ULTRA-HEAVY VERTICAL LIFT SYSTEM
"THE HELI-STAT"

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ABSTRACT: The Heli-Stat is a novel hybrid VTOL vehicle comprised of an aerostat combined with helicopters. The static lift of the aerostat supports approximately the full empty weight of the entire assembly. The helicopter rotors furnish the lift to support the payload as well as the propulsion and control about all axes. Thus existing helicopters, with no new technology required, can be made to lift payloads of ten times the capacity of each one alone, and considerably more than that of any LTA built so far.

A vehicle is described which has a 75-ton payload, based on four existing CH-53D helicopters and an aerostat of 3,600,000 cu. ft. The method of interconnection is described along with discussion of control, instrumentation, drive system and critical design conditions. The vertical lift and positioning capabilities of this vehicle far exceed any other means available today, yet can be built with a minimum of risk, development cost and time.

INTRODUCTION

Considerable interest is currently evident in the potentiality of airships as a means of lifting and transporting heavy cargo. The interest in lighter than air (LTA) ships is being revived with national attention being focused on energy conservation and recognition of potential heavy lift missions for the LTA. Some of the areas of the overall transport spectrum which favor the airship as a transport vehicle are logging operations, pipe laying, power-transmission-line tower erection, building construction, and transportation of large oversize non-roadable equipment.

The heavy lift helicopter is already being employed on a short-haul basis to transport and position loads up to 12.5 tons in the above mentioned transport areas.

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One of the design arrangements that shows promise of alleviating many of the shortcomings of conventional LTA's is the semi-buoyant, hybrid vehicle. This type of LTA vehicle does not generate complete lift from buoyancy. Vertically oriented thrust from powered rotors is employed for total lift augmentation and for providing maneuver control forces. Additionally, aerodynamic lift is generated in forward flight due to the vehicle envelope shape and airfoil surfaces.

The design referred to is called the "Heli-Stat" system and is a hybrid LTA system which utilizes four large existing helicopters in combination with an LTA vehicle. The ratio of displacement vehicle lift to helicopter lift is proportioned such that the "Heli-Stat" is deliberately flown "heavy". Thus the thrust from the helicopter rotors is the dominant means of control and stabilization. The ground handling requirements are greatly simplified, and true precision hovering over a point on the ground becomes practical. Such hybrid vehicles may have 10 or more times the payload capability of one of the helicopters used in the Heli-Stat.

The employment of existing helicopters as integrated lift, propulsion, and control units offers low technical risk, cost, and development time. The latter is especially significant in view of the immediate application requirements for heavy air-lift capability in nuclear powerplant and other public construction programs.
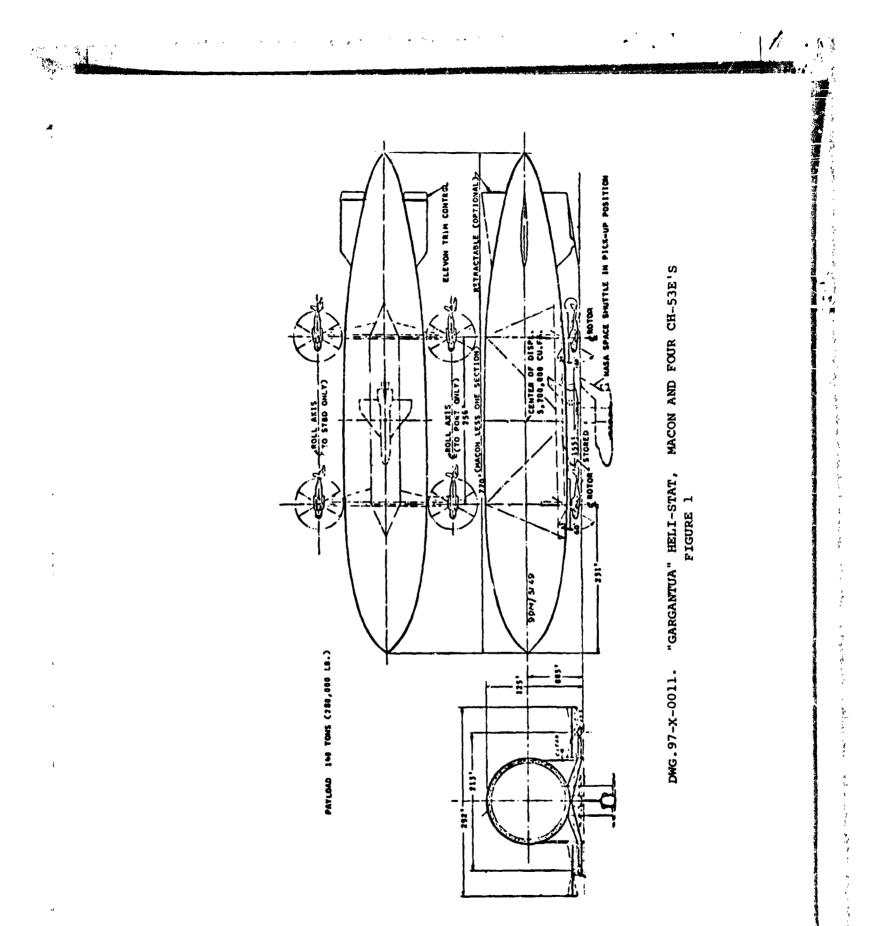
DESCRIPTION OF THE HELI-STAT

