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IMPLICATION OF HEAVY LIFT HELICOPTER SIZE EFFECT TRENDS AND MULTILIFT OPTIONS FOR FILLING THE NEED

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ABSTRACT

This paper first reviews some of the factors which appear to be discouraging development and utilization of larger helicopters and examines the history of previous investigations and experiments into the problem of harnessing two or more helicopters to the same payload. This leads to the conclusion that a twin lift capability not only can be useful not only as an alternative to a very heavy lift helicopter but also as a means of extending the capabilites of small and medium sized helicopters. The body of the paper then reviews the current status of Sikorsky investigations of concepts to accomplish twin lift safely and efficiently. It is concluded that the spreader bar approach combined with a master-slave control provides the best solution. The structural problem of the spreader bar and the control problem of the master-slave control concept are both areas where recent technological advances provide a high confidence in an efficient solution. This makes it timely to proceed with a demonstration, which will put twin lift technology in a state of readiness for use as both civil and military requirements may demand.

BACKGROUND TO THE HEAVY LIFT PROBLEM

1. Has Helicopter Size Peaked?

Sikorsky Aircraft has always had a strong commitment to heavy lift. Igor Sikorsky's personal interest in external lift and the flying crane concept is well known, and Sikorsky helicopters have consistently offered, to both the military and civil markets, the heaviest lift capabilities manufactured in the Western World. Figures 1 and 2 illustrate typical Sikorsky efforts to promote heavy lift.

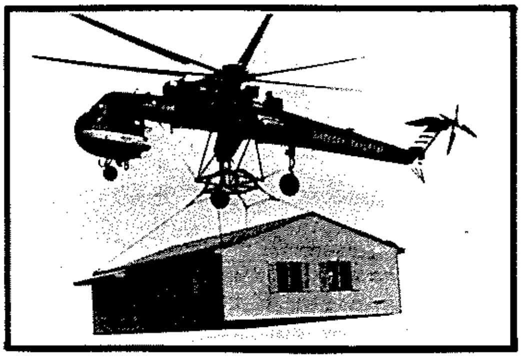


FIGURE 1 S-64 WITH PREFABRICATED HOUSE

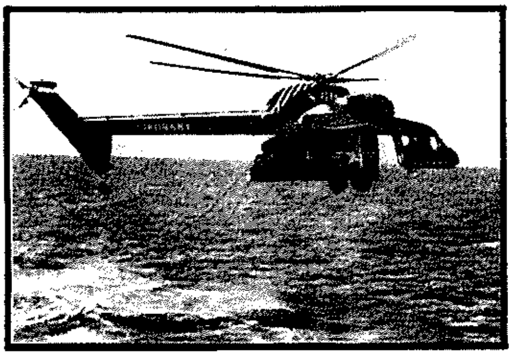


FIGURE 2 S-60 WITH MINESWEEP POD

However, in recent decades, proponents of heavy lift have suffered many disappointments. For example:

- The commercial market for the CH-54B with its 10 ton lift capability was disappointing. It was insufficient to maintain a production line, and commercial production was terminated in 1971 after delivery of only 9 aircraft.

- In the military, the crane concept of a dedicated heavy lift has somehow not caught on. A mixture of external and internal lift capability is apparently required to justify larger helicopters.

- Market studies of a commercial derivative of the CH-53D did not appear to indicate a market sufficient to support the certification costs. It remains to be seen whether the market will justify the Boeing 234 effort.

- Cancellation of the HLH program for affordability reasons has been disappointing to the entire industry, which clearly would have benefited from the operational experience that such an aircraft would have provided.

- The MIL 26, while a significant step forward by western standards, is obviously a retrenchment from the very ambitious thrust of the MIL 12.

In view of all this, we find ourselves wondering whether rotorcraft, at least as we now know them, are in fact approaching an economic size plateau just as ocean liners peaked at about a 1000 ft. waterline, and fixed wing transports may have peaked with the 747. Figure 3 illustrates the helicopter trends. Both the U.S. and Soviets have retrenched from their largest helicopter efforts, although the Soviets have consistently opted for larger helicopters than the West.

In looking for possible explanations of this phenomena, we are lead to the following observations:

- There may not be the same economy of size considerations at play in rotorcraft above 100,000 lbs that exist for fixed wing so that there is less economic incentive to build larger and larger helicopters for bulk cargo or passenger comfort.

- The relatively short ranges envisioned for both military and commercial passenger transport (with the possible exception of offshore oil missions) demands frequency of service which tends to lead to relatively small passenger payloads for any one flight.

