AD743516

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author)	2a. REPORT SECURITY CLASSIFICATION
Piasecki Aircraft Corporation Island Rd., Int'l Airport Philadelphia, Pa. 19153	Unclassified 2b. GROUP N/A

3. REPORT TITLE

MULTI-HELICOPTER HEAVY LIFT SYSTEM FEASIBILITY STUDY

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Engineering Report

5. AUTHOR(S) (First name, middle initial, last name)

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6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
February 1972	159	16

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
N62269-71-C-0581	39-X-11
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	None

10. DISTRIBUTION STATEMENT

Distribution of this document is unlimited

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
None	Naval Air Systems Command Department of the Navy Washington, D. C.

13. ABSTRACT

A study was undertaken of the feasibility of rigidly combining two CH-53D helicopters to augment their maximum payload-range capabilities. This Multi-Helicopter Heavy Lift System (MHHLS), formed by modifying existing CH-53D's to allow their interconnection using a specially designed kit, results in a vehicle with increased performance. Thus, missions requiring payloads in excess of one helicopter's basic capability may be satisfied in the multi-lift mode. The helicopters can then be returned to their normal modes of operation. After investigating various arrangements of the combined aircraft, the tandem nose-to-tail configuration was selected for further studies. A detailed study of this configuration was made to assess its feasibility and identify potential problem areas. Features discussed are weight, performance, structure, flying qualities, reliability, cost of conversion and operational aspects, particularly aboard ship. A feasible heavy-lift vehicle is postulated with a predicted payload capability up to 18.7 tons which is recommended to be carried forward to flight evaluation.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Multi-Helicopter Heavy Lift System (MHHLS)						
Heavy-lift helicopters						
CH-53D helicopters						
Flying Crane						

PIASECKI AIRCRAFT CORPORATION
PHILADELPHIA, PA.

REPORT 39-X-11

MULTI-HELICOPTER HEAVY LIFT SYSTEM
FEASIBILITY STUDY

FINAL REPORT

FEBRUARY 1972

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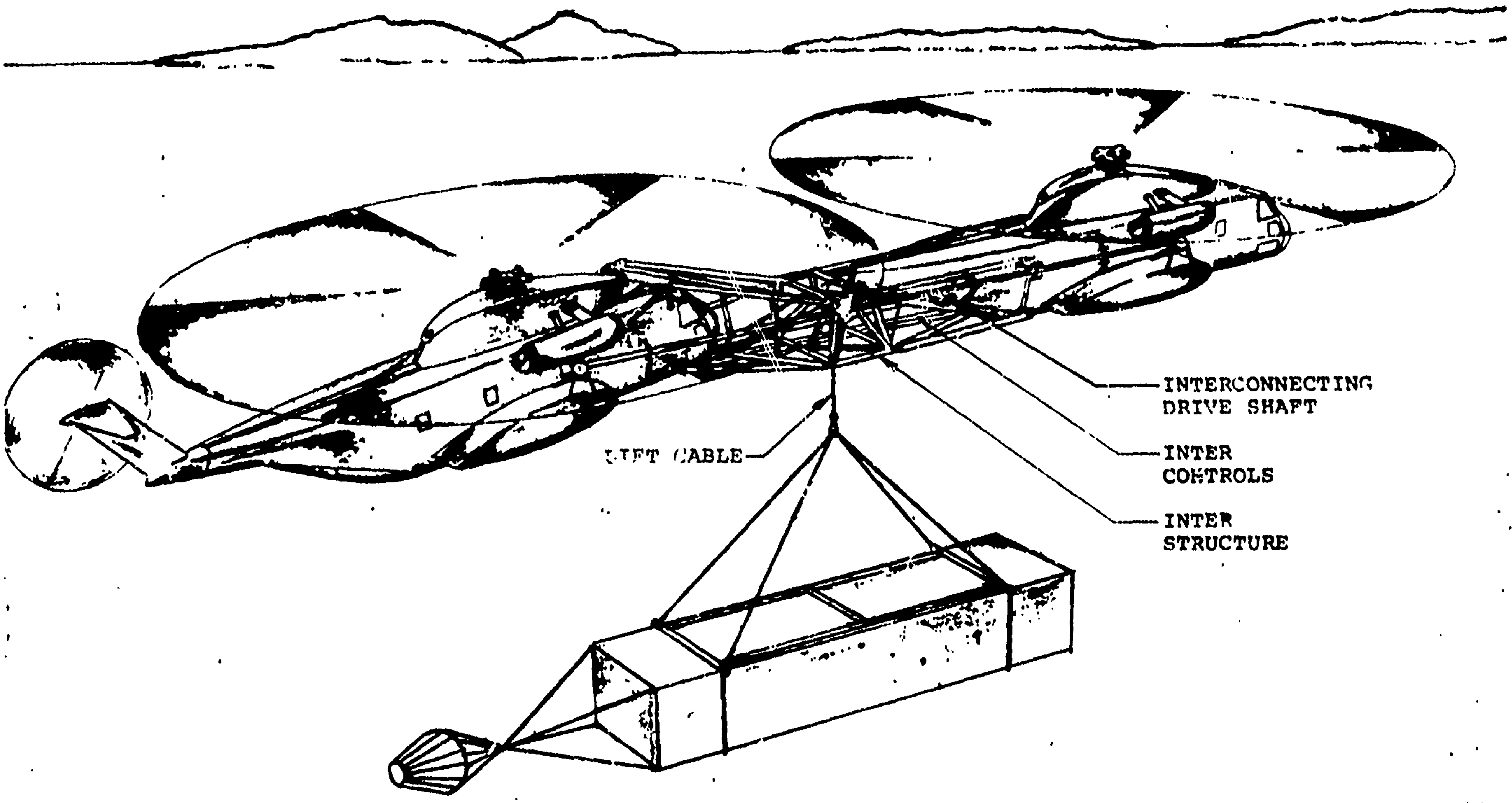
SPONSORED BY
NAVAL AIR SYSTEMS COMMAND

SUBMITTED TO
NAVAL AIR DEVELOPMENT CENTER

PREPARED UNDER
CONTRACT N62269-71-C-0581



MULTI-HELI HEAVY LIFT SYSTEM (MHHLS)
TWO CH-53D UNITS IN TANDEM

SUMMARY

This report documents a study undertaken to evaluate the feasibility of rigidly combining two CH-53D helicopters in order to augment their maximum payload-range capabilities. This Multi-Helicopter Heavy Lift System (MHHLS) is formed by modifying existi g CH-53D helicopters to provide the structural and dynamic integrity necessary to allow their interconnection using a specially designed kit. Using this kit, appropriate helicopter sub-systems - powerplants, flight controls, structure and instrumentation - may be combined to form an acceptable vehicle with increased performance capability. Thus, occasional missions requiring a lift capability in excess of the helicopter's basic performance capabilities may be satisfied in the multi-lift mode. After completion of these missions, the helicopters may be returned to their normal modes of operation.

Initially, various geometric arrangements of the combined aircraft were investigated. These arrangements were evaluated using the criteria of performance, reliability, handling qualities, ease of assembly, ship compatibility and cost, and the tandem nose-to-tail configuration was selected for further studies. This configuration is formed by positioning the nose of a modified CH-53D behind the tail of a second modified CH-53D, removing the tail of the forward CH-53D and using the kit to connect them. This configuration was selected for its low weight and higher control power.

A detailed study of the tandem nose-to-tail configuration was made to assess its feasibility and identify potential problem areas. The structural arrangement was designed from both a static and dynamic standpoint. Power transmission system and controls were analyzed, and the necessary design layouts were carried to a point of feasibility determination. A structural analysis was performed examining the applied loads for three critical flight conditions and a vibration analysis made to determine stiffness characteristics. The results of these analyses were used to estimate structural reinforcing required and its associated weight penalties. For the postulated configuration, flying qualities encompassing trim, control power and stability were calculated and evaluated. Weight analysis and performance for this MHHLS system are presented in charts of payload vs. radius of action. Assembly and disassembly procedures as applicable to fleet operations are reviewed and analyzed for compatibility of the MHHLS to an operational environment.

As a result of the above design and analysis, a feasible HLH configuration of two CH-53D helicopters, interconnected nose-to-tail in tandem has been postulated. This vehicle is predicted to have a payload capability of up to 18.7 tons.

Applications of the MHHLS to various Naval missions are discussed.

Recommendations are presented to carry this vehicle forward to flight evaluation.

FORWARD

The study reported herein on the feasibility of a Multi-Helicopter Heavy Lift System using two CH-53D helicopters was sponsored by Naval Air System Command under contract N62269-71-C-0581 with Naval Air Development Center, Warminster, Pennsylvania 18974.

The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Naval Air Systems Command or the Department of the Navy.

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LIST OF SYMBOLS

SYMBOL	NAME	UNITS
g	Acceleration of Gravity	ft/sec^2
i	Imaginary Unit $\sqrt{-1}$	-
EI_Y	Bending Stiffness About Y Axis	lb. $in.^2$
EI_Z	Bending Stiffness About Z Axis	lb. $in.^2$
GJ_X	Torsional Stiffness About X Axis	lb. $in.^2$
I_{XX}, I_{YY}, I_{ZZ}	Mass Moment of Inertia About X, Y, and Z Axes	slug $ft.^2$
L	Rolling Moment	lb.-ft.
L_p, $L_{\dot{\phi}}$	Derivative of Rolling Moment with Rolling Velocity	lb. ft./rad/sec.
L_r, $L_{\dot{\psi}}$	Derivative of Rolling Moment with Yawing Velocity	lb. ft./rad/sec.
L_v	Derivative of Rolling Moment with Side Slip Velocity	lb. ft./ft./sec.
L_{δ_P}	Derivative of Rolling Moment with Rudder Pedal	lb. ft./inch
L_{δ_S}	Derivative of Rolling Moment with Lateral Stick	lb. ft./inch
m	Mass	slugs
M	Pitching Moment	lb. ft.
M_q	Derivative of Pitching Moment with Pitching Velocity	lb. ft./rad/sec.
M_u	Derivative of Pitching Moment with Forward Velocity	lb. ft./ft./sec.
M_w	Derivative of Pitching Moment with Vertical Velocity	lb. ft./ft./sec.
M_α	Derivative of Pitching Moment with Angle of Attack	lb. ft./rad.

SYMBOL	NAME	UNITS
M_{δ_B}	Derivative of Pitching Moment with Longitudinal Stick	lb. ft./inch
N	Yawing Velocity	rad./sec.
N_p, $N_{\dot\phi}$	Derivative of Yawing Moment with Rolling Velocity	lb. ft./rad./sec.
N_r, $N_{\dot\psi}$	Derivative of Yawing Moment with Yawing Velocity	lb. ft./rad./sec
N_v	Derivative of Yawing Moment with Side Slip Velocity	lb. ft./ft./sec.
N_X, N_Y, N_Z	Load Factor in X, Y, Z Directions	-
N_{δ_R}	Derivative of Yawing Moment with Rudder Pedal	lb. ft./inch
N_{δ_S}	Derivative of Yawing Moment with Lateral Stick	lb. ft./inch
p	Rolling Velocity	rad./sec.
q	Pitching Velocity	rad./sec.
r	Yawing Velocity	rad./sec.
s	Laplace Variable	-
u	Forward Velocity	ft./sec.
v	Sideward (Sideslip) Velocity	ft./sec.
V	Flight Path Velocity	ft./sec.
w	Vertical Velocity	ft./sec.
X	Force in X-Direction (Aft)	lb.
X_q	Derivative of X-Force with Pitching Velocity	lb./rad./sec.
X_u	Derivative of X-Force with Forward Velocity	lb./ft./sec.
X_w	Derivative of X-Force with Vertical Velocity	lb./ft./sec.
X_α	Derivative of X-Force with Angle of Attack	lb./rad.

SYMBOL	NAME	UNITS
X_{δ_B}	Derivation of X-Force with Longitudinal Stick	lb./inch
Y	Force in Y-Direction (Lateral)	lb.
Y_p, $Y_{\dot{\phi}}$	Derivative of Y-Force with Rolling Velocity	lb./rad./sec.
Y_r, $Y_{\dot{\psi}}$	Derivative of Y-Force with Yawing Velocity	lb./rad./sec.
Y_v	Derivative of Y-Force with Sideslip Velocity	lb./ft./sec.
Y_{δ_R}	Derivative of Y-Force with Rudder Pedal	lb./inch
Y_{δ_S}	Derivative of Y-Force with Lateral Stick	lb./inch
Z	Force in Z-Direction (Vertical)	lb.
Z_q	Derivative of Z-Force with Pitching Velocity	lb./rad./sec.
Z_w	Derivative of Z-Force with Vertical Velocity	lb./ft./sec.
Z_u	Derivative of Z-Force with Forward Velocity	lb./ft./sec.
Z_α	Derivative of Z-Force with Angle of Attack	lb./rad.
Z_{δ_B}	Derivative of Z-Force with Longitudinal Stick	lb./inch
α	Fuselage Angle of Attack	radians
β	Side Slip Angle	radians
δ_B	Longitudinal Stick Deflection	inches
δ_R	Rudder Pedal Deflection	inches
δ_S	Lateral Stick Deflection	inches
ζ	Critical Damping Ratio	-
ϕ	Roll Angle	radians

SYMBOL	NAME	UNITS
ψ	Yaw Angle	radians
ω_d	Damped Natural Frequency	rad./sec.
ω_n	Undamped Natural Frequency	rad./sec.
ω_{n_d}	Undamped Dutch-Roll Natural Frequency	rad./sec.
$(\dot{\ })$	Time Derivative	
$(\ddot{\ })$	Second Time Derivative	

1. INTRODUCTION

Quantum jumps in helicopter lift capability are usually attained through the development of a new vehicle involving the design and testing of a new rotor system, a new transmission, a new fuselage and new engine. Development and acquisition costs increase rapidly because of the greater size and complexity of the resulting vehicles. Although new markets or uses become available with such increase in capability, these new uses or markets may not be sufficient to amortize the costs of these large helicopters. Similarly, the inventory of military equipment in a given weight class decreases as the weight increases. So each improvement in helicopter lift capability will be utilized to a smaller extent. Although a requirement exists for a particular level of capability, the utilization of this capability decreases.

This dilemma has been recognized and several design solutions as an alternative to a new helicopter have been identified. Each approach makes different compromises between development effort, versatility and simplicity of operation.

Recent Russian efforts combined two of their larger helicopter rotors, including their transmissions and turbines, into a new helicopter airframe for internal cargo, the V-12 (Mi-12), capable of lifting 34.2 tons. Although the V-12 uses dynamic components from the Mi-6 and Mi-10 series, it is essentially a new helicopter. The fuselage was designed to carry the same payload items as the AN-22 fixed-wing airplane, and uses the same cargo structure and tie-down fittings. Since the side-by-side rotors are counter-rotating, an "existing" rotor with its controls and gear box had to be redesigned and tooled from right-hand to left-hand. Moreover, the V-12 is dedicated to the heavy-lift role, and would be uneconomical to be used for other functions not requiring heavy lift.

In the U. S., heavy-lift flights have been made using a "loose" connection between separate helicopters, which share their lift capability to support a payload too heavy for one helicopter alone. Although this approach involves little or no modifications to existing helicopters, there are several drawbacks. Precision formation pilotage is required, and presently flight is restricted to a maximum of about 20 knots, and to daytime VFR conditions. To prevent collision of rotors of two separately controlled helicopters calls for a generous separation of the aircraft, thus monopolizing a large amount of air space. Most important of all, unless each helicopter individually has engine-out hover capability, the failure of any engine in any helicopter will prevent mission completion and can result in destruction of valuable cargo.

The approach analyzed in this report represents a compromise between the extremes of an essentially new helicopter on the one hand, and on the other hand, use of existing helicopters with no modifications. This is the Multi-Helicopter Heavy Lift System (MHHLS). Two or more helicopters, suitably modified, are rigidly connected together, including their drive and control systems, so that they can be flown by one pilot, and become, in fact, one helicopter. The modifications, however, do not preclude the use of the helicopters in their original individual roles when heavy-lift capability is not required. The concept is applicable to retrofitting of existing helicopters or may be applied to new designs.

This study addressed the application of this multi-lift concept to a previously designed helicopter - the CH-53D. The first phase of the study investigated several possible methods of interconnection of two helicopters from which the most promising configuration was selected. The selected system was then studied in greater depth, and analyzed for feasibility in terms of structure, drive system, controls, weight, performance and flying qualities.

2. INITIAL STUDIES OF POTENTIAL CONFIGURATIONS

The MHHLS concept as presently postulated combines two CH-53D helicopters by connecting the fuselages together with an interconnecting truss, mechanically interconnecting the flight control systems, cross-shafting the power plants and providing appropriate instrumentation. In this manner suitably modified CH-53D's may be combined so that they may be operated by a single pilot, function as a single vehicle and transport payloads beyond the capability of a single CH-53D. Modifications may be accomplished in such a way as to allow field assembly and disassembly of the CH-53D helicopters in order to operate in their normal mode and the multi-lift mode. Cross-shafting has the important advantages of permitting each engine to supply power to both main rotors, so that in the event of an engine failure, all of the remaining power is fully available; and during autorotation, rotational energy may be transferred between rotors.

2.1 DESCRIPTION OF CONFIGURATIONS

Initially, three distinct configurations of pairs of CH-53D's - tail-to-tail, nose-to-tail, side-by-side - were examined and are described in the following paragraphs.

2.1.1 Tail-To-Tail, As Shown in Fig. 2-1

The tail rotors and tail rotor pylons of both helicopters are removed at the pylon fold joint. The rear helicopter is turned to face rearwards, and the two aft cabin sections are connected by a truss structure in the area of the rear ramp door frame. The cabin structure in this area would probably have to be reinforced to take the higher applied shears, and bending and torsional moments.

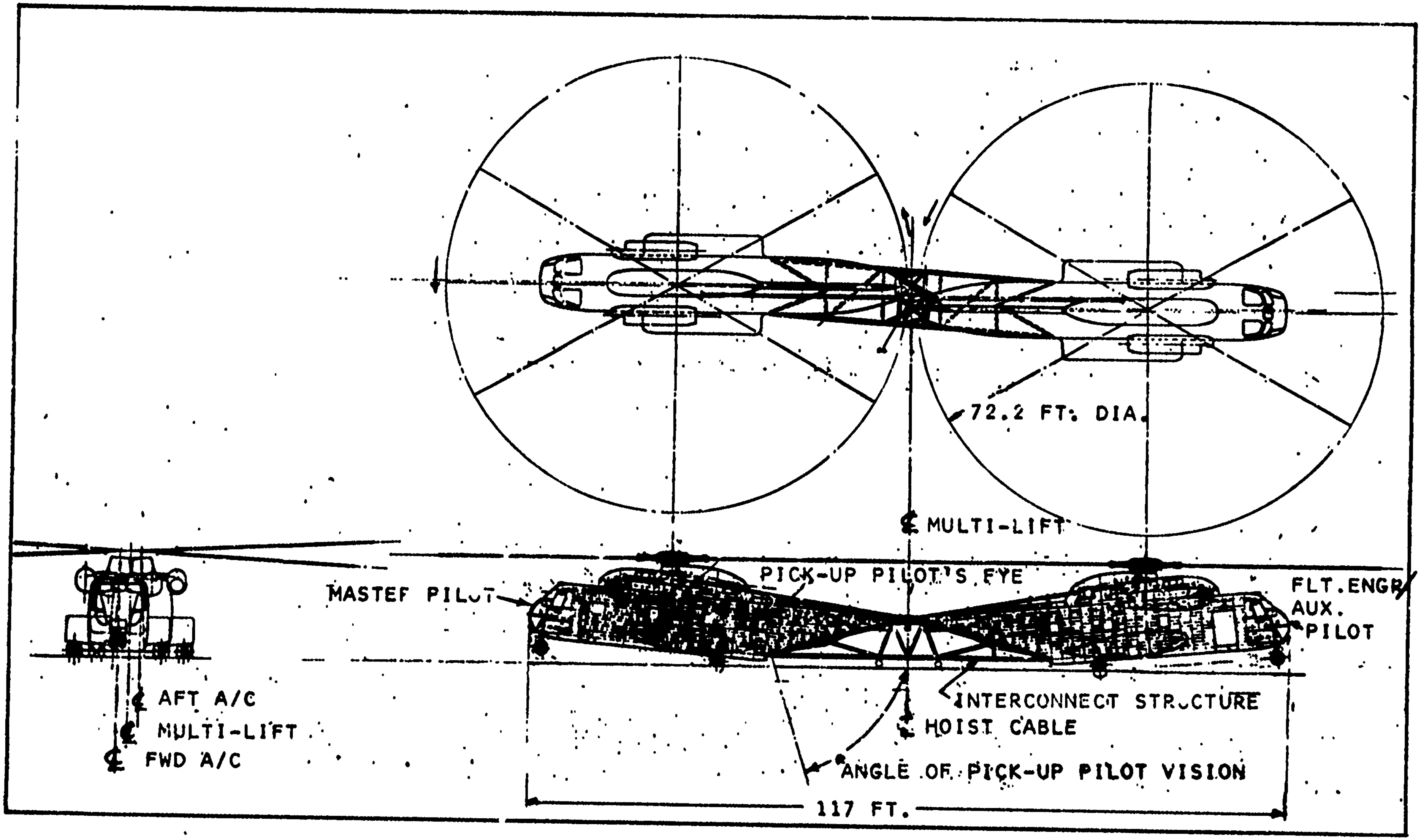
TABLE 2-1
CONTROL INTERCONNECTIONS FOR MULTIPLE HELICOPTER LIFT SYSTEM

(2 CH-53D HELICOPTERS, TAIL-TO-TAIL)

MANEUVER	INCREASE TOTAL LIFT	PITCH NOSE DOWN	ROLL LEFT	YAW NOSE LEFT
FORWARD HELICOPTER	INCREASE COLLECTIVE PITCH	DECREASE COLLECTIVE PITCH AND FWD LONG. CYCLIC	LEFT LATERAL CYCLIC	LEFT LATERAL CYCLIC
AFT HELICOPTER	INCREASE COLLECTIVE PITCH	INCREASE COLLECTIVE PITCH AND FWD LONG. CYCLIC	LEFT LATERAL CYCLIC	RIGHT LATERAL CYCLIC

TO MAKE MANEUVERS IN THE REVERSE DIRECTION, EACH CONTROL MOTION IN THE CHART IS REVERSED.

FIGURE 2-1. MHHLS DESIGN STUDY: TAIL-TO-TAIL CONFIGURATION, (2) CH-53D'S



The chart, Table 2-1, shows the method of achieving control about all axes for the tail-to-tail configuration. Since the tail rotors are necessarily removed, yaw control must be by means of differential lateral cyclic pitch (left on one rotor, right on the other). Because of the large moment of inertia in pitch, control in this axis is achieved primarily by longitudinal differential collective pitch.

2.1.2 Nose-To-Tail, As Shown in Fig. 2-2

The tail rotor and tail rotor pylon of the forward helicopter are removed in the same manner as in the tail-to-tail configuration. The rear helicopter, however, faces in the normal forward direction, and a truss structure connects the nose of the rear helicopter to the aft cabin of the forward one. Again, the areas of connection to the truss must be reinforced because of the higher imposed shears, and bending and torsional moments.

