Wankel engine) and, most recently, with a lightweight diesel engine. Power generating capability of up to 15 kva has been provided by this means. The disadvantage of the motor-generator system is the requirement to recover the aerostat frequently to replenish the fuel supply.

A relatively new development (in the past five years) has been the transmission of electrical power through the tether to operate the aerostat system. The original power tether made use of a contra-helical steel cable with the electrical conductors at the centre of the cable. The latest versions of the power tether use a Kevlar strength member and is capable of supplying up to 31 kva of electrical power to the aerostat system. The attractiveness of the power tether is its reliability in all climates at all altitudes and the inherent ability it provides for the aerostat system to remain aloft for relatively long periods of time.

The development of the Family II aerostat has been accompanied by the development of some sophisticated ground handling equipment to assist in inflation, handling and mooring operations. Due to the variety of operating sites, a safe means of inflating the aerostat outdoors needed to be developed. The smaller aerostats in the 5,600 - 7,000 cu m class are fixed to the ground with the handling lines ('closehaul' lines) and the hull inflated with helium during an extended period of quiescent weather, usually at night. The inflated pressurized hull of the smaller aerostat can be handled in relative safety in winds of up to 10 knots. The aerostat is held fast at the inflation pad until all of the rigging and essential payloads have been mounted. The fins are then inflated and the ship allowed to rise until it is flying on its single tether. The aerostat is then transferred the short distance to its permanent mooring system.

The larger aerostats in the 10,000 - 12,000 cu m class are inflated under a double net. The lower net drapes over the airship hull and is weighted down along the edges with a few hundred sandbags. The upper net, which is attached along its centreline to the lower net, is drawn taut at seven strong points around the periphery. As the helium is pumped into the hull, the sandbags are moved on the lower net and the restraining lines are adjusted on the upper net to control the location of the expanding helium bubble and to counter adverse wind forces. Unexpected winds in excess of 30 knots broadside to a large aerostat have been sustained without damage to the aerostat or ground equipment.

Once the aerostat hull is pressurized it can be held virtually indefinitely under the net while rigging and payloads are attached, provided, of course, that excessively high winds are not encountered. When the rigging is complete, the fins are inflated simultaneously while allowing the aerostat to rise up on its tether. The aerostat with the net still draped over it is transferred to the nearby mooring system after which the net is removed.

The mooring systems have varied widely but contain basically a mooring tower or mast to which the nose of the aerostat is moored. A circular monorail located with the mooring tower at its centre is used to tether the aerostat to the ground in the moored configuration. The suspension lines are either attached to a mooring trolley or fastened to the end of a mooring boom which rotates freely on the monorail. Separate winches are provided to control each of the aerostat handling lines, the nose line and the main tether.

The mooring system most widely used to date employs the rotating boom system with two closehaul winches mounted near the end of the boom, the nose line winch mounted at the bottom of the mooring tower and the entire mechanism attached to a rotating machinery enclosure which houses the main tether winch, the prime power system (diesel/hydraulic) and the control station. Five men are required for launch or recovery - one supervisor directs the operation, three men observe the three handling winches primarily to remove or attach the lines on the winches, and one man does all the work as he controls the nose latch, the three closehaul winches, the main tether winch and the diesel engine operation. The major components of the rotating boom type mooring system are shown in Figure 8.5.

Logging operations require an extensive array of ground handling equipment consisting of a system of cables, anchors and winches that allow the aerostat to rise up in the air and move from one location to another laterally and then be lowered to the ground at a second location. In addition to the winch and cable system, a heavy transporter system is required to move the balloon to the bedding down area where it is stored during periods when it is not being operated or during periods of high winds. In the bedding area, the large balloon is winched down and held tightly against the ground using its own rigging and auxiliary rigging specially designed for this purpose.

Performance Capabilities and Potential Applications

The general objective of a tethered aerostat system is to carry as large a useful payload (including the tether) to as high an altitude as possible and to operate it as long as possible at a minimum cost. The performance capabilities of different aerostat systems are thus directly related to total lifting gas volume. Performance curves for four aerostat systems of different sizes - the *25M*, *250*, *365B* and *365H*, typical of what the aerostat industry is currently offering - are compared in Figure 8.6.

The smallest system, the *25M* has a hull length of 25 m and a volume of some 700 cu m (25,000 cu ft). The system is designed to be highly mobile and readily relocatable, operating from a mobile mooring system. From the performance curve it can be seen that the system can carry a modest payload to an operating altitude of about 1000 meters (3,280 ft).