The aerostat dimensions are sized such that the static lift provided by the aerostat will support all weight-empty components, including the helicopters. The helicopter rotor thrust is then available for useful load and maneuvering control forces, providing a hovering air-lift capability many times that of the largest crane helicopter of the predictable future. The designs described following are based on characteristics from existing helicopter and aerostat designs. Fig. 1 shows a layout of four CH-53E helicopters attached to an aerostat of 5,700,000 cu.ft. displacement. This is the size and shape of the "Macon" envelope, less one section and less the upper vertical fin. A payload of 140 tons can be carried.

Fig. 2 shows a version based on four existing CH-53D helicopters. This system has a payload of 75 tons, as shown in Fig. 3.
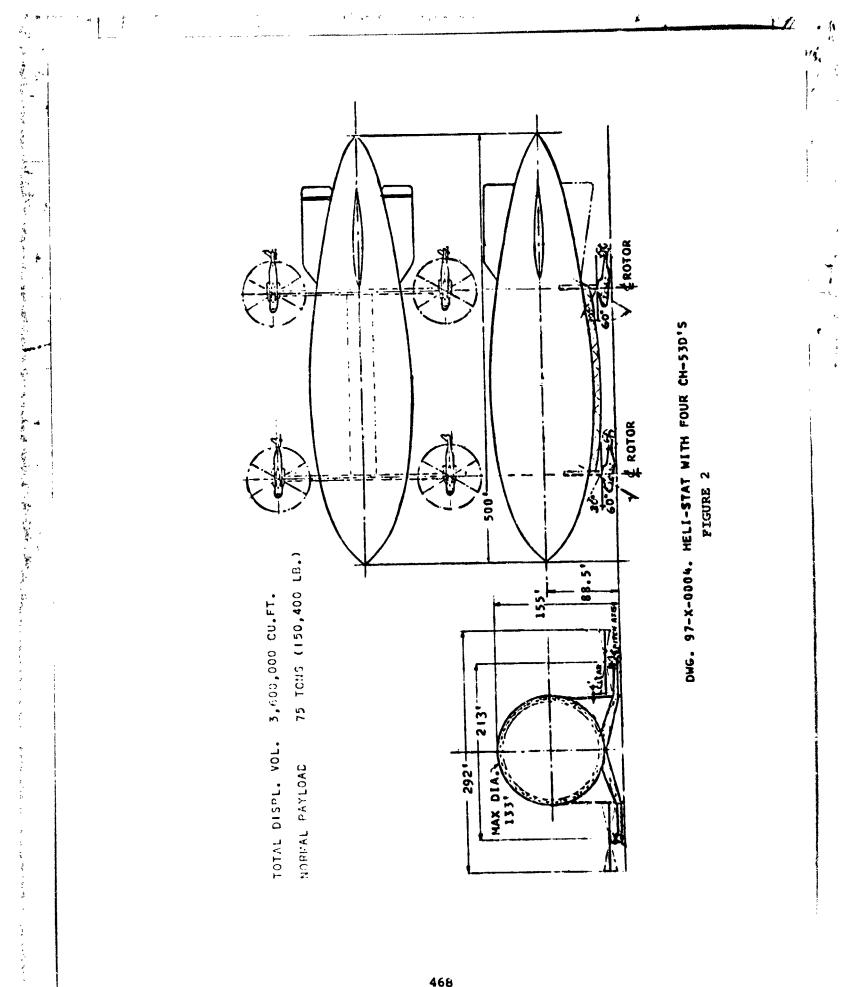
SELECTING THE AEROSTAT CONFIGURATION