The method of control about each axis is the same as for the tail-to-tail configuration, except that it now becomes possible to use the tail rotor of the aft helicopter for added yaw control, to augment the differential lateral cyclic pitch of the main rotors. The chart, Table 2-2, shows the method of control about all axes for the nose-to-tail configuration.

TABLE 2-2
CONTROL INTERCONNECTIONS FOR MULTIPLE HELICOPTER LIFT SYSTEM

(2 CH-53D HELICOPTERS, NOSE-TO-TAIL)

MANEUVER	INCREASE TOTAL LIFT	PITCH NOSE DOWN	ROLL LEFT	YAW NOSE LEFT
FORWARD HELICOPTER	INCREASE COLLECTIVE PITCH	DECREASE COLLECTIVE PITCH AND FWD. LONG. CYCLIC	LEFT LATERAL CYCLIC	LEFT LATERAL CYCLIC
AFT HELICOPTER	INCREASE COLLECTIVE PITCH	INCREASE COLLECTIVE PITCH AND FWD. LONG. CYCLIC	LEFT LATERAL CYCLIC	RIGHT LATERAL CYCLIC AND INCREASE PITCH OF TAIL ROTOR

TO MAKE MANEUVERS IN THE REVERSE DIRECTION, EACH CONTROL MOTION IN THE CHART IS REVERSED.

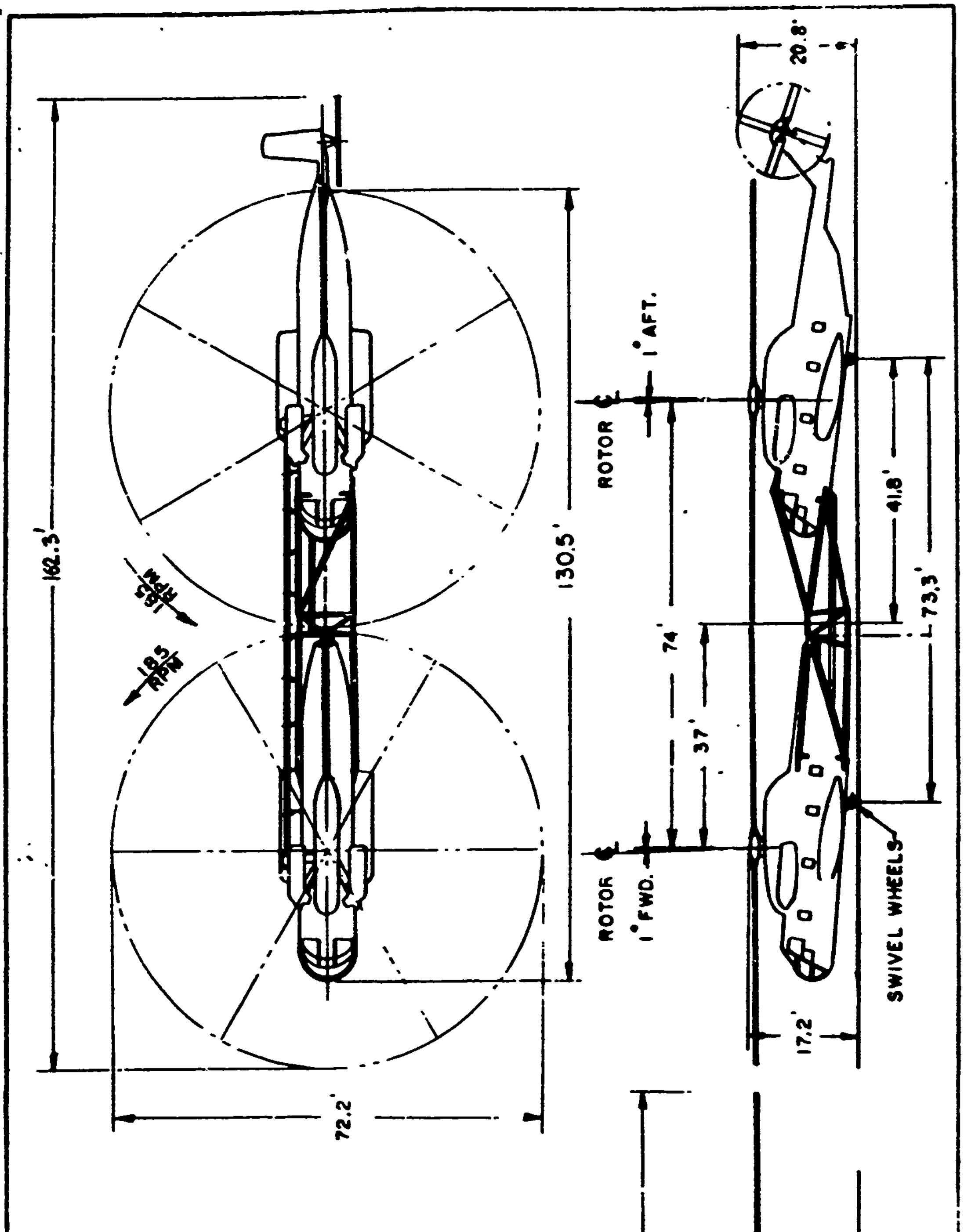


FIGURE 2-2

MHHLS DESIGN STUDY: NOSE-TO-TAIL CONFIGURATION, (2) CH-53D'S

The synchronizing rotor-drive system is connected at the right hand input bevel gear of each main rotor gear box. The plug which mounts the input bevel pinion and free-wheel clutch, and which is bolted to the gear box proper, is modified so that the free-wheel unit is moved forward sufficiently to permit the insertion of an auxiliary bevel pinion on the same shaft, fixed to the input bevel pinion. This auxiliary bevel pinion meshes with another additional gear in the modified plug, which directs the synchronizing torque down and to the right, below and outboard of the engine nacelle. Here, on each helicopter, is located another gear box with shafting interconnecting them along the right side of the structure.

2.1.3 Side-By-Side, as Shown in Fig. 2-3

The fuselages are connected by a transverse truss structure fastened to one side of each main cabin at the location of the main rotor. Suitable reinforcements of this area of the cabin would have to provide for the large torsional moments imparted by the transverse structure.

Because of the greatly increased moment of inertia in roll, roll control would be achieved primarily by lateral differential collective pitch (up on one side, down on the other). Yaw control could be achieved by differential longitudinal cyclic pitch (forward on one side, aft on the other), thus permitting the two tail rotors to be dispensed with. Alternatively, the tail rotors could remain to increase yaw control power. The chart, Table 2-3 shows the method of achieving control about all axes for the side-by-side configuration.

TABLE 2-3
CONTROL INTERCONNECTIONS FOR MULTIPLE HELICOPTER LIFT SYSTEM

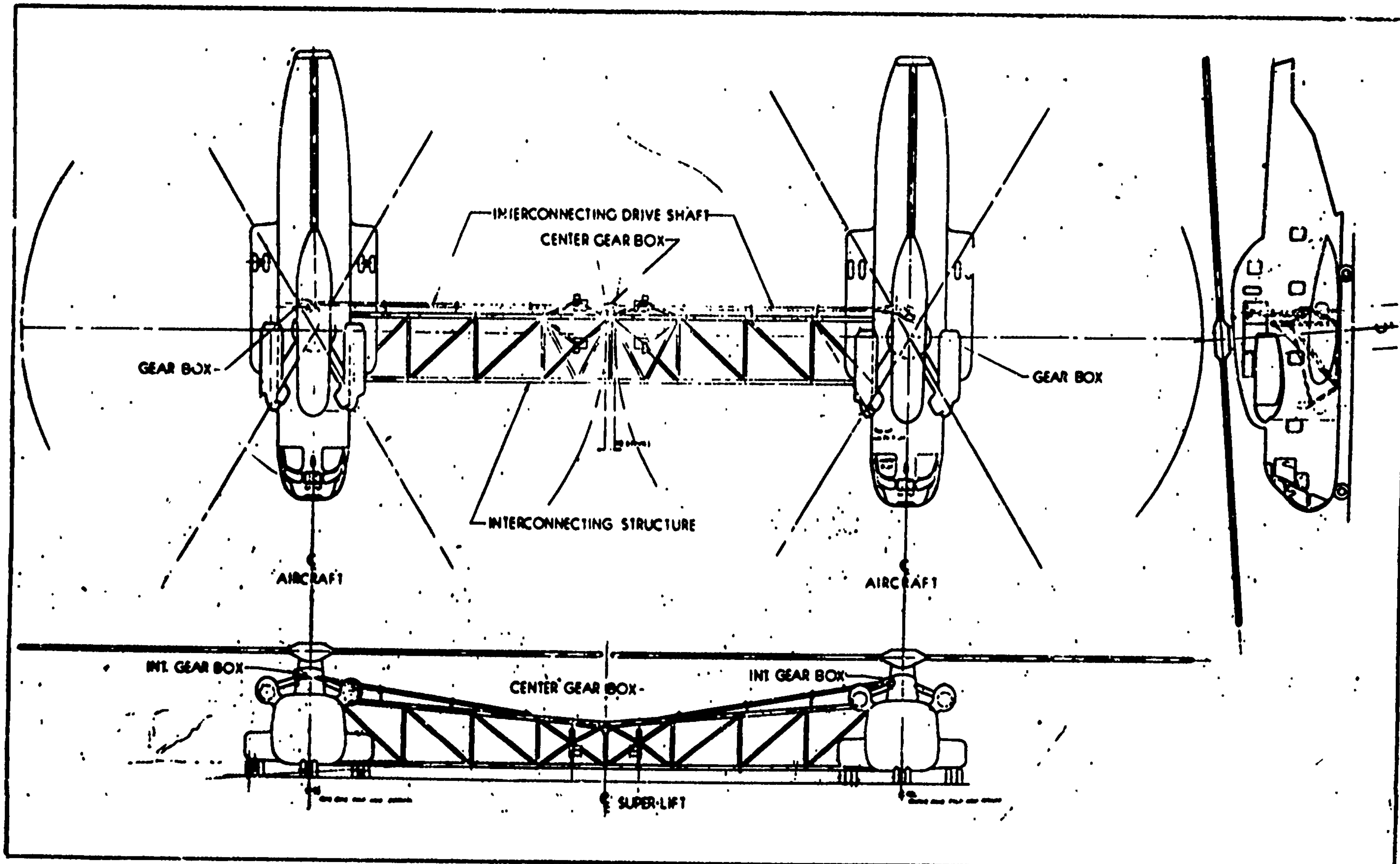
(2 CH-53D HELICOPTERS SIDE-BY-SIDE)

MANEUVER	INCREASE TOTAL LIFT	PITCH NOSE DOWN	ROLL LEFT	YAW NOSE LEFT
LEFT HELICOPTER	INCREASE COLLECTIVE PITCH	FWD LONG. CYCLIC PITCH	LEFT LAT. CYCLIC & DECREASE COLL. PITCH	AFT LATERAL CYCLIC
RIGHT HELICOPTER	INCREASE COLLECTIVE PITCH	FWD LONG. CYCLIC	LEFT LAT. CYCLIC & INCREASE COLL. PITCH	FWD LATERAL CYCLIC

TO MAKE MANEUVERS IN THE REVERSE DIRECTION, EACH CONTROL MOTION IN THE CHART IS REVERSED.

FIGURE 2-3

MHHLS DESIGN STUDY: SIDE-BY-SIDE CONFIGURATION, (2) CH-53D'S



The interconnecting drive system is similar to that for the nose-to-tail configuration, except that the interconnecting shafting runs transversely and passes through the cabin of the starboard helicopter. This latter feature could, of course, be obviated if the left hand plug were used for the starboard helicopter, thus making gear box modifications non-uniform.

2.2 REASONS FOR SELECTED CONFIGURATION

The initial studies resulted in the selection of the nose-to-tail configuration as the most promising. Considerations for the selection of the chosen configuration (with one tail rotor on the aft aircraft) are as follows:

2.2.1 Vehicle Performance

The tandem arrangements were clearly superior to the side-by-side in weight empty. This difference ranged from 2,000 lbs. to 4,000 lbs. depending on the natural frequency criteria used as a stiffness requirement as compared to the structural requirement for strength only. Further, the advantageous span effect of the two side-by-side rotors is largely negated by the additional drag in the interconnecting structure, so that there is no significant difference in the rate of fuel consumption per mile.

Payload-radius curves based on preliminary weight and performance calculations are shown for take-off weights based on hover in and out of ground effect, (Fig. 2-4 and 2-5 respectively) at sea level 90°F, and at 3,000 ft., 91.5°F, for the nose-to-tail tandem and the side-by-side configurations.

The mission profile for the payload-radius curves is derived from the basic Marine Corps heavy-lift mission, and assumes the following:

(1) Warmup, takeoff and pick-up load at the altitude and temperature noted 5 minutes at normal rated power.

(2) Cruise out at sea level, 59°F, at 100 knots.

(3) Hover out of ground effect for 5 minutes at midpoint with load.

(4) Return at sea level, 59°F, at 100 knots with no load.

(5) Land with 10% of initial fuel as reserve.

Augmentation factor for hover in ground effect was taken at 1.09, corresponding to a 15-foot wheel height. (In the analysis of the head-to-tail configuration (Section 4) the wheel height for the

FIGURE 2-4. PAYLOAD VS. RADIUS, PRELIMINARY STUDIES

HIGE, ALL ENGINES

(4) T64-GE-413 ENGINES, MILITARY POWER

T.O. GROSS WT. BASED ON H.I.G.E. AT:

——————— SEA LEVEL, 90°F.

— — — 3,000 FT., 91.5°F.

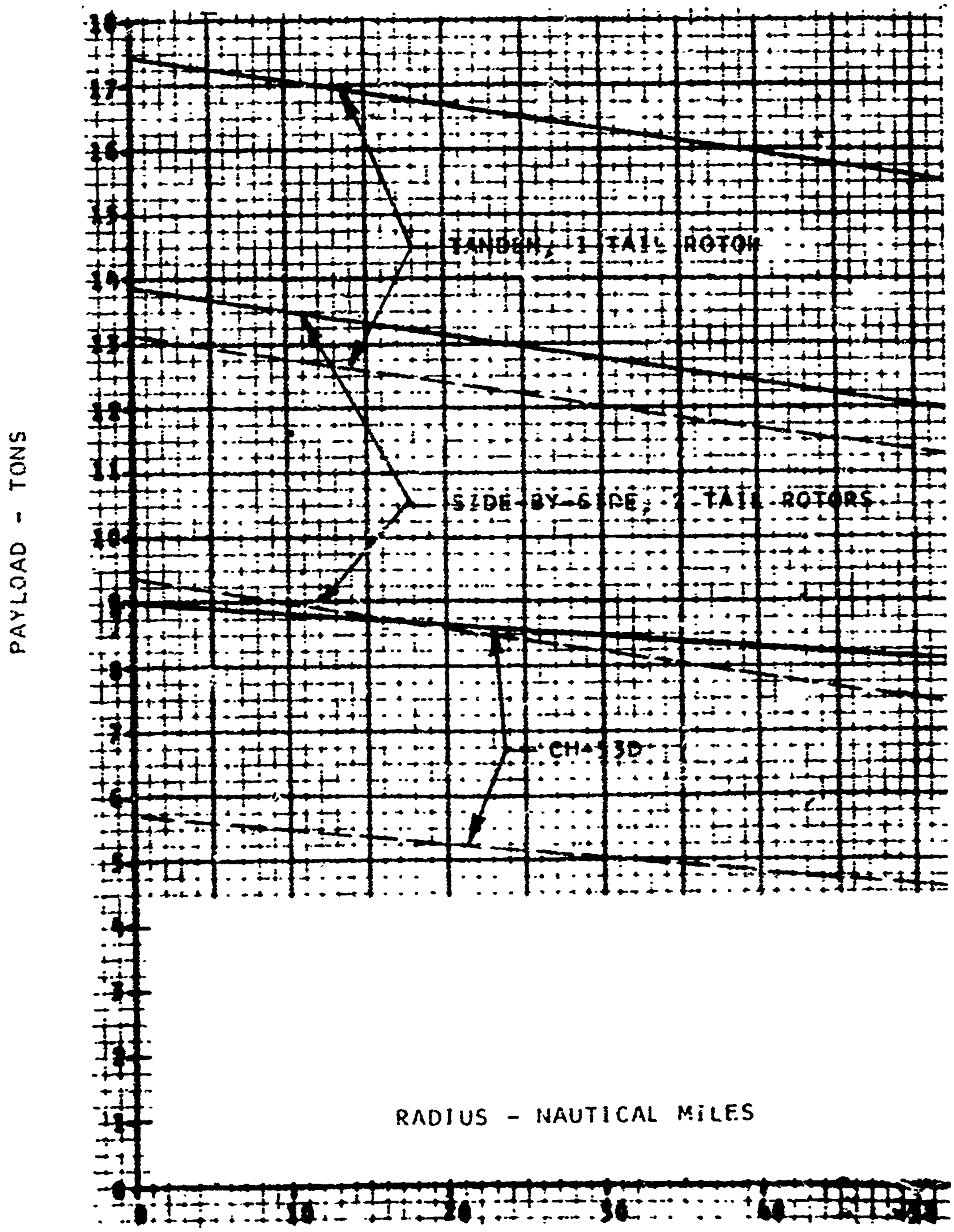
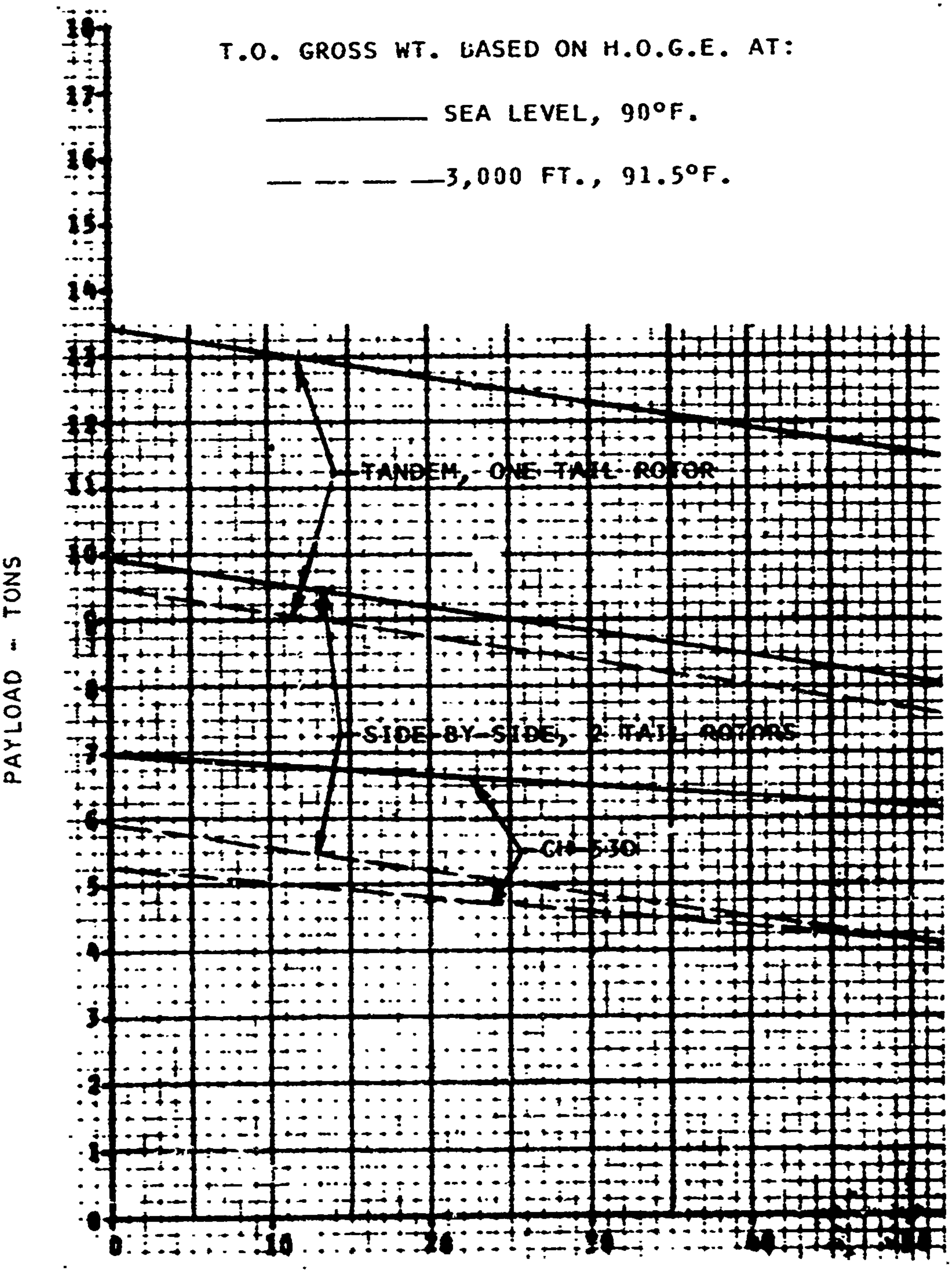


FIGURE 2-5. PAYLOAD VS. RADIUS, PRELIMINARY STUDIES

HOGE, ALL ENGINES

(4) T-64-GE-413 ENGINES, MILITARY POWER



3000-foot altitude condition is taken as 50 feet to be consistent with Navy Studies).

The nose-to-tail arrangement includes one tail rotor, and the side-by-side arrangement includes both tail rotors. The payload advantage of the nose-to-tail arrangement is partly because of the power saved by omitting one tail rotor, and partly because of its lower structural weight. The separate CH-53D is also shown for comparison.

An advantage of the "rigid" multi-lift system is the ability to carry out missions even after an engine failure. Consequently, range payload curves are also shown with take-off weight based on hover in ground effect with one engine out. (Fig. 2-6). The tandem arrangement shows a substantial capability even with this severe limitation.

The choice of a tandem arrangement may appear inconsistent with the Russian choice for their V-12 (Mi-12) heavy- lift helicopter. However, while the V-12 was designed for ranges of 300 Km (162 n.mi.) and 500 Km (269 n.mi.), the multi-lift system is being considered for typical Navy radii of action of 10 and 50 n.mi. (corresponding to 20 and 100 n.mi. ranges respectively). For these short ranges, the less aerodynamically efficient tandem system is superior because of the lower empty weight.

2.2.2 Structural Considerations

The amount of additional structure, and consequently additional weight is much less for the tandem configuration than the side-by-side.