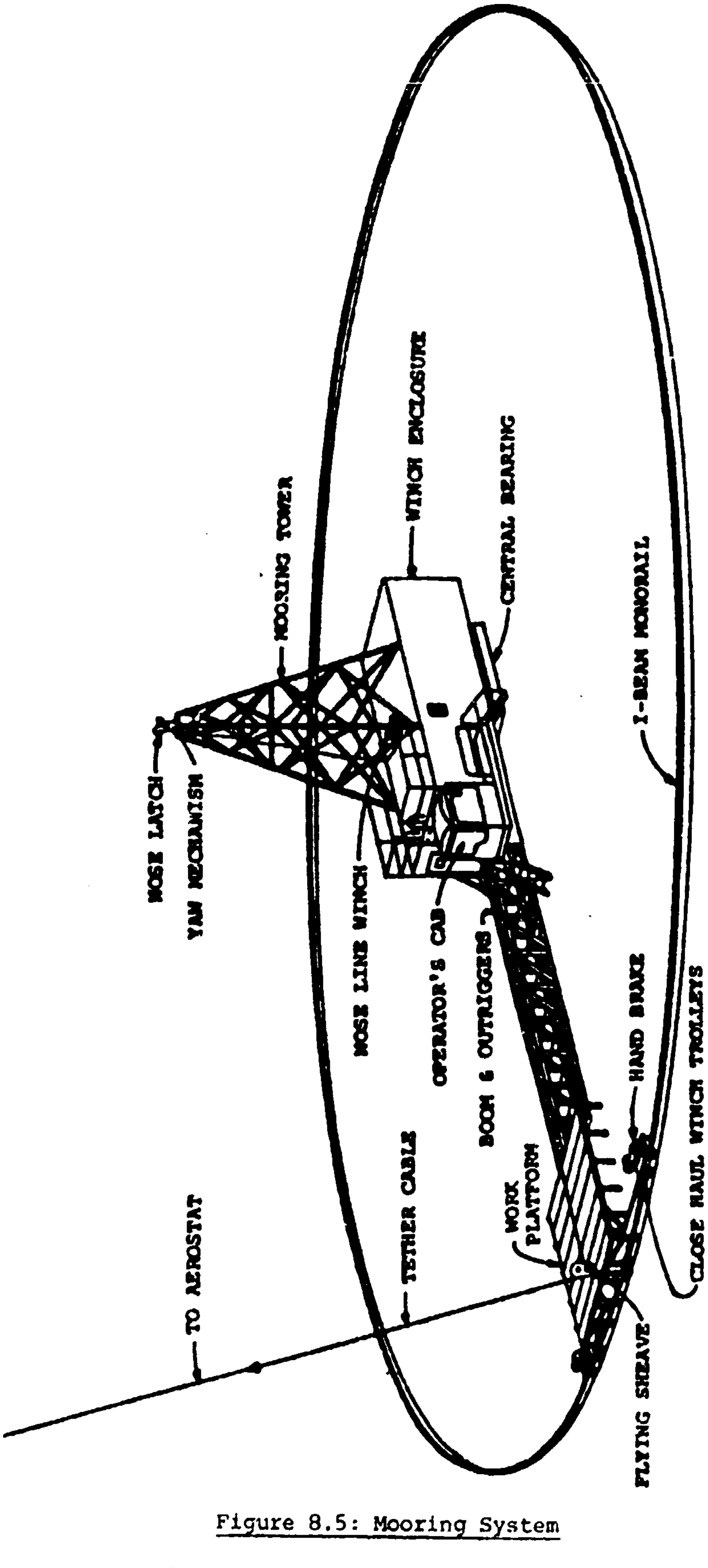


Figure 8.5: Mooring System

Source: R.L. Ashford, 'Tethered Aerostats', UNIDO 453/26 LTA-7, October 1981, p. 38

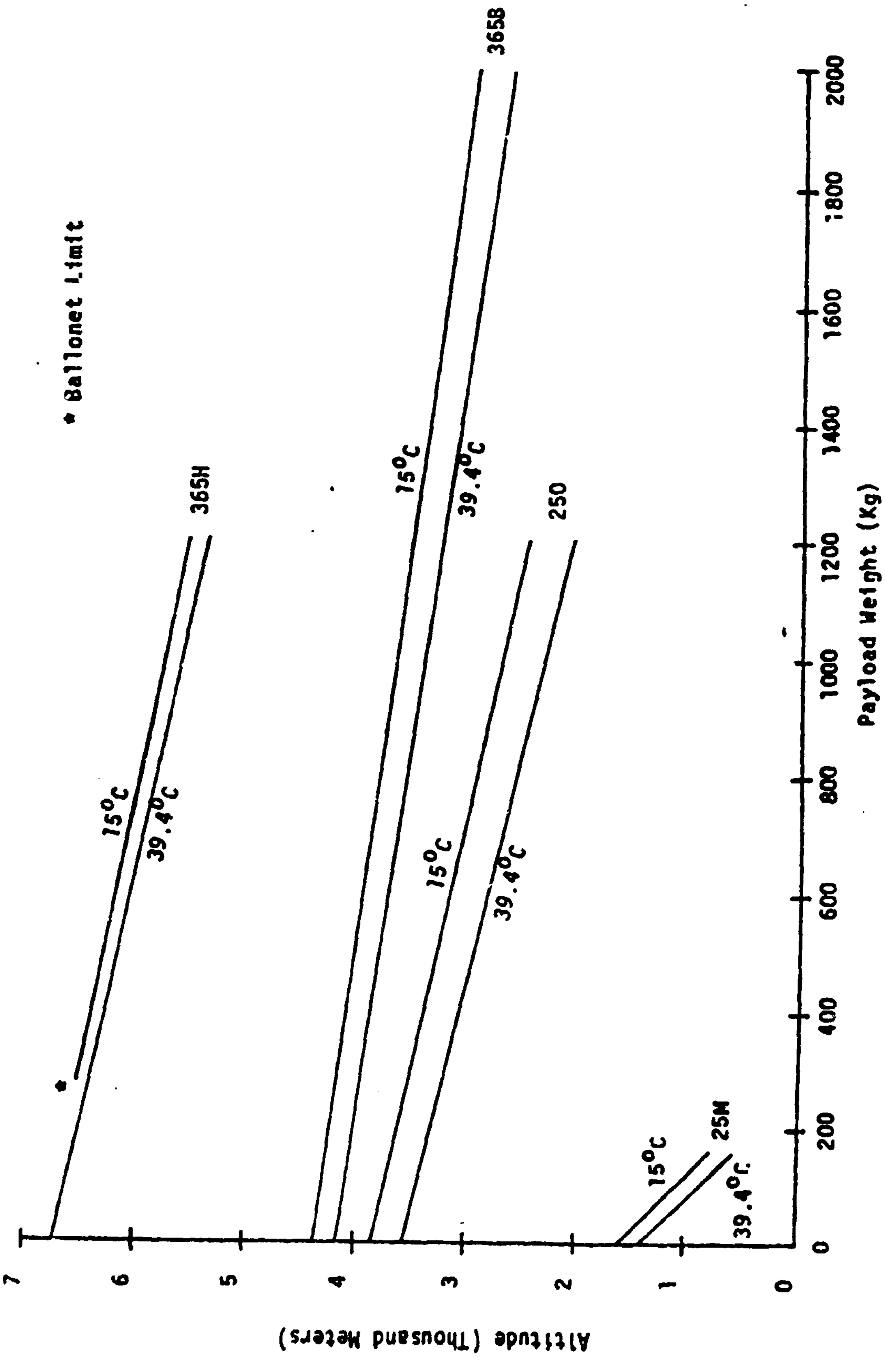


Figure 8.6: Comparison of Performance of Different Aerostat Systems

Source: R.L. Ashford, op. cit., p. 39

The *250* system, with a volume of 7,000 cu m (250,000 cu ft) is designed to operate with a 318 kg payload at an altitude of 3,000 m (9,800 ft). The *365B* system has fins inflated with air and a gas volume of 10,300 cu m (365,000 cu ft). The fins can, however, be inflated with helium to generate additional lift, increasing the total gas volume to 12,000 cu m (424,000 cu ft). This system is designed to operate at 3,000 m with a 1,900 kg payload. Both the *250* and *365B* systems are designed with a lightning protection system on the aerostat and a lightning protection jacket on the tether and for use with a power tether. Other forms of power systems could, however, be employed.