Semi-rigid pressure envelopes or rigid envelopes can be adapted to the Heli-Stat concept. The longitudinal and lateral support beam structure which serves to attach the helicopters and support the payload can be tied structurally to the structural frames of the rigid envelope. In the case of the semi-rigid, the helicopter attachment and load-support beams can be made integral with the fore-and-aft keel structure.

PAYLOAD 100 TONS (200,000 LB.)

DWG.97-X-0011.   "GARGANTUA" HELI-STAT,   MACON AND FOUR CH-53E'S
FIGURE 1

TOTAL DISPL. VOL. 3,603,000 CU.FT.

NORMAL PAYLOAD 75 TONS (150,400 LB.)

DWG. 97-X-0004. HELI-STAT WITH FOUR CH-53D'S

FIGURE 2

Figure3. HELI-STAT WEIGHTS AND PERFORMANCE SUMMARY, MODEL 97X0004

WEIGHTS	UNITS			
Heli-Stat	Lb.			345,940
Weight Empty	Lb.		177,540	
Helicopters (4) CH-53D's	Lb.	86,560		
Aerostat Envelope and Structure and Inter-connecting structure (3,600,000 cu.ft.displ.)	Lb.	90,980		
Useful Load	Lb.		168,400	
Crew (6) at 200	Lb.	1,200		
Fuel and Oil	Lb.	16,800		
Payload	Lb.	150,400		

PERFORMANCE, STANDARD ATMOSPHERE (59 DEGREES F. AT S.L.)

	UNITS	
Cruise Speed	MPH	100
Landing & Take-off Speed	MPH	0
Altitude	FT.	10,000*
Hover Ceiling	FT.	6,000
Climb, Vertical	FPM	500
Climb, Fwd. Flt.	FPM	2,000
Range (Non-Refueling)	ST.MI.	160**
Ferry Range (Non-Refueling)	ST.MI.	2,000

*FERRY
**RANGE CAN BE EXTENDED BY TRADING PAYLOAD FOR FUEL.

No machinery or facilities are carried in the aerostat except those required by the aerostat's own requirements, that is, multiple air-pressure pumps, servo systems for multiple valve operation, ballast tanks, plumbing, and ballast-shifting pumps, etc.

Two crew stations are provided in the aerostat, for the winching and stowage of cargo.

The size of the aerostat is largely a function of the size and capability of the helicopters selected. From the list of large helicopters in Fig. 4, it is apparent that military-qualified or Federal Aviation Agency certified helicopter units can be economically procured. In a dedicated vehicle the helicopter units can be without many components such as the tail cone, drive, tail rotor, landing gear, cabin accommodations, etc., thus reducing the cost significantly yet providing the essential powerplant, transmission and control for the integrated lift, propulsion and control. Alternatively each of the helicopters in the Heli-Stat assembly can be a completely flyable unit, with detachable umbilical cords that interconnect the automatic flight control system and instrumentation between helicopters.

All controls and instrumentation of the assembly of helicopters are integrated into one pilot control station. Complete cockpit instrumentation and Comm/Nav equipment would be required in only one helicopter, except for intercommunication between crew members and stand-by emergency instruments for the alternate control station.

