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DEVELOPMENT OF THE TRANSPORT AND PACKAGING REQUIREMENTS FOR THE DELIVERY OF LARGE AEROSPACE STRUCTURAL ELEMENTS BY HELICOPTER

THESIS FOR THE DEGREE OF M. S.

MICHIGAN STATE UNIVERSITY
DONALD SEWELL

1966

ABSTRACT

As the size of aerospace structural hardware becomes larger, the feasibility of transporting a structure from the area of manufacture to the using site by towing through the air becomes promising. With the increase in lifting and carrying capacities of the present helicopters, the delivery of a structure by slinging the unit under the helicopter becomes a most attractive delivery method.

A procedure was presented to develop the delivery of an aerospace structure by slinging the unit below a towing helicopter. The development of a procedure for the helicopter delivery requires the use of several areas in the engineering discipline--aeronautical, mechanical and packaging.

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BY

DONALD SEWELL

A THESIS

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SCHOOL OF PACKAGING

1966

DEVELOPMENT OF THE TRANSPORT

AND PACKAGING REQUIREMENTS

FOR THE DELIVERY OF LARGE AEROSPACE

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INTRODUCTION

The development of large, strong, lightweight structures,[1] the increase in labor costs for on-site assembly, and the sophisticated alignment requirements sometimes needed in reassembly of structures have required the delivery of units completely assembled or in large subassemblies. The varied locations of existing manufacturing facilities and the destined using sites require the delivery of these structures over land areas.

The transportation of large structural elements over land areas poses a difficult problem. The clearance profiles of road and rail right-of-ways imposed by man-made and natural obstacles make the movement of large structures by highway or rail impractical or impossible. New highway design and rail clearances offer a greater flexibility in load carrying capacity, but this change does not provide the profiles required for shipment of large structures.

The present conventional aircraft do not offer the possibilities in shipping envelopes found in the clearance profiles of land transport. On the design tables of our aircraft companies there are designs for larger freight aircraft, but the preliminary data released

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[1] Bonded Aluminum Honeycomb Panels, Large Space Components, and High Strength Lightweight Alloy Structures.

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on these do not offer anything larger than the existing land transport profiles.

Often this transport problem has been circumvented by selecting a manufacturing site serviceable by boat or barge where the destination of the structure has a docking facility. In addition to the manufacturing site limitations, disadvantages to water shipments often include long shipping periods, adverse environmental conditions, and high shipping costs.

Studies have been conducted for the transportation of large assembled structures. Recommendations of these studies have included development of special ground transport vehicles with maneuvering mechanisms to enable a load to move over, under, and around an obstacle; routes modified by means of clearing obstructions to provide the required shipping profile; utilization of lighter-than-air vehicles; development of specially modified conventional aircraft to enlarge the fuselage to the required shipping envelope and utilization of the helicopter as a cargo transport.

With the exception of the lighter-than-air vehicles and the helicopter, each of the recommended alternates has an inherent size limitation. With the ability of lighter-than-air vehicles and helicopters to carry a structure slung under the carrying vehicle over obstacles, we have a limitless size capability within the carrying capacity of the vehicles and aerodynamic loading on the structure.

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Purpose and Scope of Study

This thesis is intended to present a procedure that can be used to develop the helicopter as a long distance transport vehicle to deliver a large structural element. The method of carry is by slinging the structure to be delivered under the delivery vehicle. It is anticipated that this method of delivery could be developed into a general delivery system for specialized items and assembled structural elements.

The use of the helicopter as a crane or delivery vehicle over short distances is not a new concept. The capability of the helicopter to lift, travel and hover has long been recognized as a useful tool in the petroleum and heavy construction industry for movement or positioning of structures without the expense involved in the use of conventional construction methods. However, the proposal to extend the delivery range of the helicopter from a few miles to over a thousand brought up some interesting questions--range capabilities of the helicopter, weight that could be delivered, delivery speed, flight stability of the structure at the delivery speed, physical protection required, ground support equipment requirements and ground handling procedures. In this discussion the aspects of the problem will be presented along with an approach to the solutions used in accomplishing the delivery.

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The procedure presented in this thesis is based on a procedure developed and used by the writer to deliver large aerospace structural elements produced by the Tulsa Division of North American Aviation.

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CHAPTER I

PRELIMINARY STUDY

The initial approach to developing the helicopter, with the load suspended under the helicopter, as a long distance transport vehicle takes the form of a preliminary study. This study is conducted to view and establish the feasibility of the item transport by suspending the structure under the helicopter and identifying the general areas which require investigation in detail to develop the helicopter into a long distance transport.

The first step in the preliminary study was to identify the basic factors of the transport problem which will control the choice of helicopter as a transport vehicle. This study requires a comparison of general operating characteristics of the helicopter with the factors of the particular transport problem and structure that affect the operation of the helicopter.

Helicopter Characteristics

The operating characteristics of the helicopter that are utilized for the long distance delivery of a structure are its ability to hover, lift, and travel. These characteristics are derived from the fact that the helicopter rotor which provides the lift can use this lift in either the

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the vertical or the horizontal direction. Thus, when the helicopter is in operation, the lift supplied by the rotor is used in two ways. First, the rotor supplies the lift necessary to carry the vehicle and its load; then the remaining lift available from the rotor is converted to a horizontal component to provide horizontal movement. This characteristic of the helicopter rotor establishes a dependence between the vertical and the horizontal lift within the maximum lift available from the rotor and the mechanical limits of the rotor to convert vertical lift to a horizontal component.

The maximum lift that can be delivered by the rotor is fixed by its particular airfoil design and the power capacity of the vehicle.[2] Thus, for a particular vertical load there is a specific maximum horizontal lift available for horizontal motion.

Taking these characteristics of the helicopter into account, the weight of the structure to be lifted and the force required to tow this structure are basic factors in the choice of the helicopter required for the item delivery.

Operational range of the helicopter is another basic factor in the use of the helicopter as a long range delivery vehicle. This characteristic is dependent on the speed the helicopter can maintain towing

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[2] Standard conditions for evaluation of the lifting capacity of a helicopter is the ICAO standard atmosphere (59^{o} at sea level). Ref: National Advisory Committee for Aeronautics (NACA) Bulletin TR1235, Washington, D. C.

the load and the length of time the helicopter can remain in operation during the flight.

The interaction of the horizontal lift, which provides the power for horizontal speed, and the vertical lift required to carry the structure have been discussed. Therefore, the speed is determined by the weight and towing lift required to move the item. Since the fuel consumption of a helicopter is fairly constant at a given load and speed,[3] the time the helicopter can remain in operation for a particular load and speed is directly dependent on the amount of fuel available during the flight. The amount of fuel available is determined by the capacity of the vehicle tanks. Therefore, operational range remains dependent on the lift required to carry and tow the particular structure.

Item Characteristics

When a large structural element is suspended below a flying delivery vehicle, the structural element is subject to the aerodynamic forces of a flying article. The aerodynamic forces that affect a flying article are:[4]

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[3] S-61 Sikorsky Helicopter Flight Handbook, Sikorsky Aircraft, New Haven, Connecticut

[4] Pilot Instruction Manual, U. S. Department of Commerce, Civil Aeronautics Administration, C.A.A. Technical Manual No. 106 July 1958, Washington, D. C.

1. Aerodynamic drag
2. Gravity
3. Aerodynamic lift
4. Thrust

Each of these aerodynamic forces has its effect on the transport vehicle. Aerodynamic drag is the resistance of the air to the passage of the structure through the air and affects the towing vehicle by sapping its horizontal component of lift. Gravity constitutes the total weight of the structure being towed. This characteristic of the structure is the vertical component of force downward that must be counteracted by lift supplied from the towing vehicle. Aerodynamic lift is the vertical force upward that can be obtained from a structure passing through the air. This force is dependent on the shape of the article and varies with the speed of the air passing around the article. This force, since it is upward, reduces the lift required to carry the structure when the structure is in motion. Therefore, this lift frees the helicopter power to be used as horizontal motion. The aerodynamic characteristic of thrust is the force felt by the structure from the towing vehicle. This force is the resultant force of the horizontal component aerodynamic drag and the vertical forces' gravity and aerodynamic lift that are present during the delivery flight.[5]

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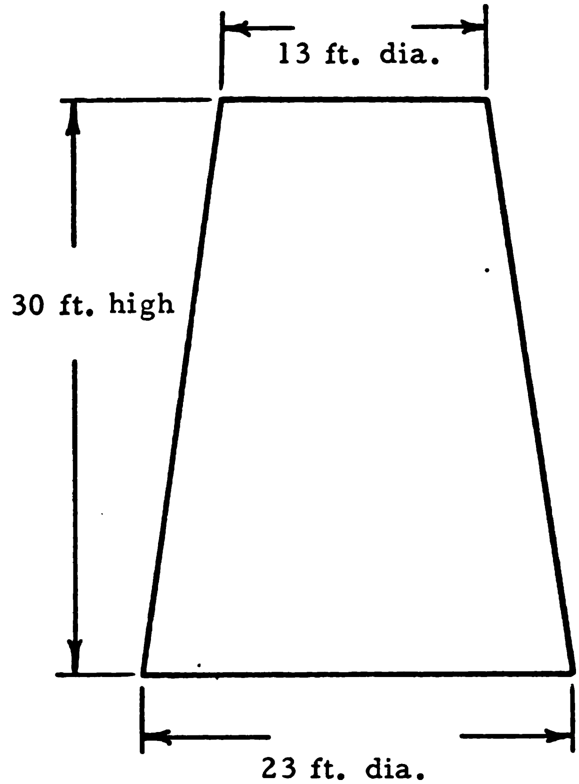
[5]Courtland D. Perkins and Robert E. Hage, Airplane Performance Stability and Control, John Wiley & Sons, Inc., New York, New York, 1957.