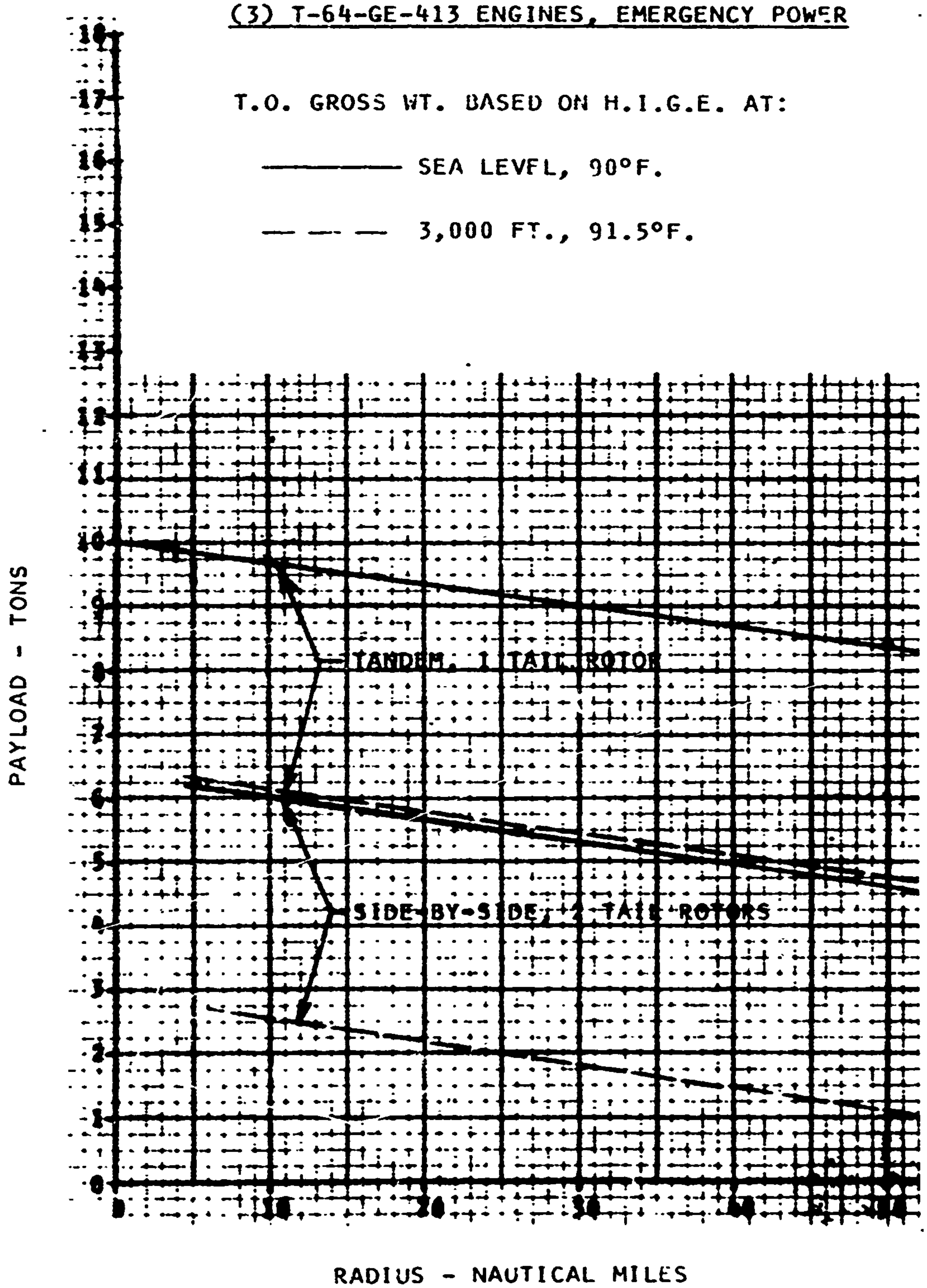
One of the critical aspects of design of the interconnecting structures is the rigidity requirement for keeping the resonant frequencies well away from the principal frequency of excitation by the rotors. For preliminary investigation purposes, a criterion for rigidity was to keep the lowest natural frequency above 1.6 times rotor speed. (In the later analysis of the selected nose-to-tail system, it was found that to make the structure so stiff would be too costly in weight, and the 1.6 criterion was discarded. However, the relative weight advantage is still in favor of the tandem.) For the side-by-side configuration, one critical mode of vibration is an anti-symmetric pitching oscillation of the fuselage, and the other, even more critical, is the vertical oscillation of the payload with respect to the fuselages. For tandem configurations, only the last mode was found to be important and was less critical because of the stiffening effect of the pitching moment of inertia of each helicopter.

Structure weight estimates were based on standard high strength steel, closed section members, with steel or aluminum

FIGURE 2-6. PAYLOAD VS. RADIUS, PRELIMINARY STUDIES

HIGE, ONE ENGINE OUT

(3) T-64-GE-413 ENGINES, EMERGENCY POWER



end fittings. No exotic materials were used such as carbon fiber with tapered diameter thickness tubing, since this would be applicable to all of the designs. However, since the structural beam is larger in the side-by-side configuration, the use of such exotic materials would have a greater advantage to that system, although it still would weigh more than the tandem system of interconnection.

2.2.3 Handling Qualities

The moment of inertia in yaw of any of the three configurations was found to be greatly increased compared to the separate CH-53, and to be substantially greater than would occur in a more conventionally designed multi-rotor helicopter, where most of the masses are within the rotor spacing. As a result, yaw control power from existing main rotor differential cyclic pitch, alone could be inadequate, and it was decided that at least one tail rotor would be needed. This decision was one of those leading to dropping consideration of the tail-to-tail configuration. The side-by-side configuration can, of course, use both tail rotors, while the nose-to-tail configuration can use only the tail rotor on the rear helicopter. However, its moment arm to the system center of gravity is 1.8 times the arm of the CH-53 (or of the side-by-side configuration), while the yaw moment of inertia is somewhat less than the side-by-side. Hence, the yaw control power of either of these two configurations is of the same order, and within the constraints of the existing CH-53D lateral cyclic pitch, is approximately two to three times the yaw control power attainable with tail-to-tail.

2.2.4 Human Factors

The pilot's visibility and the load-master pilot's visibility are both excellent and with least change of existing seating and control arrangements in the nose-to-tail configuration. A tail-to-tail configuration would provide equal visibility capabilities with the exception that the load master would have to have a new seat position located in the cargo ramp area of one of the aircraft. The side-by-side configuration visibility would be just as good for the pilot in forward flight. However, in hovering, the hoisting view would be in a sideways and aft direction, or a new pilot station would have to be made in the forward doorway of the port-side aircraft looking in a transverse direction, at considerable expense.

2.2.5 Power Transmission

Since the three-turbine gear box planned for the CH-53E will have a different input turbine RPM than the CH-53D, as well as a different main rotor transmission ratio for its larger rotor (79 vs. 72 ft.), it is not adaptable to a multi-lift system using existing CH-53's. Therefore, the starboard bevel input pinion plug has been selected as the point of attachment into the main transmission for the interconnecting drive shaft.

The nose-to-tail design permits two new bevel gear sets to provide an interconnect system in the form of two additional gear boxes (see Fig. 3-6), plus a modification of a minor section of the main transmission box where the input shaft from the starboard turbine enters. Thus, a modification to the main transmission casting is not required. Moreover, the interconnecting points on the gear box need not be left and right handed.

A side-by-side configuration would require a shaft through the cabin area near the center of the rotor (perhaps through the windows) if the same input pick-up point were to be used (see Fig. 2-3). There would not be any fewer bevel gear sets except by choosing a new pick-up point into the transmission that would be fore and aft but with a bevel gear take-off available to the left or right. However, this area is not as convenient and would require larger, more costly changes to the main rotor gear box casting.

The selected way of providing the helicopter with an additional drive outlet for the interconnection is through the replacement of the existing starboard input plug of the rotor transmission by a modified one, featuring an additional drive outlet, as shown on Fig. 3-5 . An interconnecting shaft will run from there, in outboard/downward direction, and it will pass between the engine and the fuselage (this run was mocked-up). There should be no difficulty in arranging the remaining portion of the interconnecting shaft as shown on Fig. 3-1 The shaft passes near the main entrance door of the aft CH-53. However, there is adequate space to open this door and to enter the helicopter.

A tail-to-tail system would require an offset lateral stagger of the two aircraft so that the starboard side of one would be in the same plane as the (original) starboard side of the other to give the same number of gear boxes as the nose-to-tail configuration.

2.2.6 Ease of Assembly

Ease of assembly is materially in favor of the nose-to-tail configuration, since the individual components, as well as the completely assembled system, can be handled on deck on their own wheels (See Fig. 3-17). The forward ship with the field modification kit incorporated in it is positioned on deck and the interconnecting section assembly joined to it. The interconnecting assembly can be sub-assembled in another area and brought to location on its own dolly for attachment to the forward helicopter. When the forward aircraft and interconnecting section are completely joined, the dolly is removed from the interconnecting section and the forward helicopter is positioned on its nose wheel ramp using the aircraft's existing cargo winch and cable to draw the aircraft up into position on the ramp. The aft helicopter, with its field modification kit incorporated, is moved into position on its own wheels behind the aforementioned sub-assembly and positioned on its ramp by drawing the aircraft up onto the ramp using the aircraft's existing cargo winch and cable as the positioning device. The final interconnection is made and the complete system checked out; the nose wheel ramps are removed from under both helicopters and the system is completed.

This combination has a maximum maneuverability on deck. Each element is movable individually. There is no need for ground cranes or tractors or any equipment other than the two helicopters and interconnecting section. In a side-by-side configuration, the aircraft cannot easily be moved on the deck in a precise manner sidewards on its wheels, unless it is snaked back and forth and then eventually skidded on its wheels. This could be alleviated by making both aircraft main landing gears swiveling, at a weight penalty.

2.2.7 Ship Compatibility

The landing gear pattern for the tandem arrangements requires less area within its footprints than the side-by-side, and the ease of decoupling the aft helicopter from the forward interconnect structure gives a much higher rating for the ship compatibility to the tandem arrangements. The aft helicopter of the nose-to-tail configuration, with less items removed in order to make it a part of the multi-lift system, is more quickly returnable to its normal single aircraft configuration than in the tail-to-tail arrangement. However, this is not an advantage over the side-by-side, which would also have this quick-return advantage. Both the nose-to-tail and side-by-side have the advantage of having the cargo ramp and cargo area potentially usable in at least one aircraft. In the side-by-side configuration, both cabins would be usable, provided that the interconnecting shaft would be routed so that it did not go through the cabin area. If this were not true, then only one of the pair would be available for use in internal cargo loading. Such an unsymmetrical loading condition for heavy internal cargo probably would result in an unacceptable lateral center of gravity. In the tandem configuration, the forward helicopter cabin would not be easily accessible, and again, the unsymmetrical loading of only one cabin would probably not be feasible for heavy loads.

2.2.8 Selection: Nose-To-Tail Configuration

For each of the characteristics considered above, the nose-to-tail configuration was superior or equal to each of the others.

The tail-to-tail configuration was discarded because of probable inadequate yaw control power. The side-by-side configuration is inferior in ship compatibility, structural weight, and performance, and the transmission interconnection is somewhat more complicated.

3. DESCRIPTION OF CONFIGURATION SELECTED

The configuration selected as most promising for the Multi-Helicopter Heavy Lift System is comprised of two helicopters connected together and operated as one, as shown in the Frontispiece and on Fig. 3-1. The helicopters in the system are standard CH-53's permanently modified at a depot with local fittings and reinforcements. The modified helicopters are then rigidly interconnected in the field by structural beams as indicated by the truss structures. This structure can be removable and therefore of minimum weight penalty to the helicopter when not being used in a multi-lift operation. The fittings and removable reinforcements are to be packaged in kits to be installed in the field only when required, and removed in the field when using the helicopters for their normal missions.

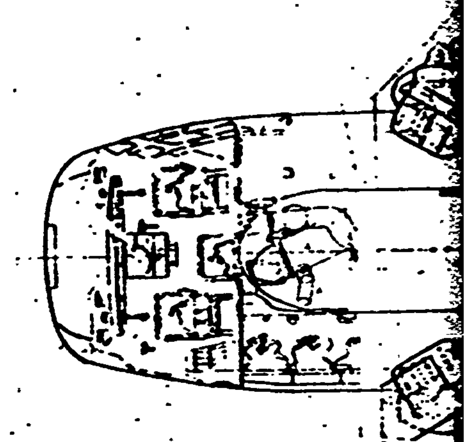
Similarly, the helicopter rotor systems are connected by modifying each main rotor transmission to accep a cross-shafting kit which may be installed in the field when re ired. Each rotor transmission is modified by the addition o a pair of bevel gears. The cross-shafting kit contains appropriate gear boxes, shaft segments, adapters and couplings. When assembled, the synchronizing shafting which is connected to one of these bevel gears in each transmission runs along the starboard side of each helicopter. Thus, any engine can supply power to all rotors as in a conventional, multi-engine, multi-rotor helicopter.

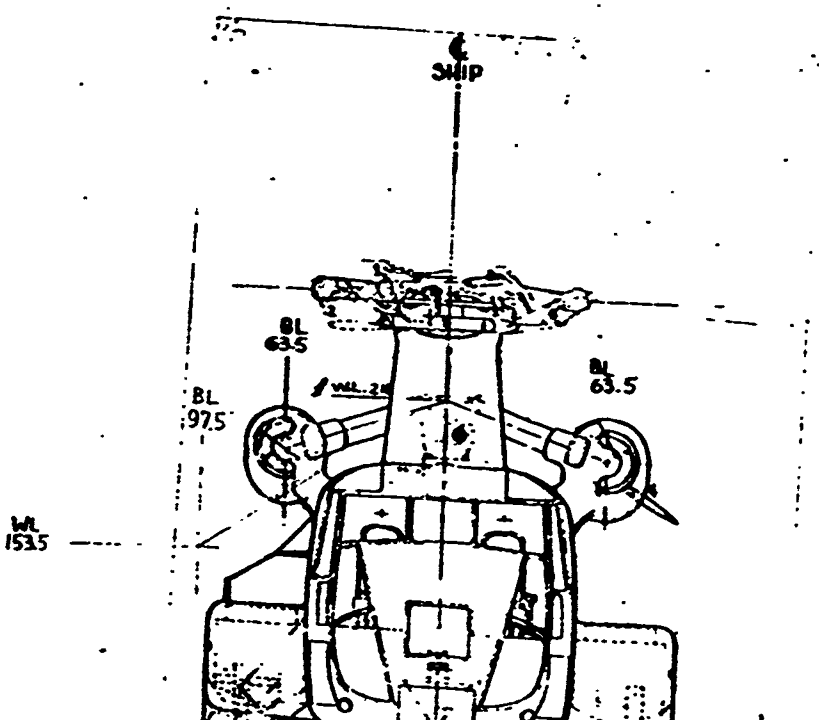
The interconnecting drive shaft is a fail safe feature in the multi-lift design. In the event of an engine failure in any one helicopter, the power in the remaining helicopter does not have to be reduced for balance as the remaining engines' power are automatically redistributed evenly to each helicopter through the cross-shafting and modulated by the turbine governor controls. In the case of helicopters loosely interconnected, an engine failure in one helicopter demands a rapid and equivalent reduction in power in the other helicopter or static equilibrium is lost. Thus, one engine failure results in an effective power loss of two engines and probably requires the payload to be dropped.

Power management used in the multi-lift design is similar to that used in a tandem rotor helicopter where the torque varies between rotors. The speed of each turbine is controlled by its own governor, all of which are set initially to the same speed by the pilot or flight engineer. Changes in power level will cause an initial small change in RPM of the entire drive system, sensed by each governor, which then automatically adjusts the fuel flow to its respective turbine. Minor vernier adjustments can be made at any time to the governor setting of any individual turbine by matching the torque indicator readings. Inadvertent inequalities in power sharing are not harmful, would not affect safe flight, and in no way differ from those which occur in existing multi-engine helicopters.

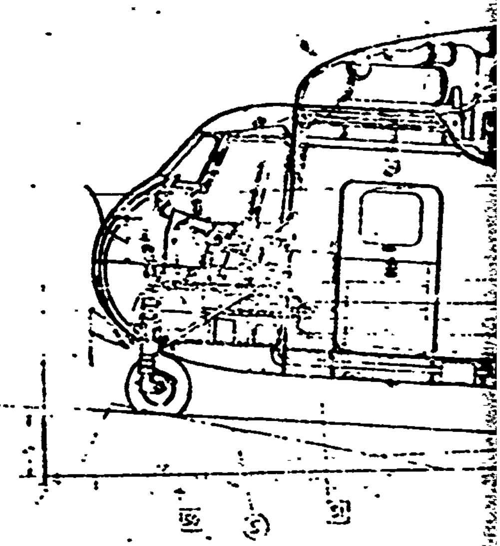
[redacted]

Details of illustrations in this document may be better studied on microfiche





FRONT ... A/C



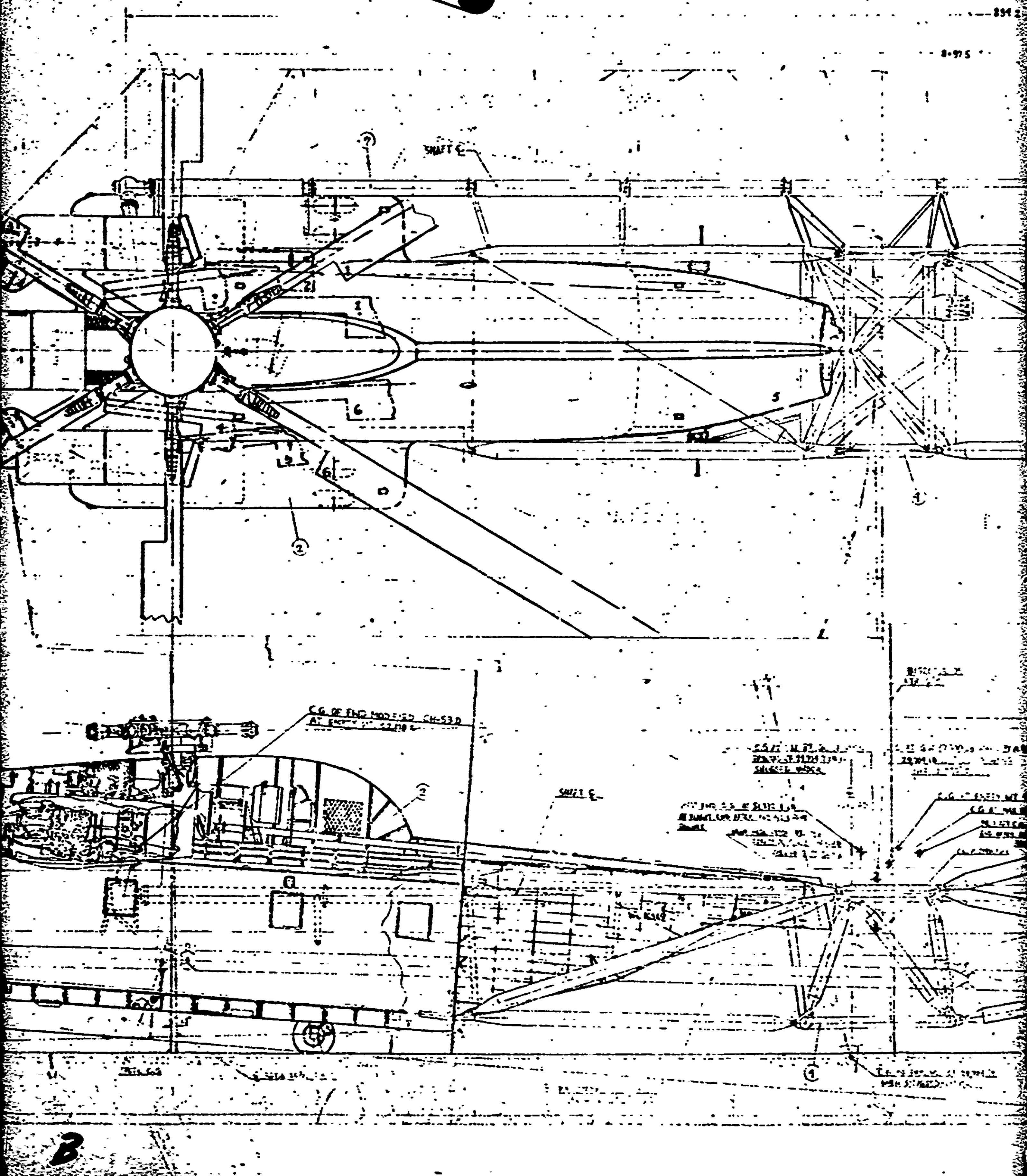
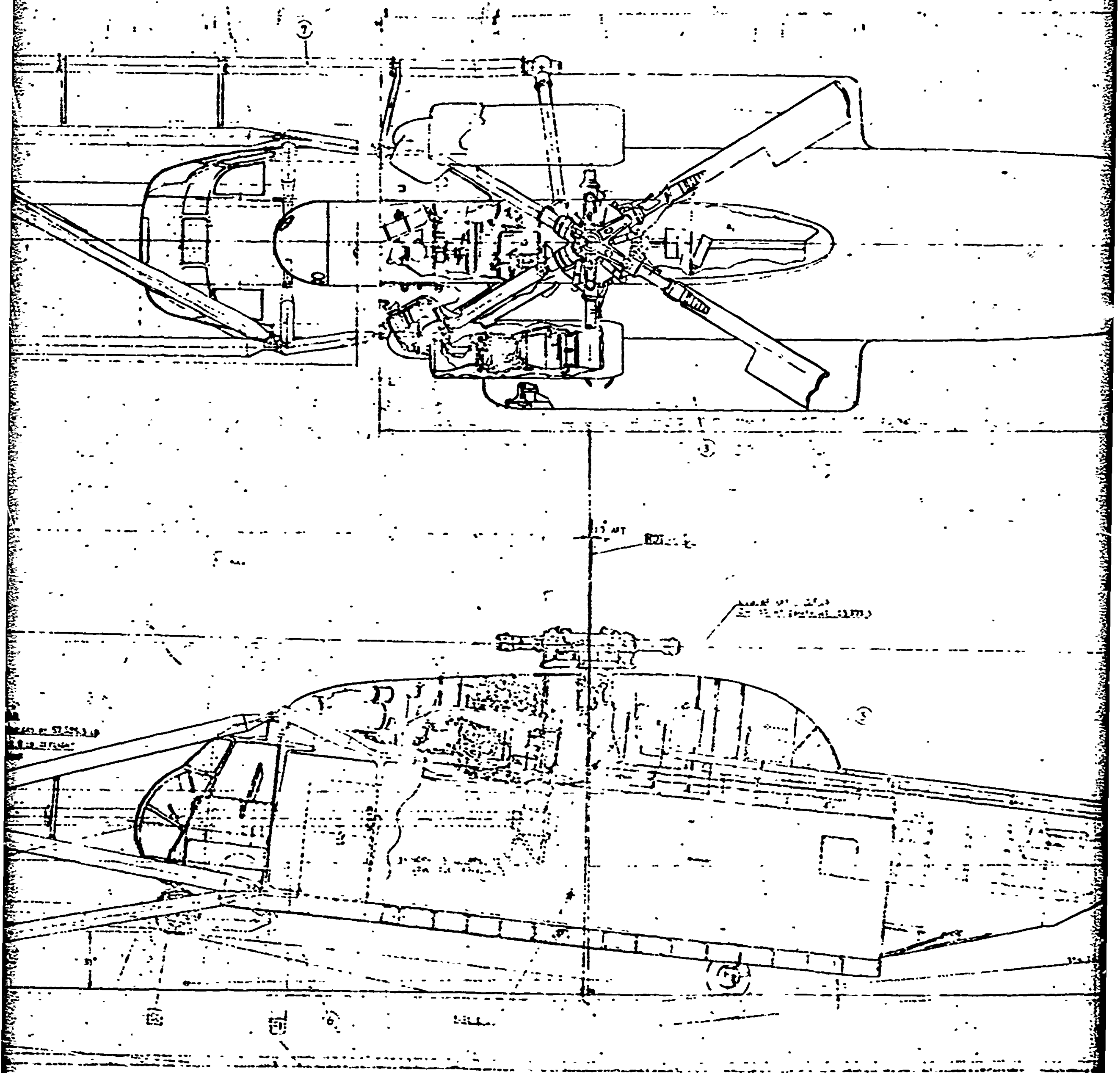
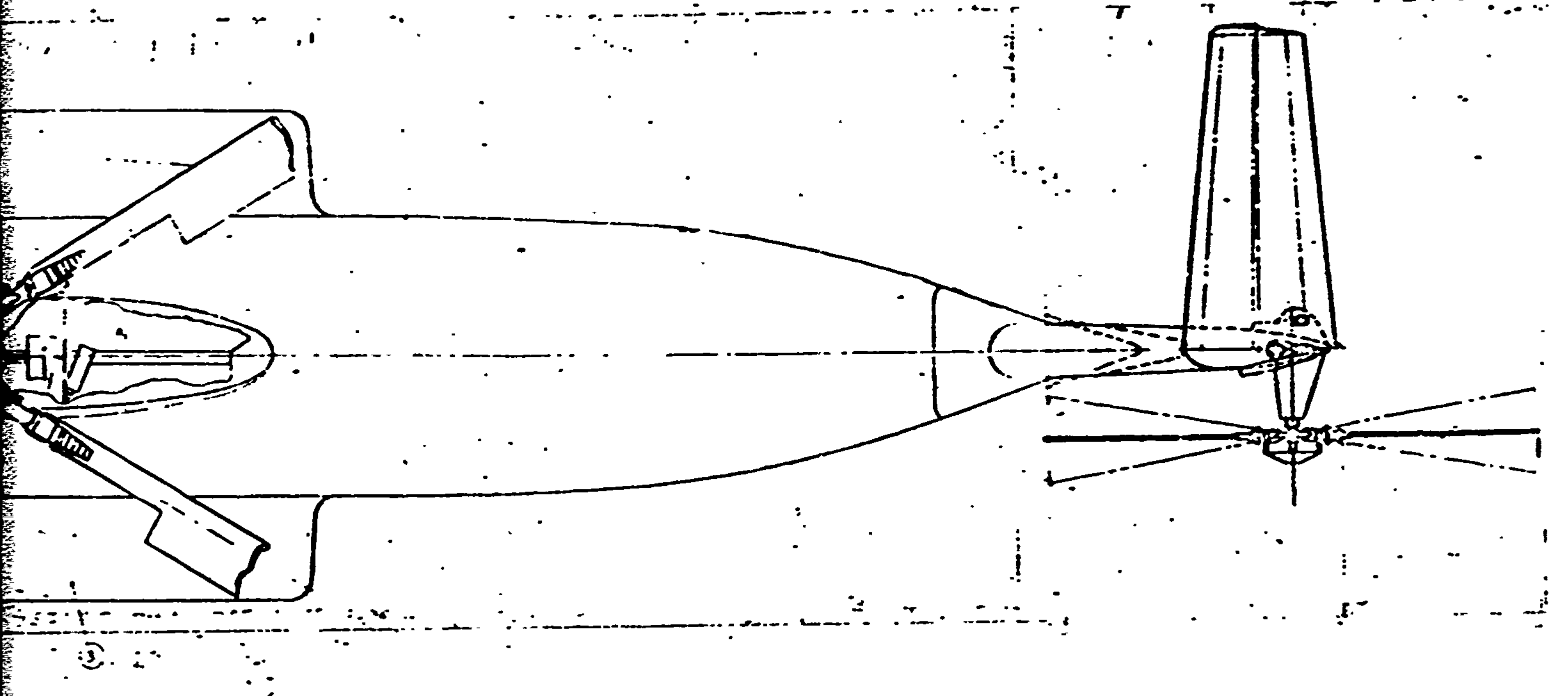