FIG. 4.   LARGE U. S. HELICOPTERS

ITEM HELI/MODEL	UNITS	HLH	CH-53E	CH-47C	CH-54B	CH-53D	V-107	S-61
Manufacturer		B-V	Sik.	B-V	Sik.	Sik.	B-V	Sik.
Gross Weight	Tons	63	34	23	23.5	21	11.5	10.5
Certification (Availability)		1st Flt '76	1st Flt '74	ARMY	ARMY & FAA	NAVY	NAVY & FAA	NAVY & FAA

Turbines
  Number
  Model
		3
		GM
		T701-
		AD-700
			3
			G.E.
			T64
			GE-415
				2
				Lyc.
				T55-
				L11
					2
					P&W
					JFTD-
					12-5A
						2
						G.E.
						T64
						GE-413
							2
							G.E.
							T-58
							GE-10
								2
								G.E.
								T-58
								GE-10

Rating (Each)
  Max.(Emerg.)
  T.O.(5 Min.)
  Mil.(30 Min.)
  Continuous
	HP
	HP
	HP
	HP
		8079
		
		7305
			4330
			
			3665
				
				3750
				3400
				3000
					4800
					
					4430
						3925
						
						3230
							
							1400
							1250
								
								1400
								1250

INTERCONNECTION OF HELICOPTERS TO AEROSTAT

Structural

Each helicopter is supported at the extremity of a lateral cantilever beam which joins the inboard fuselage structure of the helicopter to the bulkhead or keel structure of the aerostat. The flight loads acting on this beam are those supplied by each helicopter, including both aerodynamic and inertia loads. The lateral connecting beams are also designed to take the landing loads.

The structural design of the lateral connecting beams is necessarily influenced by rotor blade clearance considerations and the desirability of minimizing the rotor down-flow obstruction area. External struts or bracing tie-rods are utilized for minimizing structural weight and to achieve the necessary rigidity. The beam is a tubular truss structure having an airfoil fairing, with a passage-way provided between the two spars. The helicopter landing gear can be retained as a ground contact point, however, a main landing gear of longer travel is carried on the lateral beams at four points, with all its wheels steerable.

The port and starboard cantilever beams are interconnected through the centerline keel structure of the aerostat. The two lateral beams are structurally continuous from helicopter to helicopter, but have disconnect joints at the keel structure.

The longitudinal keel structure is composed of two central "keel" beams from which the payload is supported. This will permit the carriage of certain payload sizes internally, providing a centerline access hatch to accommodate cargo loading and unloading by hoist, for missions requiring internal storage.

Control System

The helicopters' control systems are interconnected so that they respond to one set of controls in the aft, port helicopter which is designated the master control station. This interconnection is accomplished through the use of the existing automatic flight control system which is already an integral part of the large helicopters contemplated for use in this assembly. The connecting electrical wires are fed into a mixing control box which actuates the required control of each helicopter servo control system to provide the desired control required by the commander of the assembly. The master helicopter, and its lateral mate, have a complete set of aerostat controls and instrumentation.

A qualified pilot is located in each cockpit and serves as a manual instrument-monitoring system with override in case of failure of any component. In addition to the master pilot, a co-pilot is stationed in the master cockpit with an engineer(s) to monitor the sensors and controls of the aerostat. Thus, a total crew of six to eight is carried aboard the airborne assembly. Walkways are provided for the crews to go to any helicopter and the aerostat during flight.

The primary rigging of the assembly for flight must be calculated for the fuel weight, basic weight of the individual helicopters including their crew, and ballast being carried. This will determine the weight to be balanced by the aerostat gas volume displacement lift at the altitude and temperature of the operation. Ordinarily, ballast will not be needed, since the same objective can be achieved by appropriately reducing the thrust of the various helicopter rotors.

The helicopters are free to use their cyclic pitch in all directions, approximately 11 degrees. In addition, they can be made to rotate about a transverse axle in longitudinal pitch 60 degrees forward and 30 degrees aft but are normally locked in a trim position. In the lateral direction, in addition to the rotor's lateral cyclic control of approximately 11 degrees the helicopter can be made to tilt outboard approximately 11 degrees.