The structure to be delivered is a hollow truncated cone.

Structure weight: 3500 lbs.

Structure delivered weight: 4700 lbs. with packaging delivery devices installed.

This Figure Illustrates a Typical Structure to be Delivered

Figure I

Numerical values for each of these characteristics supply the parameter for the lift requirement necessary to make the delivery.

Structural Aerodynamic Information

The numerical values of the aerodynamic characteristics of a structure can be obtained in two ways. The first is estimation through the use of mathematical formulas. There are numerous books which discuss in detail mathematical approaches for the estimation of values for each of the characteristics.[6] For the preliminary study any of the mathematical approaches is precise enough to give values that can be used to determine the feasibility of helicopter transport and data for preliminary choice of helicopter.

The second method involves the actual measurement of the required values. This requires the use of structural models and the wind tunnel. This method gives exact values and data for the aerodynamic characteristics of the structure. Though these exact values are required for the development and sanction of this transport mode, the cost and time required are usually not available during the preliminary and feasibility study time schedule; therefore, the mathematical approach is used in the preliminary stages and the empirical approach is used in the development stage of the transport method.

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[6] Ibid.

Appraisal of the Helicopter and Item Characteristics

Coupling the characteristics of the helicopter and the estimated numerical values for the aerodynamic characteristics of the deliverable structure, we can develop the parameter for the helicopter required to transport the structure.

Vector summation of the structure weight, its aerodynamic drag and lift provides the minimum useful lift requirement for the towing vehicle. This value provides the lift parameter for the choice of delivery helicopter.

Helicopter Models

With the minimum useful lift capability of the helicopter defined, we can now turn to comparing these data with the capabilities of existing helicopter models. Jane's All the World's Aircraft[7] provides in one volume a resume of the characteristics of all the helicopters built. A comparison at this point will provide several helicopter models that can perform the requirements. The final choice of helicopter is made during the development study and is based on detailed data from the manufacturers' operational manuals for the models being considered. The manuals are available from the

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[7] Jane's All the World's Aircraft, The McGraw-Hill Book Co., Inc., New York, New York. Published yearly.

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helicopter manufacturers or industrial technical libraries. Establishing the existence of a helicopter which has the characteristics required has provided the first fact toward proving the overall feasibility of delivering a particular structure by suspending that structure below the towing helicopter.

Aerodynamic Stability

With the determination of a helicopter vehicle capable of transporting the structure, the next step is to determine a practical sling arrangement to be used that will insure the structure is aerodynamically stable when being towed by the helicopter at delivery speeds. This sling arrangement must allow for the practical handling of the unit when it is not flying, allow for a practical hook up procedure of the helicopter for towing, not impose forces into the structure that will damage the structure during a delivery, and allow the unit to be aerodynamically stable while flying. Sling arrangements can be visualized by investigation and evaluation of the structure. This study can develop several arrangements that will be investigated for aerodynamic stability.

The aerodynamic stability is determined by a simple tethered test. This test is run using a scale model of the structure. This model is rigged with the determined sling arrangements and tethered to a pole attached to a moving vehicle. The stability of the structure usi

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using each of the sling arrangements is observed and photographed at different air speeds. From this aerodynamically stable sling arrangements are chosen for further wind tunnel testing and final choice.

Preliminary Study Conclusions

With the determination of a helicopter vehicle model or models capable of making the delivery and an aerodynamically stable sling arrangement for attaching the structure to the towing helicopter, we can declare that the helicopter is a feasible method to make a delivery of the particular structure.

From this study we have also determined areas which require study in detail to develop the helicopter into a long range delivery vehicle. The first is a wind tunnel test program to determine the exact numerical values for the aerodynamic characteristics of the structure. From these values and the investigation into the sources for the helicopter models chosen in the preliminary study, a final choice of transport vehicle can be made. With a helicopter having been chosen we can turn the investigation to the details of the delivery based on the particular helicopter chosen; namely, definition of the route, route requirements, and the ground handling requirements needed over the route, etc. From the data gathered above the transport plan can be developed and submitted for sanction by the Federal Aviation Agency (F. A. A.).

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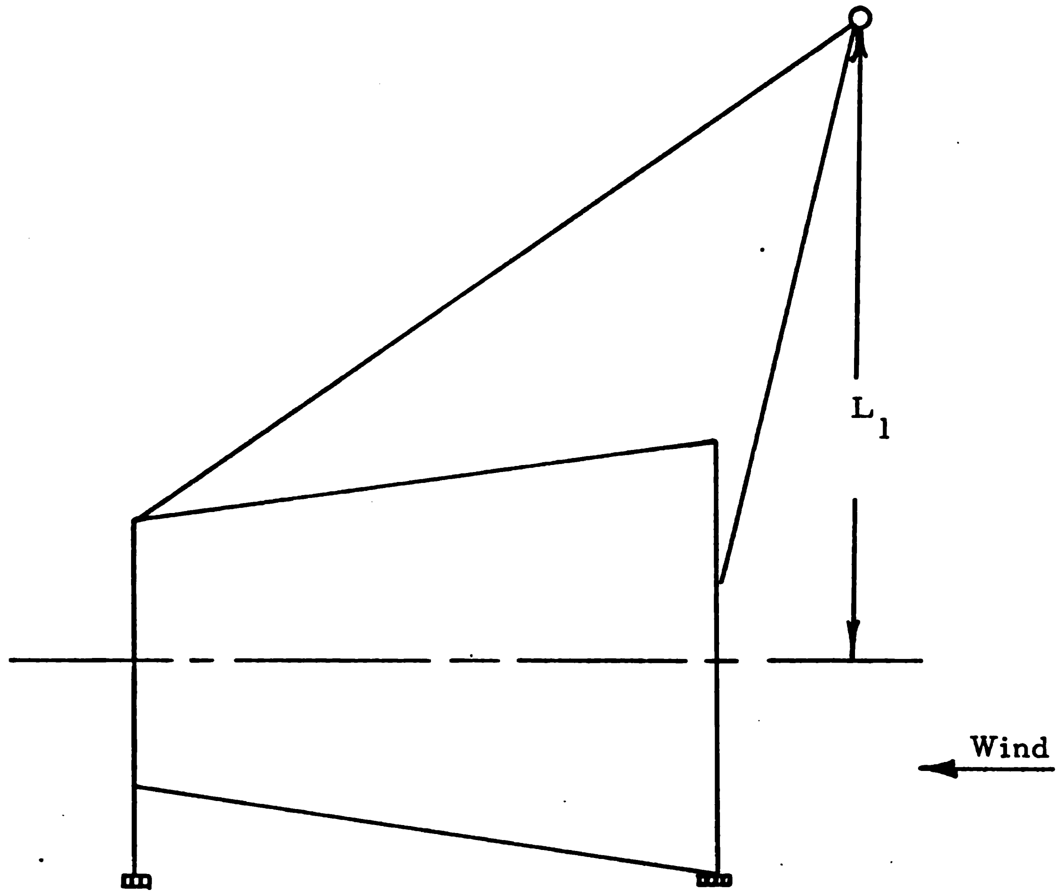
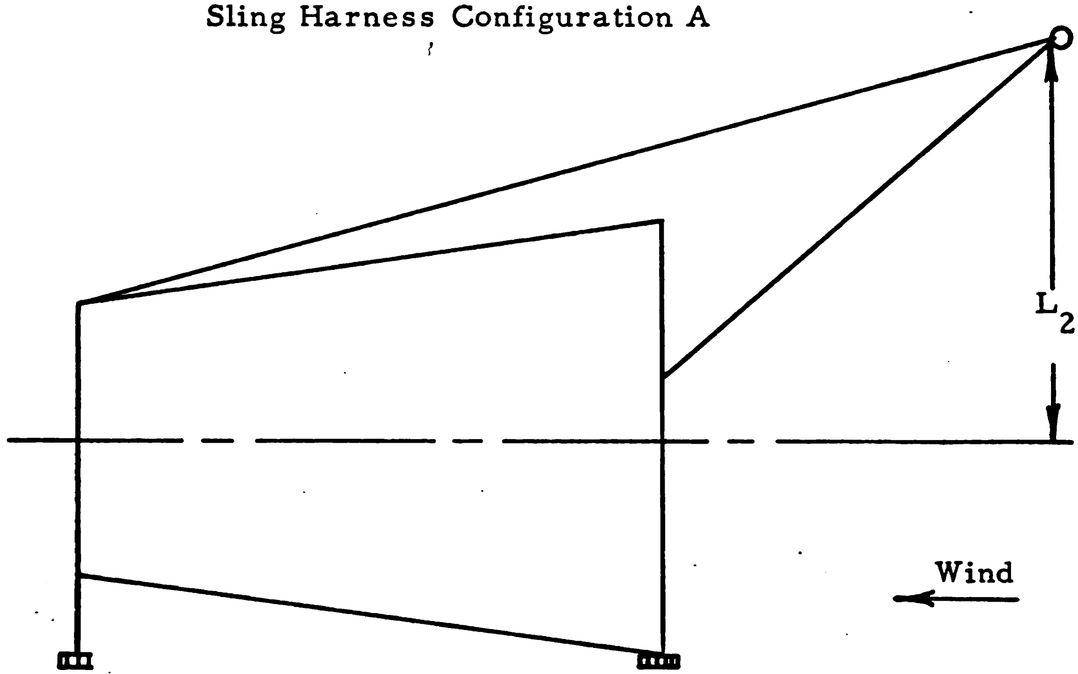
The following figures illustrate the helicopter towing arrangements that can be adapted to the structure shown in figure I. These figures illustrate the slinging approach that should be considered in the development of the towing arrangement for the delivery of an item.