The *365H* system is designed for high altitude operation in a climate where the probability of thunderstorms is very low and the likelihood of damage from a lightning strike virtually non-existent. The *365H* aerostat is the same size and volume as the *365B* but contains no lightning protection, uses a lighter weight tether with no lightning protection and fewer blowers in the pressurization system. The lighter weight *365H* system is designed to carry a payload of 1,200 kg (2,640 lbs) to an altitude of 5,500 meters (18,000 ft) with a very much reduced operational safety factor.

In Figure 8.6 two performance curves are shown for each aerostat system to show the effect that the surface temperature has on the performance of the system. In each case, of course, the systems perform better in cold weather.

The relative sizes of the four aerostat systems are shown in Figure 8.7.

A typical tethered aerostat payload can include up to two tons of communications equipment to be lifted to an altitude of 3 km (9,800 ft) with a significant loading safety margin. This payload

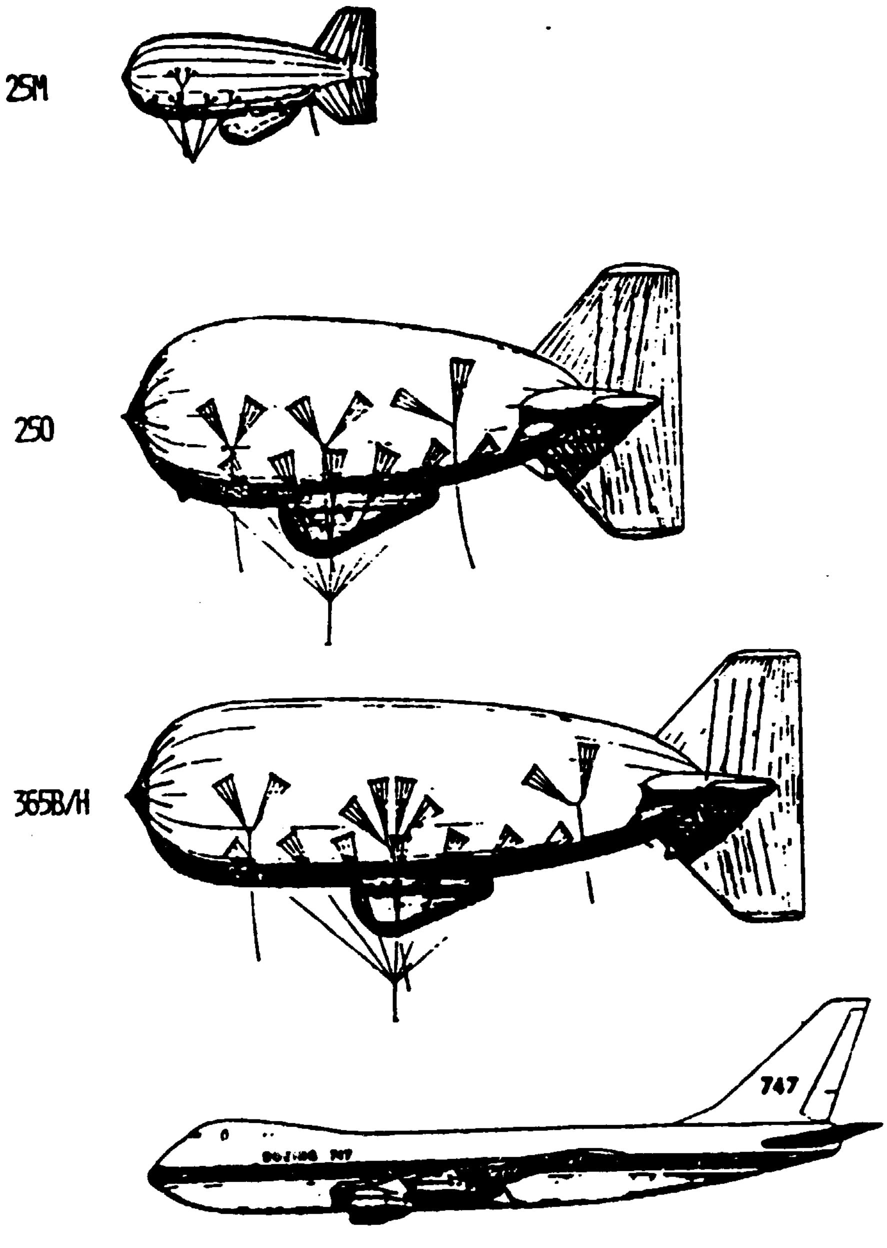


Figure 8.7: Relative Sizes of Aerostat Systems

Source: R.L. Ashford, op. cit., p. 41

may include commercial and educational television, a.m. and f.m. radio broadcasting equipment; off-the-air receivers; radar surveillance equipment; translating equipment; high-density wideband communications equipment for multichannel voice and data transmission; mobile and maritime networks; and equipment performing numerous other functions such as wide area paging, emergency radio broadcasting, wide area data collection, remote area meteorological observation, optical scanning and monitoring.

Several studies prepared by government agencies and independent consultants have concluded that aerostat systems can be a cost-effective solution to a wide range of communication problems. From these studies it would appear that tethered aerostat systems merit consideration when the following conditions are met: (3)

. The area to be served is large. Aerostat systems perform best at altitudes of 3,000 - 4,000 m, between the zones of ground wind turbulence and high altitude, high velocity winds. The operating altitude determines the coverage area and at a height of 4 km some 200,000 sq km can be reached.

. A multiplicity of communication services is to be provided. The aerostat and mooring system represent a fixed cost. The electronic payload is composed of independent sub-systems. The more communications services provided, the smaller the share of the fixed cost for the aerostat system which is attributable to any particular communications service.

. Existing investment in communication infrastructure in the area under consideration is small. Where large investments in communications systems have already been made (i.e. where broadcasting towers, radio relay repeaters and access roads are in place and installed facilities can accommodate future growth), it will as a rule be more economical to solve a communications problem through the expansion of existing infrastructure.

Other factors contributing to the selection of aerostat systems over competing solutions are:

. Difficult geographical conditions, for example riverine and delta areas, archipelagos, or many scattered communities in difficult terrein. (The aerostat system minimizes the need for ground facilities).

. A shortage of skilled manpower for maintenance. (The aerostat system concentrates maintenance activities at a single point and is less manpower-intensive than many other solutions).

. Security considerations. (All equipment is concentrated at a single location and is easier to defend against sabotage or attack).

. Exclusive national control over an important communication resource. This is not the case in systems using leased facilities, for example from international satellite organizations. (The aerostat system is under national control).

. Quick implementation time and early generation of revenue are desirable. (Aerostat systems can generally be made operational quicker than any other type of system on the same scale).

