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CIVIL MARKETS FOR BUOYANT HEAVY-LIFT VEHICLES

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Abstract

A study has been made of worldwide civil markets for heavy-lift airships. Substantial potential market demand was identified for payloads of from 13 to 800 tons. The largest markets appear to be in applications to relieve port congestion, construction of power generating plants, and, most notably, logging. Because of significant uncertainties both in vehicle and market characteristics, further analysis will be necessary to verify the identified market potential of heavy-lift airship concepts.

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I. Introduction

Recent studies have determined that modern air-buoyant vehicles (airships) would be able to satisfy the need for air transport of heavy and/or outsized payloads over short distances. Such aircraft, called Heavy-Lift Airships (HLAs), appear to be attractive for both civil and military heavy-lift applications because of several factors. Primarily, HLAs offer a means of obtaining a dramatic increase in vertical lift capability over existing helicopters without the need for development of new rotorcraft propulsion systems. HLAs may also offer lower fuel consumption, noise, pollution, and operating costs than other vertical heavy-lift systems in many situations. Buoyant heavy-lift vehicle concepts are reviewed in Ref. 1. Figure 1 shows two versions of the buoyant quad-rotor concept. This promising concept, which consists of a nonrigid buoyant hull and four rotor systems, has received more study and technology development than any other HLA configuration but is not the only concept of interest. Figure 2 illustrates two variations of another feasible HLA concept, the rotor-balloon.

In January 1978, NASA-Ames awarded a contract to Booz, Allen Applied Research, to conduct a study of civil markets for heavy-lift airships. This paper summarizes the findings in the contract Final Report.[2] A more detailed summary may be found in Ref. 3. The primary purposes of the study were to identify viable civil applications for HLAs and to determine the size of the world market in terms of the number of vehicles required. Specifically, the study objectives were to: 1) define the potential applications and identify those most likely for earliest introduction; 2) define the probable operational suitability of the HLA; 3) estimate the number and size of HLAs for each application; and 4) describe the effect of HLA system characteristics on this market. The study was to be as independent of vehicle concept as possible.

The HLA Market Study consisted of five tasks. In Task 1, potential applications were identified and quantified, including the cost and service characteristics of the HLA and competing systems. Task 2 efforts were directed toward defining the operational characteristics of the HLA. Task 3 was concerned with the development of a parametric cost model for heavy-lift airships. In Task 4, detailed case studies were conducted for those applications that were found to be feasible and probably competitive. The studies determined the operational characteristics and costs of existing heavy-lift operations, the potential competitive operations using the HLA, and the "break-even" or "threshold" cost of HLA services at which the overall user costs would be the same as with existing operations. The actual costs of using the HLA in each of these competitive operations were then developed, and the number and size of HLAs to satisfy the domestic and worldwide market for each application were determined. Finally, in Task 5, the effects on the results of Tasks 1-4 of varying critical operational and cost parameters were determined, and the topics of institutional factors, military commonality, point design changes and entry into service were examined.

The rest of this paper covers in order: 1) a review of the methodology, its assumptions and its relationship to "real-world" competition, 2) a summary of applications and case studies, and 3) a summary and discussion of the main study results.

II. Review of the Methodology

The methodology is based on experience using conventional, ground-based heavy-lift equipment (e.g., cranes and flatcars). The principal advantages of the HLA accounted for in the study are the much shorter point-to-point transport time and the capability to carry very large and/or very heavy loads without the need for extensive surface infrastructure. In some cases, HLAs were also compared with aerial heavy-lift systems such as helicopters and tethered aerostats. It was assumed that HLA concepts had the capability for precise positioning during payload pickup and placement.

The concept of HLA "threshold" cost is used to determine HLA market share. For a given application the threshold cost typically consists of the algebraic sum of three components as follows:

$$\begin{bmatrix}\text{HLA}\\ \text{threshold}\\ \text{cost}\end{bmatrix} = \begin{bmatrix}\text{direct cost of the lift}\\ \text{using existing}\\ \text{heavy-lift system}\end{bmatrix} + \begin{bmatrix}\text{indirect cost which would be saved if HLA}\\ \text{were used instead of existing system (e.g.,}\\ \text{surface infrastructure costs)}\end{bmatrix} - \begin{bmatrix}\text{indirect cost which would be}\\ \text{incurred if HLA were used}\end{bmatrix}$$

To determine the ability of the HLA to compete in a specific market, HLA direct operating costs and threshold costs are computed and compared. The HLA direct cost is the cost an HLA operator would charge for the job, and the threshold cost is the cost the heavy-lift user would use to compare with the direct cost to select the best heavy-lift mode. If the HLA direct cost is lower than the threshold cost, then the HLA will be the least expensive means of performing the job when all factors are considered.

The situation is clouded by the fact that the market share of a given mode is usually not 100% or 0% but some intermediate value. In the HLA Market Study, this was accounted for by defining two values of the difference between the threshold and actual HLA costs for each market area. The lower value corresponds to the savings relative to the threshold cost at which the HLA would begin to share in the market in competition with other heavy-lift methods. The higher value defines the savings at which the HLA would have essentially captured the entire market. The two values in each application area are based on past experience and on discussions with shippers and operators.