II - 1

Sling Harness Configuration A

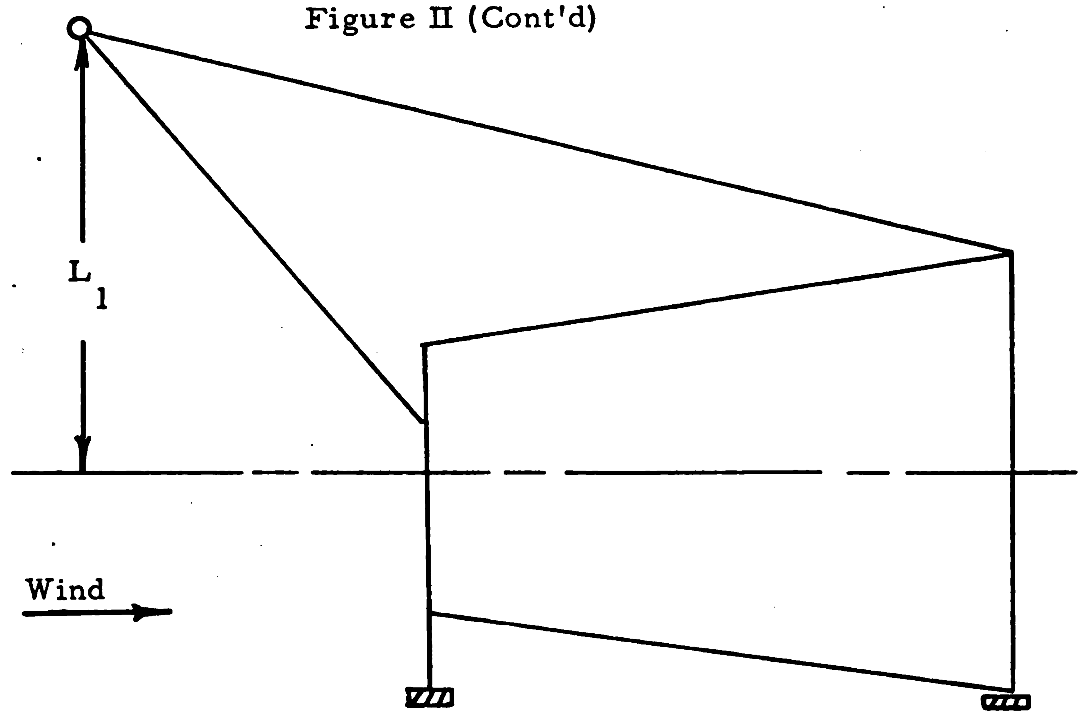


II - 2

Sling Harness Configuration B

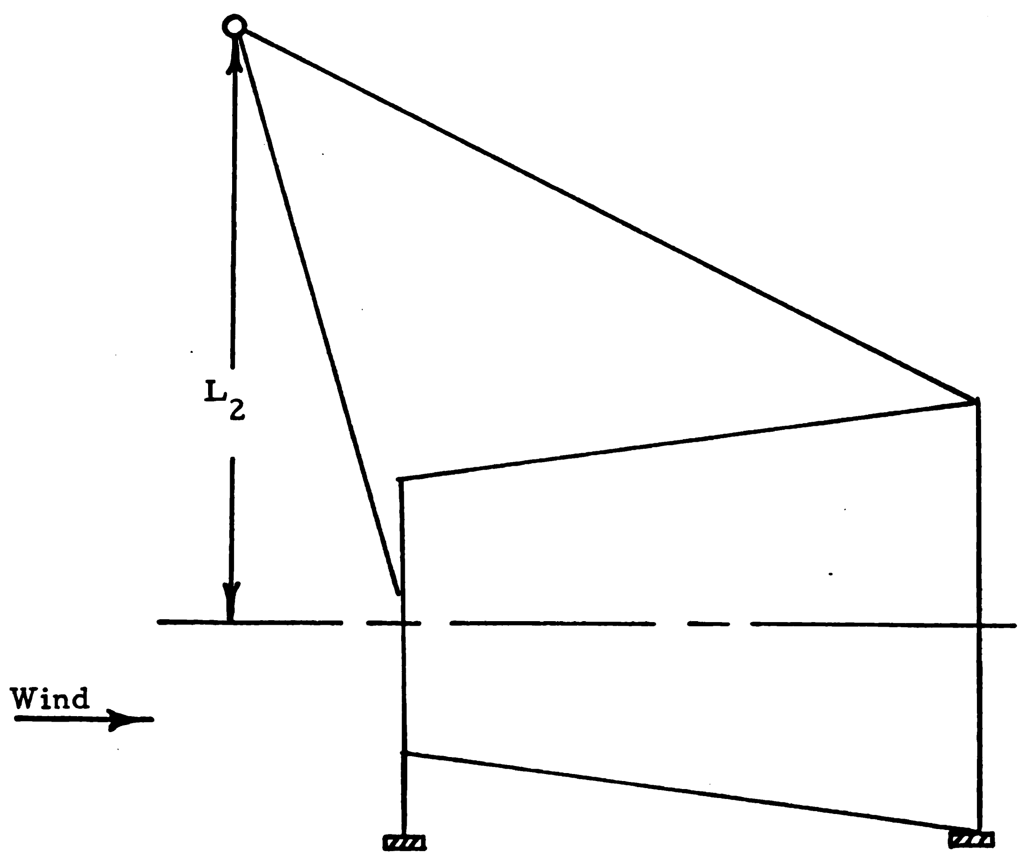
Figure II

Figure II (Cont'd)