The above clearly indicates that aerostat systems have considerable potential in developing countries. Several systems have in fact been partially installed in Iran and Nigeria by the TCOM Corporation, a subsidiary of Westinghouse, and the main producer of aerostat systems. In Iran, a system was operated under the direction of the national broadcasting company in the Baluchestan area for 4500 hours before being discontinued in 1979. During the operation-

Example: An Aerostat Broadcasting System

An aerostat TV broadcasting system has an inherent advantage over conventional broadcasting systems in its ability to cover a vastly greater area with a single transmission system. Lower costs, frequency conservation and performance improvement are the ultimate results. Since broadcasting in the United States is regulated by the FCC (Federal Communications Commission) the regulations of that body are used as a basis for comparing the performance of a typical TV system with that of conventional broadcasting systems. The FCC describes coverage in terms of field strength leading to Grade A or B picture quality. Considering the lower v.h.f. band, the median field strengths required for channels 2-6 are 2,500 μV/m for Grade A, and 225 μV/m for Grade B service. The factors affecting the actual received field strength are so numerous and difficult to predict that a statistical approach is required. This approach predicts field strength present in the best 50% of receiving locations for 50% of the time.

Using these field strength predictions the chart in Figure 8.8 has been developed which shows the obvious advantages of the tethered aerostat system over conventional broadcasting. Conventional transmission is normally restricted, by practical considerations, to an effective tower height of 300 meters (1,000 ft); a tethered aerostat antenna is nominally at an altitude of 3,000 meters (9,800 ft). The aerostat system, with a lower effective radiated power (e.r.p.) of 2.5 kW, provides a much larger and superior coverage than a conventional terrestrial system would provide with an e.r.p. of 10 kW. FCC signal quality is based on a typical receiver with a noise figure of 12 dB for v.h.f. and 15 dB for u.h.f. and antenna gains of 6 dB for v.h.f. and 13 dB for u.h.f. Low-cost receivers with 6 dB noise figure for v.h.f. and 8 dB for u.h.f. and antennas with 13 dB gain at v.h.f. and 18 dB at u.h.f. are now available which can be utilized to provide still further improvements.

Similar statistical techniques are used to estimate f.m. broadcasting service quality on a 50-50% basis. The objective field strength on this basis is 1,000 μV/m for urban areas, and 50 μV/m for rural areas. Figure 8.9 compares conventional and tethered aerostat systems for f.m. radio broadcast coverage at frequencies of 88 to 108 Mhz.

Similar performance analyses can be applied to many other forms of communications relay missions fulfilled by tethered aerostat. No less important than technical performance is the 'cost performance' of the aerostat system. Here it can be shown that, in most areas of the world, the initial cost of the aerostat system, its installation and, in particular, its operating cost, are very competitive with conventional terrestrial communications systems.

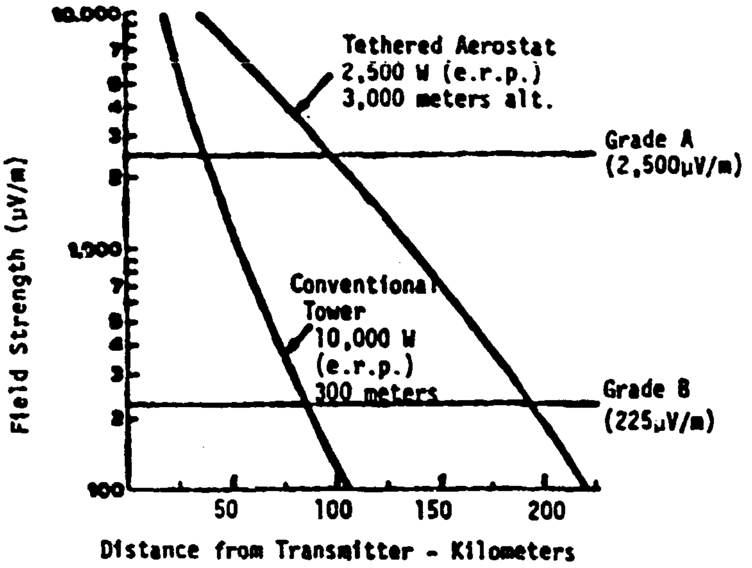


Figure 8.8: Comparison of Tethered Aerostats and Conventional TV Broadcast

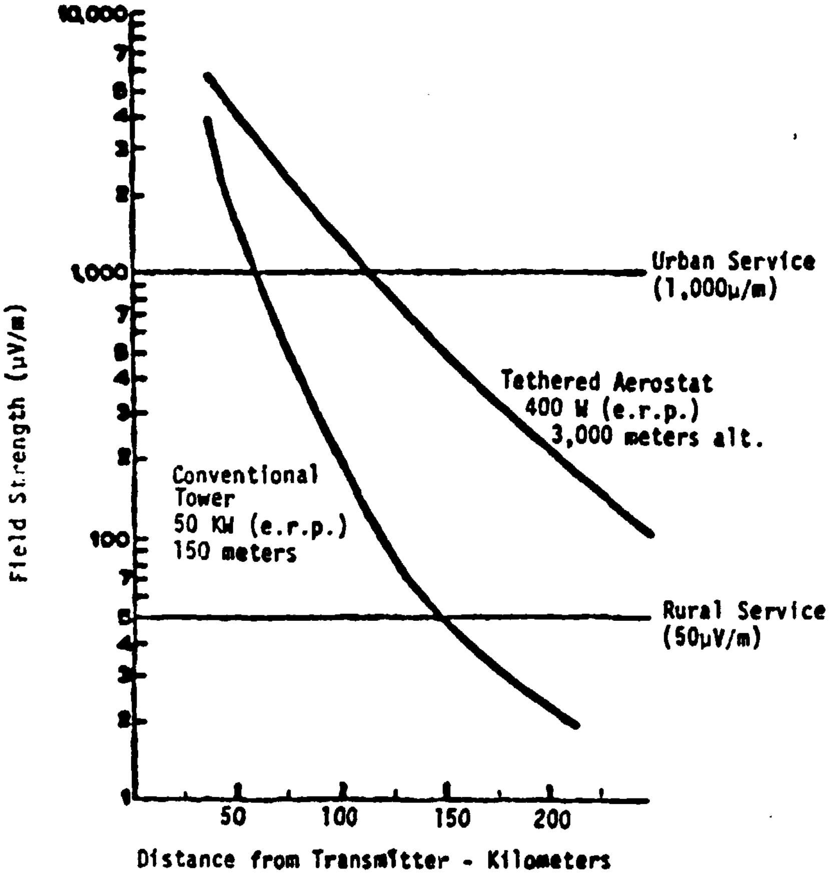


Figure 8.9: Comparison of Tethered Aerostats and Conventional FM Broadcast

Source: R.L. Ashford, op. cit., p. 43

al period the aerostat flew daily providing 16 hours of radio and television programmes to an area of 125,000 sq km. A second system for the Persian Gulf area of the country was planned when aerostat activities were terminated.