SHAFT ℄
C.G. OF END MODIFIED CH-53D
SHAFT ℄

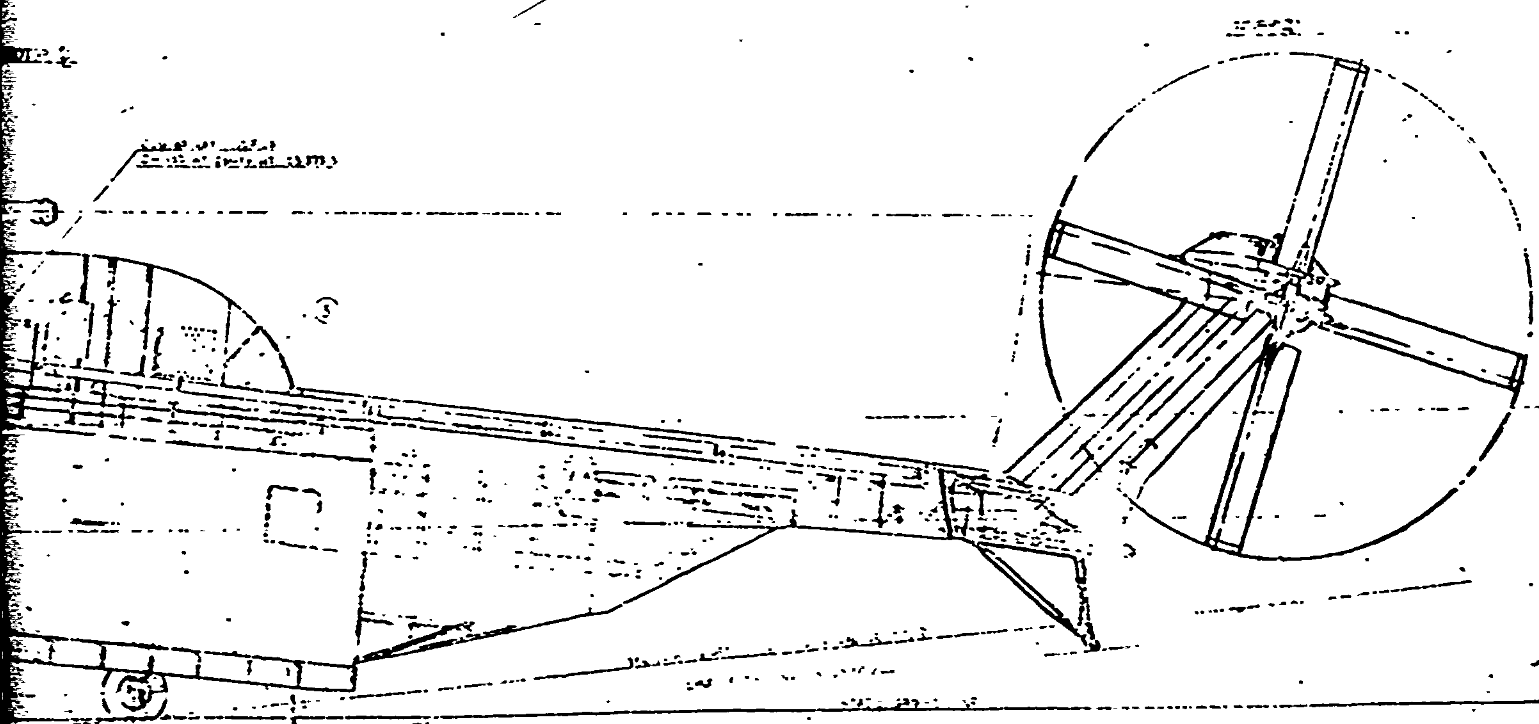
FIG. 3



C

FIG. 3-1. GENERAL ARRANGEMENT, CH-53D MULTI-LIFT SYSTEM, NOSE-TO-TAIL.





In the multi-lift system involving a beam or spreader-bar loosely carried by two or more helicopters, it is an absolute requirement to be able to release the beam together with its load, since if either of the helicopters is in distress, failure to release would involve disaster to both. In the scheme proposed herein, however, the coupled helicopters become, in fact, one helicopter with redundant power, controls and even structure. If an emergency should develop which prevents a safe landing with the supported load, it can be jettisoned at any time.

To permit the complete interconnected system to be controlled by one pilot, the flight control systems are mechanically interconnected. When the pilot in the master helicopter operates his cockpit controls in the normal manner, the rotor controls in both helicopters follow immediately.

If the requirement for a crane no longer exists in a given theater, the helicopters are separated and made available for their normal missions. Thus, the utility of the individual helicopters and the flexibility of operation may be greatly enhanced.

A more detailed description of the MHHLS subsystems, both depot modifications and field modifications, appears in the following sections:

a. Structures
b. Power Transmission System
c. Controls
d. Assembly and Disassembly Procedures

A summary of the modifications and additions to the CH-53D's is shown in Table 3-1.

TABLE 3-1. MODIFICATIONS AND ADDITIONS REQUIRED

MODIFICATIONS REQUIRED

NEW TRANSMISSION STARBOARD INPUT PLUG (WITH NEW BEVEL GEAR SET)

NEW STARBOARD ENGINE INPUT SHAFT

FUSELAGE STRUCTURAL REINFORCEMENTS

NEW ELECTRICAL EQUIPMENT DOORS

RIGHT ENGINE COWLINGS

ROTOR CONTROL MIXING UNIT

A.F.C.S.

SWIVELABLE MAIN LANDING GEAR, LOCKABLE FORWARD

TABLE 3-1 (CONT'D)

ADDITIONS REQUIRED

INTERCONNECTING SHAFTING AND GEARBOXES
INTERCONNECTING TRUSS
MECHANICAL INTERCONNECTION OF FLIGHT CONTROLS
INTERCOM AND INSTRUMENTATION BETWEEN FRONT AND REAR HELICOPTER
ENGINE CONTROLS FOR AFT HELICOPTER IN FORWARD HELICOPTER
HOIST SYSTEM OR SLING

3.1 STRUCTURE

Depot structural modifications to the CH-53D's for use in MHHLS consist of installing the interconnection fittings and of reinforcements required to safely transfer the concentrated loads from these fittings to the fuselage shell.

The interconnection fittings are made from heat treated aircraft quality steel. They are protected from corrosion in accordance with MIL standards and are attached to the fuselage using standard hardware.

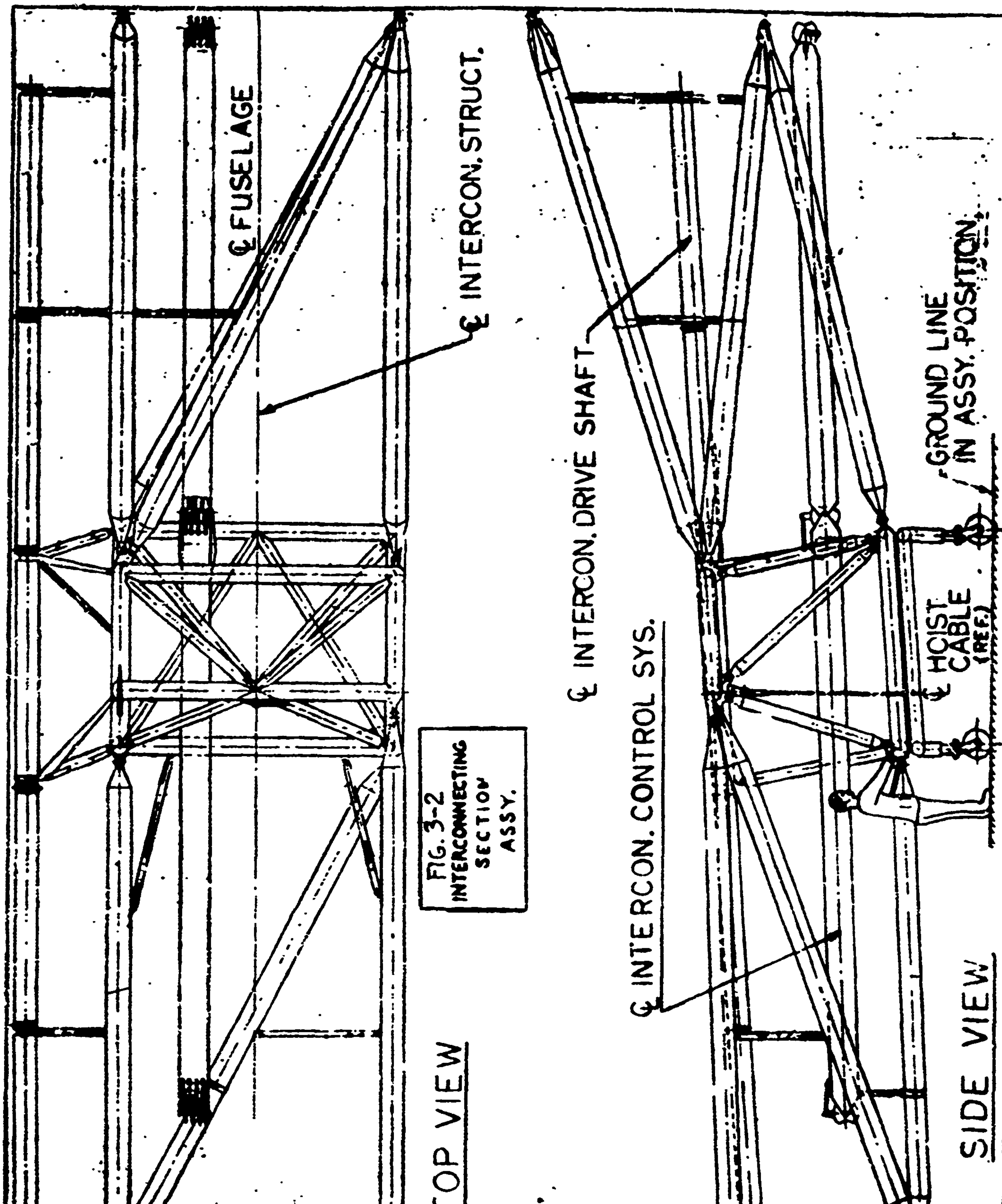
In order to increase the fuselage strength locally under the fittings, heavy gage external and internal local reinforcements, made from high strength aluminum alloy, are provided. Further transfer of the fitting loads is by means of light gage doublers and stringers. These reinforcements cover fuselage sections from CH-53 station 162 to 202 and from station 482 to 522.

The interconnecting structure, shown on Fig.3-2 has an upper and lower truss, made from high strength steel tubing, heat treated after welding. The upper truss contains provisions for attachment of the external load suspension hook cable.

These trusses are joined by 10 struts to form a rigid, statically determinate central space framework. The struts are made from high strength aluminum alloy tubing and have high strength heat-treated steel end fittings.

The central space framework is joined with both helicopters by means of 15 long struts, also made from high strength aluminum alloy, with high strength steel end fittings.

All struts are designed to have resonant bending vibrational frequencies well above the exciting frequency of the air



℄ FUSELAGE
℄ INTERCON. STRUCT.
FIG. 3-2
INTERCONNECTING
SECTION
ASSY.
TOP VIEW
℄ INTERCON. DRIVE SHAFT
℄ INTERCON. CONTROL SYS.
GROUND LINE
IN ASSY. POSITION
HOIST
CABLE
(REF.)
SIDE VIEW

flow disturbances, caused by the rotor blades.

Quick attachment of the struts to the fuselage fittings is by means of "Expando-Grip" pins which are described in paragraph 4.4.1.

The tail end of the modified forward helicopter is directly attached to the central framework by means of a link which takes only lateral fuselage shear.

The nose wheels of the forward helicopter are not used in the MHHLS. Instead, the forward helicopter main wheels become the front wheels of the MHHLS, and must be made swivelling.

The aft (main) swiveling landing gear of the forward unit of the MHHLS is a modified CH-53D nose wheel assembly. In addition, each assembly is made manually lockable during the depot modification so it can be used in the single CH-53D configuration.

An additional feature considered, but not added to the MHHLS design, was power steering of the forward unit's wheels. This could assist in the deck handling characteristics. However, its need is uncertain and can be one of the items determined from prototype testing.

3.2 POWER TRANSMISSION SYSTEM

The drive systems of the forward and aft helicopters are interconnected by a synchronizing system which permits the flow of power from any engine to either rotor, and which permits the transfer of rotational kinetic energy between rotors in the autorotation (power-off) condition.

The synchronizing rotor drive system is connected at the starboard input bevel gear of each main rotor gear box (Fig. 3-3). The plug (Fig. 3-4) which mounts the input bevel pinion and free-wheel clutch, and which is bolted to the gear box proper, is modified as shown in the preliminary layout drawing, Fig. 3-5 so that the free-wheel unit is moved forward sufficiently to permit the insertion of an auxiliary bevel pinion on the same shaft, fixed to a new input bevel pinion which replaces the existing one. This auxiliary bevel pinion meshes with another additional gear in the modified plug, which directs the synchronizing torque down and to the right, below and outboard of the engine nacelle. Here, on each helicopter, is located an intermediate gear box as shown in preliminary layout drawing, Fig. 3-6 with shafting interconnecting them along the starboard side of the structure. Figures 3-7 and -8 are photographs showing an approximate mock-up of the synchronizing shaft routing under the engine nacelle.