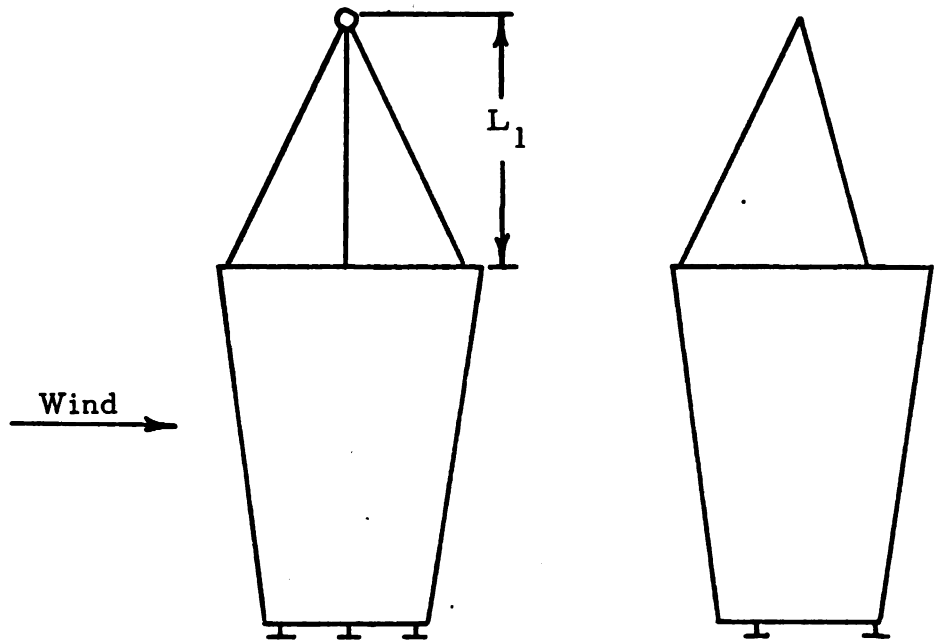
II - 3

Sling Harness Configuration C



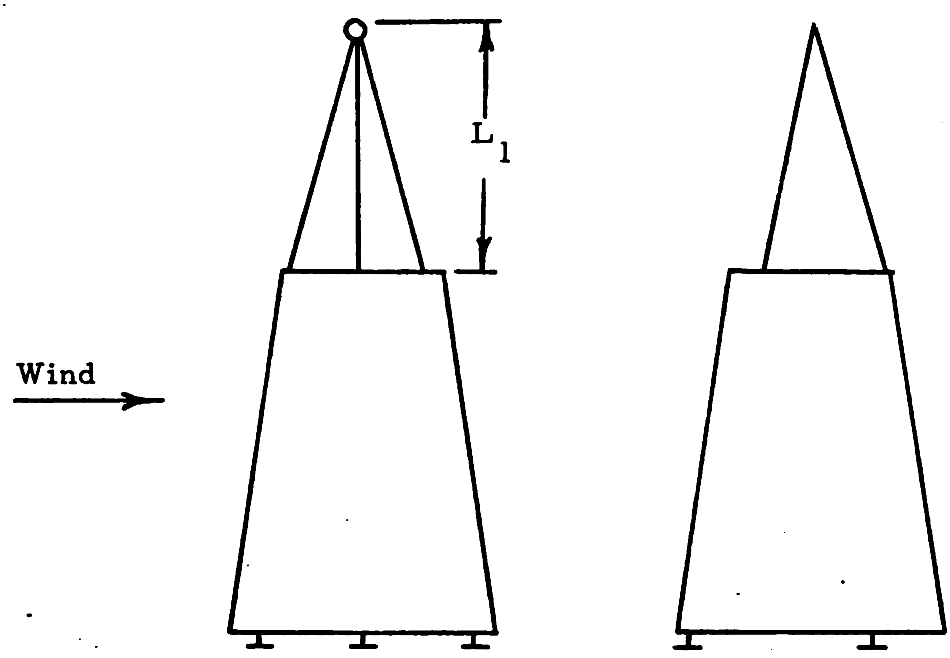
II - 4

Sling Harness Configuration D



III - 5

Sling Harness Configuration E



III - 6

Sling Harness Configuration F

Figure III

CHAPTER II

DEVELOPMENT STUDY

With the establishment of the feasibility for the delivery vehicle, the study turns to the development of a detailed transport plan that will be sanctioned by the Federal Aviation Agency (F. A. A.). The civil air regulations specify that a modification of an aircraft changes the classification of the aircraft to experimental.[8] The experimental classification of a vehicle requires an F. A. A. sanction for the operation of that vehicle. This sanction is obtained by submitting to the F. A. A. a plan of operation for the vehicle and submission of test values that will prove that the operating procedure will not endanger the crew, the vehicle, or the area over which the aircraft will travel.[9] The transport plan can also serve as an operational manual for the delivery of structures over the specified route. The material provided by the plan includes route layouts, outlines of facilities and equipment required at the shipping point, delivery point and intermediate stops, ground handling requirements

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[8] Civil Air Regulations and Flight Standards for Pilots, Civil Aeronautics Board, Washington, D. C.

[9] Letter from the Regional Director of Federal Aviation Agency, Oklahoma City, Oklahoma.

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and procedures for the structure being delivered, servicing requirements and flight procedures for the delivery helicopter.

Wind Tunnel Testing

The first step in the development of the final transport plan is to gather the exact numerical values for the flight characteristics of the delivery structure. These values are used to provide information required in the final choice of helicopter and submission to the F. A. A. for sanction of the plan. The values for the aerodynamic properties of a structure are obtained by the use of a wind tunnel. There are two areas that require testing--final aerodynamically stable sling assembly and numerical values for the drag.

Tethered Tests

The first item that must be confirmed is the choice of sling arrangement that will provide the most practical and aerodynamically stable system of the helicopter and structure. This is accomplished in the same manner as in the preliminary study except the conditions are controlled in the wind tunnel. The scale model of the structure with its sling arrangement is tethered in the tunnel and allowed six degrees freedom of movement. The test is run using different airspeeds. Motion and still pictures are taken to provide working source papers and documentation for the test. From this test the final choice of sling arrangement is made. The criteria for the choice are its aerodynamic stability and practical ground handling characteristics. The stability of the unit flying is the most important of the two determining factors, but this factor should not impose ground handling problems to the delivery if it can be avoided.

This test will provide information on the trail angles the structure will assume when being towed at different air speeds by the helicopter. These values provide information that is used in calculating the resultant thrust required to lift and tow the structure. These values also become important if the angle becomes so great that the structure in being towed rises from the vertical to a horizontal position which would hinder the operation of the helicopter. If this were to happen, it would be a limiting factor in the speed the helicopter could maintain.

Force Testing

The numerical values for the aerodynamic characteristics of the structure are collected through the use of the wind tunnel. A scale model of the structure is mounted in the wind tunnel using the delivery attitude dictated by the sling arrangement chosen. This mounting uses a truncated pyramid balance. Mounting the model utilizes a three-point suspension system with two mounting trunnions located in the forward portion of the model and a pitch strut in the aft portion. This six-component balance separates and measures lift, drag, pitch, roll, yaw, and side forces independently. These measurements provide the numerical values and data used in mathematical evaluation of the structure's aerodynamic stability and the specific values of drag and lift of the structure that provide the parameters required for the final choice of delivery helicopter.

Helicopter Choice

With the feasibility of the delivery confirmed and the parameters of the delivery helicopter established by the wind tunnel testing, the next step is to choose a delivery helicopter and select a source from which this vehicle can be obtained for the program.

From the Jane's All the World's Aircraft[10] models of the helicopter capable of making the deliveries were outlined in the preliminary study. After a study of the manufacturers' operational manuals for each of the models, the field of choice should be narrowed to those models which have the most versatile capabilities to make the delivery.

The next step in the choice of the delivery helicopter is to locate operating firms that have helicopter models of the type chosen. This is done by contact with the helicopter manufacturers. The manufacturers will do two things for the project. They will provide

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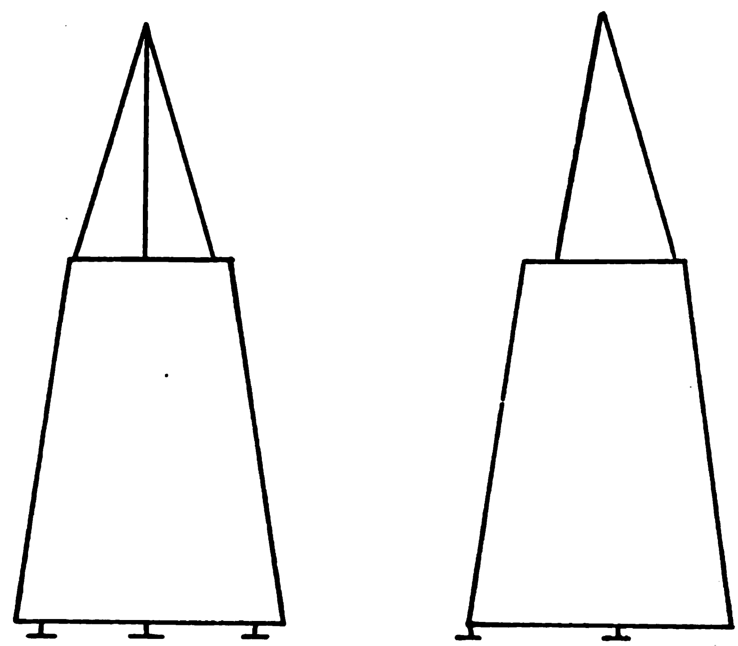
[10] Jane's All the World's Aircraft (op. cit.)

The following figures illustrate the type of information derived from a wind tunnel test program. It should be noted that the presentation of the data in this manner allows for correlation of the information of one figure with that found on any of the other figures.

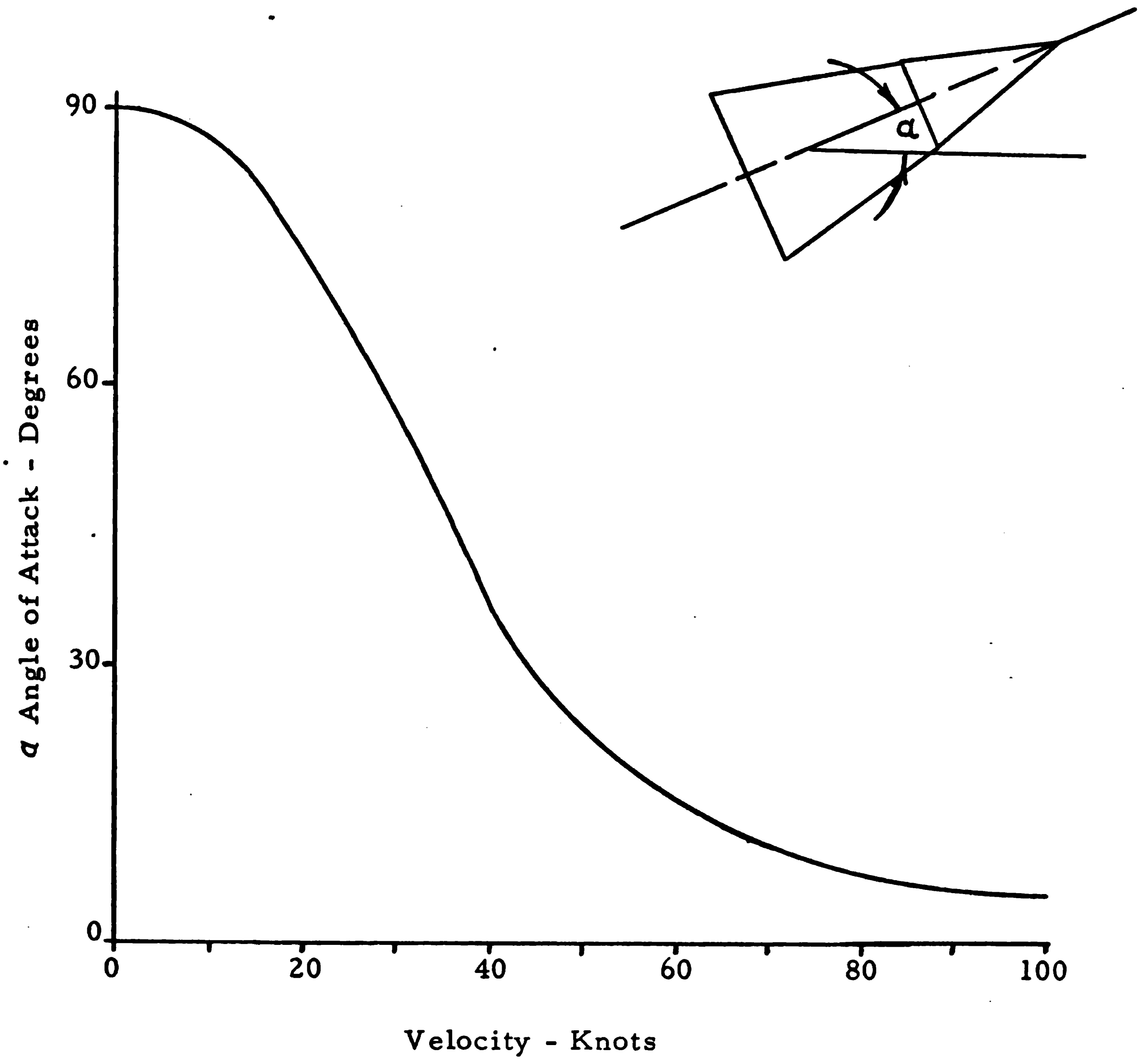


A vertical carry with the small diameter forward was found to be the most stable at air speeds to 120 knots.