- The major incentive for heavier payloads therefore becomes single element payloads that cannot be easily broken down into separate parts for shipping, and these are relatively few and far between.

- There is a chicken and egg effect: as long as markets are small the non-recurring cost factors and financial risks begin to play a very significant role in the cost of acquisition and hence, operations.

- Economics of heavy lift operations become drastically impacted by ferry cost considerations: Figure 10, discussed on page 1.2-6, illustrates the situation.

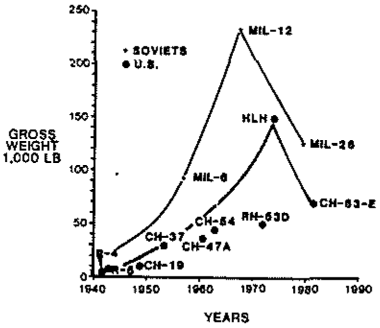


FIGURE 3 HELICOPTER SIZE VS TIME

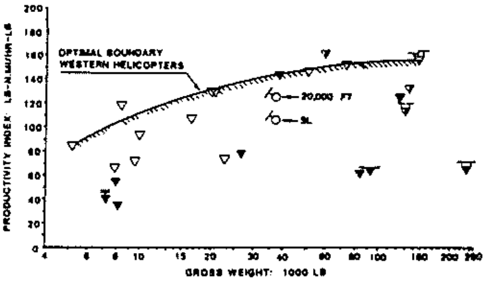

FROM REF. 3

FIGURE 4 IDEAL RELATIVE PRODUCTIVITY AT 100 NAUTICAL MILES

Each of these observations could be debated at considerable length. Reference (1) discusses a number of these in some detail, including some of the technological factors related to size in particular. Reference (2) in addressing the heavy lift subject to this same forum two years ago took strong exception to a good bit of Reference (1) and suggests that perhaps the productivity trends cited in support of the first point above apply only to single rotor helicopters.

It isn't the purpose of this paper to prolong that debate, but it should be stated for the record that, while the gross weight at which an overlapping tandem helicopter configuration peaks out economically may be somewhat higher because of its smaller rotors for a given gross weight, the same general square cube law trends are at work. There have always been trade offs between the two configurations which is the only reason they both still persist in service. It is interesting to note that the largest production helicopter programs in both the U.S. and in the Soviet Union are single rotor helicopters. In any case Reference 3 serves to sum up the situation well. Figure 4 from this paper, which combines data on all configurations and establishes an "optimal boundary for western helicopters", shows a distinct leveling off of specific productivity as size approaches 100,000 lbs gross weight.

But the real question is whether larger helicopters than those currently available are something the customer will buy in sufficient quantity. We can let the record speak for itself. Suffice to say available civil heavy lift helicopters and heavy lift military programs have not been selling well and its not that they can't be built. Until something drastic occurs either in the technology or in the market place it seems unlikely that very much larger helicopters will be available in any quantity and certainly not in the next 5 to 10 years. So the question remains: what alternatives exist to provide a vertical lift capability for very large loads which cannot be broken down?

2. The Twin Lift Option - Early History

The major proposition of this paper is that there is another way to address the requirements for the few and far between heavy lift payloads. Sikorsky feels that the time has come to seriously consider the potential of harnessing two or more helicopters to the same payload, the so-called multi lift or twin lift concepts. While not a new idea, it is an approach that is particularly timely to reconsider in the light of the potential offered by technological advances in digital flight controls and composite structures.

The first multi-lift work, to the best of our knowledge, was conducted by Vertol (now Boeing Vertol) in the late 1950's. Apparently this got as far as initial flight experiments with a spreader bar before being terminated. Reference 4 reports on some of Vertol's early studies. Low disc loadings, which demanded long spreader bars for small payloads, limited control power, and the primitive stage of automatic flight control undoubtedly limited these early experiments.

By the late 1960's however, helicopter technology had advanced considerably. Ten-ton lift capabilities were available with 72 ft. rotors, increased control power was available with larger flapping hinge offset and automatic flight control systems were beginning to perform a number of complex functions.

Sikorsky began examining the twin lift idea in 1968 in the light of these advances. Work started with studies to re-examine the possible configurations for harnessing two helicopters to the same payload. Concepts considered included those shown in Figure 5.

It was concluded that the "Flexible Coaxial" system, although having the advantages of not requiring a spreader bar or large pitch/roll attitude to maintain aircraft separation, has the inherent danger of slack cables fouling in the rotor system and required structural modifications to the two aircraft. In addition, load acquisition and release would appear to be potentially complex and downwash effects could be adverse. Unless separated by a very long cable, the effective disc loading of the system is essentially doubled. This system was therefore not considered for further investigation.