In Nigeria TCOM designed and began installing a 5 station, 10 aerostat system capable of providing communications coverage over 90% of the country's land area. Designed to provide radio and television services, a nationwide telephone system with significantly improved rural telephone services, and an improved mobile telephone service, the system has not yet been completed due to problems in the completion of the required ground works. The aerostats have been deflated, awaiting the completion of the ground works.

TCOM remains convinced of the potential of aerostat communication systems in the Third World and, despite apparent set backs in Iran and Nigeria, hopes to sell some 20 systems to developing countries for different purposes during the course of the next five years.

Cost of the Systems

The cost of the small *25M* aerostat system was given as approximately $ 850,000 in 1981. This price includes the aerostat, the electronics equipment to suspend the payload and monitor aerostat functions, the tether, and a mooring and operations trailer, but excludes the cost of the electronics payload.

The price of the much larger *365B* and *365H* systems is $ 5,400,000, excluding payload. This also covers all aerostat-borne subsystems and the site ground control subsystem. The cost of the payload would be in the order of $ 1 million - $ 3 million depending upon the type, quantity, and complexity of the services to be provided.

3.2. Remotely Piloted Aerostats

Remotely piloted aerostats are unmanned vehicles that receive their instructions by telemetry command from a ground station. There are two main types: small vehicles that can be instructed to fly according to flight patterns selected by ground control; and much larger high altitude platforms which remain in a fixed position. Several demonstration models of the first type have been constructed and flown. The technical feasibility of high altitude platforms has been examined but none have as yet been constructed.

Unmanned Mini RPVs

RPVs have become standard military hardware. They have been used most extensively as drones in missile testing, but much more complex vehicles have been used for various purposes in battlefield conditions. (4) Since the early 1970s efforts have contrived to couple RPV technology with aerostat technology to produce relatively low cost, high performance monitoring and surveillance platforms able to fulfil a wide range of civilian missions, such as law enforcement and traffic surveillance, maritime patrol, oceanographic and atmospheric research, customs and border patrol, and pollution monitoring. (5) The main advantages of the remotely piloted mini blimp (RPMB) are those of low operating costs, high levels of safety, and long endurance with low energy consumption and pollutant levels.

Work on the RPMB has been pioneered by the California based company Development Sciences, Inc. (6) It flew a small 'proof of concept' vehicle in 1975. Five metres long and a little over one metre in diameter, the helium inflated test vehicle was powered by a ¼ hp model aircraft engine. This small vehicle carried a 1½ kg payload that included a super 8 movie camera.

It went on to construct a larger demonstration vehicle that first flew in Spring 1977. This 8 m vehicle has a tapered hull for improved aerodynamic performance and 3 low weight composite fins, two horizontal and one vertical, each with an active control surface. A 2 hp engine was mounted on the vertical control surface and model electronics were used for command and control. The vehicle took off 'heavy' carrying up to 16 kg of payload and ballast, including, in later tests, a real time battery powered TV system. The craft achieved a top speed of 50 kph and its typical altitude of operation was 100 - 200 m. The photographic and video coverage was good and the vehicle proved easy to fly.

Following this successful trial, Development Sciences, Inc. was commissioned by the City of Bell Gardens Police Department (within the Los Angeles metropolitan area) to build and demonstrate a "fully capable" RPMB for law enforcement. The vehicle developed was similar to manned non-rigids in most ways with a centrally positioned 'car', an empennage of four fins set in the form of a cross, and an ellipsoidal envelope of 4,000 cu ft. The envelope was constructed of a 60z nylon laminate and the fins of high strength, low weight Kevlar-epoxy/honeycomb sandwich 5 cm thick. Each fin has a control surface and actuator. A single ballonet, located midships pressurized by a small pump driven off the engine shaft, was used to maintain internal gas pressure. Propulsion was provided by a 280 cc two-stroke, two-cylinder powerplant producing 20 hp at 7,800 rpm. The engine drove a 65 cm diameter shrouded propeller. A 600 watt alternator was driven at engine speed.

The helium inflated vehicle, 13 m long and 4.5 m in diameter, could carry up to 50 kg of fuel and payload. For law enforcement it was equipped with 27 kg of payload, including a pan and tilt low-light-level TV/video camera, public address system and floodlight. The camera was able to transmit daytime illumination pictures during darkness.

Performance was found to be very satisfactory. The vehicle could take off by its own thrust and be recovered by a single attendant. It proved stable, responsive and easy to fly. The patrol speed of 23 knots gave fuel consumption of a little over one kg of gasoline per flight hour. During a 20 hour patrol, the vehicle used 7.7 gallons of fuel. Camera coverage was found to be excellent. When flown at the design altitude of 100 - 150 m the vehicle operator could recognize faces at distances of up to 200 m. The operator, who can select one of three modes - manned, patrol or loiter - has a continuous readout of airspeed, heading, altitude, fuel remaining, signal strength, engine rpm, engine temperature, and envelope pressure.

Although the demonstration in the City of Bell Gardens was terminated due to the tax cuts enacted in California, Development Sciences. Inc. believes that the RPMB has proved its effectiveness and expects the system to find a range of civilian applications in the coming decade. One of the more promising areas is as a low-cost patrol vehicle for the monitoring and surveillance of maritime zones. Given the RPMBs low altitude performance it would be well suited to over-the-water operations and is capable of providing the most important information required from a surveillance system: is there anyone there who should not be there and, if so, who is it and where is it headed.

High Altitude Platforms

NASA has conducted investigations into the feasibility of very high altitude remotely piloted aerostats for communications and surveillance missions. Two proposals have received most attention: project HI-SPOT, which employs an aerostat of 85,000 cu m capable of remaining on station at an altitude of 21 km (70,000 ft); and project HAPP (High Altitude Powered Platform) with a similar capability but a difference source of power. Both systems would combine the useful features of geostationary satellites (wide area coverage, frequent observation) and aircraft (high resolution). For these reasons, HI-SPOT and HAPP concepts are sometimes referred to as 'mesoscale geostationary satellites'.