Values of market share parameters used in the study are shown in Table 1. Logging is typical of a market which is very cost competitive, and a new system would begin to share in the market when its direct costs matched the threshold costs. The entire market would be captured if direct costs are approximately one-third lower than threshold costs. In contrast, transportation of high-value components represents a very conservative market area for which a substantial reduction in costs would have to be demonstrated before a new system could even begin to enter the market.

A key parameter in the estimation of market share is the direct cost of doing the job by an HLA. To keep the study as independent of HLA vehicle concept as possible, the direct operating costs of several HLA concepts were computed for each application, resulting in a range of HLA costs. The costs were generated using an HLA job cost model designed for the study and proprietary cost input data. To preserve the proprietary nature of the cost information, the results are presented as an average of a range of possible costs, together with sensitivity data to allow assessment of the effects of changes in HLA direct costs.

The HLA job cost model has two major components — the costs accruing from actual operations and the annual capital and support costs prorated for those operations. The operational costs consist of crew costs, maintenance costs, direct labor burden, and fuel costs (hover, cruise, and ferry). The annual capital and support fixed costs consist of vehicle cost (including the cost of capital), insurance, helium replenishment cost, and administration and other support costs. The total costs are obtained by prorating the annual fixed costs by the hours of operation over an assumed annual utilization and adding the result to the operational costs to give a job or direct operating cost. The vehicle and development cost algorithms reflect both the size of the vehicle and the number of vehicles produced.

In some of the market areas, the threshold cost was either constant or a function of only one or two parameters; in others, it was influenced by many parameters. Thus, to determine how much the threshold cost could vary by changing the scenario in which the HLA provided the heavy-lift services, these parameters were varied one at a time for each particular application, and the change in threshold cost from the application nominal value was computed.

The total number of HLAs of a given size that satisfies the annual heavy-lift requirement in a given application depends on the amount of travel or ferry time necessary between applications as well as on the HLA's share of the market for that application. The need for ferry time can either increase or decrease the number of vehicles required. If the HLA direct costs are significantly below the threshold costs so that capture of the entire market is assured, and if the ferry cost is relatively low, then the number of vehicles required to satisfy a fixed market demand will tend to increase as ferry requirements increase. If, on the other hand, the direct and threshold costs are comparable so that other modes are sharing in the market, and if ferry cost is relatively high, then the number of vehicles required will tend to decrease as ferry requirements increase. These effects are illustrated in Fig. 3. The "ferry factor" accounts for these effects and depends on the direct cost-to-threshold cost ratio, ferry cost, ferry time, and total job time.[2]

The approach to determination of HLA market size is based on competition with existing modes in specific market areas. It reflects the basic characteristics of the markets and the competing vehicles. However, it is not possible to include many "real-world" factors in a broad preliminary study. Therefore, the estimates of market share and numbers of HLA vehicles ascertained in this study should be considered to be an upper limit to the actual HLA market. Before operator investment decisions can be made, a rigorous analysis of specific markets should be undertaken to determine the immediately realizable portion of the potential market.

III. Potential Applications and Summary of Case Studies

A list of potential heavy-lift applications was developed based on a literature search and a survey of and discussions with trade associations, government agencies, international organizations, users and purveyors of heavy-lift services and equipment, and with consultants interested in heavy and outsized transportation and lifting.

The competitiveness of the HLA depends on the capability of the existing transportation infrastructure. In order to screen out the areas where the HLA could not be competitive, all applications were arranged in a matrix and subdivided into segments based on the transportation infrastructure and the existing cargo dimension and weight criteria (Table 2). Each market segment was then ranked on a qualitative basis as to the ability of the HLA to compete with the existing modes of transportation (Table 3). This ranking formed the basis for the development of worldwide market data and the selection of case studies to evaluate the economic feasibility of using the HLA. These case studies were formulated to define not only the characteristics, procedures and costs of current operations but also the characteristics of postulated HLA operations.

Thirteen case studies were selected, many of which were subdivided into several subcases. Each case study consisted of two elements. First, an analysis was made of the activities and events included in current operations and the opportunities that exist to reduce costs by using HLA vehicles (possibly through elimination of capital equipment, shortening of project time, increasing labor productivity, etc.) in addition to possible reductions in direct cost of heavy lift. Second, the effect of the HLA in the market was assessed. This includes definition of the market operational scenario, delineation of operational and cost assumptions compatible with accepted practice in the industry, identification of the potential areas of cost savings resulting from HLA use, definition of the elements of HLA threshold cost, and detailed definition of the HLA operation in the scenario. Cases which did not lead to HLA market requirements included transportation of prefabricated structures and support of refinery plant construction; estimated HLA operating costs were not competitive for these applications.

The cases that led to definitive HLA requirements are listed in Table 4. These case studies varied widely in content and complexity; each had to be examined and analyzed in detail to determine the critical parameters and magnitude of the HLA direct and threshold costs. The following three brief case study descriptions illustrate the differences from case to case. These case studies are presented in much greater depth in Ref. 2.

Construction of Power-Generating Plants

Current operations in this industry involve the following heavy-lift services: 1) transportation of heavy equipment from manufacturer to laydown area or construction site; 2) transportation from the laydown area to the construction site and emplacement; and 3) lifting and erection of heavy components and modules at the site.