The small diameter forward provided the best aerodynamic characteristics of lift and drag.

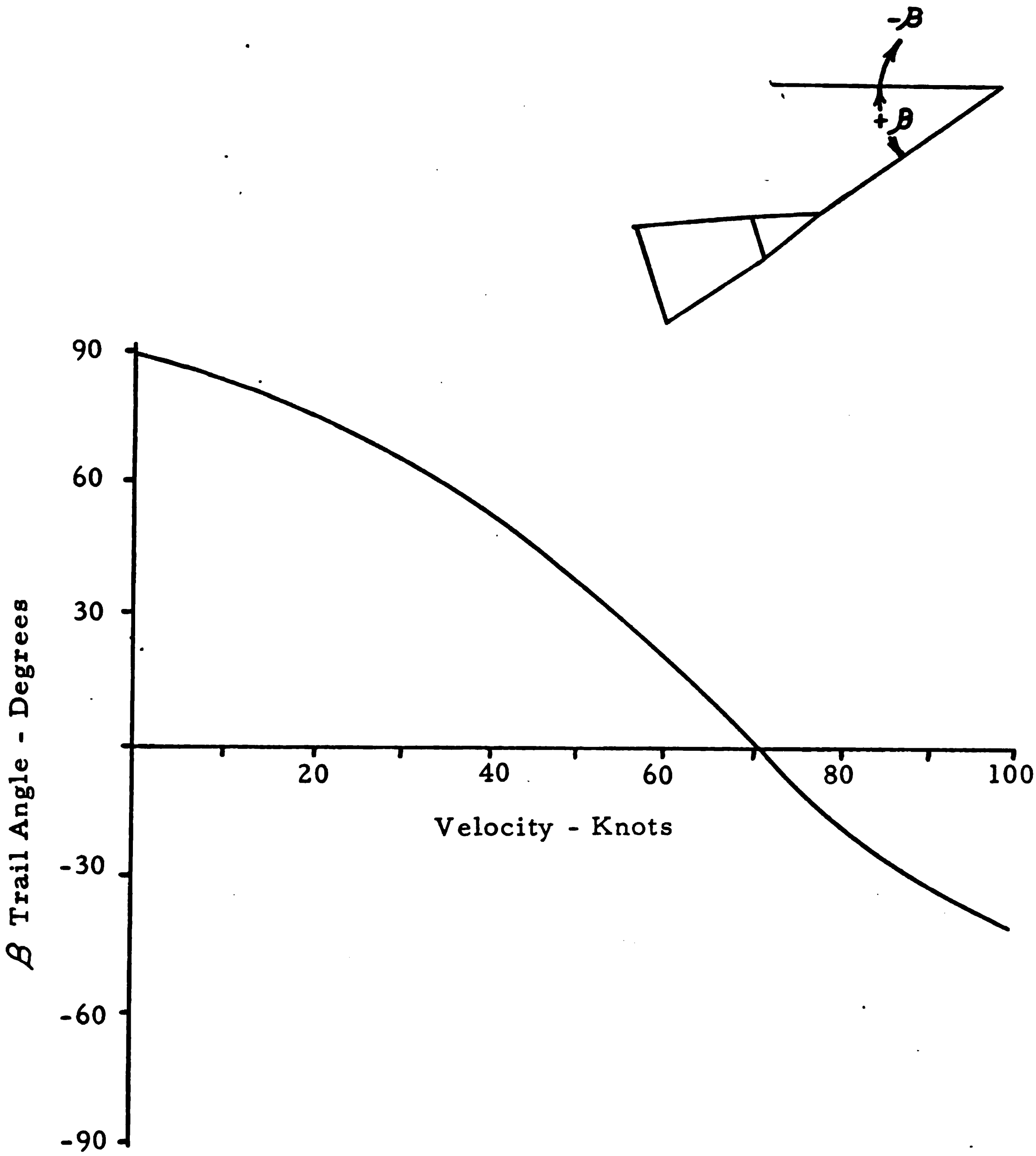
Final Sling Configuration Choice

Figure IV



Angle of Attack Vs. Velocity

Figure V

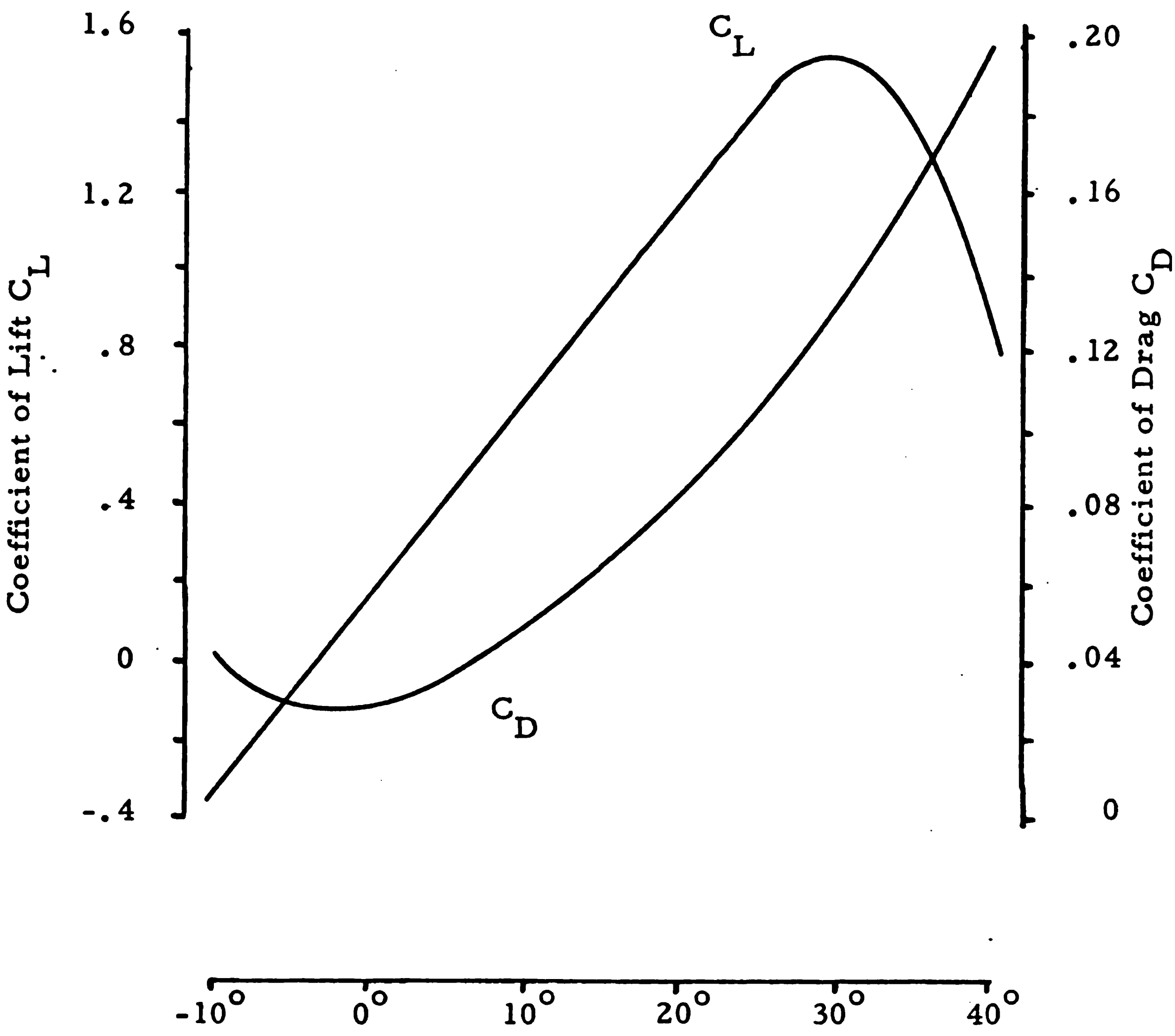


Trail Angle Vs. Velocity

Figure VI

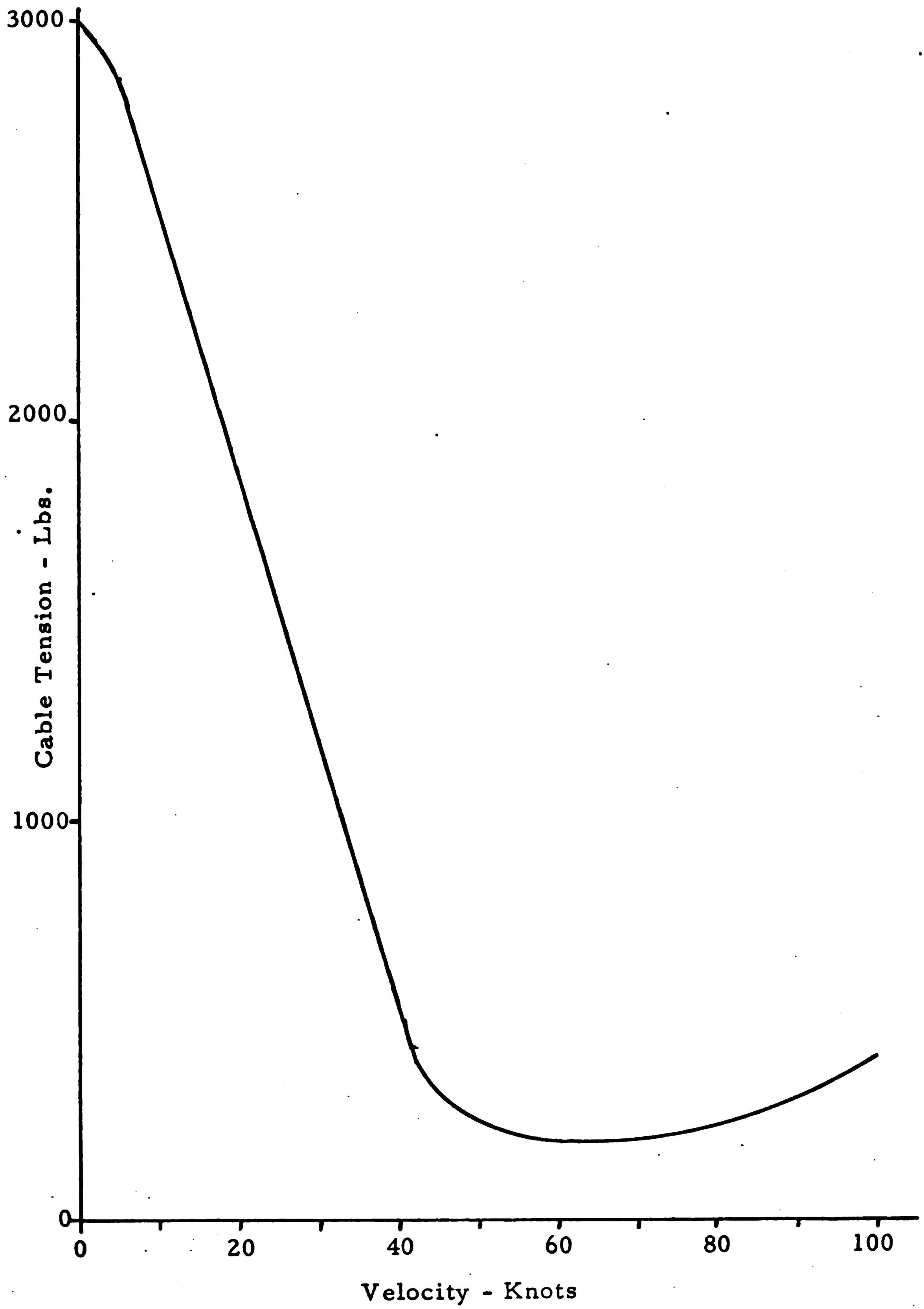
Typical Aerodynamic Information

Obtained From Wind Tunnel



Angle of Attack

Figure VII



Tension Vs. Velocity
Figure VIII

contacts with commercial operators of their helicopter models. If the commercial operators are not available for the particular model of interest, the manufacturers can provide a helicopter for development work and make the deliveries until a commercial operator is available. This service is provided under the manufacturers' development program for the helicopter. The cooperation and assistance that the manufacturers will give in developing the transport plan for delivery of an item by helicopter should not be overlooked. Since they know their vehicles and their capabilities, information about their models not published can be made available through coordination with their engineering departments.

The most practical source for a delivery vehicle is the commercial helicopter operators. There are several operating firms in the United States which can provide the delivery vehicle. These firms are divided into two classes. The first classification involves the transportation of people. These firms are located in the major city airports, are more experienced in the movement of people, and usually have vehicles available that can be scheduled for the project immediately. With additional coordination and possible modification of their vehicles these firms can be developed into a source for the delivery vehicle.

The second classification of commercial operator is the industrial firm. These firms are situated in various locations around

the country. Their operations are centered around industries which use the capabilities of the helicopter such as crop dusting, off-shore platform servicing for the petroleum industry, and the construction industry, etc. These firms are the most experienced and best suited to make a delivery in this fashion. Their practical experience in varied areas of operation would bring to the project detailed information that might be overlooked until after the actual deliveries were made. This advantage could save many dollars and hours to the project.

Another source of helicopters is the military. This source is available only to firms making deliveries to the government. Many problems are posed, however, in the particular planning for the delivery. The advantages are servicing the delivery vehicle, handling of the vehicle over the route, and supplying the operating personnel since the military bases and military personnel can be used in addition to commercial bases in making a delivery.

From one of these sources a helicopter and firm to supply the vehicle are chosen. Once the vehicle model is determined, the development of the transport plan turns to the details based on the specific requirements of the helicopter chosen.

Route Study

Combining the numerical values of the aerodynamic characteristics of the structure with the operating characteristics of the chosen delivery helicopter, the specific value of the range capability during the delivery is ascertained. This value establishes the legs of the delivery route from the point of manufacture to the point of delivery.

With the range value established details of the specific route can be developed. Information about the route that must be gathered for the transportation plan is:

1. Required stops along the route.
2. Emergency fields available along the route.
3. Air distances from point to point.
4. Estimated flight time from point to point.
5. Facilities available at each stop.
    a. fuel
    b. tie-down areas
    c. hangar facilities (repairs, etc.)
    d. power available (electric)
6. Radio frequencies at the regular and emergency stops.
7. Airport elevations.
8. Obstructions surrounding airport.
9. Particular and significant airfield regulations.