The spreader bar system and the two point pendant system are basically similar except that the means of maintaining aircraft separation differ. In each system a payload penalty must be paid to provide multi-lift capability but the penalty exists only during twin lift operations. In the spreader bar configuration, the bar weight results in a payload penalty, while the reduction in vertical thrust component resulting from thrust inclination to maintain separation yields a payload penalty in the pendant system. Studies showed that the power dissipated, in maintaining separation for the pendant system, offset the advantage of eliminating the spreader bar weight penalty unless the vertical separation of the load below the helicopters in the two pendant system was at least 2.5 times the rotor diameter (assuming a tip path plane separation of one diameter).

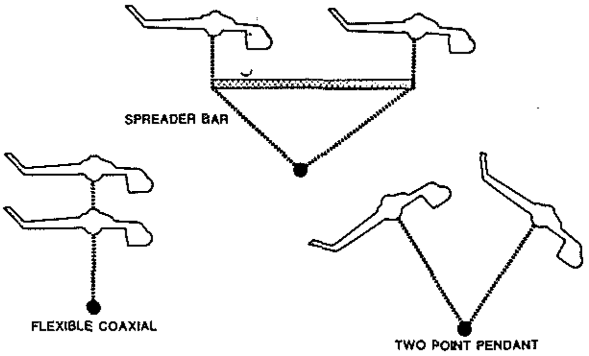


FIGURE 5 FEASIBILITY STUDY CANDIDATE CONFIGURATIONS

FIGURE 6 CH-54B'S WITH A 20 TON LOAD

In 1970 the Army became reinterested in the twin lift concept with an eye towards the problem of retrieving heavier downed aircraft in Vietnam and gave Sikorsky a contract for a flight demonstration. Flight tests proceeded to the point of actually lifting, in an air taxi mode, a 17.5 ton payload with two CH-54's (see Figure 6). Including the weight of the improvised and very heavy spreader bar the total lift was 20 tons. A 150 ft. bar was used, providing a tip path separation of approximately one rotor diameter. The trail helicopter was positioned at about 60° aft of the lead helicopter's beam and about 15 ft above it.

However, once again testing was limited. After exploratory operations in a manual mode, the next phase to demonstrate an automatic solution was not funded for non-technical reasons. However, these tests did show that while the vertical mode was statically stable and dynamic stability was better than expected, trail pilot workload was still very high and there was a marked tendency for the load to distribute itself unequally between the two helicopters whenever the formation accelerated or changed direction. This tendency was apparently a result of the need to bank the bar to provide coordination during accelerations and decelerations, a requirement which an automatic control solution will have to anticipate. Forward flight beyond the confines of the flight field was not undertaken because of the workload and because of safety considerations related to the immediate neighborhood of the test site which did not provide any open area for emergency load jettison. These tests are reported in Reference (6).

3. Civil Twin Lift Experience

In the meantime, the commercial operators have been demonstrating in a small way that twin lift is feasible, and that a commercial need exists. Rolls of cable too heavy for single lift by available helicopters are often carried by two helicopters flying in formation as shown in Figure 7. More recently, PLM helicopters in Scotland have been routinely carrying 50 ft long 2,200 lb poles using two Jet Rangers for distances up to 3 miles at speeds up to 60 knots (see Figure 8). This operation has been accomplished with no automatic flight control assistance and only a chin window mirror to help the pilot sense how the cable is tending as a means of controlling trail helicopter station. The formation is also considerably tighter than in the Sikorsky experiments: rotor tip separation in the horizontal plane with a 50 ft. pole between two helicopters with 33 ft. rotor diameters is only 50% of rotor diameter. A significant number of twin lift missions have been accomplished and a procedure for such operations documented for the U.K. CAA. Similar undocumented experiments have been carried out by the lumber industry again using small helicopters.