Some components must be disassembled prior to transportation and then reassembled on-site. Transportation from manufacturer to laydown area is by specialized but standardized equipment using road, rail, or waterway or a combination thereof. Transportation from laydown to construction site depends on site conditions, particularly in remote areas or wetlands, and may require construction of a special access road, a rail spur, or a temporary landing for barge transport. Lifting or erecting of components at the construction site is usually accomplished by a 500-ton crane, which historically has a low utilization rate (approximately four uses at capacity per year).

Savings can be effected through use of the HLA by: 1) eliminating both the ground transport used to convey the unassembled components and the disassembly and assembly costs; 2) eliminating the ground transportation system from laydown area to construction site as well as the crane at the site; and 3) reducing construction time and cost by permitting reassembly of steel structures into modules at laydown or assembly areas and transporting and lifting them into place for final assembly. The HLA threshold costs for this case consist of the sum of elements from these three areas as appropriate for a specific application.

Load and Discharge of Containers in Congested Ports

Growing containerized trade with developing countries coupled with lagging port construction is resulting in severe congestion in many locations. Delays before unloading have become costly due to congestion surcharges on the cargoes and accumulated ship operating costs. Delays of up to 180 days with ship costs of up to $15,000 per day have been experienced. Also, loading and unloading costs are very high in ports not fully equipped for containerized cargo. Two solutions now in effect are to unload containers onto chassis carried either on converted landing craft or on converted deck barges, powered by tugboats. These require a protected harbor or calm seas, a roll-on, roll-off berth, and a ship equipped and ready to load and offload containers in this manner. Since the HLA will be in direct competition with these alternatives, the HLA threshold cost is equal to the job cost of either alternative.

In cases where no alternatives are available, the HLA can reduce costs not only by eliminating long periods of waiting and the corresponding daily ship costs, but also by eliminating the cost of loading and unloading when the ship eventually does get a berth. In this case, the sum of these eliminated costs constitutes the HLA threshold cost.

Logging and Forestry

Briefly, the HLA can be used to log areas that are currently inaccessible or uneconomic to log by conventional methods. At present, the helicopter is serving this function to a limited extent. Use of an HLA instead of surface methods can reduce the need to cut roads into the logging area, the cost of loading the logs onto trucks, and the time required to log an area. The HLA threshold cost will be the sum of costs saved from these three factors plus the cost of the conventional logging system minus the cost of ground support to the HLA operation. In the case where the HLA is competing with a helicopter, the helicopter job cost is the HLA threshold cost.

The worldwide annual logging market is estimated to be between 75 and 80 billion cubic feet of roundwood timber, approximately 7% of which is in the United States. This represents an enormous potential market for aerial heavy-lift vehicles since capture of even a small fraction of this market would create a demand for many vehicles. Therefore, analysis of the logging market received particular emphasis in the HLA Market Study.

As defined in Ref. 4, the basic sequential stages of logging operations are the same regardless of the technique employed. Cost and operational data were developed for each of these stages for several alternative approaches to logging, based on the study reported in Ref. 5. This study compared as realistically as possible the total costs required to log an actual location in British Columbia. For each alternative technique, the logging operation was planned in detail, starting with virgin territory and supplementing the main logging technique with others where necessary to most efficiently complete the task.

The analysis of the alternative systems resulted in a cost estimate for each which included the cost of equipment ownership, maintenance, labor, fuel, depreciation, interest, and insurance, as required to perform all functions to completely log the designated area (Table 5). The proportion of the designated area actually logged by the main alternative system varied significantly among alternatives.

An HLA would operate in the same way as helicopter logging systems on the same proportion of the area to be logged and would use the same ground and wood crews to load and unload the logs onto the HLA. In areas where the aerial mode is less efficient or impractical, conventional systems would be utilized.

Assuming a ground system cost of $30/cunit (1 cunit = 100 cubic feet of timber), an HLA payload of 25 tons, and a ground cruise speed of 25 mph, the HLA threshold cost was computed at $15.7/cunit. With the same assumptions, the direct operating cost of a hypothetical 25-mph HLA was estimated to vary from $12.0/cunit to $22.0/cunit as the yarding distance varies from 2000 ft to 6000 ft. For a 60-mph ground speed hypothetical HLA design, the operating cost would be in the $9.8 to $15.3 range. This indicates that HLAs would be directly competitive with ground systems in many situations. Comparing HLAs with existing helicopters shows a substantial cost advantage for the former.

Table 6 shows the number of HLA vehicles which would be required to satisfy 100% of the logging market available to aerial vehicles (disregarding operating costs). The data are given as a function of the principal operational parameters of the logging market. Lower speeds, longer yarding distances, higher turnaround times, and smaller payloads all result in more vehicles being required to satisfy this fixed market demand.

To determine the market share for HLA vehicles in competition with surface logging systems, the direct operating costs of a hypothetical 25-mph HLA and a hypothetical 60-mph HLA were compared with the threshold costs associated with surface logging methods. The resulting numbers of vehicles are shown in Table 7. HLA vehicles with relatively high speeds, short yarding distances, low turnaround times, and large payloads tend to capture most of the potential market. The conflicting trends of more efficient vehicles capturing a larger share of the market and less efficient vehicles requiring larger numbers of vehicles to satisfy a fixed market share are evidenced in Table 7.