Answers to the above requirements can be gathered by one of two methods. The first is quite simple and requires only the investigation of the airport through the Airport Directory[11] and the air navigation sectional maps[12] for the areas in which each of the airports is located. When all the information is gathered by the above method and if time and money permit, it is very helpful to the documentation of the plan to visit each of the chosen stops to verify the gathered information. While at each of the designated stops, it is advisable to take pictures of the field. These pictures would be helpful to the pilot in planning approaches to the field during deliveries. A check list of information useful in the transport plan can be found in Figure IX. These check lists are compiled into the manual and provide information for the pilots in planning the operation of the helicopter during the delivery.

Full-Scale Flight Test

A full-scale flight test of a dummy structure may or may not be a requirement. This requirement is dependent on the firm making the delivery, the value of the structure to be delivered in terms of

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[11] Airport Directory, Aircraft Owners and Pilots Association, Washington, D. C.

[12] These maps are produced by U. S. Department of Commerce Coast and Geodetic Survey and are available from any airfield office.

Figure IX illustrates a useful check list that can be used to gather required information about the airports used as intermedial stops over the delivery route.

Airport ____________________

Address ____________________ Phone __________

Manager ____________________ Phone __________

Alternate ____________________ Phone __________

Alternate ____________________ Phone __________

Fuel ____________________ Type __________

Supplier ____________________

Address ____________________ Phone __________

Contact ____________________ Phone __________

Alternate ____________________ Phone __________

Radio Frequency Available ____________________

*Repair Facilities Available ____________________

*Tie-Down Facilities Available and Surface ____________________

Emergency Facilities and Equipment Available ____________________

*Obstructions Surrounding Airport ____________________

Local Eating Accommodations ____________________

Local Sleeping Accommodations ____________________

Surface Transportation Available ____________________

Remarks:

*Take Pictures

Figure IX

its cost in dollars and program schedule if lost in a mishap, the firm supplying the delivery vehicle, and the test requirements of the F.A.A.

This test involves making a full size dummy structure that will simulate the structure to be delivered and a trial flight with the helicopter.

This test can offer many advantages; first, provide a shake-down run for the transport plan and confirm the values obtained using the wind tunnel, such as:

1. Gross weight lifting capabilities of the helicopter.
2. Trail angles of the structure being delivered.
3. Thrust requirements of the delivery structure.
4. Flying speeds expected during deliveries.
5. Fuel consumption values.
6. Check out of ground handling procedures and equipment.
7. Check out of flight procedures and equipment.

This test as well as the verification of values and check out of procedures can provide a chance for a crew training period in both the helicopter operating procedures and the ground support operations. Last but not least, this test can also provide to the F.A.A. the final proof of the delivery feasibility and safety of crew and aircraft for their sanction of the delivery plan.

This type of testing is expensive. The decision of whether or not to perform this test is based on the opinion of the parties involved. Testing of this type has been run and correlated with values obtained from wind tunnel tests.[13] If this correlation of values can be accepted by the parties involved, the expense of this test can be eliminated.

Transport Plan

With the choice of delivery helicopter made, wind tunnel tests conducted and aerodynamic values compiled, full scale flight test made, route defined, investigated, and information gathered, and ground handling and delivery vehicle operational procedures established, the development study culminates in a transportation plan to be submitted to the F.A.A. for their sanction.

This plan should include:

1. A map showing the specific route and stops including the scheduled stops and emergency fields available.
2. Detailed layouts of approaches to scheduled fields if these approaches require movement over populated areas.

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[13] Noel Eugene Stalnaker, Theoretical Prediction of Full Scale Flight Parameters from Wind Tunnel Data, (unpublished Masters thesis), Department of Mechanical Engineering, University of Tulsa, Tulsa, Oklahoma.