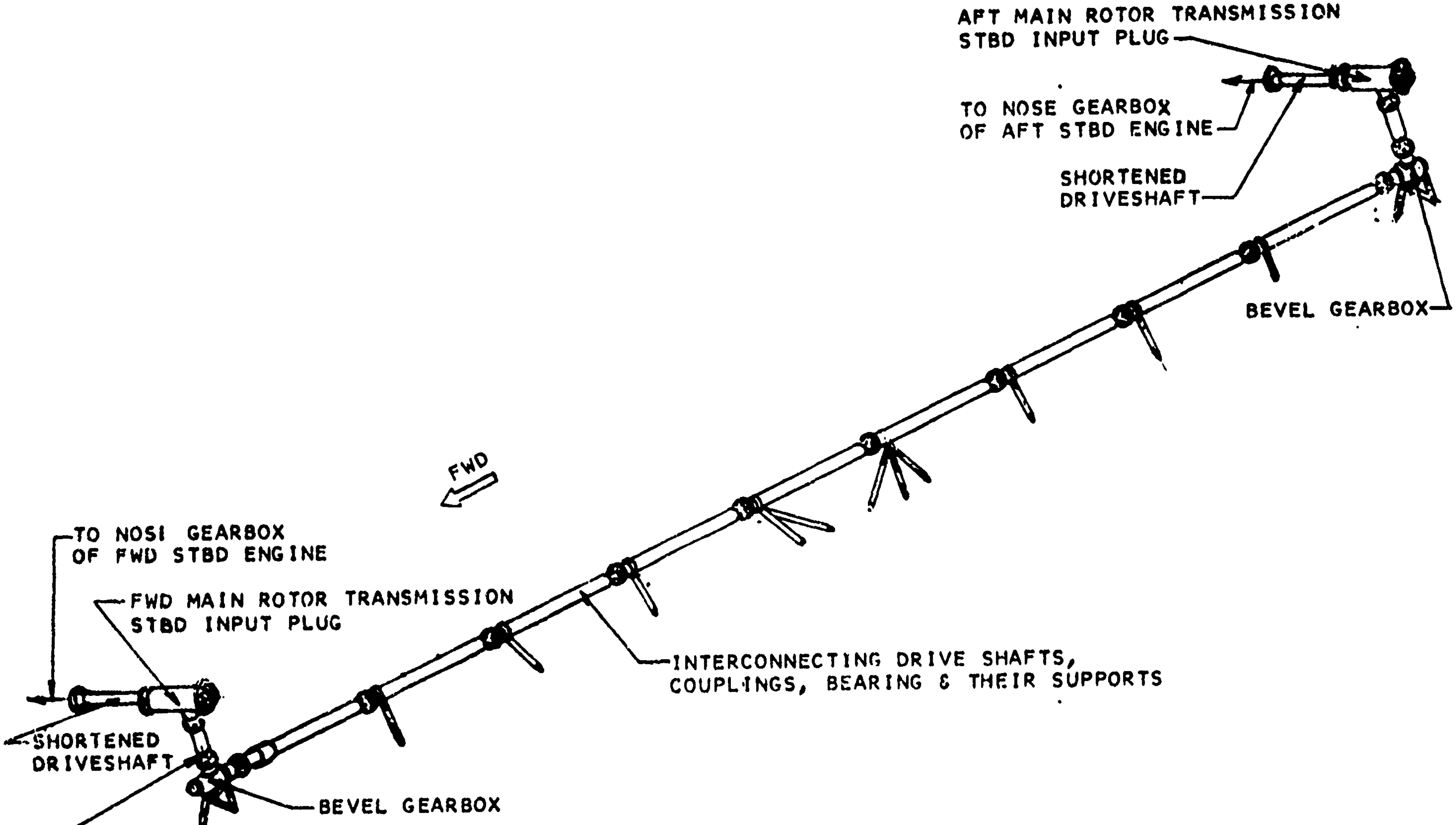


FIGURE 3-3. INTERCONNECTING DRIVE SYSTEM

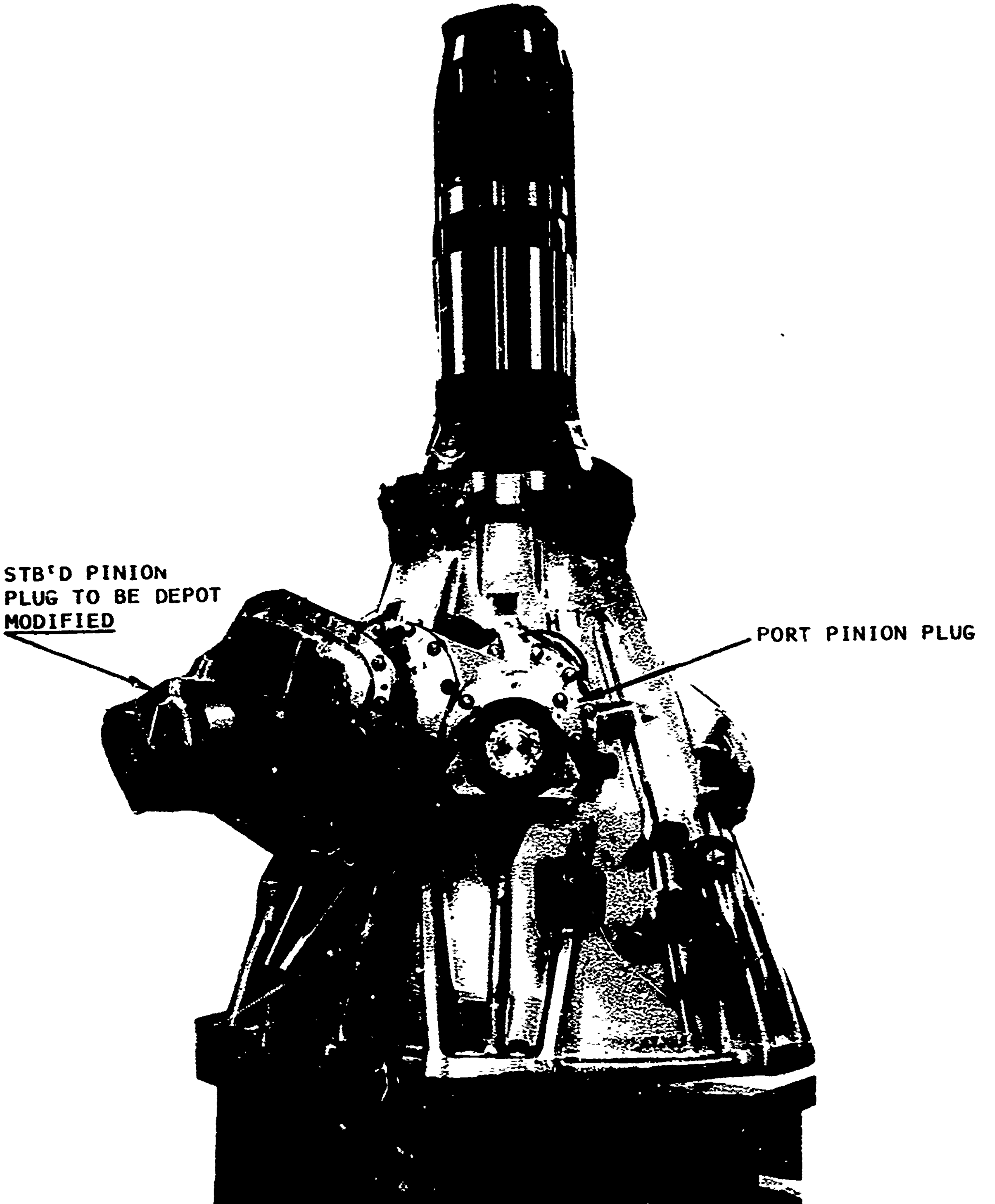
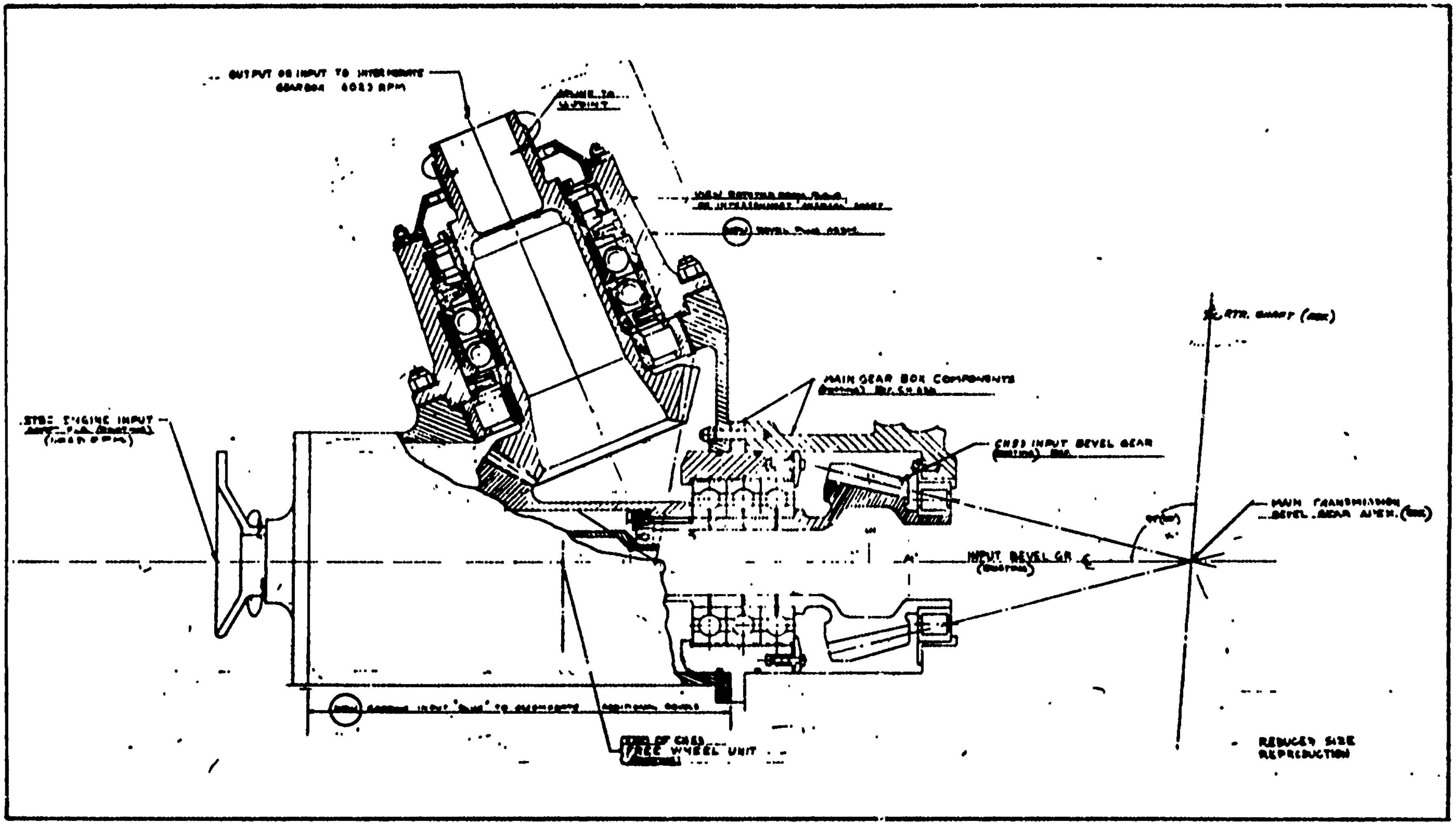


FIGURE 3-4. CH-53D MAIN ROTOR GEAR BOX

FIGURE 3-5

PRELIMINARY LAYOUT, CH-53D GEAR BOX MODIFICATION



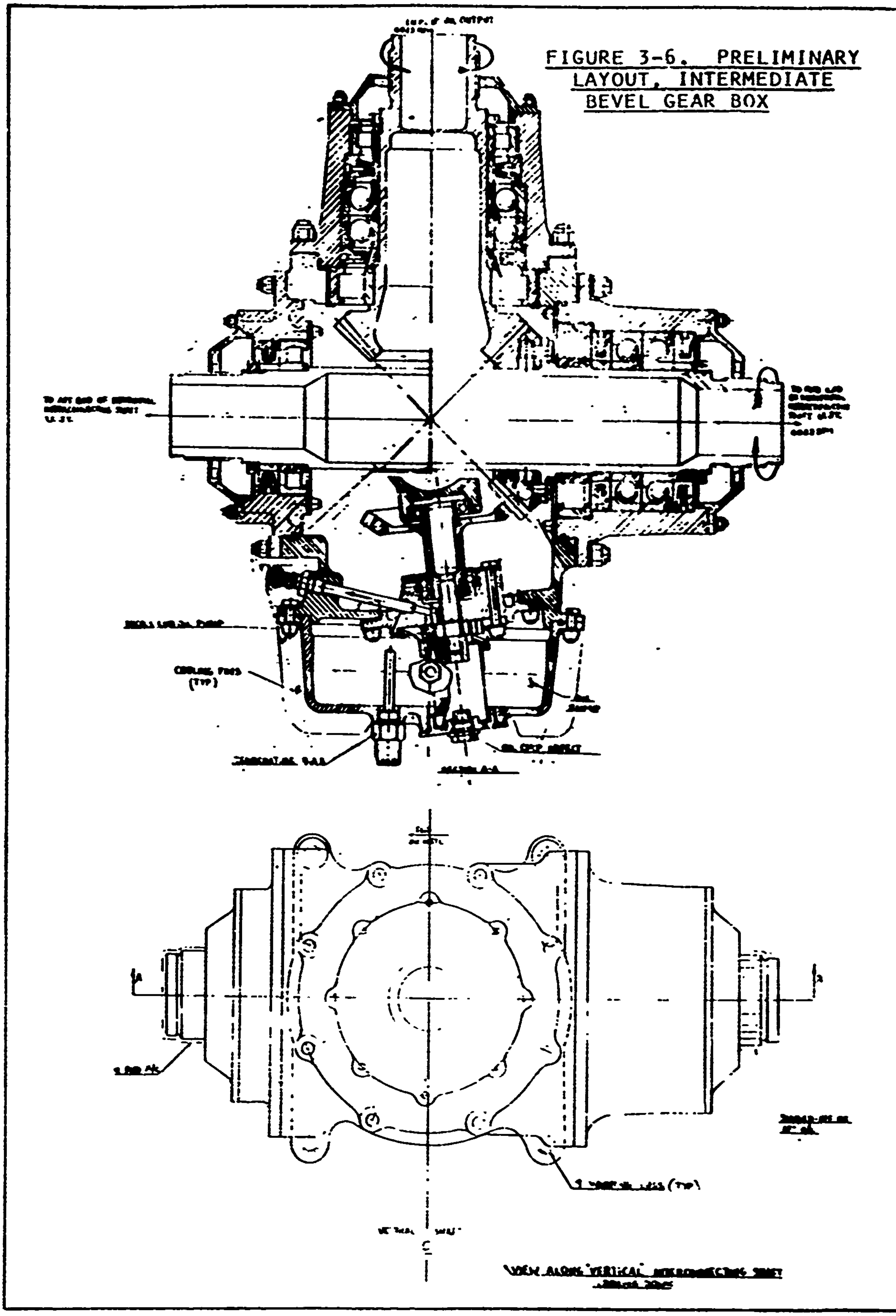


FIGURE 3-6. PRELIMINARY LAYOUT, INTERMEDIATE BEVEL GEAR BOX

FIGURE 3-7. VIEW ALONG EXHAUST AXIS;

INTERCONNECT SHAFT, CLEARANCE PATH

CH-53D

FIGURE 3-8. SIDE VIEW OF INTERCONNECT SHAFT, CH-53D

The new plug is a factory built and assembled unit that is part of the modifications installed during the depot overhaul period. The lengthened plug requires replacement of the shaft from the turbine "nose gear box" on that side with a new shaft approximately twelve inches shorter.

3.3 CONTROLS

To permit the complete interconnected system to be controlled by one pilot, the cockpit controls of the two helicopters are interconnected and the relationship between control inputs from the cockpits and rotor motions are modified from the CH-53 values. When the pilot in the master helicopter operates his cockpit controls in the normal manner, the controls in both helicopters follow immediately, and in the ratios desired for the tandem configuration. Table 3-2 shows the required flight control actions for typical maneuvers. The load pick-up pilot in the rear helicopter can also operate the flight controls through the same interconnected linkage.

The basic task is to actuate the controls of the "slave" helicopter from the master helicopter cockpit, along with those of the master helicopter itself.

An overall schematic of the flight controls is shown in Fig. 3-9. The controls in the two aircraft are mechanically interconnected in the area just behind each cockpit. A low-gain power assist can be added to eliminate friction, but at this stage is not considered necessary.

TABLE 3-2
CONTROL INTERCONNECTIONS FOR MULTIPLE HELICOPTER LIFT SYSTEM

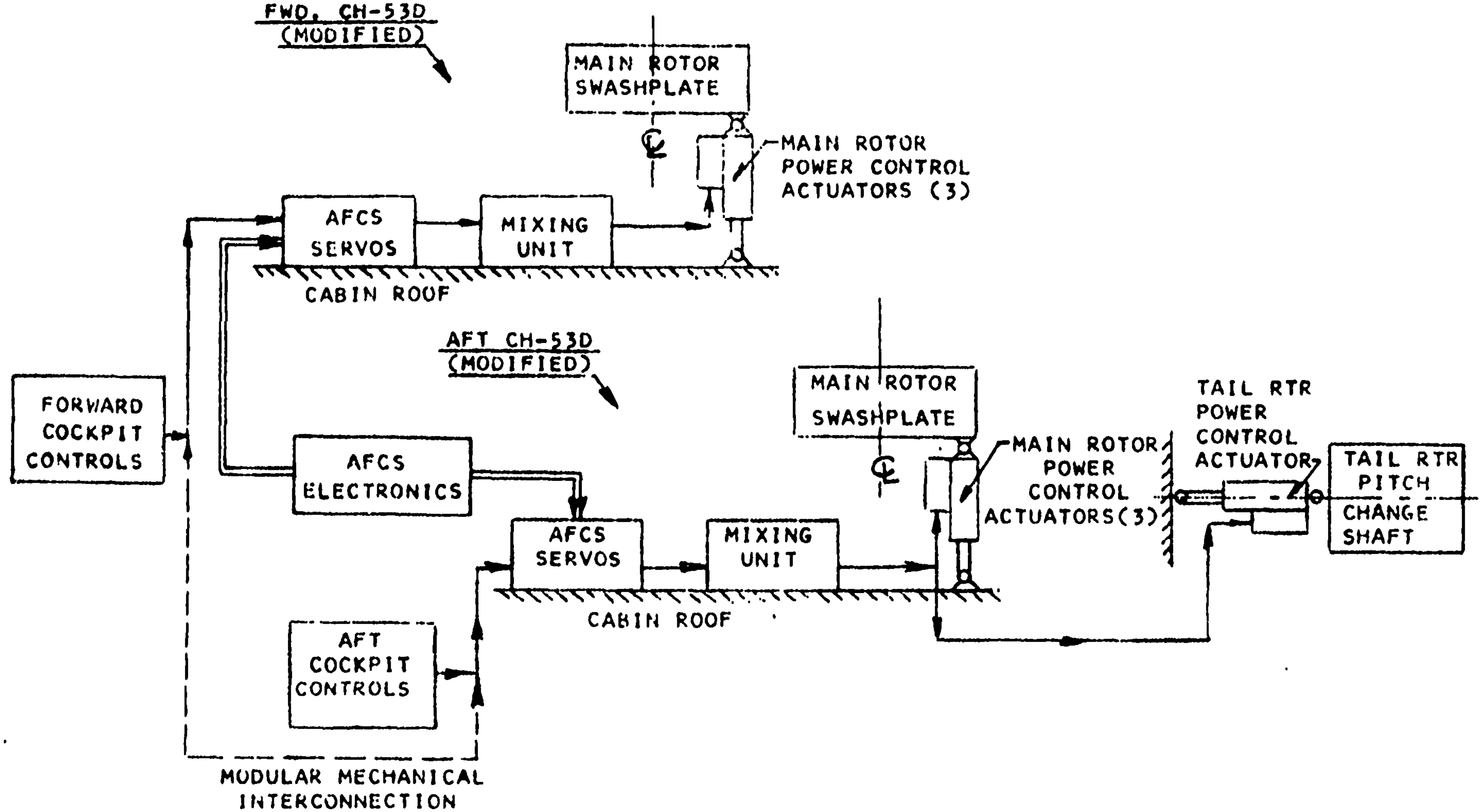
(2 CH-53D HELICOPTERS, NOSE-TO-TAIL)

MANEUVER	INCREASE TOTAL LIFT	PITCH NOSE DOWN	ROLL LEFT	YAW NOSE LEFT
FORWARD HELICOPTER	INCREASE COLLECTIVE PITCH	DECREASE COLLECTIVE PITCH AND FWD. LONG. CYCLIC	LEFT LATERAL CYCLIC	LEFT LATERAL CYCLIC
AFT HELICOPTER	INCREASE COLLECTIVE PITCH	INCREASE COLLECTIVE PITCH AND FWD. LONG. CYCLIC	LEFT LATERAL CYCLIC	RIGHT LATERAL CYCLIC AND INCREASE PITCH OF TAIL ROTOR

TO MAKE MANEUVERS IN THE REVERSE DIRECTION, EACH CONTROL MOTION IN THE CHART IS REVERSED.

FIGURE 3-9. MHHLS CONTROL SYSTEM, SCHEMATIC

(2) MODIFIED CH-53D'S



Flight controls use most existing aircraft control system components, including:

a. Non-modified upper rotor controls of both aircraft.

b. Non-modified cockpit controls of both aircraft.

c. Non-modified AFCS tandem servocylinders.

d. Non-modified push-pull rods and some bell-cranks of the mechanical linkage of each helicopter.

Field modification of controls include the following:

a. Replacement of existing control mixing units by new mixing units.

b. Addition of mechanical linkage interconnecting the control systems of the two helicopters.

c. Removal of the tail rotor controls from the for ward helicopter.

d. Replacement of existing AFCS amplifier by a modified AFCS amplifier

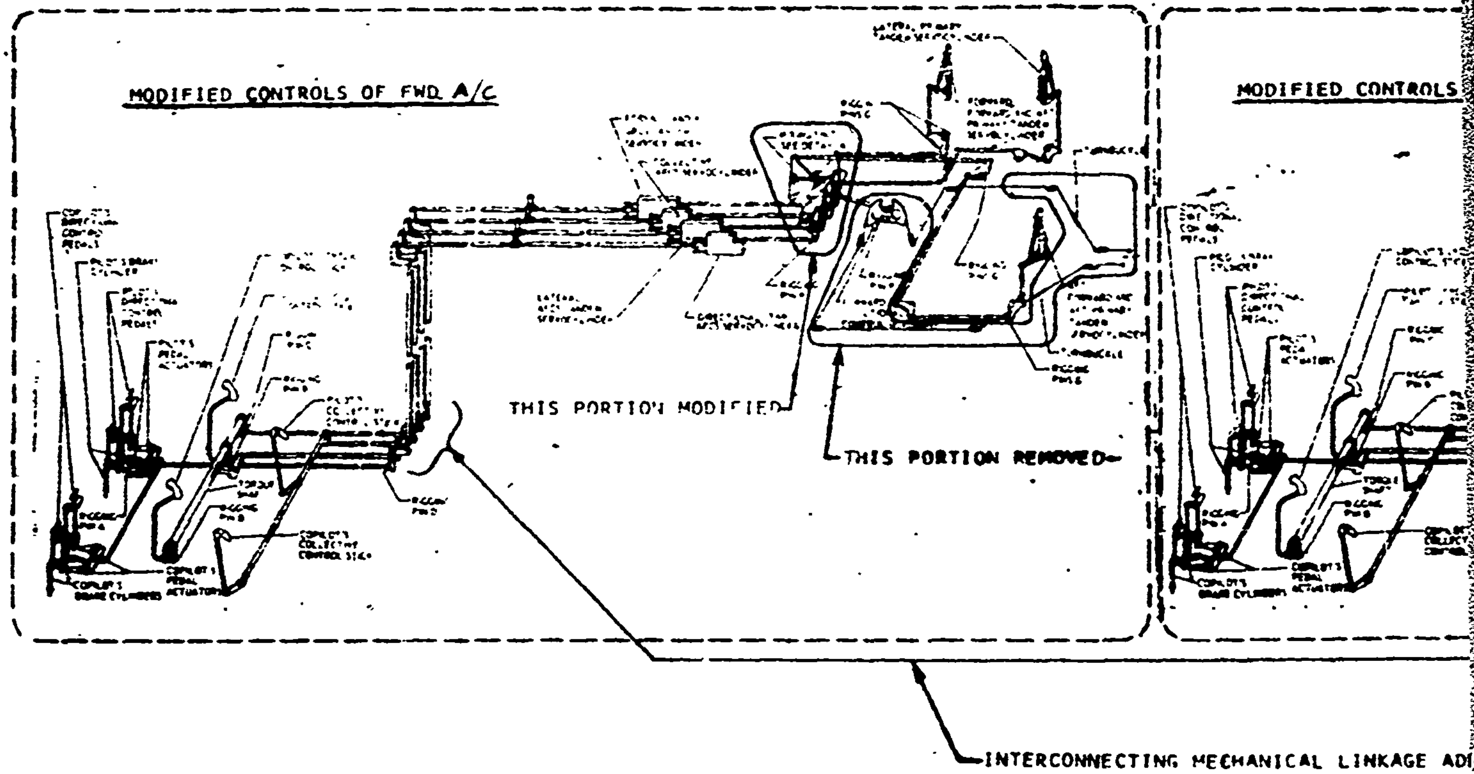
Depot modifications consist primarily in installing wiring provisions for the alternate AFCS, and brackets for acceptance of either the original or the modified mixing units.

A mechanical schematic is shown in Fig. 3-10.

3.3.1 Interconnection of Cockpit Controls

Interconnection of the controls between the two cockpits is by means of a "conduit" containing all required mechanical and electrical connecting members. The conduit is comprised of four modules, arranged in tandem, the foremost of which is shown schematically in Fig. 3-11. When connected together, and supported flexibly from the airframe structures, the four modules serve to transmit control motions accurately between the cockpits, independent of structural deflections. Actual connection to the controls of each helicopter is at the lower bell-cranks at station 162, which are modified for this purpose.