The share of the logging market for which HLA vehicles are competitive is extremely sensitive to variations in several key paremeters. For example, Fig. 4 shows the sensitivity of market share to payload, cruise speed, yarding distance, and turnaround time. The baseline case is the hypothetical 60-mph vehicle with a 25-ton payload, 4000-ft yarding distance, and 2-min turnaround time. The total market for this case from Table 6 is 1800 vehicles, of which approximately 60% (1082 vehicles as shown on Table 7) is actually captured in competition with surface logging systems. Figure 4 shows, for example, that if the payload were decreased to 15 tons the market share would drop to zero whereas if it were increased to 60 tons the entire potential market would be captured.

IV. Summary and Discussion of Study Results

Tables 8 and 9 present the total estimated civil market for HLAs distributed by application and payload size, for designs with 25-mph and 60-mph ground cruise speed, respectively. Also given is the percentage of the market in North America, indicating that the majority of the market potential is overseas.

The HLA civil market tends to fall into two categories. The first category consists of services that are now or could be performed by helicopters, but perhaps only on a very limited basis. Payloads range from about 13 to 75 tons. Specific markets include logging, containership discharge (of interest also to the military), transmission-tower erection, support of remote drill rigs, and pipeline construction. HLA vehicles would be able to capture a greater percentage of these markets than helicopters due to their projected lower operating costs. Most of these applications are relatively sensitive to cost and vehicle performance parameters, and therefore further market verification is necessary. The largest market in terms of the potential number of vehicles required is logging.

The second HLA market category involves heavy payloads of from 150 to 800 tons and thus is a totally new application of vertical aerial lift. This market is concerned primarily with support of heavy construction projects, especially power-generating plant construction. As discussed earlier, the availability of vertical aerial lift in this payload range would have many advantages in addition to direct cost savings. It will make the expensive infrastructure associated with surface movements of heavy or bulky items largely unnecessary. Use of HLA systems would allow greater flexibility in plant site locations; remote areas heretofore inaccessible by heavy surface transportation would become feasible. Further, it could substantially reduce construction costs of complex assemblies by allowing greater preassembly at manufacturing areas. This application is relatively insensitive to cost of service.

Tables 8 and 9 illustrate the effects of changes in utilization rates and vehicle sizes on the market potential. Both higher utilization rates and larger vehicle sizes can either increase or decrease the number of vehicles required to satisfy a given market, depending on the competitive position of the HLA vehicles in that market.

With respect to production quantities, all the smaller sizes up through 150 tons' payload require production quantities well in excess of the nominal 25 vehicles assumed in the cost analyses. However, larger sizes fall far below this production quantity, with the consequence that their job costs have been underestimated. This may force them into a less competitive position, making sales and adequate utilization more difficult to achieve and possibly decreasing the market.

Operational requirements and constraints were briefly considered in the study. For most applications, and especially for repetitive tasks such as logging, the need for high productivity is critical. This puts a premium on high speed and acceleration, short turnaround time at staging areas, and the ability to operate in a wide range of weather and terrain conditions. The inefficiency of buoyant vehicles at high altitudes may be a constraint for a few applications. Many heavy-lift tasks require emplacement of very large components with a high degree of precision. It is clear that the operating characteristics and requirements of HLAs need further study and validation.

The military has stated a requirement for vertical heavy-lift of 75-ton payloads. Tables 8 and 9 show that there is also a civil requirement for this payload capacity. There appears to be a high degree of commonality between the civil and military requirements, except that the military applications may involve operation in more severe weather conditions.

The validity of the approach used in the HLA Market Study depends heavily on the accuracy of the worldwide market assessment, the share of each market that might accrue to the HLA, and the rate of work achieved by each HLA size in a given application. The accuracy of the worldwide market assessment varies widely from one application to another. It is based on current experience and trends but contains many uncertainties, particularly in market areas where high growth potential exists but where ideology and environment impose restraints.

The assessment made in this study of the share of the market that might accrue to the HLA neglects many factors which would be considered in an actual operator's decision to investment in a new heavy-lift system. It also assumes that all opportunities will be seized and is therefore an overestimate or upper-bound, as mentioned earlier. The HLA market share depends directly on the HLA threshold and direct costs. The HLA threshold cost estimates are uncertain because they actually vary sharply in different situations within a market area. HLA job cost estimates are, of course, as critical as estimated threshold costs and at this stage of HLA development, probably just as uncertain because HLA vehicle concepts are not well defined at present. Also, basing philosophy and the need for ferry have a strong impact and are presently not well defined.

V. Concluding Remarks

The HLA Market Study has identified several promising civil markets for heavy-lift buoyant vehicles, notably in logging, relief of port congestion, and construction of power-generating plants. The potential logging market is very large but is sensitive to vehicle costs and performance parameters. The availability of vertical heavy-lift to the power-generating plant construction industry will have many beneficial effects in addition to direct cost savings. To ensure that the markets identified can be captured, more detailed study is required to assess the implications of: 1) basing strategies and ferry requirements; 2) more precise real-life market conditions; and 3) estimates of more refined vehicle performance, cost, and operational characteristics based on optimized vehicle configurations.