3. Detailed procedure specifications for the operation of the helicopter.

4. Detailed procedure specifications for the ground handling of the structure and proof of compliance with the enroute airfield regulations.

5. Detailed information on each of the airfields included for the scheduled stops and emergency stops available.

6. Proof test records for the towing cables and helicopter-to-structure attaching equipment.

7. A summary presentation of the numerical values for the aerodynamic characteristics of the structure.

The presentation of this plan and subsequent sanction of the transportation method provide the governmental authority to proceed with the delivery of the structure.

CHAPTER III

PACKAGING REQUIREMENTS FOR HELICOPTER DELIVERY

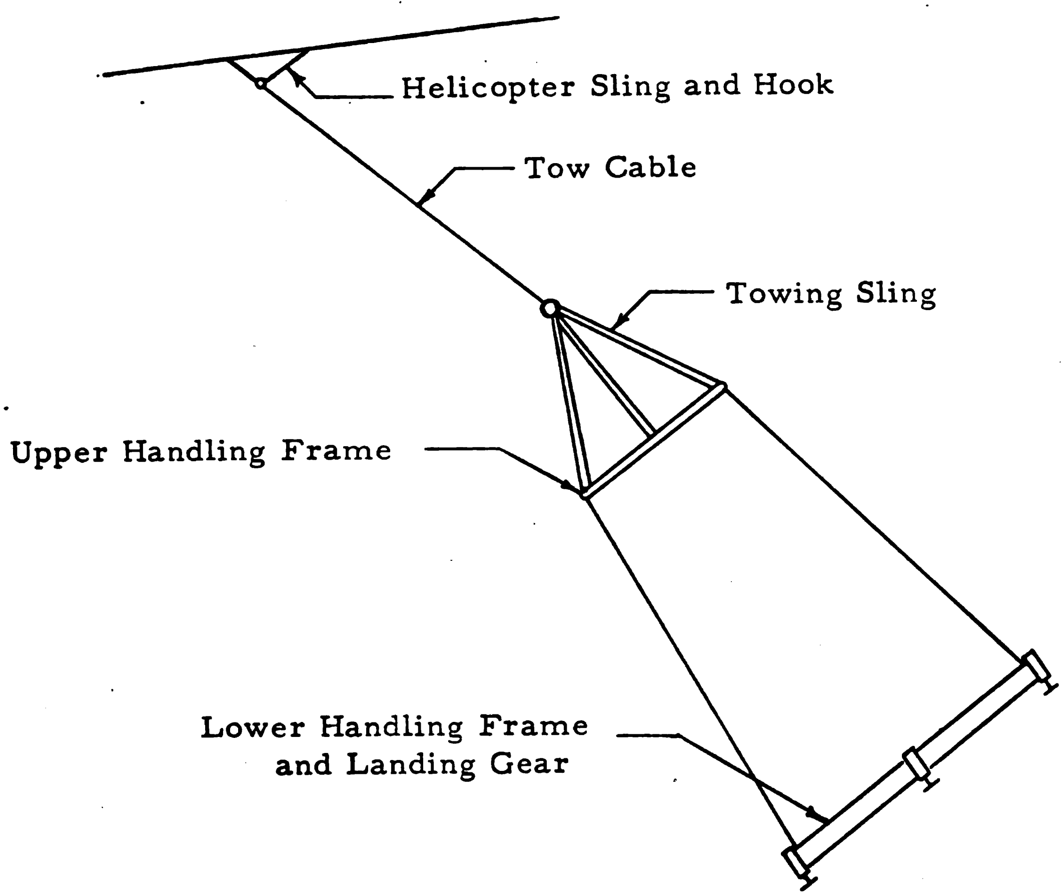
A packaging system provides the devices for the transport of the structure without damage from its point of manufacture to its point of use. This function of the system identifies two areas in which the packaging system must operate for the delivery of a structure by helicopter. The system must provide the physical protection for the structure and the means of harnessing the capabilities of the helicopter as a transport vehicle.

The package system devices required for the delivery must be included in the weight to be carried and will have an effect on the drag of the structure during the delivery. The effect of this equipment must be accounted for in the studies for the development of the helicopter transport. Therefore, package development must be concurrent with the development studies of the delivery system. The weight to be carried and the force required to tow the structure are critical factors in the delivery of a structure by helicopter. Therefore, the values of these factors must be minimized in the design of the helicopter delivery hardware. The minimization of the weight and drag values for the helicopter delivery offers a challenge to the packaging engineer to combine the physical protection for the item with the means of carrying the structure so as not to destroy the feasibility of the delivery.

Helicopter Delivery Hardware

The helicopter delivery hardware is that equipment required to carry the structure by helicopter and return that structure safely to the ground during a delivery flight. A study of a typical helicopter/structure delivery system (Figure X) identifies five pieces of equipment required to harness the capabilities of the helicopter and ensure the safety of the structure during the delivery. These five pieces of equipment are:

1. A sling carrying a hook that spreads the delivery loads into the structure of the carrying helicopter.
2. A towing cable from the sling/hook assembly of the helicopter (item 1) to the carrying sling of the structure (item 3).
3. A towing sling that spreads the delivery load into the handling frame of the structure (item 4).
4. The handling frames of the structure that carry and spread the delivery load into the structure and ensure the structural integrity of the unit during the delivery.



Helicopter Delivery Equipment

Figure X

5. The landing gear that absorbs the forces involved in landing the structure.

The helicopter sling and hook assembly is supplied with the helicopter. This assembly is designed by the helicopter manufacturer and is supplied as an accessory with a delivery vehicle. This assembly is designed to harness the total lifting capacity of the helicopter plus the normal aircraft industry safety factor. This assembly also incorporates a disconnect system that can be actuated from the helicopter to disconnect the load from the lifting vehicle.

This disconnect feature of the helicopter sling and hook may be used in two ways by the delivery system. The quick disconnect system can be utilized into the pick up and release system of the delivery procedure and can provide a quick emergency disconnect of the load should this become necessary to prevent loss of the delivery vehicle or personnel injury.

The wind tunnel test on the scale model structure establishes the value for the thrust loading encountered during a delivery. This value establishes the loading value of the towing cable (item 2). Using this value and the normal safety factor for wire rope design, we can determine the cable size required. The pick up and release procedure will establish the criteria needed in the choice of sling end fittings. This procedure may dictate a special shape or size of fitting designed. If no special fitting is required, standard wire

rope sling hardware is used.

With the thrust value established from the wind tunnel test, a mathematical evaluation of the load-carrying capabilities of the structure will provide the design criteria for the design, development of the structure's towing sling (item 3), and the structural handling frames (item 4).

The design of the structure's towing sling (item 3) is influenced by two other factors besides its loading. The first is the stability of the structure in flight. Wind tunnel testing has shown that the configuration of the structure's towing sling has a great influence on the stability of the flying structure. Wind tunnel testing and aerodynamic studies of the structure will determine the most efficient and stable method of towing. (See Chapter II).

With the unit stability assured through a choice of the structure's towing configuration, the second factor that may influence the sling design is the hook up procedure. Through a comparison and trade off study between the required towing configuration and the most practical hook up procedure, a final compromise sling design can be established.

The design criteria for the structural handling frames (item 4) is determined from the towing loads involved during the delivery, the load distribution dictated by the towing sling, and the load distribution into the structure required by the strength of the

structure. These data, plus the weight and drag consideration, provide the necessary information to design and develop the structure's upper handling frame.

The remaining piece of equipment required for the delivery is the landing gear (item 5) that must provide protection to the structure from the landing shocks. Like the towing sling the landing gear imposes loads into a handling frame which in turn imposes loadings into the structure. The design criteria of the lower handling frame is similar to the design criteria of the upper handling frame. The design criteria is determined from the loads the structure can withstand, the distribution of this load into the structure required by the strength of the structure, and the load distribution dictated by the placing of the landing gear units. These data, plus the required weight and drag considerations, provide the necessary information to design and develop the structure's lower handling frames.

The design or choice of landing gear units is made through a determination of the load absorption requirements necessary in making a landing. This rate is determined by subtracting the load the structure can withstand without damage from the load encountered during a landing operation. The sinking rate during the landing of the helicopter/structure system can be obtained from the operating manual of the delivery helicopter. This sinking rate for a

landing, plus the weight of the structure, gives the information necessary to calculate the load imposed in making a landing. The calculated energy absorption requirement, plus a safety factor, provides the design criteria to develop the landing gear design.

The design of the landing gear requirements and choice of hardware complete the equipment necessary to harness the capabilities of the helicopter and provide for the structural integrity from mechanical damage by forces inherent in a helicopter delivery.

Protective Requirements

The role of the packaging system is to provide physical protection for the structure. This physical protection is divided into two functional areas: the first is to protect the structure against mechanical damage resulting from shock, vibration, or abrasion; the second is to provide protection for the structure against deterioration resulting from the environment through which the structure is delivered or the environment in which the structure is stored.

Inherent mechanical hazards to a structure being delivered by helicopter are:

1. Shock loadings incurred during lift off, landing, and buffeting encountered during gusty wind conditions.
2. Vibration induced into the structure from the vibration inherent in the operation of a propeller driven vehicle.

3. Abrasion encountered from the blowing of sand or small stones from the landing surface onto the structure by the downwash of the helicopter rotor blades. This condition may damage the structure by destroying the painted surface and inflicting dents and scratches to the structure's surfaces.