Each module contains six sets of quadrants, interconnected by stainless steel cables which are preloaded to eliminate stretching under control loads. The quadrants are supported by a structure, composed of steel elements taking the module conversion loads. Since, under temperature changes, both the cables and the structure elongate the same amount, the cable preload does not change with temperature. Low-friction ball bearings are used to support the


MODIFIED CONTROLS OF FWD A/C
THIS PORTION MODIFIED
THIS PORTION REMOVED
MODIFIED CONTROLS
INTERCONNECTING MECHANICAL LINKAGE AD

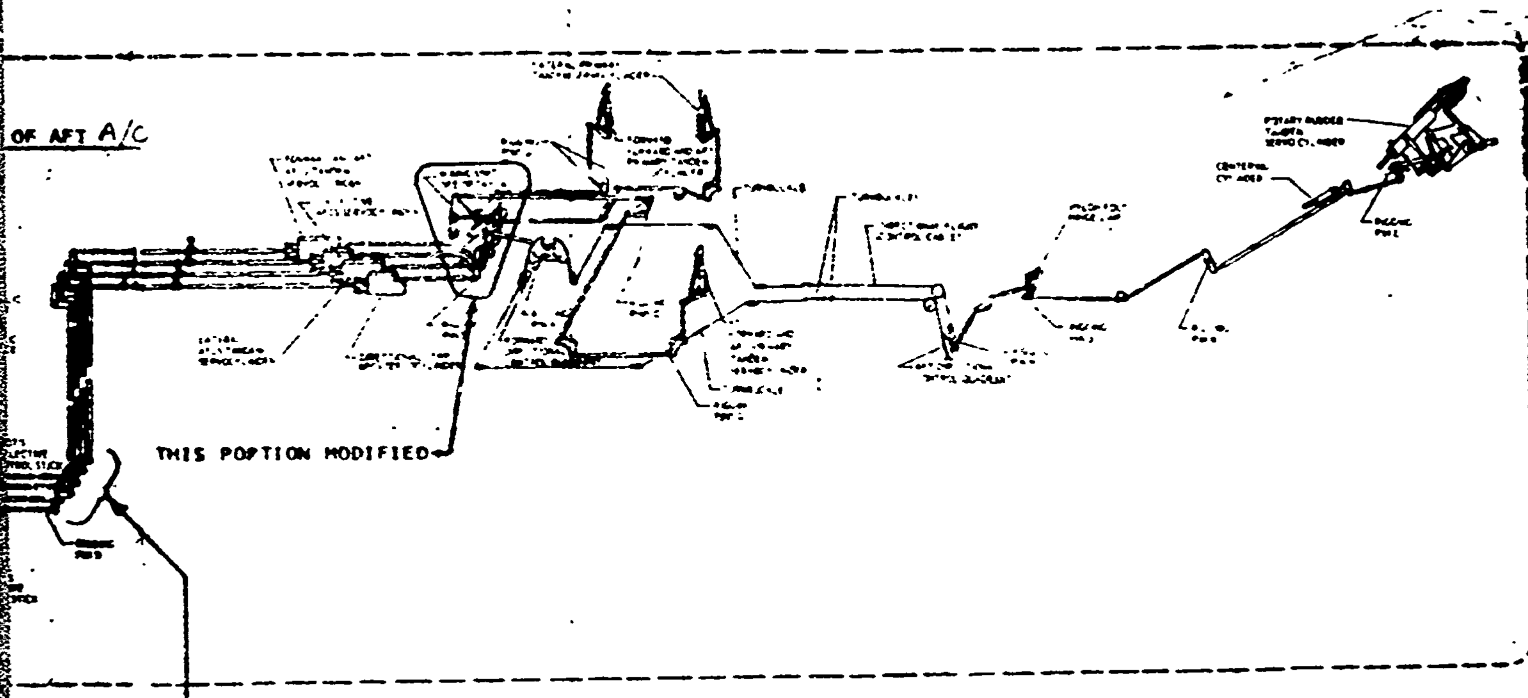
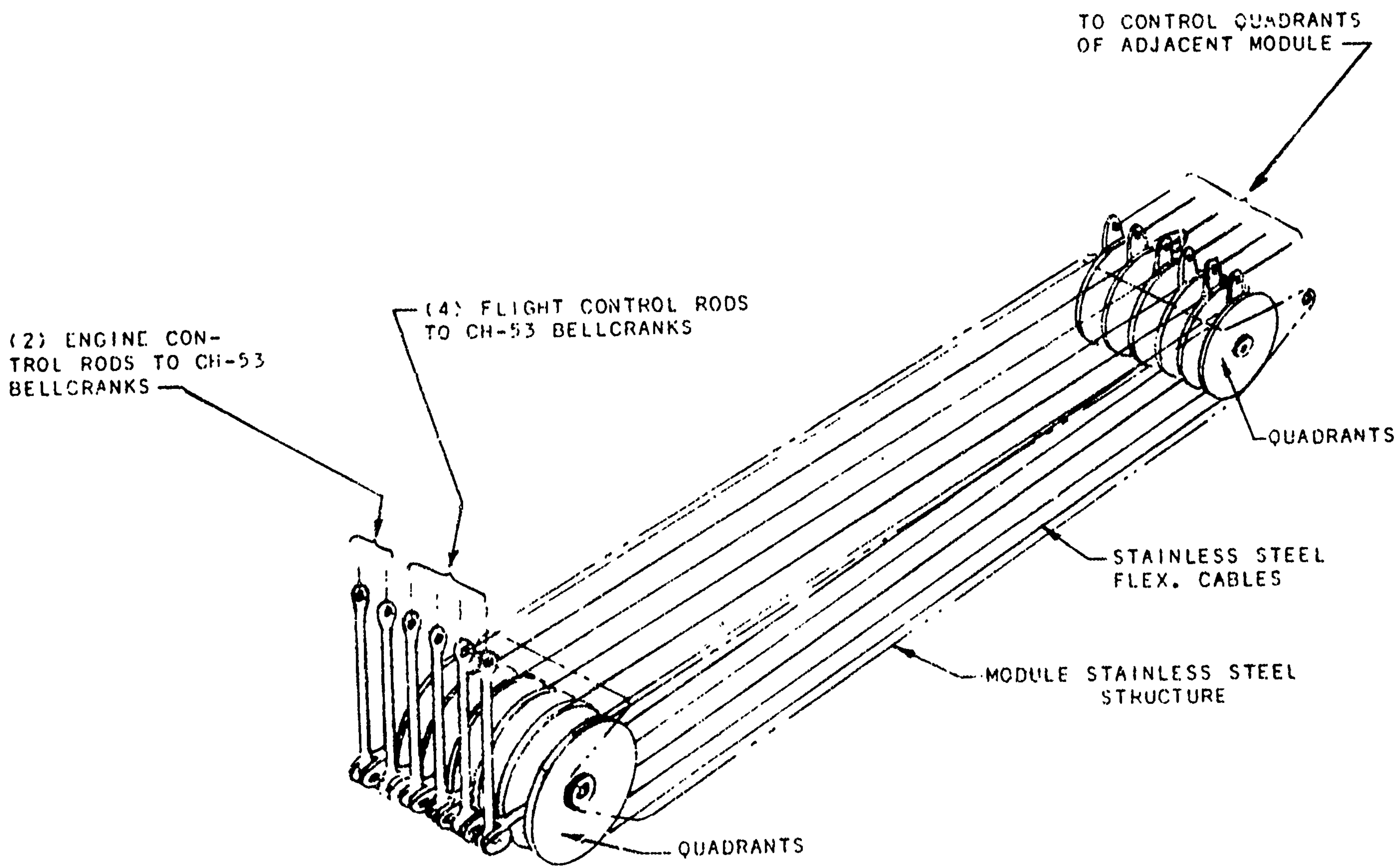


FIGURE 3-10. MECHANICAL SCHEMATIC OF FLIGHT CONTROLS FOR MHHLS

DED

B

FIGURE 3-11. CONTROL MECHANICAL INTERCONNECTION MODULE (TYPICAL)



quadrants.

Each quadrant is equipped with a lever for interconnection with the adjacent quadrant on the next module or with the helicopter bell-crank, by means of push-pull rods. Bearings used in the push-pull rod-ends are free of backlash.

The modules are supported by the MHHLS structure in a manner that isolates the effects of relative structural deflections on the interconnecting controls. The assembled conduit is of fixed length, and is supported on vertical links, so that fore-and-aft structural deflections do not affect the relative positions of the bell-cranks at each end of the conduit. Transfer of motion from the bell-cranks at each end of the conduit to the CH-53D controls is in essentially a vertical direction, and is nearly independent of any fore-and-aft motion of the conduit relative to either helicopter. The actual connection to the CH-53D controls occurs in the so-called "broom-closet" behind the pilot's seat, where bell-cranks for accepting the interconnection are installed in the depot modification.

All electrical interconnections also utilize the conduit, to house the necessary multi-conductor cables, although the isolation feature is of no importance to electrical signals.

3.3.2 Flight Control Mixing

The CH-53 helicopter incorporates a "mixing unit" in its control system mounted above the cabin roof deck, just ahead of the rotor. This mixing unit receives "pure" inputs from the cockpit controls; i.e., collective stick (thrust control), longitudinal and lateral cyclic stick, and rudder pedal motions. It "mixes" these inputs in appropriate ratios, and three of its outputs go to hydraulic actuators which move differentially to tilt the swashplate for cyclic pitch, and raise or lower it for collective pitch. A fourth output from the mixing unit controls tail rotor pitch, and a fifth one is an input to the engine power control. When the pilot operates the collective stick, the mixing unit produces an input to tail rotor pitch and main rotor lateral cyclic pitch as well, so that rotor torque is essentially automatically balanced. Collective pitch input to the mixing unit also produces an appropriate change in engine power setting.

In order to explain the method of producing control mixing in the MHHLS, the operation of the unmodified CH-53D will be described in detail, referring to Fig. 3-12. An input from the cockpit collective pitch lever rotates bell-crank 1, which is fastened to torque-tube 2. Bell-cranks 3, 4, and 5 are also fastened to torque-tube 2, and rotate in unison with bell-crank 1. Mounted on each of bell-cranks 3, 4, and 5 is a second bell-crank 6, 7, and 8 respectively. These latter bell-cranks are additionally operated by inputs from the stick and pedals to bell-cranks 9, 10,

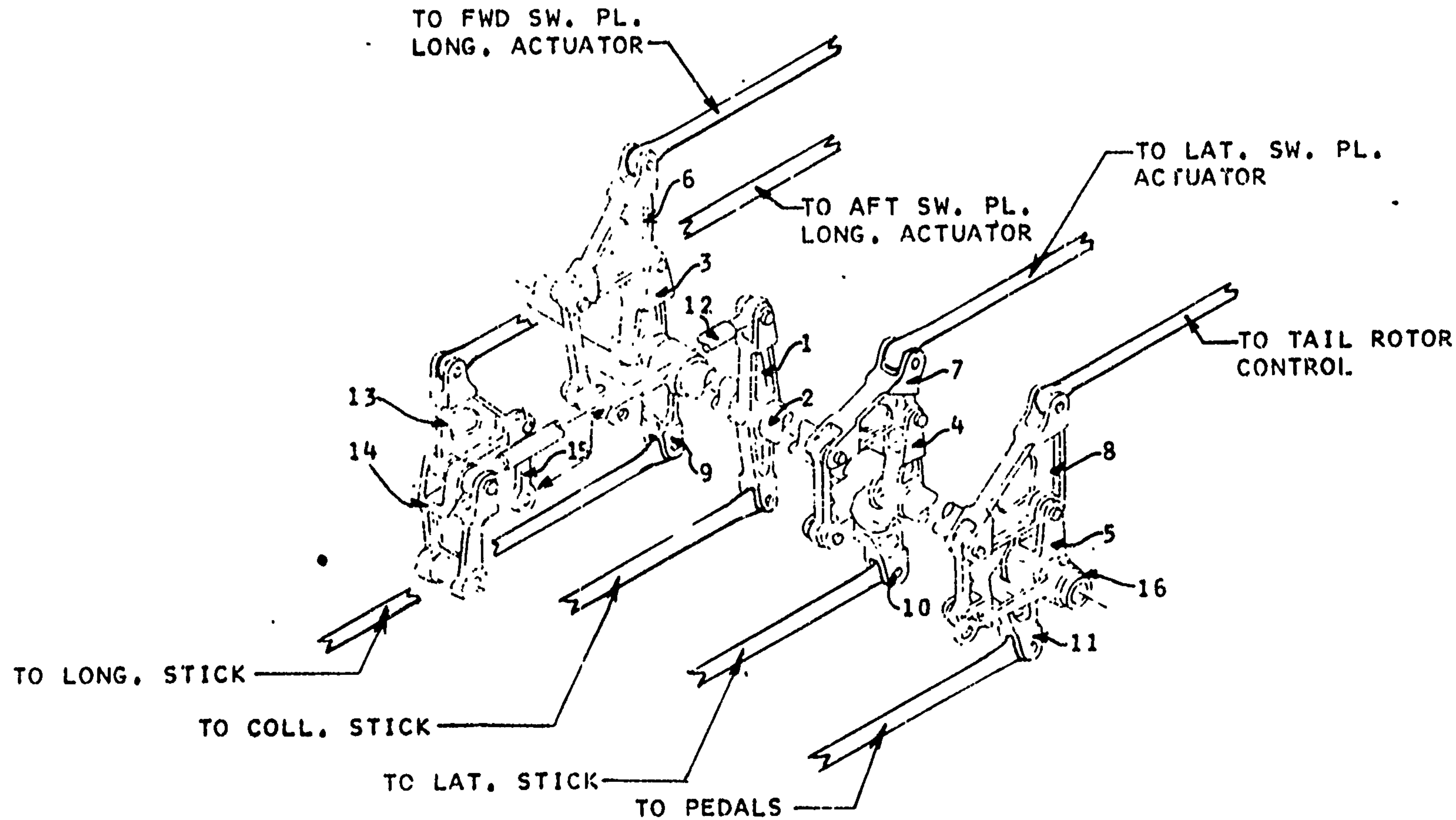


FIGURE 3-12. CH-53 MIXER INSTALLATION BEFORE MODIFICATION

and 11, which are mounted to turn freely on torque-tube 2. If the stick and pedals are held fixed while bell-crank 1 is rotated clockwise in response to a collective pitch input, then the output points of bell-cranks 6, 7, and 8 will all move aft. A similar motion is imparted through rod 12 to bell-crank 13, mounted on idler 14. Members 13 and 14 are shown out of true position for clarity. The lower end of link 15 is actually mounted on bell-crank 9 as indicated by the arrows. Therefore, an input is given, in the same direction, to all three swashplate actuators, and to the tail rotor, as a result of a collective pitch input. If bell-cranks 6, 7, and 13 all had the same length output arms, the swashplate would move with "pure" collective pitch. Bellcrank 7, however, is shorter than the other two, so that a lateral cyclic pitch component is introduced in conjunction with collective, in order to compensate for the tail rotor pitch introduced by bell-crank 8.

If the cyclic stick is moved fore and aft while the collective pitch stick is held fixed, bell-crank 9 is rotated, and motion is imparted to bell-cranks 6 and 13, but in opposite directions, causing the swashplate to be tilted for longitudinal cyclic pitch. Lateral stick motion causes motion of only bell-cranks 10 and 7, to tilt the swashplate laterally. Rudder pedal motion causes motion of only bell-cranks 11 and 8 to change the tail rotor pitch.

Arm 16, which is bolted to torque-tube 2 is connected to the turbine fuel control system, so that a change in collective pitch, which rotates torque-tube 2, will reset the turbine governor to counteract the normal governor droop resulting from a change in power level.

The design task, therefore, is to change arm lengths on appriate bell-cranks of the mixing unit in each helicopter to produce the desired combinations of cyclic and collective pitch for the new tandem configuration. The major constraint is not to exceed the extremes of cyclic or collective pitch available on the CH-53. The requirement for differential collective pitch reduces the amount available for "pure" collective pitch, and the requirement for differential lateral cyclic pitch for yaw control reduces the amount available for roll control.

Most of the functions of the CH-53D mixing unit are also applicable to the multi-lift system. The major difference is that longitudinal cyclic stick motion must produce differential collective pitch on the front and rear rotors. It is also desirable to combine this with longitudinal cyclic pitch for better precision hovering over a spot. A second point of difference is that for torque balance a collective pitch increase should produce a left lateral cyclic pitch in the front rotor (just as in the single CH-53), but a right lateral cyclic pitch in the rear rotor. A third change is that the rudder pedal input should not only change tail-rotor pitch (on the aft helicopter), but should also cause differential lateral cyclic pitch on the two main rotors to provide a more effective yaw control. These changes are shown schematically in Fig. 3-13 and 3-14.

3.3.3 Interconnection of Engine Controls

MHHLS system has all 4 engines fully controllable from the forward cockpit. A duplicate engine control quadrant will be installed on the cockpit roof, adjacent to that which controls the engines of the forward CH-53D. This quadrant will be linked mechanically with engine control levers of the engines of aft CH-53D, as shown schematically in Fig. 3-15.

Additional electric speed trim switches will be installed on the pilot's and co-pilot's collective stick control panels to trim the speed of the engines of aft CH-53D.

3.3.4 Automatic Flight Control System (AFCS)

The CH-53D AFCS is basically suitable for stabilizing the MHHLS. The following changes are required.

a. Replace the removable "gain capsule" with one with gains adapted to the MHHLS requirements (forward helicopter only).

b. Disconnect the AFCS electronics from the AFCS servo actuators (aft helicopter). It is not needed for the MHHLS.

c. Install wiring so that signals from the forward AFCS electronics unit operate on the AFCS servo actuators in both helicopters. The AFCS servo actuators are connected "upstream" of the mixing unit, so that the modification to the mixing units for the cockpit controls are equally suitable for the AFCS.

3.3.5 Summary of Control System Modifications

a. Interconnect the cockpit flight and engine controls mechanically, in a flexibly mounted conduit which isolates the controls from structural deflections between the two helicopters.

b. Replace the mixing unit in each helicopter with one in which the mixing ratios are adjusted and suitable interconnections are added to suit the requirements of the MHHLS.

c. Install wiring so that the AFCS in the forward helicopter will operate the AFCS actuator in both helicopters.