In the yaw direction, the helicopters are rigidly fixed to the aerostat structural keel. For yaw moments, the port and starboard helicopters can differentially incline their longitudinal cyclic.

For lateral roll control, differential rotor collective pitch on one side, versus the opposite side, is utilized.

Pitching attitude of the assembly is via differential collective pitch of the forward rotors versus the aft.

Propulsion is achieved from the forward cyclic pitch of all rotors. Inclination of the helicopters can be utilized as the dynamic lift of the aerostat develops with forward speed. The aerostat angle of attack, and hence its lift, can be independently adjusted by the use of its longitudinal trim elevators. Retardation is accomplished by tilting the rotors aft.

Instrumentation

Each helicopter contains its own internal instrumentation, communication and navigation equipment. Additional sensors for the aerostat are distributed throughout the gas cells, interconnecting structure and controls with their readout in the master helicopter and its backup unit. A computer unit with memory circuits of basic weight data, balance and external environmental conditions provides immediate readouts for the master pilot, his deputy and the flight control system.

Drive System

With a single power failure in one helicopter under any flight condition, the diagonally opposite helicopter must reduce its rotor thrust to match, in order to maintain longitudinal and lateral trim. The two helicopters with the reduced power can maintain rotor rpm by decreasing their rotor blade pitch and adjusting to a compatible shaft angle. The other two diagonally opposite helicopters, which have been operating with a reserve of power and thrust, must now increase their thrust to pick up the load from the failed helicopter and its mate. The central control mixing computer would automatically adjust for these conditions since the power levels of each turbine are continuous inputs into the computer.

In forward flight, the dynamic lift on the aerostat envelope can help balance the lift lost by these two helicopters. However, dynamic lift is zero at zero speed, and thus will not balance this loss in hovering. Therefore, either sufficient change in fuel weight, ballast dumping, altitude or temperature changes, etc. must occur or the Heli-Stat must carry a reserve hover lift.

An alternative balancing method can be supplied by mechanical interconnection of all helicopters as detailed in our work on the Multi-Helicopter Heavy Lift System, Refs. 1 and 2. This involves the interconnection of the rotor-drive systems of all the helicopters "downstream" of the engine free-wheel units, and requires appropriate modification to the drive system. However, the power of each engine is then available to all the rotors, and if one engine fails, the diagonally opposite helicopter is not forced to reduce power. The rotor in the partially disabled helicopter "borrows" power from the other three. However, this feature will increase the weight empty and cost.

CRITICAL DESIGN CONDITIONS

A design condition for the Heli-Stat would be the partial loss of rotor thrust in one helicopter resulting from a failure of one of its turbines. In the FAA airworthiness requirements for Category "A" rotorcraft (multi-engine with completely separate, dual powerplant systems) failure of more than one engine is considered so remote that there are no requirements for that condition.

A power failure in one unit would normally be a loss of part of the thrust of that helicopter unit plus the reduction of an equal amount about the center of total lift. If it is necessary to make a hovering landing in this emergency, the gross weight must be sustained by the buoyancy of the aerostat at the landing altitude

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and temperature plus the thrust produced by one-half maximum power
in the disabled helicopter and its opposite mate, and full power
in the two unaffected helicopters.

If a run-on type landing can be made, for example at 50 mph air-
speed, then the dynamic lift of the aerostat body can be counted
on to augment the other sources of lift. In addition, all four
helicopters can produce substantially more thrust, for a given
power, at 50 mph than at zero speed. The Heli-Stat could then,
with equivalent safety, carry 20% additional payload compared
to the limitation of a hovering landing.

The above discussions all deal with an emergency situation in which
two of the four helicopters were supplying only half power. It is
clear then, that in the normal situation, when all four helicopters
are fully operational, each will be operating at approximately
3/4 of its maximum level of thrust and power. Thus, to allow for
the emergency condition, there is inherently a large reserve lifting
capacity in each helicopter, which can be called on for high
temperature/altitude combinations, or loss of up to 20% of the
helium in the aerostat.