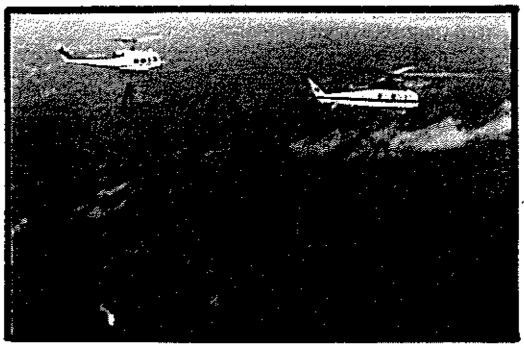


FIGURE 7 TWO HELICOPTERS CARRYING CABLE

FIGURE 8 PLM HELICOPTER TWIN LIFT OPERATIONS

CURRENT STATUS

With the advances that have recently been made in digital flight control and composite structures technology, with better similation tools to study the problem, with the revival of some interest in heavy lift, and with a new appreciation of its potential value for application to small or medium sized helicopters, Sikorsky is once again studying the twin lift possibility to see how it can best be accomplished today and to see how it might fit into a number of operational scenarios. The balance of this paper will serve as an interim report on the conclusions being reached, and the technical data available.

4. Mission Application

As has already been discussed we see two situations in which twin lift is applicable.

In the first and most obvious case twin lift offers the means for almost doubling the payload capacity of the largest helicopter an operator or government agency can justify buying or developing. But because of its logistic complications, increased mission times, and higher crew costs, twin lift is certainly not a substitute for having the right helicopter sized for the job if the need is frequent enough and the market large enough to warrant development, acquisition and maintenance of the helicopter sized to the specific requirement. But if the maximum payload need is infrequent a very large aircraft will be under-utilized most of the time and will be an extremely inefficient solution. Similarly if the market is small, the non-recurring cost burden to be written off against a small buy becomes prohibitive. This is where twin lift comes in. In this role, twin lift becomes a compliment to, rather than a substitute for, the largest helicopter that the requirement can truly justify.

Figure 9 illustrates the sort of scenario for which twin lift is ideal. The ordinate in this figure is the percent of a given inventory which is equal to or less than the gross weight indicated along the abscissa. Given an inventory of equipment to be airlifted, one would want to size a helicopter to carry 80 to 90% of a payload in the single lift mode. But for the last 10 or 20 percent, which might demand twice the helicopter size, twin lift becomes the obvious answer. Note that in this typical inventory there remains a significant payload beyond any currently forseeable single lift capability.

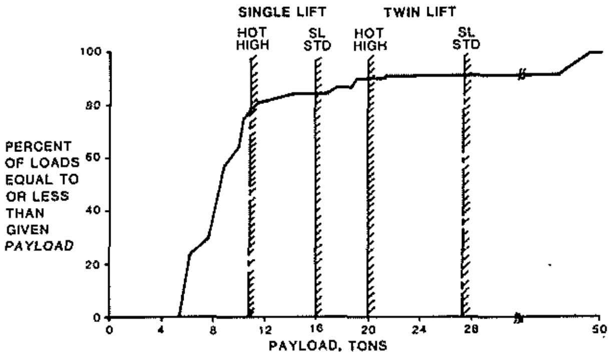


FIGURE 9 TYPICAL INVENTORY DISTRIBUTION

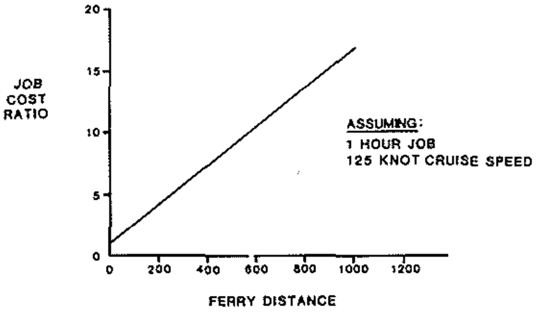


FIGURE 10 *IMPACT OF FERRY RANGE ON JOB COST*

The other situation is the one in which the helicopter to do the job exists, but is simply not available to the operator or is not on the site without extensive ferrying. The savings possible from using two helicopters that might be available on site are obviously immense in such a situation. Figure 10 illustrates the mission cost increase that would accrue against a mission because of the ferry requirement plotted against ferry range for a one hour mission requirement and assuming a ferry speed of 125 knots. For instance, if only one hour is required to do an actual mission but the helicopter is based 1000 miles away and must return to that base, 94% of the cost of doing the job results from the ferrying requirements. A rapid deployment force limited to air transportable helicopters, or an expeditionary force with relatively small ships on which to base helicopters, presents a similar situation. We expect that when twin lift techniques become accepted this sort of situation may well produce the majority of the usage.

5. Safety Considerations

There are three aspects of safety to be considered: Separation maintenance and the reliability of any special flight control provisions to maintain it, inadvertent unsymmetrical release; and engine failure.