A study of the technical feasibility of the HAPP was conducted for NASA by the Stanford Research Institute (SRI). (7) Two concepts were identified as being most promising: a LTA platform and a fixed wing HTA platform that would remain on station by flying in a tight circle. Both platforms would be free flying and receive their energy for station-keeping via a microwave beam directed from the ground. An onboard antenna would convert the microwave energy into electrical energy that would drive electric motors onboard the aerostat or airplane. These motors would provide the necessary power for station-keeping and would be sufficient to power any remote sensing or communications equipment onboard the platforms. The aircraft would be kept on station at 21 km (70,000 ft), a region of minimum wind and above storms, for up to a year over a given location. The airship and airplane concepts are compared in Figure 8.10 and Table 8.1.

The HAPP could be equipped with a very broad range of instruments. All of the communications equipment and sensors currently found onboard satellites and airplanes, such as real aperature radar, microwave and infrared radio meters, multispectral scanners, low-light-level television, laser line scanners, and radar altimeters and scatterometers, could be fitted to the HAPP. According to the SRI study, 6000 kg payloads for the HAPP would be technically feasible, adequate for almost any forseeable communications and surveillance application.

	BLIMP		AIRPLANE	
	MISSION 1	MISSION 2	MISSION 1	MISSION 2
1. TOTAL WEIGHT (LBS)	1,300	4,800	1,800	4,500
2. WING SPAN (FT) OR VOLUME (FT^3)	0.5×10^6	1.3×10^6	100	100
3. PAYLOAD (LBS)	300	1,000	300	1,000
4. NOMINAL ALTITUDE (FT)	70,000	70,000	[illegible]	70,000
5. AVAILABLE POWER (KW)	FEW KW	FEW KW	–	–
6. MISSION DURATION (YR)	1	1	1	1
7. ANNUAL COST ($)	430,000	580,000	470,000	730,000

Table 8.1: HAPP Main Characteristics

Source: D. Escoe, P. Rigterink, J.D. Oberholtzer, 'Potential Applications of a High Altitude Powered Platform in the Ocean/Coastal Zone Commodity', AIAA Paper 79-1602

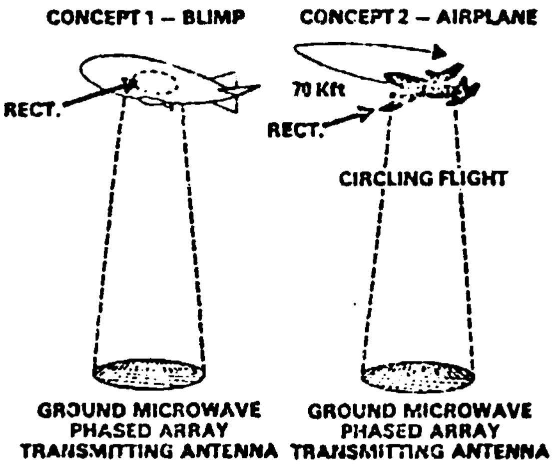


Figure 8.10: Comparison of HAPP Concepts

Source: D. Escoe, et al, op cit.

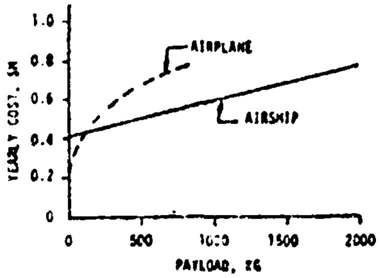


Figure 8.11: HAPP Operating Costs

Source: M.B. Kuhner, 'Applications of a High-Altitude Powered Platform (HAPP), AIAA Paper 79-1603

The SRI study declared both the airship and airplane alternatives technically feasible. Although cost estimates are bound to be provisional, the airship HAPP was found to be the most cost-effective. The annual cost of a 1000 kg payload was estimated at $ 800,000 for the HTA craft, and less than $ 600,000 for the LTA platform. The operating costs of the two systems are compared in Figure 8.11.

Computer Sciences Corporation (CSC) was contracted by NASA to investigate potential user interest in the HAPP and Battelle's Columbus Laboratories to examine its potential applications in remote sensing and communications. These studies show that user interest is considerable and that the HAPP could be a cost competitive platform for a wide variety of communications and surveillance tasks. (8)

The CSC study notes that the HAPP was well received by much of the maritime/coastal zone community and that many believed that it could provide operational capabilities not currently available in satellites and HTA craft. The study identifies 44 possible Coast Guard type missions, some of them requiring a resolution of one meter. Most of the missions identified, the study concludes, could be performed by the HAPP.

At 70,000 ft a HAPP would have a radar horizon of 600 km. With this horizon, six HAPPs would be sufficient to provide continuous coverage of the 2 million sq mile Exclusive Economic Zone of the continental U.S.

The Battelle study estimates the total annual operating cost of a HAPP maritime surveillance system for the U.S. at $ 10.2 million. By comparison, the costs of carrying out four times a day surveillance with conventional airplanes is estimated at $ 35.8 million a year. The HAPP surveillance system would thus cost about one-third of a comparable HTA system, and it would supply information on a continuous basis rather than four times a day. As we saw in chapter 6, personnel costs are an important factor in any surveillance system. The HAPP, because it is unmanned, reduces these costs very considerably.

Similarly, the Battelle study concludes that the HAPP has significant potential as a communications relay platform. With an operational altitude of 21,000 m the HAPP would be able to cover an area 33 times larger than can be served by a 300 m tower, and 7 times larger than the tethered aerostats discussed earlier. Assuming horizon-to-horizon coverage, 13 HAPPs would be sufficient to cover the continental United States.

The Battelle study suggests that the HAPP would appear to possess a special potential for direct broadcasting over large areas to unmodified home TVs. The use of the HAPP for this purpose, the study's authors conclude, "could lead to a new era in broadcasting". (9)

Notes and References

1. This section is based on Robert L. Ashford, 'Tethered Aerostats', in B.B. Levitt, H.K. Rappoport, F.R. Nebiker and R.L. Ashford, 'Application of Lighter Than Air Technology in Developing Countries', UNIDO (document 453/26 LTA-7), Vienna, October 1981, pp. 32-45.

2. Up to six trainees are carried aloft to about 300 m using the lift of the aerostat. They make their training jumps from this altitude from a personnel support structure under the balloon, after which the craft is hauled back to the ground by its tether and another load is carried aloft. The cost of this operation is only a fraction of the cost of other parachute training methods and has been in use more or less continuously since the Second World War to the present time.