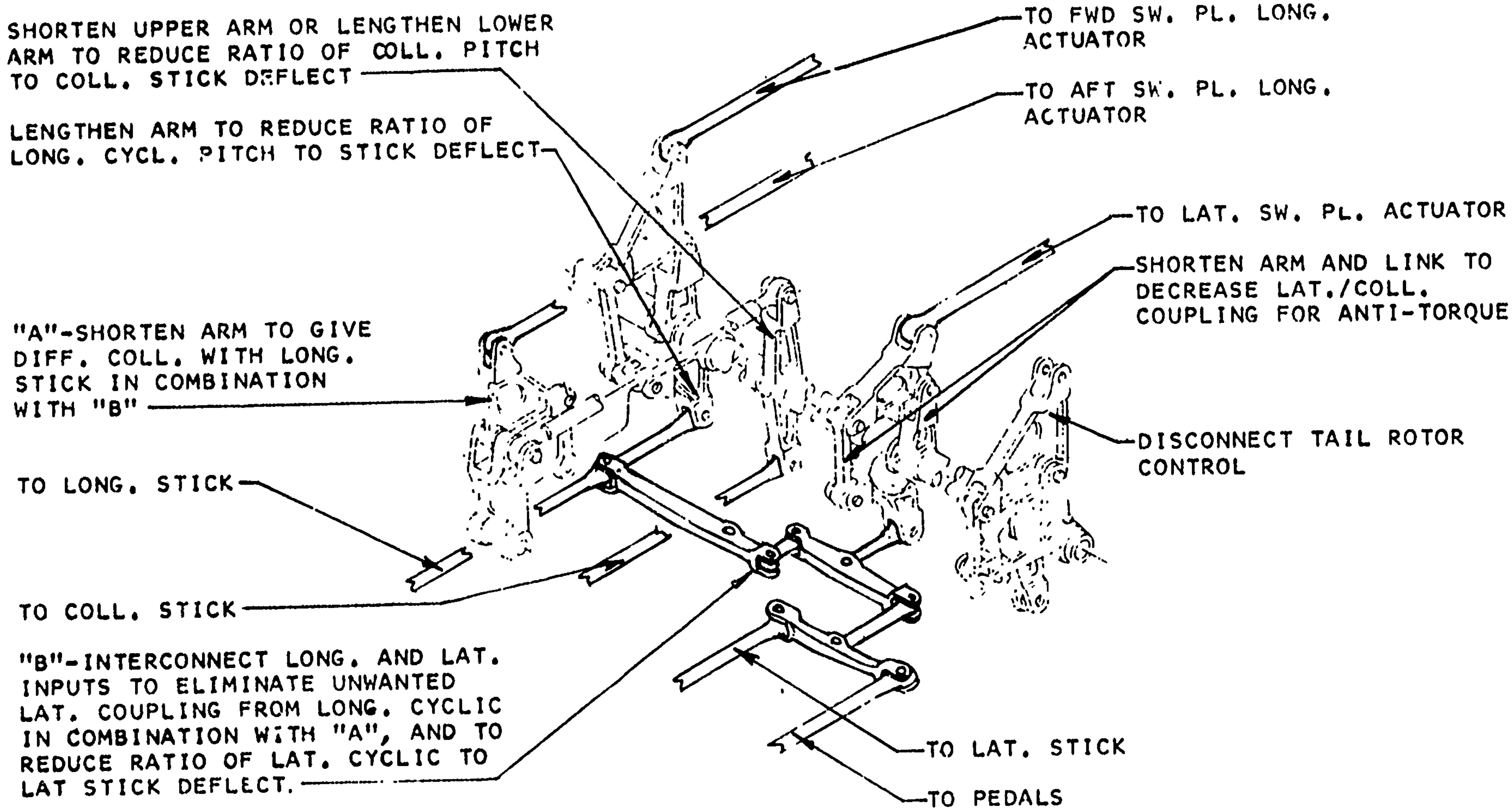


FIGURE 3-13. MODIFIED MIXER INSTALLATION, FORWARD HELICOPTER

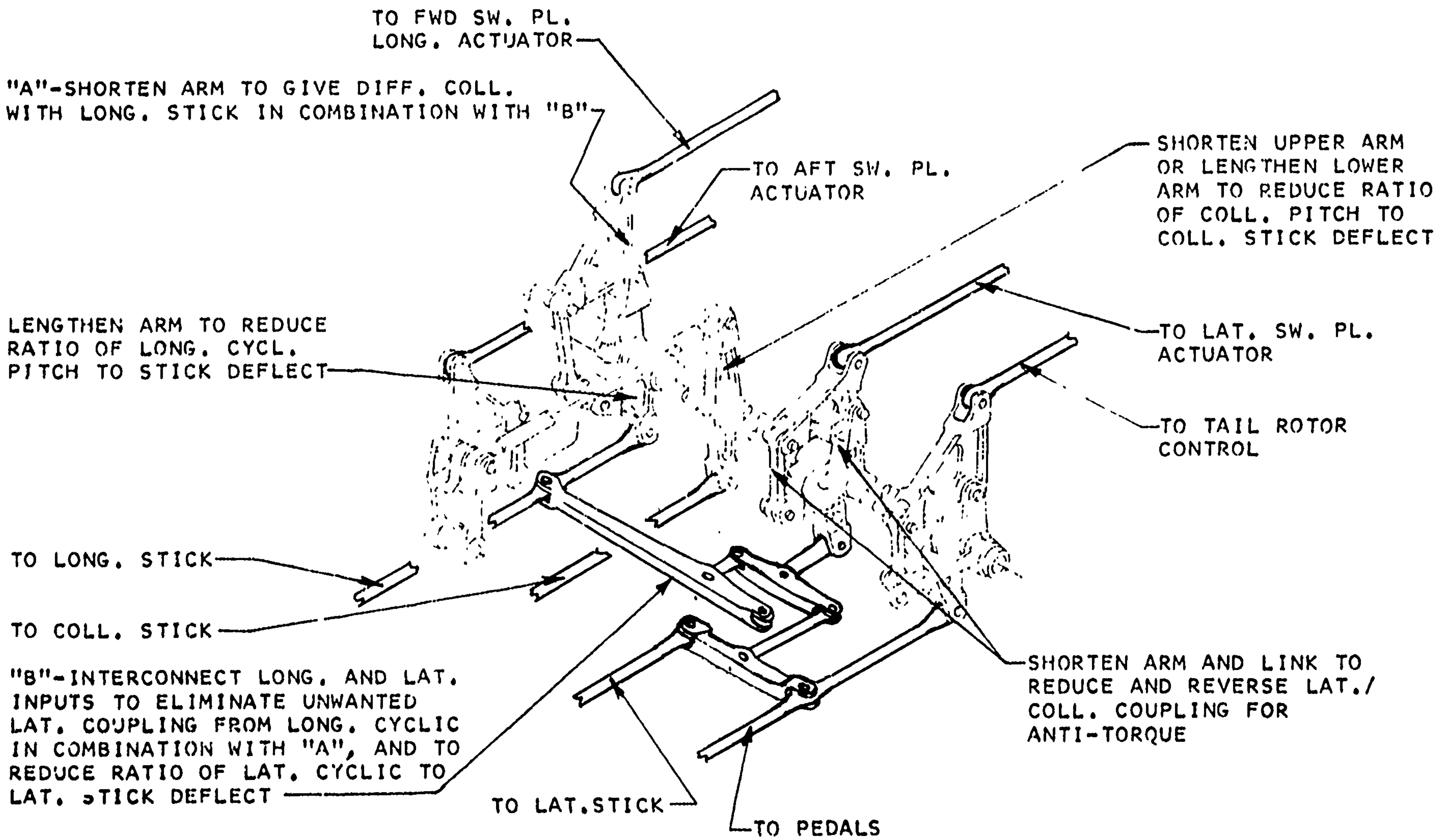
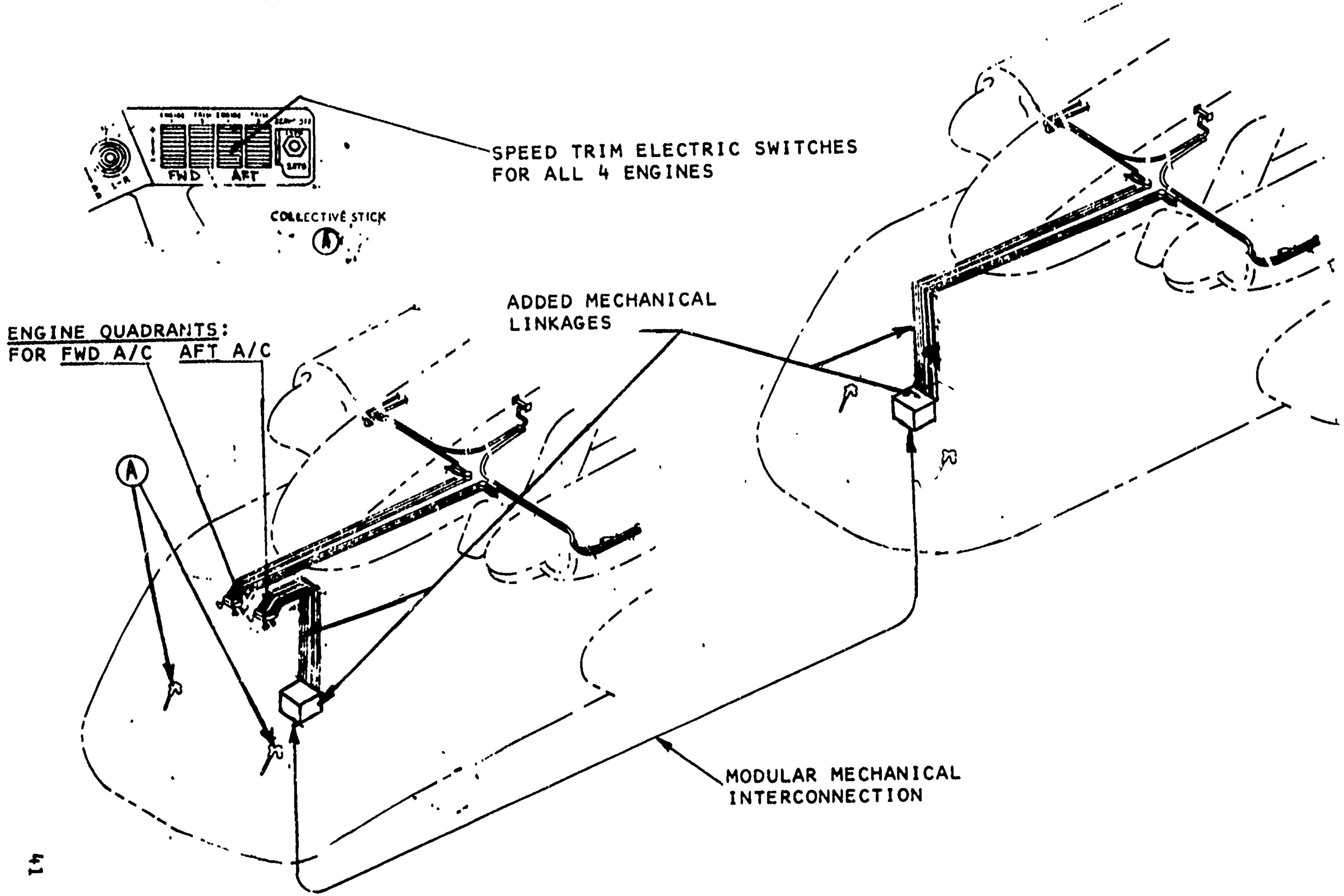


FIGURE 3-14. MODIFIED MIXER INSTALLATION, AFT HELICOPTER

FIGURE 3-15. MHHLS ENGINE SPEED CONTROL SYSTEM SCHEMATIC



d. Replace AFCS electronics unit with a modified unit which has the proper gains for the MHHLS configurations.

3.4 ASSEMBLY AND DISASSEMBLY PROCEDURES

The total conversion process to provide an MHHLS capability may be divided into two distinct tasks - the first being the permanent aircraft modifications required to accept the MHHLS field conversion kit and the second being the final assembly of an MHHLS system in the field using two modified CH-53D's. A flow chart of assembly procedures for converting two CH-53D's into one MHHLS is shown in Fig. 3-16.

Prior to utilization as a unit of a MHHLS, a CH-53D must be modified to accept the various attachments, additions and variations that will occur later when it is assembled in the field or on shipboard to be an MHHLS. The depot modifications are discussed in Section 4.5. This "standard depot modification" enables the CH-53D to serve as either a forward or aft unit of the MHHLS.

The final assembly of an MHHLS system may be divided into three major areas of effort: first, the field preparation of the two depot modified CH-53's as a forward or aft vehicle by the installation of the respective field kit; second, the pre-assembly of the interconnecting structure preparatory to joining the two aircraft; and last, the joining together of the three elements -- forward aircraft, aft aircraft and interconnecting structure -- into a complete MHHLS system. The assembly sequence is illustrated in Fig. 3-17, and details of the assembly procedure and man hour estimates are discussed in Operational Aspects.

FIGURE 3-16

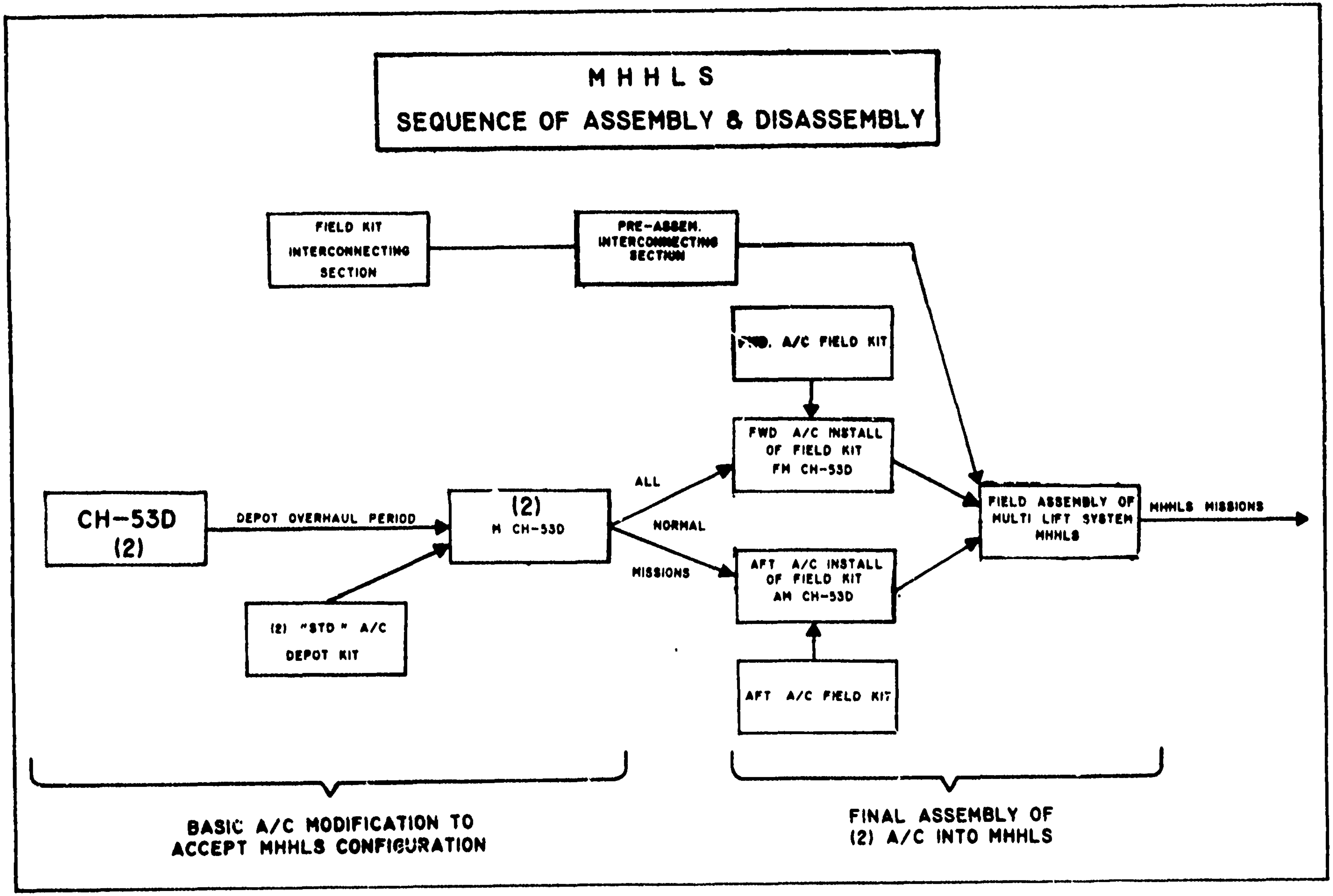
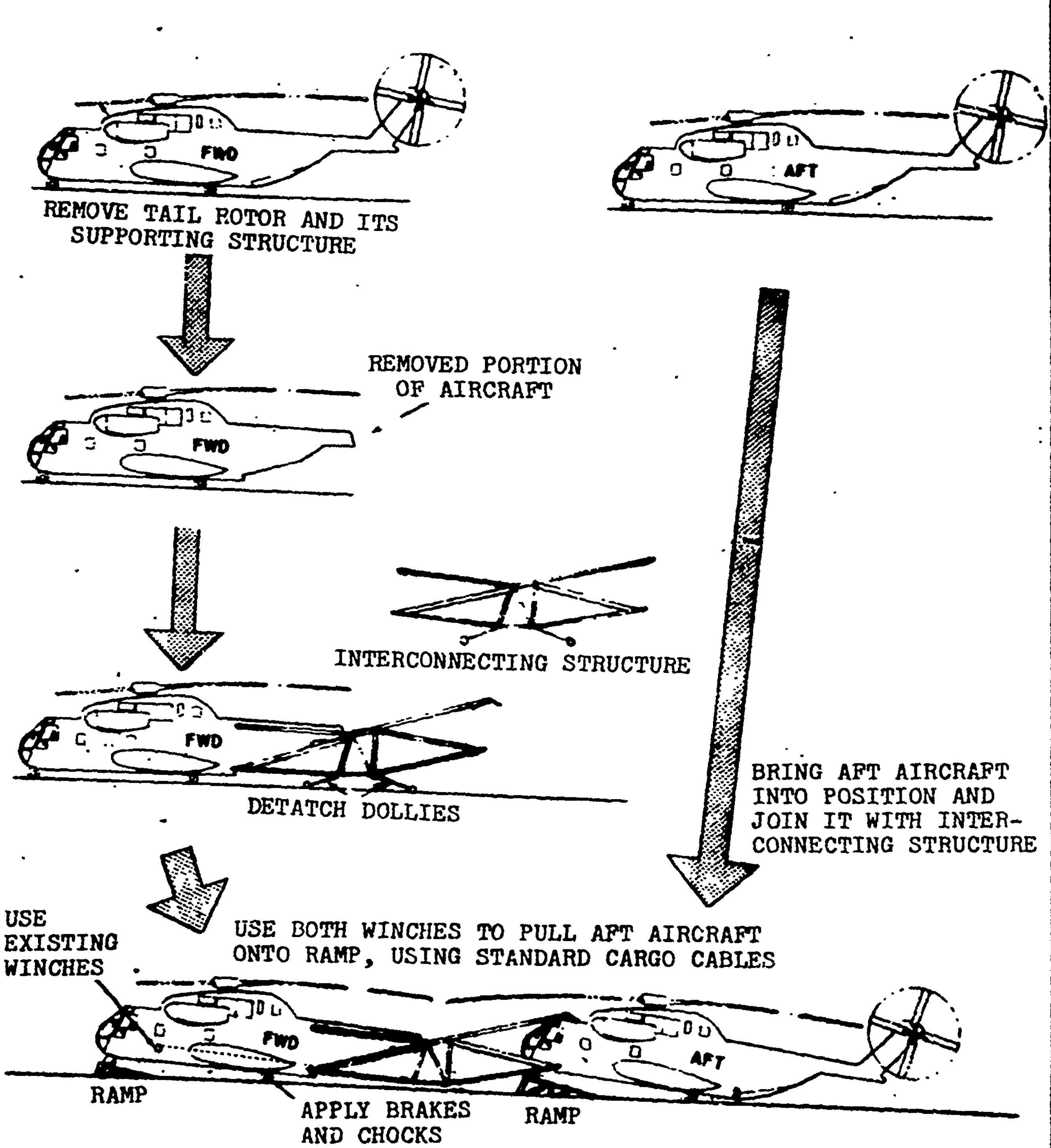

MHHLS
SEQUENCE OF ASSEMBLY & DISASSEMBLY
FIELD KIT INTERCONNECTING SECTION
PRE-ASSEM. INTERCONNECTING SECTION
A/C FIELD KIT
FWD A/C INSTALL OF FIELD KIT FM CH-53D
CH-53D (2)
DEPOT OVERHAUL PERIOD
(2) M CH-53D
ALL
NORMAL
MISSIONS
AFT A/C INSTALL OF FIELD KIT AM CH-53D
FIELD ASSEMBLY OF MULTI LIFT SYSTEM MHHLS
MHHLS MISSIONS
(2) "STD" A/C DEPOT KIT
AFT A/C FIELD KIT
BASIC A/C MODIFICATION TO ACCEPT MHHLS CONFIGURATION
FINAL ASSEMBLY OF (2) A/C INTO MHHLS

FIGURE 3-17

ASSEMBLY SEQUENCE DIAGRAM NOSE-TO-TAIL CONFIGURATION



4. ANALYSIS OF SELECTED CONFIGURATION

A feasibility investigation was made of the selected MHHLS configuration, which consists of two CH-53D helicopters mounted nose-to-tail in tandem, with the tail rotor and its pylon removed from the forward helicopter. The investigation considered the following aspects of feasibility.

a. Weights and Performance

b. Structure

c. Flying Qualities

d. Reliability and availability

e. Complexity and cost of conversion

f. Operational aspects

The remainder of this report presents the results of the investigations in the order given above.

4.1 WEIGHTS AND PERFORMANCE

4.1.1 Weight and Center of Gravity

Weight empty of the MHHLS has been estimated on the following basis.

a. Incorporation at depot level of all required permanent modifications so that any modified CH-53D can become either a forward or an aft aircraft. This is designated as a "standard" aircraft. The MHHLS is then field assembled as shown by removing "mandatory" items (such as the tail rotor of the forward helicopter) and adding necessary components as shown in table 4-1.

b. Field removal of those items of equipment which can be removed or re-installed within thirty minutes, as shown in Table 4-1. These "optional removal items" save 1258 pounds per CH-53D, for a total of 2516 pounds per MHHLS.

Payload-Radius curves are shown on the basis of the weights shown in Table 4-1, which shows an operational, zero-fuel weight of 50,468 pounds.

4.1.1.1 Balance

At the operational weight with full fuel and no payload, the c.g. of the MHHLS lies 1 inch forward of the bisector of the rotor

TABLE 4-1. MHHLS SUMMARY WEIGHT STATEMENT

	(2) CH-53D DEPOT MODS			FIELD MODS					
				MANDATORY CHANGES				OPTIONAL CHANGES	
	UN-MODIF	DEPOT MODS	DEPOT MODIFIED	FWD A/C	AFT A/C	INTERCON ASSY	MAX.WT. MHHLS	30 MIN. REMOVALS	BASIC MHHLS
ROTOR GROUP									
BLADE ASSEMBLY	4,239.8		4,239.8				+4,239.8		+4,239.8
HUB	800.4		800.4				+800.4		+800.4
HINGE AND BLADE RETENTION	3,969.2		3,969.2				+3,969.2		+3,969.2
TAIL GROUP									
TAIL ROTOR	744.0		744.0	-372.0			+372.0		+37[illegible].0
STABILIZER-BASIC STRUCTURE	202.4		202.4	-101.2			+101.2		+101.2
BODY GROUP									
FUSELAGE OR HULL-BASIC STRUCTURE	6,393.2	+654.0	7,047.2	+52.1	+345.0	2,346.0	+9,790.3		+9,675.3
BOOMS-BASIC STRUCTURE	1,037.6		1,037.6				+1,037.6		+1,037.6
SECONDARY STRUCTURE-FUSELAGE OR HULL	1,345.8		1,345.8				+1,345.8		+1,345.8
BOOMS	3.4		3.4				3.4		+3.4
DOORS, PANELS & MISC.	2,743.8	+40.0	2,783.8	-3.0	-5.0		+2,775.8	-697.4	+2,078.4
ALIGHTING GEAR	2,054.6	+128.0	2,182.6	-39.7			+2,142.9		+2,142.9
FLIGHT CONTROLS GROUP									
COCKPIT CONTROLS	252.0		252.0				+252.0		+252.0
AUTOMATIC STABILIZATION	193.6	+40.0	233.6				+233.6		+233.6
SYSTEM CONTROLS-ROTOR NON ROTATING	490.0	+34.0	524.0	+117.3	+38.0	+125.0	+804.3		+804.3
ROTATING	524.8		524.8				+524.8		+524.8
HYDRAULIC BOOST	889.6		889.6				+889.6		+889.6
ENGINE SECTION OR NACELLE GROUP	788.4		788.4				+788.4		+788.4
DOORS, PANELS AND MISC.		+20.0	20.0	-6.0	-6.0		+8.0		+8.0
PROPULSION GROUP									
ENGINE INSTALLATION	2,776.0		2,776.0				+2,776.0		+2,776.0
ACCESSORY GEAR BOXES AND DRIVES	218.8		218.8				+218.8		+218.8
AIR INDUCTION SYSTEM	102.8		102.8				+102.8		+102.8
EXHAUST SYSTEM	69.8		69.8				+69.8		+69.8
LUBRICATING SYSTEM	109.4		109.4				+109.4		+109.4
FUEL SYSTEM	777.8		777.8				+777.8		+777.8
ENGINE CONTROLS	99.2	+60.0	159.2				+159.2		+159.2
STARTING SYSTEM	304.4		304.4				+304.4		+304.4
DRIVE SYSTEM		+12.0	12.0		+107.0		+119.0		+119.0
GEAR BOXES	6,317.0	+140.0	6,457.0	-42.6	+250.0		+6,664.4		+6,664.4
LUBE SYSTEM	123.6		123.6				+123.6		+123.6
CLUTCH AND DISC	191.4		191.4				+191.4		+191.4
TRANSMISSION DRIVE	596.2		596.2	+54.0		+507.0	+1,157.2		+1,157.2
ROTOR SHAFT	900.0		900.0				+900.0		+900.0
AUXILIARY POWER PLANT GROUP	480.4		480.4				+480.4		+480.4
INSTRUMENT AND NAVIGATIONAL EQUIPMENT GROUP									
INSTRUMENTS	515.4	+8.0	523.4	+20.0			+543.4		+943.4
NAVIGATIONAL EQUIPMENT	299.6		299.6				+299.6		[illegible]
HYDRAULIC AND PNEUMATIC GROUP	277.0		277.0				+277.0		+277.0
ELECTRICAL GROUP	1,239.0		1,239.0				1,239.0		1,239.0
ELECTRONICS GROUP	1,346.2	+12.0	1,358.2			+175.0	+1,533.2		+1,533.2
ARMAMENT GROUP-INCL GUNFIRE PROTECTION	47.0		47.0				+47.0		+47.0
FURNISHINGS AND EQUIPMENT GROUP									
ACCOMMODATIONS FOR PERSONNEL	1,230.8		1,230.8				+1,230.8	-288.6	+942.2
MISCELLANEOUS EQUIPMENT X INCL	780.0	+12.0	792.0				+792.0	-248.2	+543.8
FURNISHINGS	427.0		427.0				+427.0	-388.0	+39.0
EMERGENCY EQUIPMENT	155.2		155.2				+155.2		+155.2
AIR CONDITIONING AND ANTI-ICING EQUIPMENT	641.4		641.4				+641.4	-223.0	+418.4
AUXILIARY GEAR GROUP	767.8		767.8				+767.8		+767.8
LOAD HANDLING GEAR				-42.0		+400.0	+358.0	-669.6	-311.6
MANUFACTURING VARIATION	-381.2		-381.2				-381.2		-381.2
TOTAL WEIGHT EMPTY	47,089.6	+1,160.0	48,244.6	-363.1	+729.0	+3,553.0	52,163.5	-2,514.8	49,648.7

TRAPPED FUEL	30.0
TRAPPED OIL	8.0
ENGINE OIL	96.0
WINDSHIELD WASHER FLUID	26.0
CREW (3)	660.0
OPERATIONAL-ZERO-FUEL WEIGHT	50,468.7

axes. At maximum gross weight, the c.g. lies 9 inches forward of the bisector. The reason for this relatively small c.g. shift is because only one point is assumed for lifting the cargo. This point is 23 inches forward of the c.g. without payload.

The most forward and most aft c.g. positions are obtained by assuming a flight mission using full fuel, during which an engine failure occurs just after take-off and the mission continues until fuel is exhausted in one CH-53D and half of the fuel still remains in the other CH-53D. Under these conditions, the most aft c.g. is 18 inches aft of the bisector and the most forward is 20 inches forward of the bisector. These c.g. locations are shown on Fig. 3-1.

Because of the interconnecting shafting, gearboxes, and supports located on the starboard side, the lateral center of gravity is 2 inches to the right of the vertical plane through the rotor axes in the no-payload configuration. Locating the payload in this "central" vertical plane reduces the center-of-gravity effect in the fully loaded configuration to 1.36 inches to starboard.

"Standard" depot modifications of the CH-53D which make it suitable for use as either forward or aft MHHLS aircraft increase its weight empty by 580 pounds and move the c.g. forward by 1.6 inches, compared to its allowable range of 24 inches. The 580 pound increase in empty weight reduces the CH-53D payload capability by the same amount.

4.1.2 Performance

Performance has been calculated using CH-53D performance as a base, taken from Ref. (9). Hovering performance, out-of-ground effect, data was corrected for the fact that the MHHLS (2) coupled CH-53D helicopters have only one tail rotor and, therefore, only one-half the tail rotor loss per helicopter.

In hovering, the power transmitted through the interconnecting system is of the order of 4% of total power, and the losses in the interconnecting system would be 4% of this, or less than 0.2%. This loss was neglected in calculating hover performance, but it is included in forward flight calculations, where it increases to the order of 1% at 125 knots.