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Table 1. Market share parameters

Market area	Percent savings to enter market	Percent savings to capture market
Logging	0	30-35
Port congestion, cargo unloading	20	50
Transmission line towers construction support	0	30-35
Remote drilling rigs support	5-10	20-30
Power plant construction support	20-25	50
Oil and gas production platforms	20	50
High rise construction industry support	0-5	25-30
Home building	20	50
Refinery construction	20-25	50
Transportation of damage sensitive components	25-30	50-60
Transportation of damage insensitive components	10-15	35-40
Transportation of agricultural products	15-20	30-35
Pipeline logistic support	20-25	30-40
Strip mining shovel transport	10-15	35-40

Table 2. Transportation characteristics

	Cargo dimensions and weight category			
	1	2	3	4
Weight, tons	Up to 50	50 to 100	100 to 200	Over 200
Length, ft	Up to 45	45 to 80	80 to 100	Over 100
Width, ft	Up to 10	10 to 14	14 to 15	Over 15
Height, ft	Up to 10	10 to 12	12 to 15	Over 15
Transport modes	All modes.	Most U.S. railroads. Some highway.	Heavy-lift railroad cars. Limited highway.	Special heavy lift freight cars; often special train service. Very limited highway.
Clearance problems	None.	No major problems even on foreign railroads.	May cause major reroutings over the road.	Long rail route deviations, sometimes prevents rail transport. Roads/bridges may require costly rebuild. Very careful planning required.
Special permits required	None.	Yes (for highway transport).	Yes (for highway transport).	Yes.

Table 2. Concluded

	Cargo dimensions and weight category			
	1	2	3	4
Special transport equipment required	None.	Trailers (for highway transport).	Yes (for highway transport).	Highly specialized equipment and expertise.
Lifting and rigging	Normally readily available.	Available from most operators.	Generally only available from major rigging and crane operators.	Highly specialized crane and rigging equipment and expertise.

Table 3. HLA applications matrix

Transportation geography	Urban				Developed				Undeveloped				Remote			
Cargo dimensions and weight category:	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Application																
Construction industry support																
• Refinery and chemical plants	L[a]	L	M	H	L	L	M	H	L	M	M	H				
• Offshore oil production platforms													L	L	M	H
• Mining sites					L	L	L	L	M	M	M	M	H	H	H	H
• Power transmission lines					M	M			H	H			H	H		
• Electric generating plants	L	M	H	H	L	M	H	H	M	H	H	H	H	H	H	H
• Homes	M	M			M	M			H	H			H	H		
• Pipelines					L	L	M	M	M	H	H	H	H	H	H	H
• Heating/ventilation/air conditioning unit emplacement	H	H			H	H										
• Other construction	M	M	H	H	M	M	H	H	M	H	H	H	H	H	H	H
Oil and gas drilling	L	L			L	L			M	M			H	H		
Logging and forestry									H				H			
Port activity	L	L	L	L	L	L	L	L	M	M	M	M	H	H	H	H

Table 3. Concluded

Transportation geography	Urban				Developed				Undeveloped				Remote			
Cargo dimensions and weight category:	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Application																
General transportation in remote and undeveloped regions									M	M	M	M	H	H	H	H
Heavy and outsized cargo transportation	L	M	M	H	L	L	M	H	M	M	H	H	M	H	H	H

[a]Ranking — Relative to existing modes of transportation

L - Low   Not competitive with, or at a competitive disadvantage

M - Medium   Not competitive in general, but may be so in special conditions

H - High   Is competitive and, in some cases, may have substantial advantage.

Table 4. Case studies showing HLA potential

Case study	Application	Potential HLA tasks
1.	Construction of offshore oil and gas platforms.	Transportation and positioning of deck sections; assist with other heavy lifts.
2.	Transportation of power shovels used in strip mining.	Transport large power shovel modules to and in mine area.
3.	High voltage power transmission line construction.	Transport and position complete towers.
4.	Construction of electric generating plants.	Transport and position assembled components; lift and position preassembled structure modules.
5.	Construction of oil and gas pipelines.	Transport equipment in large modules to and from sites, pipeline and around obstacles, regardless of permafrost condition.
6.	Support of high-rise construction industry.	Lift and position rooftop equipment, lift and remove crane segments.

Table 4. Concluded

Case study	Application	Potential HLA tasks
7.	Support oil and gas drill rigs in remote areas.	Transport equipment in large modules to and from remote drill site.
8.	Support logging.	Lift and transport aggregated logs from less accessible areas, without roads.
9.	Load and unload containers in congested ports.	Lift and transport aggregated containers between ship and dock.
10.	Transportation and rigging of heavy/outsized loads.	Transport heavy items to avoid major obstacles or costs (bridges, road construction, use of special equipment).

Table 5. Costs of alternative logging systems

	System				
		Running skyline			
Function	Highlead	Fixed span	Yarding crane	Balloon	Skycrane
Road access	5.40	3.50	2.86	2.92	1.51
Felling	4.70	4.81	4.91	5.14	5.20
Yarding	9.23	10.69	9.87	15.07	32.88
Hauling	4.15	3.26	3.31	3.71	2.04
Loading	6.37	6.31	5.05	6.29	5.46
Total \$/cunit[a]	29.85	28.57	26.00	33.13	47.09

[a] 1 cunit = 100 ft^3 of timber.