3. See J.P. Hirl, 'Tethered Telecommunications, Broadcast, and Monitoring Systems', AIAA Paper 79-1609.

4. RPVs were used, for example, by Israel in the Lebanon for a range of tactical and observation purposes. See 'Scout Mini-RPV Used Over Lebanon', *Flight International*, 4 December 1982, p. 1609.

5. For a discussion of possible areas of application, see G.R. Seeman et al, 'A Technology Tool for Urban Applications - The Remotely Piloted Blimp', AIAA Paper 73-981 (September 25, 1973); G.R. Seeman et al, 'Remotely Piloted Mini-Blimps for Urban Applications, *Astronautics and Aeronautics*, February 1974, pp. 31-35; and G.R. Seeman, G.J. Brown, G.L. Harris, 'Unmanned Mini-Blimp System', AIAA Paper 79-1610.

6. For a description of its RPMB activities, see Seeman, Brown and Harris, op. cit., on which this section is based.

7. See J.W. Sinko, *High Altitude Powered Platform Cost and Feasibility Study*, SRI Report 5655-502, Stanford Research Institute, Stanford, California, 12 October, 1977.

8. See M.B. Kuhner, R.W. Earhart, J.A. Madigan, G.T. Ruck, *Applications of a High-Altitude Powered Platform (HAPP)*, Report No. BCL-OA-TFR-5,Battelle Columbus Laboratories, Columbus, Ohio, September 1977; M.B. Kuhner, 'Applications of a High-Altitude Powered Platform (HAPP), AIAA Paper 79-1603; and D. Escoe, P. Rigterink (both Computer Sciences Corporation) and J.D. Oberholtzer (NASA), 'Potential Applications of a High Altitude Powered Platform in the Ocean/Coastal Zone Community', AIAA Paper 79-1602.

9. Kuhner, op. cit., p. 154.

9. CONCLUSIONS: FINANCING LTA DEVELOPMENT

This report has attempted to show that airships and other LTA craft do have considerable potential for different types of applications in both the developed and developing world. As we have seen, market studies conducted by and for the LTA industry have identified a potential for 1000+ vehicles for aerial logging operations, 100+ vehicles for maritime patrol, 100+ vehicles for heavy lift operations. In 1977, a study conducted by Sodek, a French government sponsored organization, predicted that by 1990 4000 airships would be in use around the world in civilian and military roles.

The fact is, however, that the industry has so far failed to capture a share of the market for which its products have an undoubted potential. The cancellation by the U.S. Navy of its heavy lift hybrid requirement and by the U.S. Coast Guard of its maritime patrol airship requirement were major blows to the industry, and the largest LTA demonstration project currently underway, the Piasecki *Heli-Stat*, has reportedly run into difficulties and may be scrapped. Goodyear, a name that has appeared frequently in this report and a company that has built 304 airships, is considering terminating its LTA activities. In the past eight years it has spent $ 7 million of its own money on airship investigations and has pursued an aggressive LTA policy. It has received hundreds of expressions of interest in its airships but has yet to receive a single order. It has been unable to convince prospective customers that its product is a flying and economic proposition. It has come to the conclusion that airships are a 'negative business', an unacceptable drain on its shareholders' money. It is reassigning its LTA group - 50 engineers, including 15 modern airship engineers - to other positions within the enterprise.

Outside the U.S., the situation is less gloomy. Airship Industries is making progress in selling its Skyships 500 and 600. The orders for three Skyships (one 500 and two 600s) announced by the company in 1982 represent the first orders placed for airships in more than three decades. Other firm orders are expected soon. In Germany, WDL is operating on a self-financing basis, largely as the result of revenues from aerial advertising. LTA activity is continuing in Canada with prototype airship development and even attempts to create a Canadian airship industry.

In a real sense the airship industry appears to stand before a threshold. Whether it can cross it remains an open question. The market requirement for maritime patrol and heavy lift aircraft would seem to suggest that it is now or never. It is important for the airship to establish itself, in its conventional or one of its new forms, in these areas while there is still time for it to do so. For while the airship industry edges forward, the world of civil and military aviation is making rapid strides.

One of the airship's great assets is its fuel efficiency. The 'oil crisis' has not only led to a reappraisal of the airship, it has also led to new generations of airplanes with significantly reduced fuel burn. A number of LTA studies have shown that passenger carrying airships can be competitive with HTA craft over 300-400 km. It is questionable whether this will remain the case when the new commuter, feeder and regional aircraft now under development - such as the DH Canada Dash 8, EMB-120 Brasilia, CN-235, ATR 42, SF 340 and BA 748AT - enter airline service in the next few years. All these aircraft have a STOL capability, are quiet, and could be operated from short fields in urban areas. They are also significantly more fuel efficient that the aircraft they will replace.

Even in the new area of maritime patrol, light aircraft are beginning to come 'on line' which can be operated at a quarter of the cost of helicopters. Some of these have a low speed capability, three times the duration of helicopters, and are virtually vibration free, which means they are suitable for fitting with sensors. Tilt-rotor V/STOL HTA craft are also being developed for military uses and civilian versions will almost certainly follow.

Whether LTA vehicles are able to cross the threshold is essentially a question, not of technology, but of money. Here there are two main obstacles to future LTA development: high R & D costs; and the small numbers of vehicles produced. The two are obviously related.

The development of airships is expensive. Estimates of the cost of building a 75 ton HLA vary between $ 100 million - $ 350 million. A large rigid would cost in excess of $ 100 million. A prototype non-rigid with a 25 ton payload capability would cost $ 30 million or more. These are large sums of money which fall beyond the resources of the industry. They are, however, small when compared with other areas of civil aviation. The development costs of a new regional airplane for 50-60 passengers can be as high as $ 1 billion. A new generation 150 seat passenger aircraft, at present the subject of much discussion within the aviation industry, could involve R & D costs of up to $ 4 billion for airframe, engines and avionics. In the automobile industry, relatively minor style changes can cost hundreds of millions of dollars. General Motors, according to its own estimates, spent $ 2.7 billion in the development of its front wheel drive models introduced in 1979, which involved no radically new technology. (1)

Such high R & D costs can, of course, be justified by the large numbers of vehicles produced. The costs can be recuperated over long production runs, although there are numerous cases of aircraft and automobiles that have cost their manufacturers money. (2) If airships could be produced in significant numbers, their costs would similarly fall. Numerous examples of this have been given in this report.

. The first *ZP-X* maritime patrol airship for the U.S. Coast Guard would cost an estimated $ 15-20 million. The unit price would fall to about $ 5 million if 50 vehicles were produced.

. The Goodyear HLA with a 75 ton payload capability could be sold for about $ 35 million if produced in large numbers even after an initial R & D investment of $ 300-350 million.