Separation maintenance is assured, to a degree, by the spreader bar itself but is fundamentally the problem of control, which will be treated in detail below. The safety pilot's ultimate recourse in case of control malfunction is, of course, to jettison the bar and load. With the use of redundant fail operational flight control technology we would expect this to be an extremely rare event. In a demonstrator program we would certainly also investigate flight director displays of the error function information with various sorts of quickening to also provide the slave helicopter with a possible means of continuing twin lift operations at least to an emergency landing without undue fatigue following loss of part or possibly all of the automatic control provisions.

The means for coping with emergency release requirements including inadvertent unsymmetrical bar releases were well developed on the CH-54 flight demonstration program. Figure 11 illustrates the release options that were made available. In normal operation, either pilot could release the load from the bridle electrically. Each pilot also had an electrical emergency release which released both ends of the spreader bar simultaneously. Finally, a mechanical release was provided that would release the remaining cable on the spreader bar if the angle of the bar exceeded a prescribed amount in order to provide automatic release in case either of the electronic releases malfunctioned. As a last resort, a cable guillotine was also provided at each helicopter's hard point. All of these provisions might not be required in a production system but were deemed desirable for the experimental program.

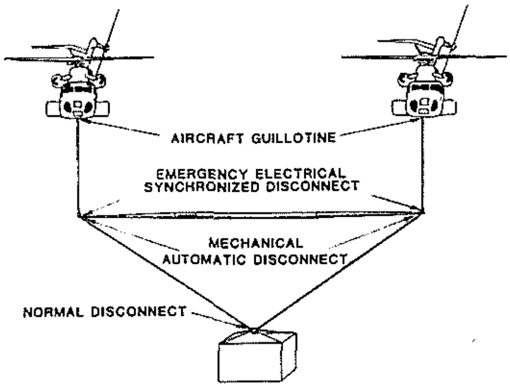


FIGURE 11 TWIN LIFT DISCONNECT FEATURES

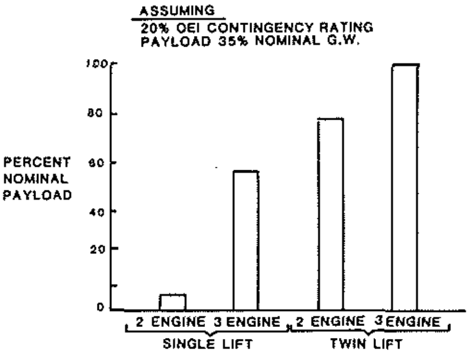


FIGURE 12 PAYLOAD ALLOWABLE TO RETAIN OEI HOVER CAPABILITY

The question of engine failure brings up a unique advantage of twin lift. Because the loads are automatically redistributed towards the high helicopter if either helicopter allows its end of the spreader bar to be lowered, the means are automatically provided to redistribute power requirements evenly between the remaining engines following loss of an engine. Thus, a twin lift formation with a pair of two-engined helicopters has the after engine failure capabilities of a 4-engine helicopter. With three engines in each pair, such as would be the case with two CH-53E's, six engine reliability margins are provided. For example, if a two CH-53E twin lift formation with a 60° bridle lost one engine, only 14° of tilt on the spreader bar would redistribute the power requirement evenly over the five remaining engines and only a 20 percent contingency power rating would be required to sustain all engine operative performance. Thus, for the first time we have an external lift operation which should not require payload jettisoning in case of engine failures, a capability of considerable interest for high value cargos. Figure 12 compares the payload as a percent of nominal OGE hover payload that can be carried while retaining the capability to land the payload safely following an engine failure for two and three engine helicopters operating in single and in twin lift modes. For purposes of this simple example a 20% contingency power rating is assumed, nominal payload is assumed to be 35% of nominal gross weight and power required to hover is assumed to reduce 30% for a 24% reduction in gross weight (the characteristic of the CH-53E at maximum gross weight).

6. Payload Efficiency

Twin lift does not come entirely without compromise. Three factors must be considered: The amount of payload used up by the weight of the spreader bar, cables and hooks, the additional fuel used because of the aerodynamic drag of the bar and slower cruise speeds, and the logistics problems of having the spreader bar on location when needed.

In the 1970 tests a 150 ft steel spreader bar was designed to support a 20 ton payload and to provide approximately a one diameter tip path plan separation. No attempt was made to optimize this design. Designed for 2.0g's and with a load suspended 130 ft. below the bar (a 60° bridle angle), it weighed 5,000 lbs. or 12-1/2 percent of payload. In addition about 3.5% of the design payload was required for cables, hooks and wiring. Studies at that time of an aluminum truss spreader bar indicated such a design would weigh less than half as much or about 6% of payload. Mission studies indicated a total fuel increase in the two aircraft of about 5% of payload are required.