Table 6. Number of HLA vehicles for 100% of the logging market, 2000 hr annual utilization

HLA cruise speed, mph:		25			60		
Yarding distance, ft:		2000	4000	6000	2000	4000	6000
Payload size	Turnaround time per cycle, min						
15 tons	1	2130	3070	4330	1800	2330	3130
	2	2800	3730	5000	2470	3000	3800
	3	3470	4400	5670	3130	3670	4470
25 tons	1	1280	1840	2600	1080	1400	1880
	2	1680	2240	3000	1480	1800	2280
	3	2080	2640	3400	1880	2200	2680
75 tons	1	430	610	870	360	470	630
	2	560	750	1000	490	600	760
	3	690	880	1130	630	730	890

Table 7. Number of HLA vehicles to satisfy the HLA share of the logging market in competition with surface modes, 2000 hr annual utilization

HLA cruise speed, mph:		25			60		
Yarding distance, ft:		2000	4000	6000	2000	4000	6000
Payload size	Turnaround time per cycle, min						
15 tons	1	1138	153	216	1800	869	156
	2	140	186	250	921	150	190
	3	173	220	283	156	183	223
25 tons	1	1280	529	130	1080	1400	1166
	2	1185	112	150	1480	1082	114
	3	321	132	170	1094	110	134
75 tons	1	430	610	870	360	470	630
	2	560	536	50	490	600	709
	3	690	295	66	630	681	501

Table 8. Number of 25 mph HLA vehicles that would satisfy the worldwide heavy-lift market

	Payload, tons									
Application	7 to 15		25 to 30		75	150	200 to 300	500	800	NA%
Heavy lift										
Logging	372/186	or	224/112	or	1072/536					10
Port congestion relief			75/37	or	26/13					0
Transmission tower erection			22/12							30
Remote drill rig support			11/6							35
High rise construction	1		2							100
Pipeline construction					3					40
Ultra heavy lift										
Power plant construction						1	19/10		1	45
Strip mining power shovel movement							1			50
Offshore oil/gas rig support								0/2		50
Transportation								10/5		30
TOTALS	373/187	or	334/169	or	1101/552	1	20/11	10/7	1	

Utilization (hr) - 1000/2000.

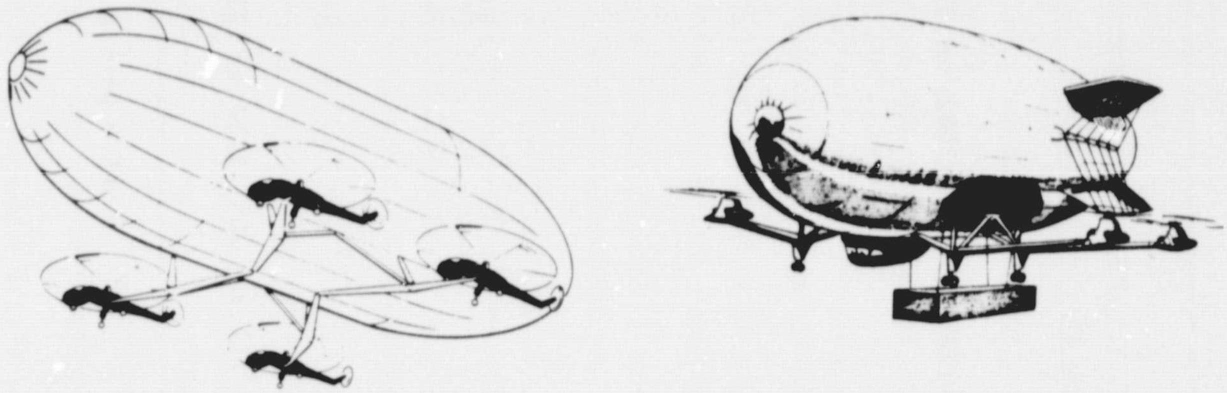
NA% - percent of market in North American continent.

Table 9. Number of 60 mph HLA vehicles that would satisfy the worldwide heavy-lift market

Application	Payload, tons							
	7 to 15	25 to 30	75	150	200 to 300	500	800	NA%
Heavy lift								
Logging	300/150 or	2164/1082 or	1200/600					10
Port congestion relief		54/27 or	20/10					0
Transmission tower erection		17/9						30
Remote drill rig support		6/3						35
High rise construction	1	2						100
Pipeline construction			4					40
Ultra heavy lift								
Power plant construction				1	9/5		1	45
Strip mining power shovel movement					1			50
Offshore oil/gas rig support						3/2		50
Transportation						7/4		30
TOTALS	301/151 or	2243/1123 or	1224/614	1	10/6	10/6	1	

Utilization (hr) - 1000/2000.

NA% - percent of market in North American continent.



ORIGINAL

ADVANCED

Figure 1.- Buoyant quad-rotor heavy-lift airship concept.