. Kawasaki Heavy Industries believes its 120 passenger hybrid *Helistat* could sell for $ 7.5 million if a minimum of 10 craft were produced.

. A non-rigid with a 25 ton payload capability would cost $ 30 million or more to build. If it were to become a 'workhorse' it could probably sell for around $ 5 million.

Large production runs - 20-50 ships - change airship economics very significantly.Multi-mission capable maritime patrol airships and 25 ton utility non-rigids costing $ 5 million would be paying propositions for their operators. Ships costing $ 20-30 million would not. By way of comparison, the 3 types of small non-rigids now flying cost $ 1.5 million (*WDL-1*), $ 2.5 million (*Skyship 500*), and $ 4.0 million (*Goodyear GZ-20A*). These ships have payload capabilities of only 1.5-2.0 tons. Airship Industries believes that the price of its *500* could be brought well below $ 2.5 million if it were to be produced in larger numbers. The same applies to its *600* which, due to fly in 1983, is to sell for $ 2.9 million.

If airships were to be built in numbers, engine manufacturers may be inclined to develop propulsion systems geared to the needs of the airship industry. At present, the industry is forced to adapt engines produced for automobiles, helicopters and airplanes.

Investments in airships are essentially long-term investments. Investors, large and small, are unwilling to wait perhaps up to a decade before they see a return. As Vladimir Pavlecka, chief scientist with the California company Airships International, has observed: "Private corporations shy away from (airships) because they want profits tomorrow". (3) Whereas it is true that the small airships now flying have been built with investors' money, it is unlikely that the sums required to carry the airship over the threshold can be raised from private sources. If airships are to 'take-off', it will be government financing that will get them airborne.

In the contest for public monies, airships have a five-fold disadvantage. Firstly, the lion's share of government R & D funds in many Western countries is reserved for military applications: in France and Britain, for example, it is between 40-50%. While some maintain that the airship has military applications (4) and that new AEW and ASW technologies and missions may be tilting operations back in the airship's favour (5), the airship is not a destructive weapon nor is it necessarily a weapon of war. When a technology has no direct military applications or, as in the case of the airship, has military applications which do not fit within current military thinking and priorities, it is cut off from the major source of government R & D expenditures. Airship development has made most rapid strides when armies, air forces, and especially navies believed that they were in need of them. They no longer believe they are.

Secondly, the airship, we have suggested, is preeminently a Third World vehicle. In the industrialized countries very little in the way of public R & D funds are allocated to the development of technologies geared to the needs of the developing countries. About 95% of the world's total R & D expenditures are devoted to developing the technologies which the rich countries believe that they need. They have yet to be convinced that they need airships. The developing countries evidently feel the same way. They are inclined to believe that if airships really do have the potential that their designers claim, they would receive all the public backing they need. That this potential may be greatest in the developwng world has either escaped their attention or it is not something they as yet believe.

Thirdly, interest in LTA systems has reached its peak at a time of economic recession, retrenchment and government cut-backs. Plans to develop and built airships and other LTA craft have in the past few years fallen to the knife of public spending cuts. This was the fate of the sub-scale demonstration maritime patrol airship planned by the U.S. Coast Guard. The $ 9 million it had allocated for this project was cut when its own budget for 1982 was reduced by $ 168 million. This project, had it gone ahead, would have been of major importance to the LTA industry. In a period of economic retrenchment, it is financial support for longer-term civilian projects which gets cut first, the military R & D budget last.

Fourthly, one of the main attributes of the airship is its fuel-efficiency. The frenzied search for fuel-efficient forms of transportation that followed the 1973-74 'oil crisis' led, among other places, to the airship. The airship, so it appeared, had an important role to play in a world to be characterized by energy scarceties. Politicians in the industrialized world are no longer as preoccupied as they were with the prospect of rising energy costs and oil shortages. Some studies have told them that there will be energy enough and that the power of OPEC has or will become a

Support from the public sector would make it possible for the industry to take the fullest advantage of advances in technologies and materials, to develop completely new systems rather than to modify and improve existing technologies, the path the airship industry has so far been compelled to follow. The fact that so few vehicles have been built and flown has seriously hampered learning-by-doing and prevented the collection of the 'hard' operational data on the basis of which informed decisions on the feasibility of the airship can be taken. Airship designers, constructors and pilots are a dying race and a point may soon be reached where it is both cheaper and more challenging to begin with a fresh piece of paper rather than to relearn the lessons of the past.

The airship industry has so far been unsuccessful in securing the funds it requires to capture the markets for which its products seem ideally suited. Without the market, the acquisition of funds becomes an even greater problem. Unless the prospective customer is convinced,he will continue to give preference to other modes - the truck, helicopter, airplane - even in cases where the airship could do the job more efficiently and cost-effectively. The markets are still there, but they are slowly slipping away as other vehicles become ever more firmly established.

That airships have a potential for a range of applications is beyond dispute. It does not necessarily follow, however, that this potential will be realized. The rebirth of the commercial airship is still a possibility. But unless the industry is successful in attracting R & D funds - and soon - the airship may prove to be still born.

NOTES AND REFERENCES

(1) See L.R. Brown, C. Flavin and C. Norman, *The Future of the Automobile in a Energy Short World*, Worldwatch Institute, Washington, D.C., September 1979, viz. p. 30.

(2) The classic case in the automobile industry is of course The Edsel. A recent example in civil aviation is the L-1011 Tristar, some 250 of which have been sold. Lockheed, its manufacturer, is reported to have lost $ 10 million on every one and has now decided to leave the civil aviation market.

(3) Quoted in R. Lamb, 'Airships Again?', Earthscan, International Institute for Environment and Development, London, 1980, p. 4. (mimeo)

(4) See, for example, B.B. Levitt, 'Military Applications of Rigid Airships' in Joseph F. Vitteck, Jr., (editor), *Proceedings of the Interagency Workshop on Lighter than Air Vehicles*, Flight Transportation Laboratory, MIT, Cambridge, Mass., January 1975, pp. 509-515; and G.A. Pasquet, 'Lighter-than-Air Craft for Strategic Mobility', AIAA Paper 79-1597.

(5) See P.S. Stone, B.O. Koopman and G. Raisbeck, 'Potential ASW Missions for Lighter Than Air Ships'; and L.E. Mellberg and R.T. Kobayashi, 'The Surveillance Airship'; both in Vitteck, op. cit.

(6) See M.D. Ardema, 'Economics of Modern Long-Haul Cargo Airships', AIAA Paper 77-1192.

GLOSSARY

in preparation