Shock loadings induced into the structure by a helicopter delivery are eliminated in two ways. First, the use of a careful helicopter operating procedure can all but eliminate the shock loadings encountered during a normal lift off and landing by using the maximum ability of the helicopter to hover, which will allow lifting or lowering of the structure slowly. This procedure will eliminate any great change in the vertical movement of the structure, thus eliminating a shock loading. Loadings induced by wind gusts are decreased by slowing the forward travel of the vehicle. The second method of elimination of shock loadings is to provide shock absorbers in the carrying hardware. In the case of the helicopter delivery these shock absorbers are incorporated into the landing gear for landing shocks. By the use of a wire rope towing cable and helicopter towing sling, which are springs within themselves, we provide a fine shock absorber for lift off. The towing cable and sling also provide protection from shock induced by gusty wind conditions.

The only vibrational loadings encountered by a helicopter delivery are those generated by the helicopter itself. Since the wire rope slings and towing cable are inherently a dampened spring as well as not being rigidly attached to one another thus breaking up the vibrational modes, these pieces of delivery hardware have been found to eliminate any vibrational loading encountered with the helicopter operation.

The elimination of abrasive damage to the structure by blowing sand or small stress can be eliminated by:

1. Cleaning the landing area of this material. An evaluation of the helicopter delivery procedure establishes the fact that the mechanical factors are only present during the landing and lift off phases of the delivery. Since the area required to land the structure and ground effects of the helicopter downwash are small, this is a most attractive, efficient and economical method of protection for the structure from the mechanical factors of the delivery environment.
2. Covering the unit with a resilient material that will protect the structure's surface by absorbing the energy of the impact encountered from the blowing sand and small stones. During our studies of a structure delivery at North American Aviation, Tulsa Division, we found

that a 5 mil coating of a strippable polyvinyl chloride plastic coating would protect the surface finishes of the unit.

The remaining physical protection to be provided by the packaging system is deterioration of the structure resulting from the environment in which the structure is to be delivered and stored. This deterioration of the structure by the environment comes from the corrosion of precipitation, salt air, humidity, and general cleanliness of the structure which is undesirable and may support the growth of microorganisms.

The development of protection for the environmental factors for helicopter delivery is dependent to some degree on the ability of the structure to sustain itself for a delivery and storage time. The packaging system is developed to provide that protection required beyond what the item can sustain.

The protection for the structure from environmental factors requires covering the structure. In the design of a protective system for a flying structure three factors are involved: the type of required protective devices, weight of these protective devices, and the ability of these devices to sustain the aerodynamic loads of a helicopter delivery.

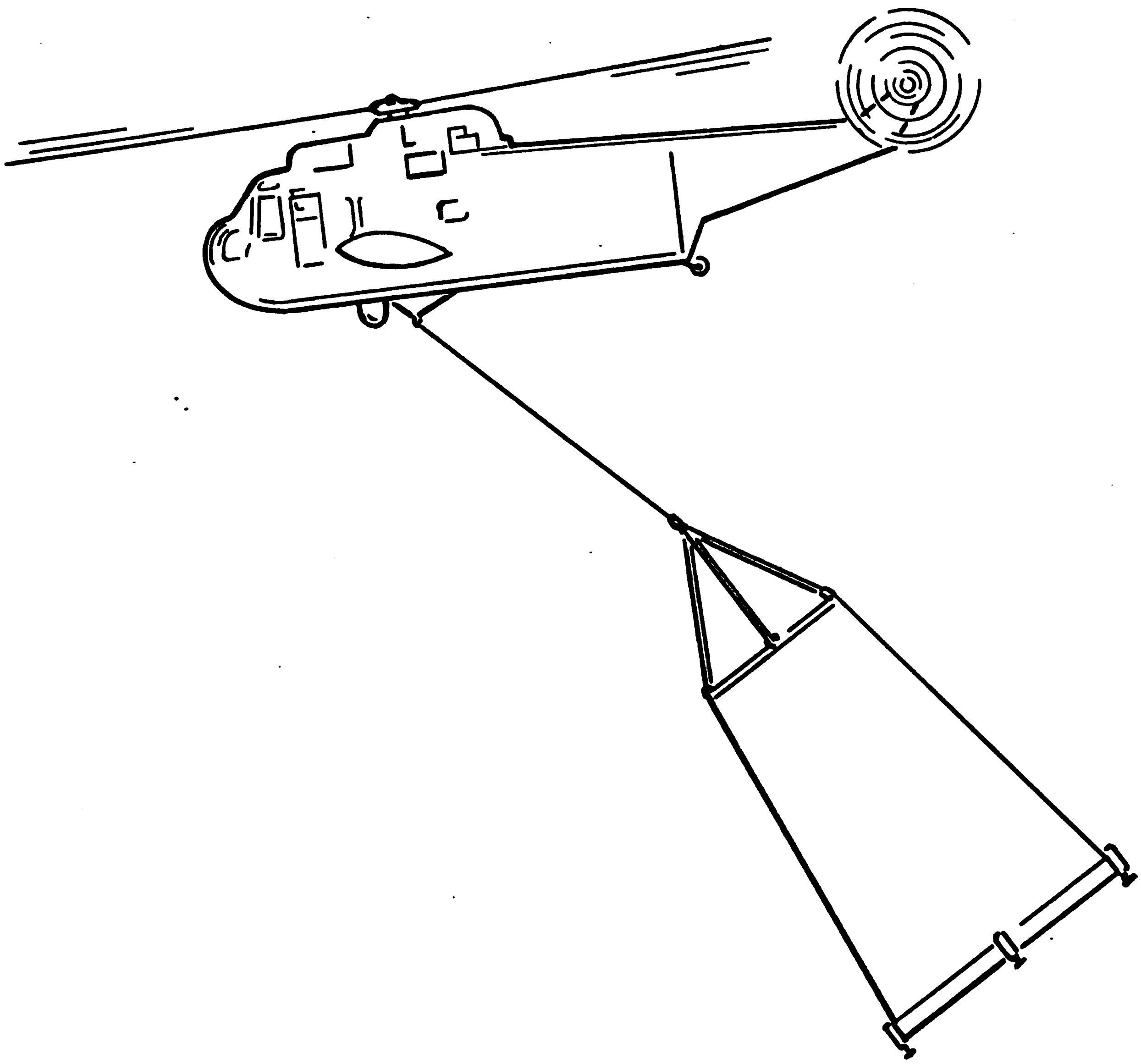
Through our testing of protective devices at North American the best method of protection for the environmental factors is the use of a strippable/sprayable plastic coating that can be applied to all the exposed surfaces of the structure. Wind tunnel testing and use has proven that this material can withstand the aerodynamic loading involved in a delivery and provide the environmental protection needed.

This material is a polyvinyl chloride compound that can be applied to a surface with conventional paint spraying equipment. The removal of this material is a hand operation. The material is stripped from the surface leaving the surface clean and undamaged.

This material comes in two types. The first is a solvent-based vehicle. The second material has a water-based vehicle for application to surfaces that could be damaged by a solvent-based vehicle.

This material when applied to all the exposed surfaces provides a continuous film that will protect the structural surfaces from precipitation, salt air, and humidity and provides a barrier to the introduction of dirt to the surface of the structure.

The utilization of the helicopter delivery equipment provides the means of harnessing the capabilities of the helicopter and protecting the structural integrity from mechanical damage of the helicopter delivery. This, along with the procedure and the devices for the protection of the structure from the delivery and storage environment, completes the requirements of a packaging system for the delivery of a structure by slinging the item under the delivery helicopter. Figure XI illustrates a typical delivery configuration showing the relative position of the delivery equipment structure in relation to the delivery helicopter.



Helicopter Delivery Configuration
Figure XI

CONCLUSIONS AND RECOMMENDATIONS

The procedure presented in this work will provide the basis for the development of the transportation of a structure by slinging that structure below a delivery helicopter. The procedure presented is a generalization of the procedure used to develop the transport procedure for a particular structure. This procedure when used should be utilized as a guide with the particular characteristics of the specific structure involved being the controlling aspect in the approach to the development for a delivery of the structure in this fashion.

When approaching a delivery of this type, the first contact that should be made is the Federal Aviation Agency. Since an F.A.A. sanction is required for the delivery procedure, coordination with this agency is most important. Their suggestions for testing and development procedures in the early stages of the project can save time in acquiring their sanction of the delivery method.

As the requirements for the delivery in one piece of large structures and items increase, the possibility of delivery by slinging the unit below a flying vehicle becomes an attractive method. With the lifting and range capabilities of helicopters increasing with each new helicopter model, this vehicle holds the most promise as a delivery vehicle for this type of delivery. This method of transport could develop into a general delivery method for large and bulky structural units and items that would be difficult to transport by other means.

An increase in the use of this method of delivery would provide a background of data and experience from which a delivery procedure could be developed without the extensive testing required in the procedure presented in this work. This battery of data and experience would enable the F.A.A. to sanction the delivery procedure presented for a new structure or item with a greater degree of confidence.

Along with the convenience and practicality of a delivery of a structure by helicopter there is the matter of economics. A study of the possible means of moving a bulky structural element shows that the only other practical transportation method is a highway/barge combination.

In a cost comparison study conducted at North American Aviation of a delivery by helicopter versus a highway/barge delivery, the cost of the highway/barge delivery was 8.5 times greater than the helicopter delivery. This ratio, of course, is proportional to the distance the highway must be modified and the extent that the route must be modified to the barge port.

The cost comparison plus the difference in delivery time involved with a water route delivery makes the helicopter delivery method the most attractive and economical of the methods available to deliver a large bulky structure.

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