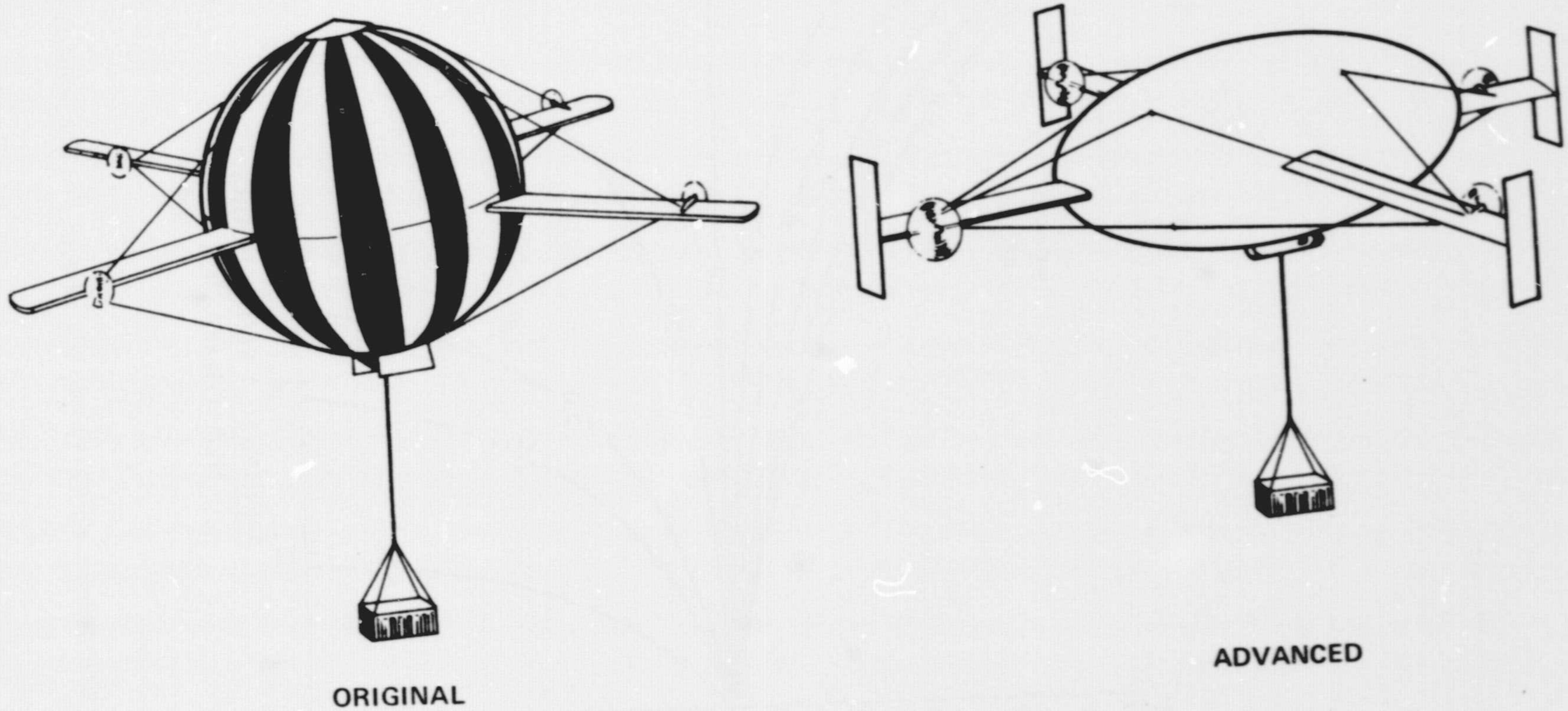


Figure 2.- Rotor-balloon heavy-lift airship concept.