More recently, studies have been conducted to understand the basic tradeoffs in spreader bar design. From these, it can be deduced that the optimum spreader bar will have an aspect ratio of about 25, that a sling cable angle of 60° is about optimum from an overall point of view, and that bar weight fraction tends to hold constant with size effect except for a rise at very small sizes because of minimum gauge effects. Some of these trends are illustrated in Figures 13 and 14.

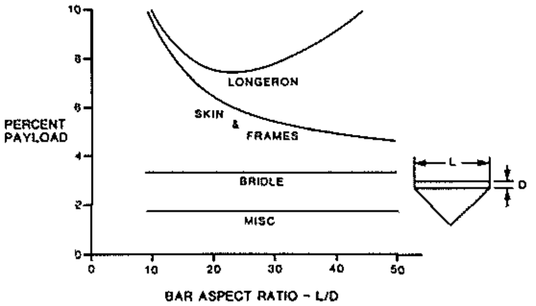


FIGURE 13 BAR ASPECT RATIO EFFECT IN WEIGHT FRACTION

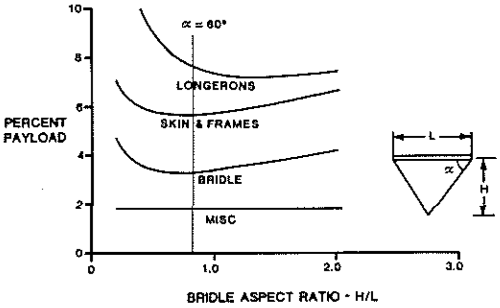


FIGURE 14 EFFECT OF BRIDLE ASPECT RATIO IN ON WEIGHT FRACTION

From these studies, the effect of material selection and bar length (tip path separation) can also be derived. If control technology can be brought along and redundancy provided to assure a fail operational or at least a fail safe situation, then lesser clearances and a shorter, lighter bar would be possible. Vertical separation is also a cheap way to provide a large increase in tip clearance for modest increases in cable weight. Figure 15 illustrates the degree to which a high confidence control solution could allow a more compact formation. Similarly, the spreader bar weight can be reduced with composite technology.

Figure 16 sums up the benefits to be obtained from advanced technology. Thus, with composites technology, it seems reasonable to assume that a total weight penalty between 7 percent and 10 percent of payload will accrue depending upon the separation deemed feasible after development of the control technology. Ultimately it may even be possible to take advantage of induced power formation flight advantages to reduce fuel, but this has not been considered in this analysis.

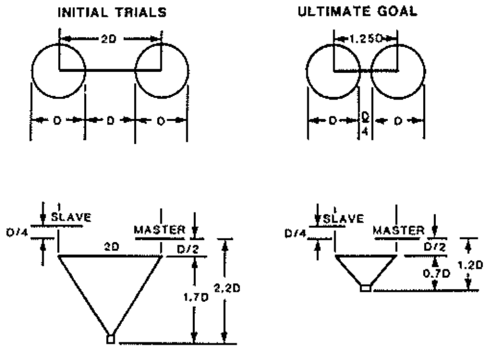


FIGURE 15 FORMATION OPTIONS

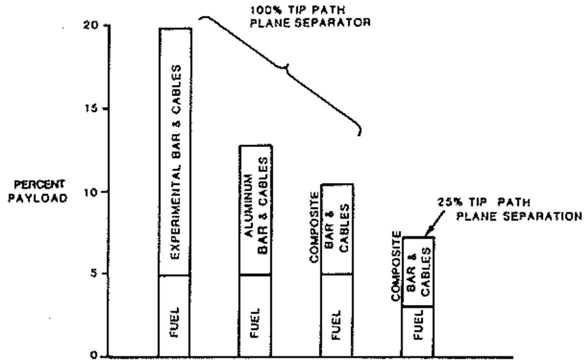


FIGURE 16 TWIN LIFT PAYLOAD PENALTIES

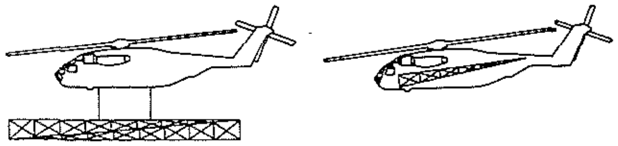
7. Spreader Bar Logistics

Reducing the separation requirement and hence spreader bar length and weight is probably even more important to simplifying logistic problems than it is to increasing payload efficiency. Perhaps the pacing factor in establishing the operational feasibility of twin lift will be the ability to have the spreader bar available when needed.