It is for this reason that, ordinarily, the use of ballast will not
be necessary. In a fully buoyant LTA, loss of helium can be
compensated only by dumping or shifting ballast. In the Heli-Stat,
however, a far more rapid response can be achieved by changing
collective pitch on one or more of the helicopter rotors using
the power reserved for emergencies. Moreover, the saving in ballast
weight results in either a smaller aerostat or in lower rotor loadings
on the helicopters, with consequent savings in helium, fuel and
maintenance.

For purposes of (certification) design, it is proposed to use the FAA
criteria for category A rotorcraft, Ref. 4.

> A. Take-off. After failure of one engine, make a
>   safe landing on the take-off area or continue
>   in flight.
>
> B. Anywhere else. Continue in flight to an area
>   where a safe landing can be made.

(With no dumping of fuel or payload).

These criteria are more severe than those under which current crane-
type helicopters are operated. The latter are not capable of hovering
at full gross weight with one engine out, and a heavy payload must
be dropped. This is not considered to be economically feasible with
the very large and costly payloads anticipated for the Heli-Stat, and
thus the design criteria should require the ability to hover with
full payload, with one engine out. Ref. 5 states, "No pilot in command

of a civil aircraft may allow any object to be dropped from that aircraft in flight that creates a hazard to persons or property. However, this section does not prohibit the dropping of any object if reasonable precautions are taken to avoid injury or damage to persons or property".

As mentioned above, failure of more than one engine is considered so remote that the FAA has no requirements on the subject for multi-engine Category A helicopters. Nevertheless, should a complete power failure occur in one helicopter of the Heli-Stat during cruise, it can be put into autorotation and supply a portion of its normal thrust. The lift and propulsive forces must then be redistributed among the remaining helicopters, augmented by dynamic lift on the aerostat, and a landing with some forward airspeed would be necessary.

MOORING SYSTEM

Present aerostats have been moored from a nose point to a mast, and thence attached to a car, truck or gondola with wheels that are behind the center of bucyancy with sufficient weight to resist the vertical forces, yet free to rotate on the ground or on a track whilst the aerostat weather-cocks into the wind.

It is important that the aerostat be allowed to position itself into the wind. At large angles of yaw the total wind force can be thirty or more times the zero-degree magnitude. On an airship the size of the Akron a wind of 60 m.p.h., striking broadside, would exert a force of about 400 tons (800,000 lb.). Not only would such a large force involve a substantial ground anchor system, but even more important, it would require a multitude of mooring lines in order to distribute the loads into the balloon without severe stress concentrations which could rupture it.

On the other hand, allowing the aerostat to swing about the nose preempts a sizeable amount of clear land for mooring purposes. For the 75-ton Heli-Stat this would be a 1000-ft. diameter circle, which is nearly 20 acres. This circle can be reduced in area by 50% or more by mooring the Heli-Stat in such a way that it pivots around a point aft of the nose, but ahead of the most forward position of the center of pressure.

One method of accomplishing this is to actually attach the aerostat at a mooring fitting located at the desired pivot point. For many applications, however, it would be advantageous for this area of the Heli-Stat to be accessible, as in loading cargo, for example, or boarding passengers.

CONCLUSION

From previous helicopter crane operational experience and regulatory criteria, and performance characteristics of aerostats, and helicopters, a viable precision hovering air-lift system can be designed and constructed with the minimum of risk and development costs.

The resulting vehicles will provide a unique service of heavy vertical lift and positioning far exceeding the capabilities of any other means available today, and extend man's orderly development of his environment.

MODEL OF HELI-STAT BASED ON SHORTENED MACON ENVELOPE
FIGURE 5

REFERENCES

1. Piasecki Aircraft Corp., Report 39-X-11, Multi-Helicopter Heavy Lift System, Philadelphia, Pa.

2. U.S.Patent No. 3,656,723, Multiple Helicopter Lift System, Piasecki et al (April 18, 1972).

3. U.S.Patent No. 3,008,665, Helicopter and Balloon Aircraft Unit, Frank N. Piasecki (November 14, 1961).

4. Federal Aviation Agency, FAR Part 29, Airworthiness Standards, Transport Category Rotorcraft.

5. Federal Aviation Agency, FAR Part 91, General Operating and Flight Rules.