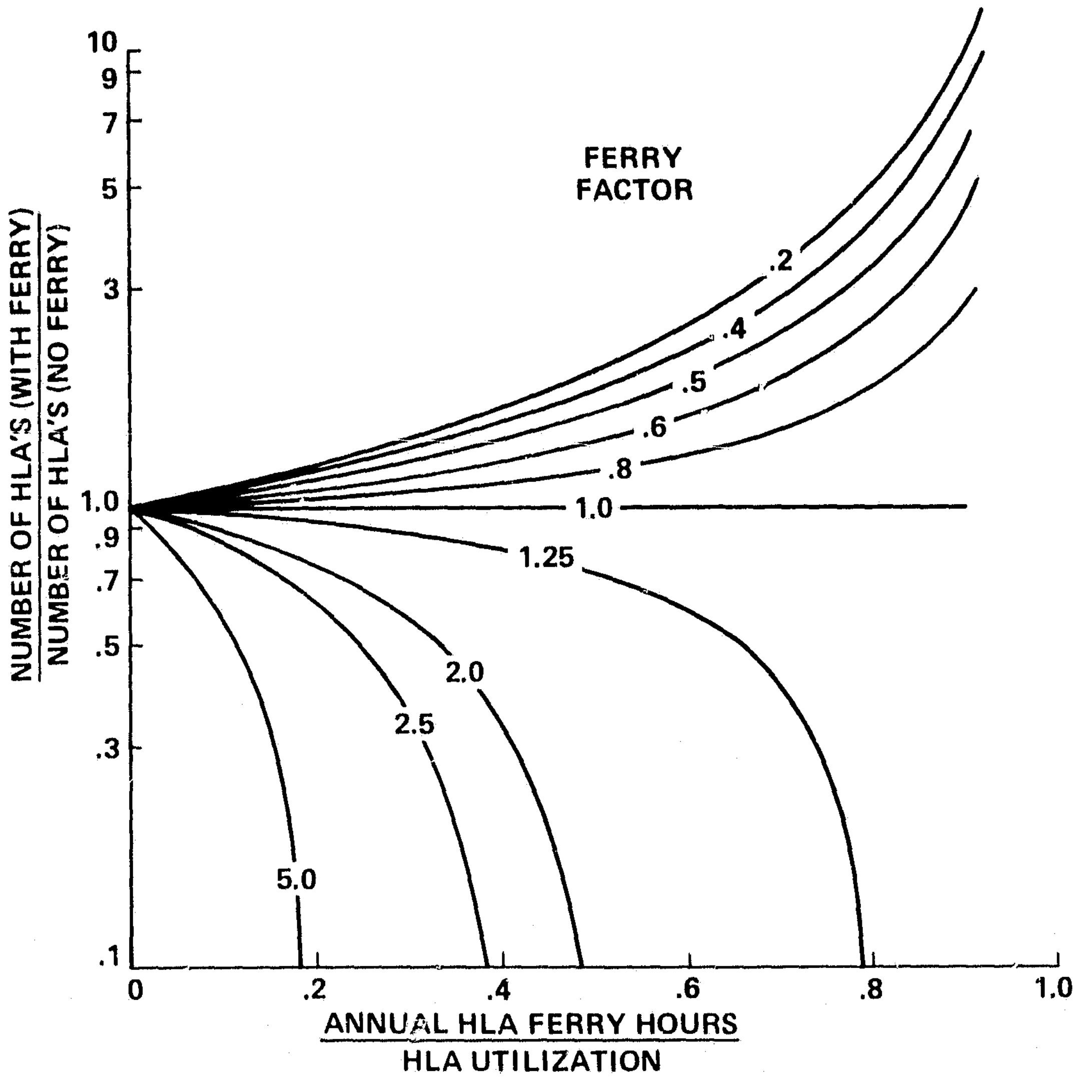


Figure 3.- The effect of ferry on the number of HLA vehicles required.

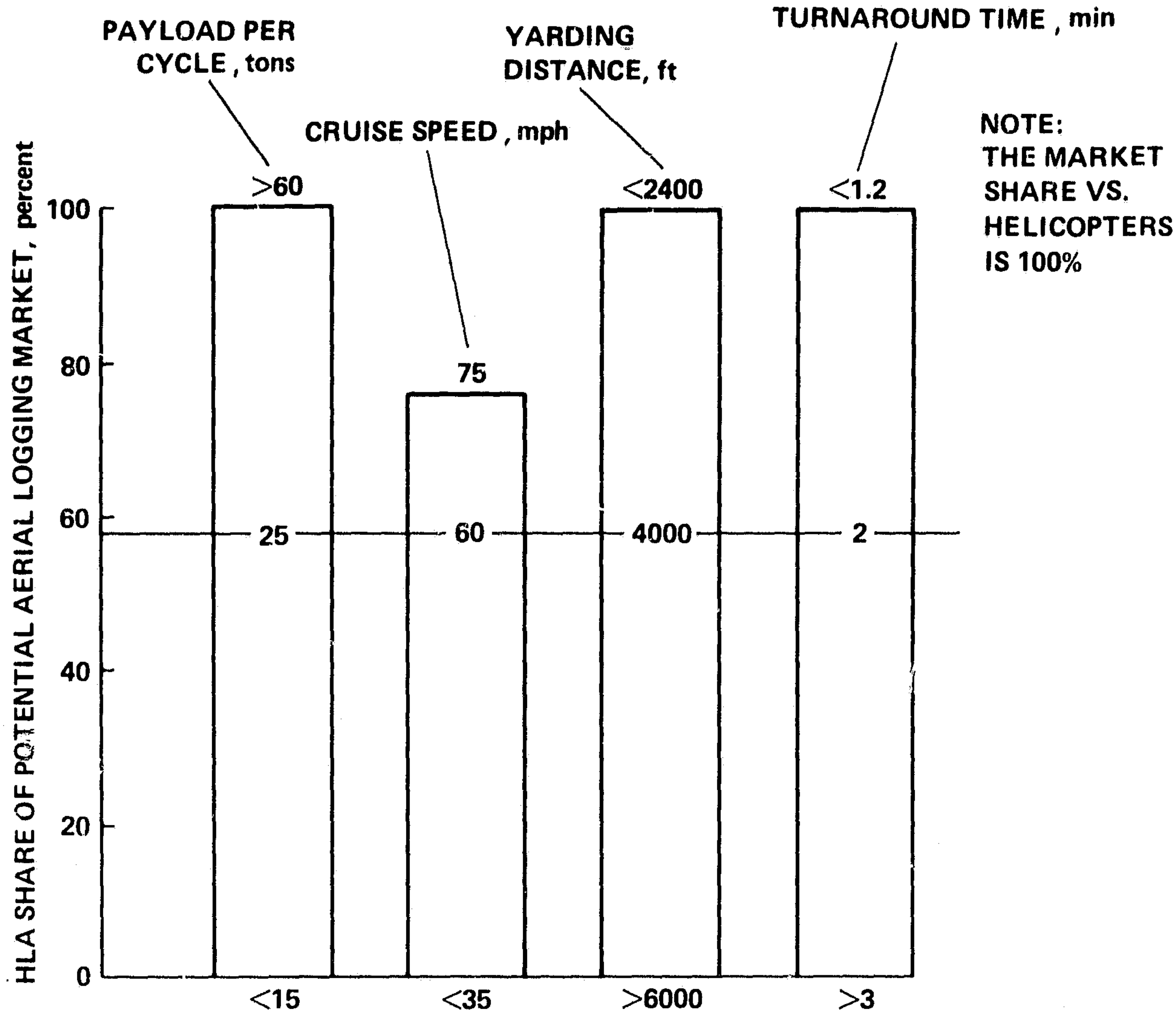


Figure 4.- HLA logging market share vs. ground systems and sensitivities.