The ideal situation, of course, is one in which the payload itself is its own spreader bar like the transmission poles carried by the PLM helicopters. A long bridge section is another example. The large hatch covers on cargo ships may be another. The next best situation would be one in which a payload could be provided with its own collapsible spreader bar, but it's difficult to visualize many situations in which this would not compromise the payloads excessively.

So we must come up with ingenious foldable structural concepts. The ability to at least fold the spreader bar in two or break it into two pieces is probably the simplest solution. The reduction of the tip path plan horizontal separation with highly reliable control technology can simplify the situation considerably. If tip separations of 25 percent of rotor diameter could be achieved, it would probably be possible to develop a bar, which in two parts would be carried internally by a CH-53E for ferrying the bar. (Figure 17.)

A more compact solution could undoubtedly be achieved by taking advantage of the natural taper in the optimum pin ended column, to provide a telescoping configuration. Of course, some weight penalty will certainly accrue in proportion to the sophistication of the telescoping concept. This is an area that has probably not had all the study it deserves. Any contributions will be welcome.



EXTERNAL STORAGE
100% TIP PATH PLANE SEPARATION

INTERNAL STORAGE
25% TIP PATH PLANE SEPARATION

FIGURE 17 SPREADER BAR FERRY OPTIONS

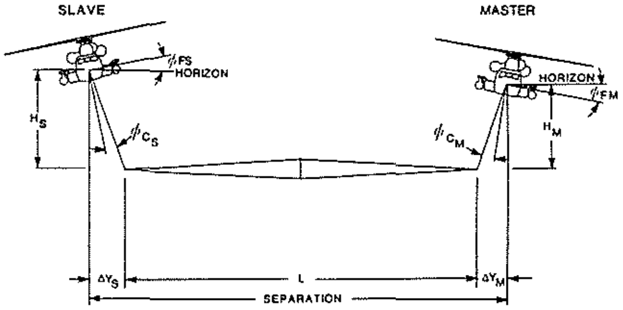


FIGURE 18 LATERAL CONTROL

8. The Master Slave Automatic Control System Concept

Clearly, the key element of the twin lift problem that needs development and demonstration before an effective operational evaluation can be undertaken is the control problem. While most engineers will concur that virtually any automatic control requirement can be met reliably with today's fail operational flight critical, digital control technology, until the solution is actually demonstrated doubts will remain on the part of the user and a clear grasp of how a system will work out in practice cannot be attained.

The control approach espoused by Sikorsky from the onset of the 1970 experiments has always envisioned an automatic control solution. A detailed description of the system originally envisioned will be found in Reference 5. A master-slave concept is proposed by which the master or lead helicopter with control augmented only by conventional stabilization, and perhaps some load stabilization feedback, is positioned by its pilot as required to place or move the load as desired. The slave helicopter function then consists solely of holding its end of the spreader bar so as to maintain separation, to maintain the bar level in the desired azimuthal orientation and to maintain its own heading parallel to that of the master.

In a hover, a side by side orientation as shown in Figure 15 is envisioned. Without the benefit of the rear facing cockpit which the S-64 provided for the master pilot, the master aircraft would be located to the left so that the master pilot can watch the load from the right side bubble window. The slave helicopter would be on the right and somewhat above so that the safety pilot in the left seat could monitor the performance of the automatic station keeping and be prepared to take any corrective action that might be required.

Figure 18 illustrates a typical error function which an automatic control system might be designed to null in a hover. In forward flight the only extension of the error function concepts might be a requirement to hold the bar at an attitude parallel to the lateral axis of the master helicopter to assure coordination.

While the error function shown in Figure 18 assumes a side-by-side formation of the two helicopters, it is probable that in forward flight, the slave helicopter might better station itself 60° abaft the beam as was done in the CH-54 experiment. While this implies some control function mixing, it should be a relatively simple matter for today's digital computer to adjust the feedbacks required for the slave to cope with the coupled functions that result in a skewed formation. Error functions for all degrees-of-freedom in this configuration are described in Reference 5.

Figure 19 summarizes, in block diagram form, the control functions envisioned. It is proposed that the outer loop or "parallel" control functions of the slave helicopter (full authority stick commands) be utilized to replicate, in the slave helicopter, the motions of the master helicopter's stick. Thus, the monitor pilot in the slave helicopter is continually aware of the control functions being performed by the master, much as the conventional copilot sees the stick activity of the command pilot. The inner loop or "series" limited authority capabilities of the automatic control system can then be reserved for the feedbacks necessary to null the prescribed error functions. Since stick position is always tracking the flight condition selected by the master helicopter, there are no steady state demands on inner loop functions.

Note that a certain amount of load stabilization is envisioned in the master as well as the slave helicopter in order to damp out any tendency for the bar and cable to oscillate as a parallelogram.

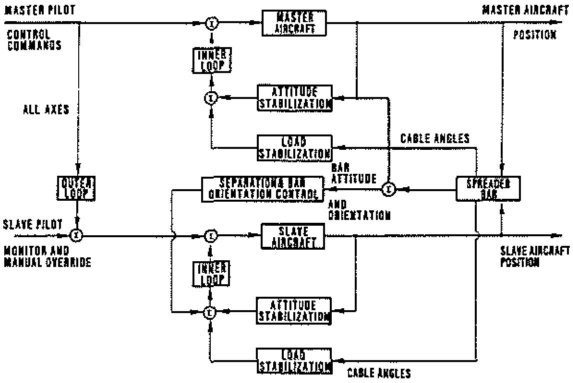


FIGURE 19 MASTER SLAVE CONTROL CONCEPT

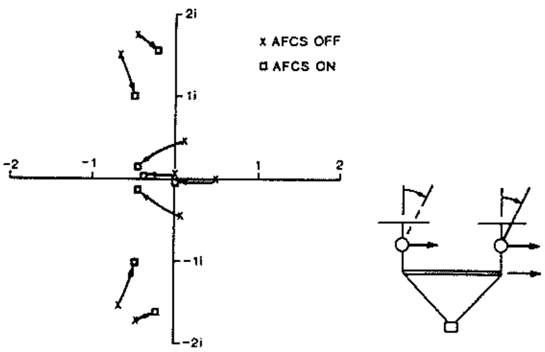


FIGURE 20 LATERAL CONTROL ROOT LOCUS

9. Control System Technology Status

Fortunately, there is considerable prior experience available to apply to the proposed feedback control functions required. The yaw and vertical control problem is directly analagous to any number of heading and altitude control functions conventionally provided in automatic control systems while the lateral and longitudinal control functions are quite similar to those utilized in the cable angle couplers of the ASW Sonar hover system. Dynamic damping of a swinging load with load stabilization feedbacks has already been demonstrated by a very successful flight demonstration on the CH-54 in 1974.

While today we would plan to utilize the highly developed non-linear digital simulations available such as the Sikorsky Gen Hel simulation before flight, a linear analysis of system dynamics is already available. Both Reference 4 and parallel Sikorsky work provide linear equations of motion for the helicopters and spreader bar. Using these equations of motion, the root locus plot of Figure 20 for the lateral control of separation can be constructed to get a first order feel for system dynamics and how they will respond to conventional stability augmentation feedbacks.

While it is proposed for initial demonstration at least, to use error functions generated from the cables and spreader bar, the ultimate potential of a universal formation flight coupler deriving its signals from ultra short range, range, bearing and elevation sensors in the slave helicopter are intriguing. Not only would it provide another use (formation flight workload reduction) for the automatic control coupler but, as a facility that could be used any time two helicopters are flying together, it would undoubtedly be used more often thus assuring a higher degree of maintenance and training readiness when needed for twin lift missions. An automatic coupler for formation flight on prolonged ferry missions in adverse weather would certainly be a useful facility for reduction of pilot fatigue and might well justify on its own, the cost and weight of the automatic formation flight control system.

In short, the control problem appears to be a straightforward extension of previously demonstrated automatic control facilities which should be particularly amenable to implementation by digital techniques, and which have important potential rake offs for other formation flight problems.

CONCLUSIONS

In summary it is Sikorsky's position that:

1) Twin lift is a highly cost effective means of extending the capabilities of the world's fleet of helicopters in all size categories and is certainly the only immediate means of achieving a significant increase in payloads beyond the 16 tons now available in the Western World.

2) Twin lift is not a substitute for the heaviest lift helicopter which mission requirements can justify but rather a means of augmenting the capabilities of the largest helicopter available in any given situation.

3) The control problem is amenable to highly reliable solutions with today's flight critical digital flight control technology.

4) Advanced structural composites can reduce the spreader bar weight to relatively insignificant proportions in terms of efficiency, but more importantly, can greatly ease the logistics and handling problems of having spreader bars available where needed.

5) The safety considerations are well in hand; twin lift offers greater potential tolerance to engine failure than single lift.

6) An operational demonstration is needed to prove these points.

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