In assessing vertical drag (download), it was assumed that the interconnecting structure between the forward and rear helicopters replaces the tail rotor and pylon which is removed from the forward helicopter. To be consistent with the Navy study, Ref. (2), HIGE gross weights are obtained by applying the HIGE augmentation factor of 1.09, used in Ref. (2), for a 15-foot wheel height, to sea level conditions, and a factor of 1.034 for a 50-foot wheel height, for the 3000-foot altitude condition.

Power versus gross weight, and turbine power available, is shown on Fig. 4-1 for hovering in and out of ground effect at sea level 59°F., sea level 90°F., and 3000 feet, 91.5°F and for hover out of ground effect at 4000 feet, 95°F. The latter condition is not a naval requirement, but is included because it is the design condition for the Army heavy-lift helicopter.

Vertical rate of climb was calculated on the basis that, at the same disk loading, altitude and temperature, the MHHLS would have the same rate of climb as the CH-53D, taken from Ref. (9), for the same excess power per rotor (excess above the power required to hover out of ground effect). This implicitly assumes that excess power is distributed between main and tail rotors in the same proportion as for two single CH-53D's, and is conservative because the MHHLS has only one tail rotor. Vertical climb versus gross weight curves are shown on Fig. 4-2, -3 and -4, for sea level/59°F., sea level 90°F., and 3000 feet/91.5°F, respectively

For forward flight calculations, rotor profile power was taken from the CH-53D, per rotor, at the same weight, speed, and air density. Rotor induced power was taken as twice the CH-53D value at the same disk loading, then further increased to account for tandem rotor mutual interference. The factor for interference was derived from the longitudinal trim computer program for sea level, 59°F (see Section 4.3 Flying Qualities) which gives front and rear rotor power as an output and is a linear function of speed, varying from 1.00 at hover to 3.05 at 140 knots. As in the hover calculations, tail rotor losses were conservatively assumed as one-half the amount per rotor as the CH-53D. A plot of tail rotor loss versus speed, from Ref. (9), is shown on Fig. 4-5. Other mechanical losses were taken at 5.8% of total power for main gear box and accessory drives, and 4% of synchronizing shaft power for the additional gear meshes. Fig 4-6 shows the increase in equivalent drag area assumed for the MHHLS compared to a single CH-53D (taken from Ref 9) The drag area of the MHHLS, as given in Fig. 4-6, was calculated as follows. The drag area of the CH-53D was broken down into three parts: (a) the drag area at 0° angle of attack, less the rotor hub drag; (b) rotor hub drag; (c) the incremental drag varying with angle of attack. Part (a) was assumed to be increased by 50% in the MHHLS, since at 0° angle of attack, the frontal area is nearly the same, and the rear helicopter is largely blanketed by the front one. Part (b) was doubled for the MHHLS, since it has two hubs. Part (c) was increased by 70% because of the partial loss of blanketing in the range of angles of attack of interest.

Plots of power required versus speed are shown in Fig. 4-7, -8, and -9 for sea level/59°F., sea level/90°F , and 3000 feet/91.5°F , respectively. On each plot is also shown the power available from all four turbines, from three turbines (one-engine-out condition), and from two turbines (two engines out). Fig. 4-7 shows that at sea level, 59°F., the MHHLS with no payload can hover with two engines out, using 10-minute power on the remaining two, and can fly

FIGURE 4-1. 2 CH-53D MULTI-LIFT
HOVER POWER VS. GROSS WEIGHT

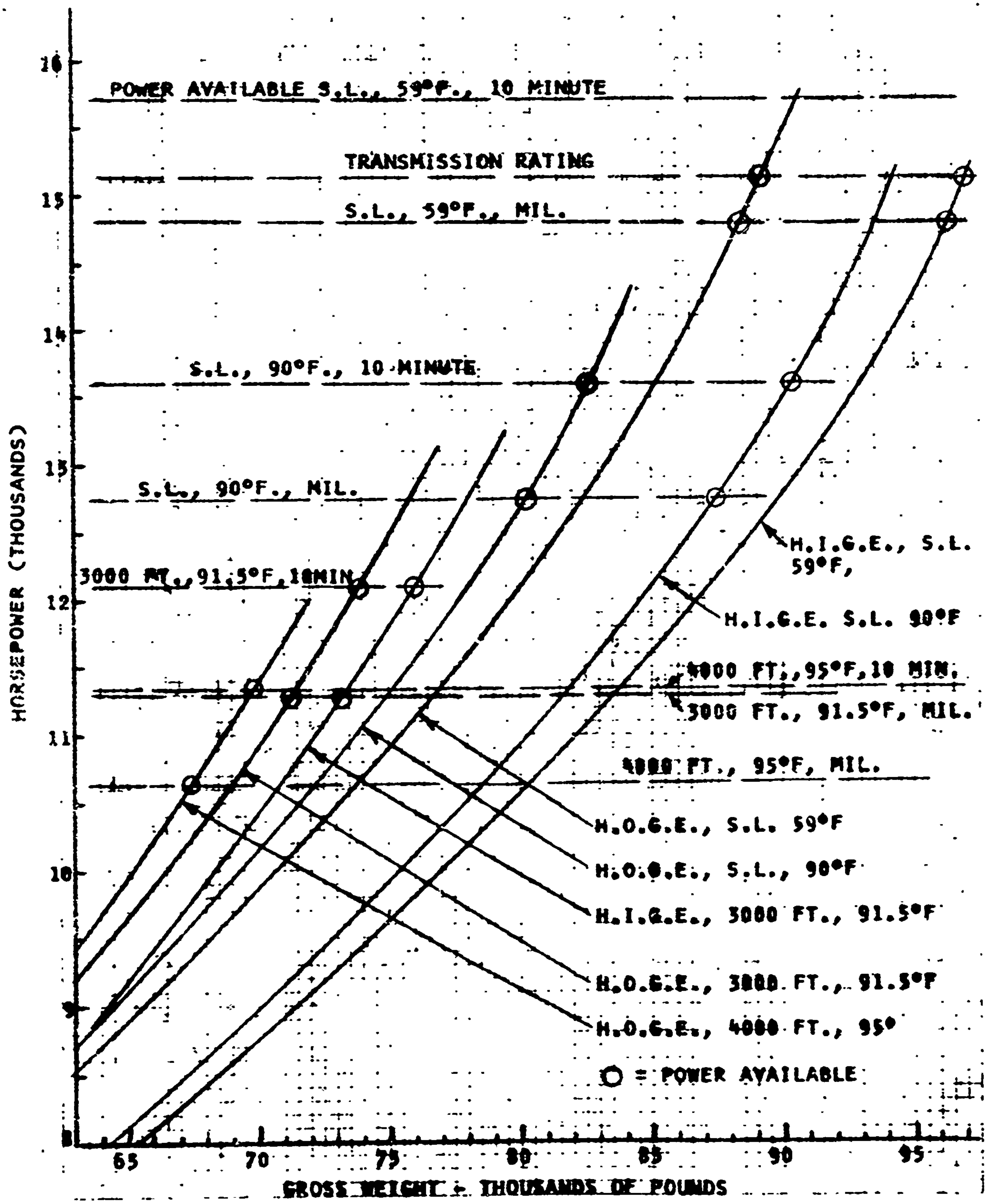


FIGURE 4-2. 2 CH-53D MULTI-LIFT

VERTICAL CLIMB VS. GROSS WEIGHT

SEA LEVEL, 59°F.

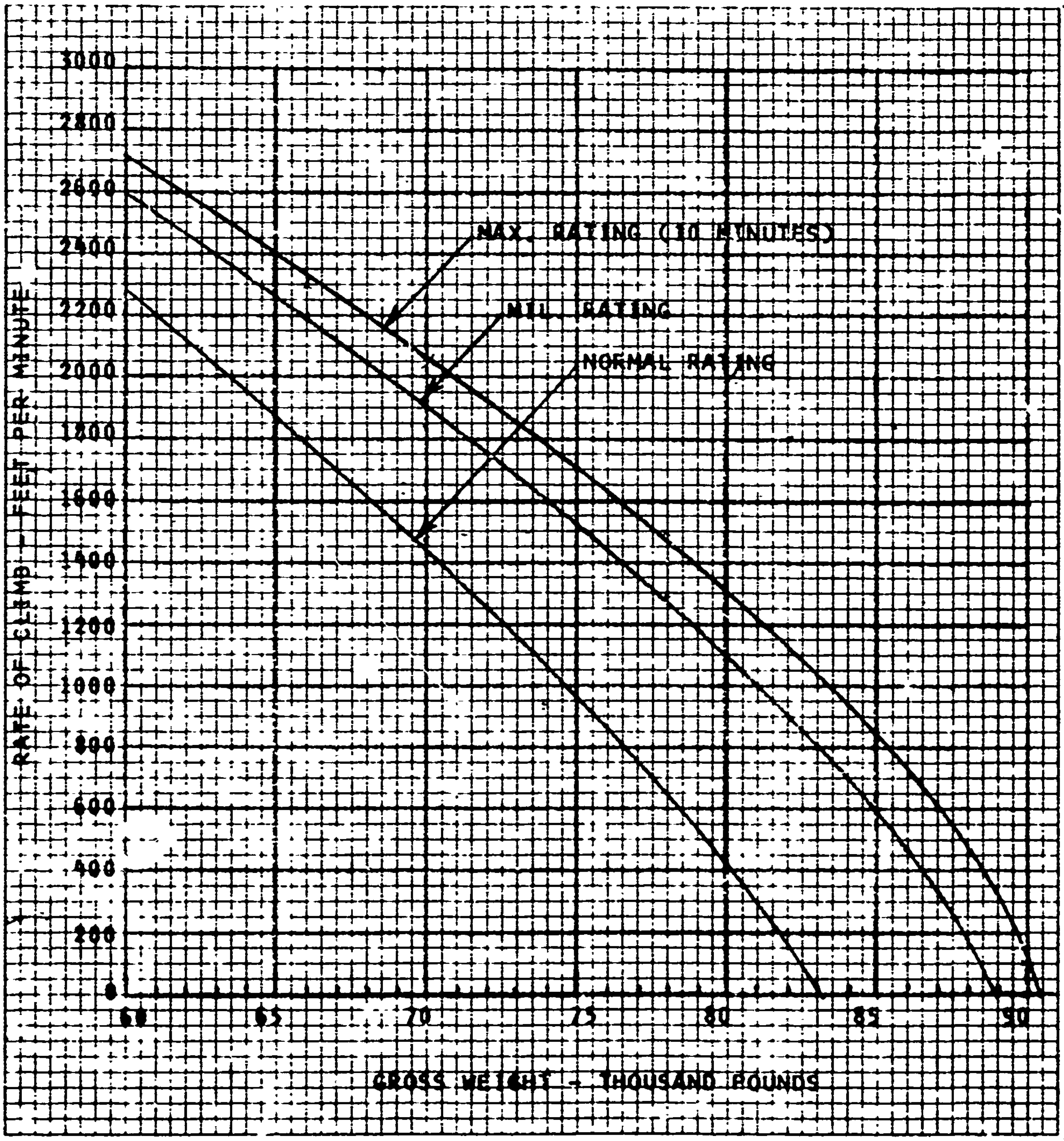


FIGURE 4-3. 2 CH-53D MULTI-LIFT

VERTICAL CLIMB VS. GROSS WEIGHT

SEA LEVEL 90°F.

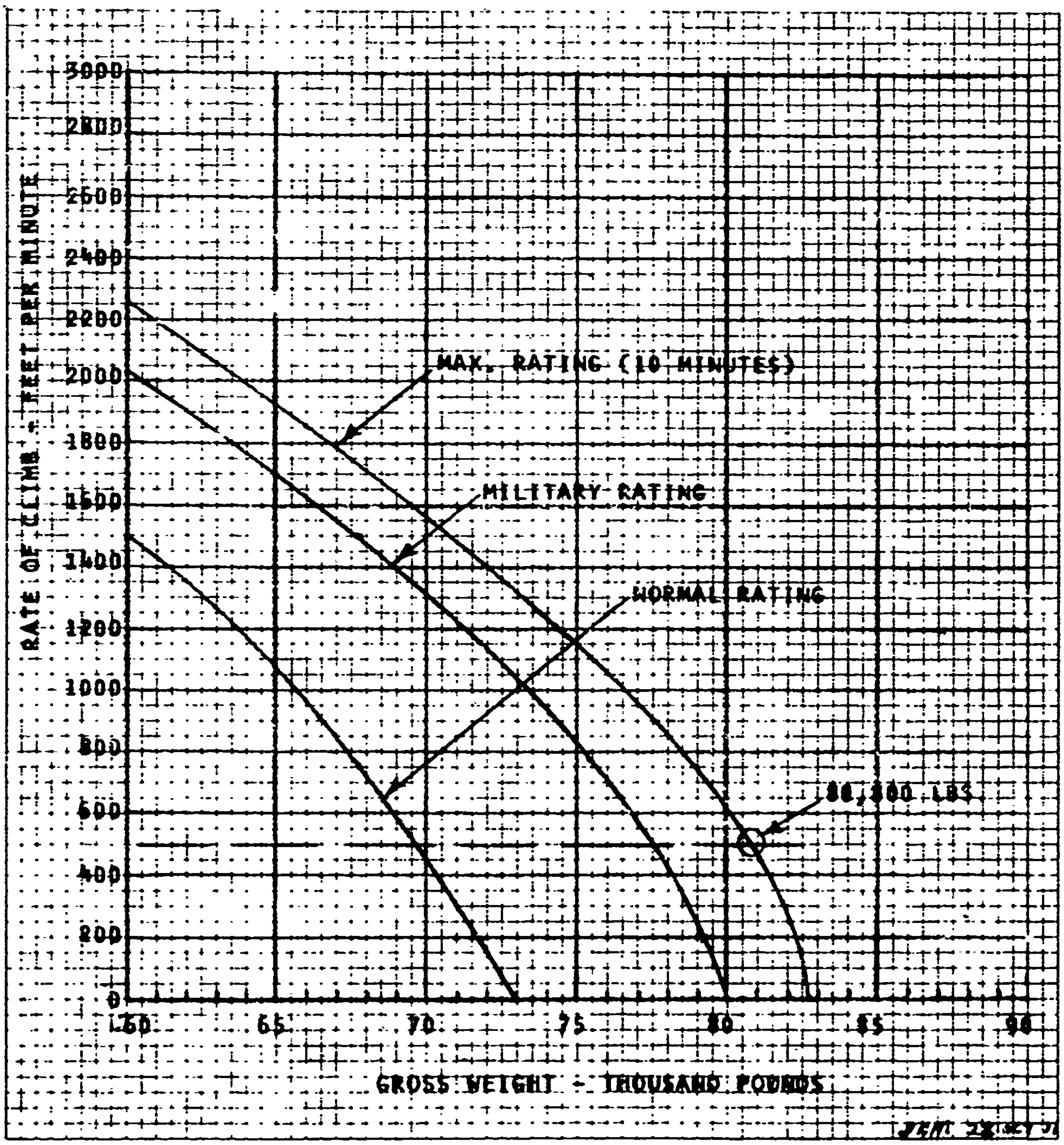


FIGURE 4-4. 2 CH-53D MULTI-LIFT

VERTICAL CLIMB VS. GROSS WEIGHT

3,000 FEET, 91.5°F.

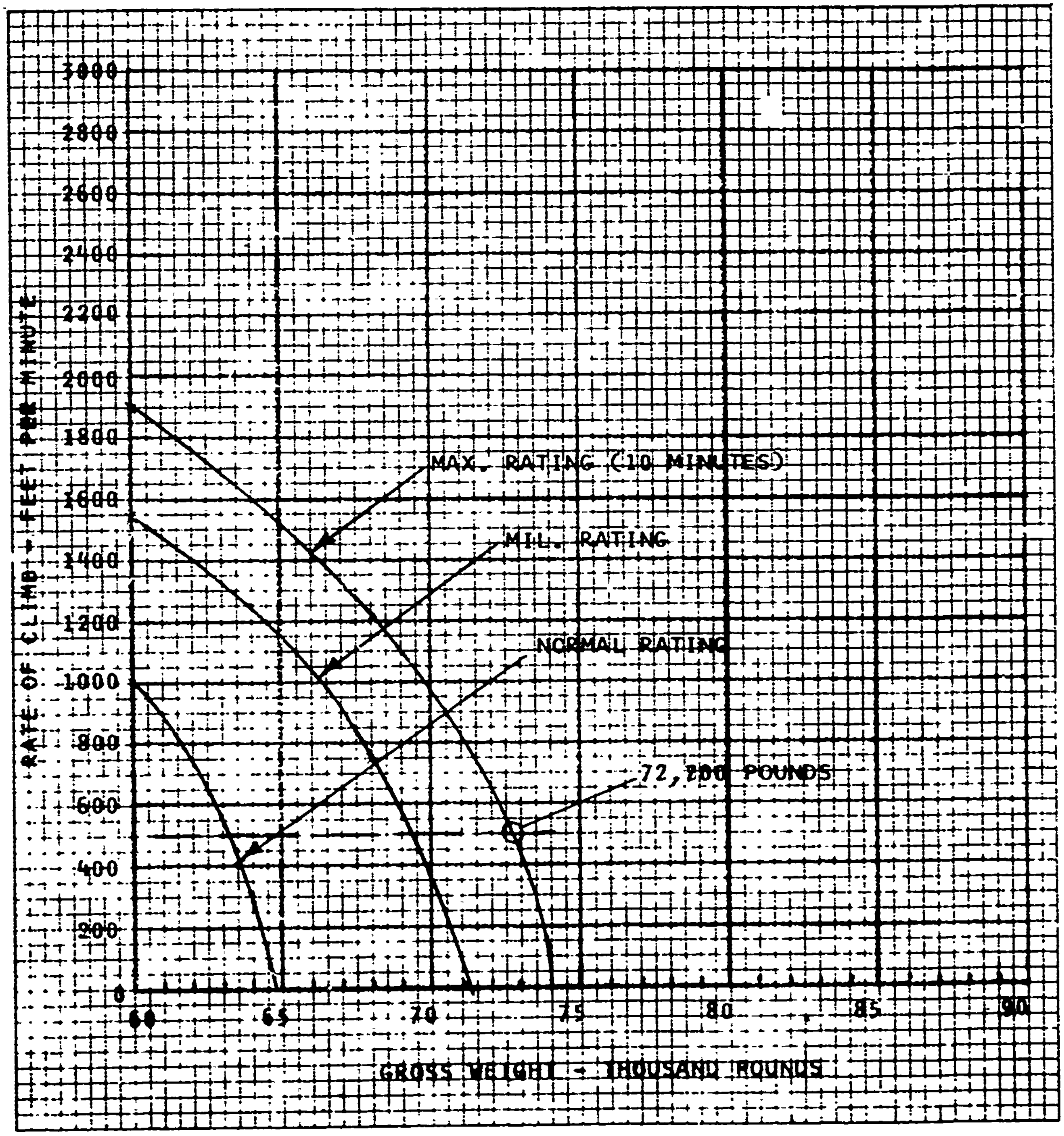


FIGURE 4-5. MECHANICAL AND AERODYNAMIC

TAIL ROTOR LOSSES VS. AIRSPEED

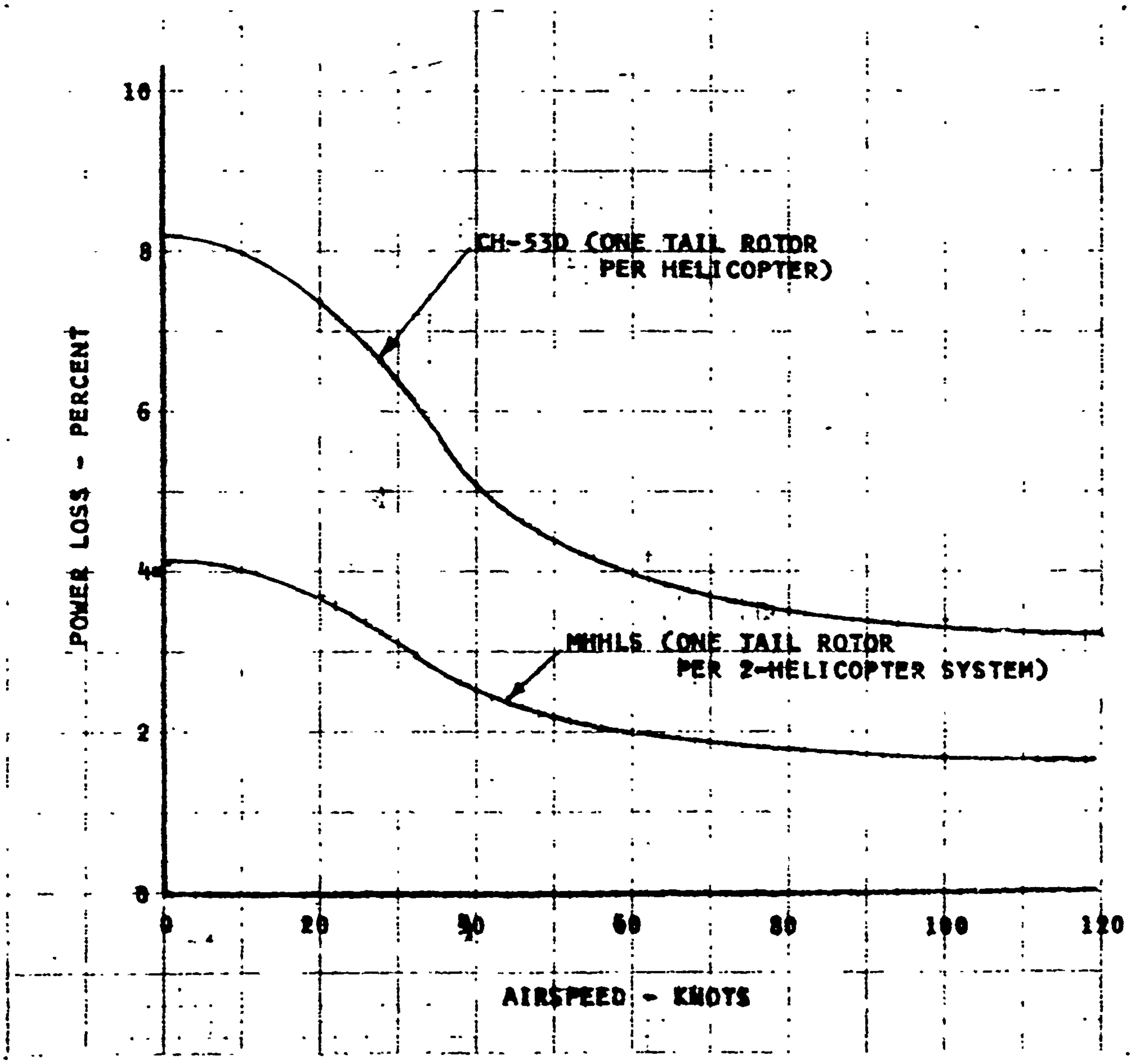


FIGURE 4-6. EQUIVALENT DRAG AREA VS. FUSELAGE ANGLE OF ATTACK

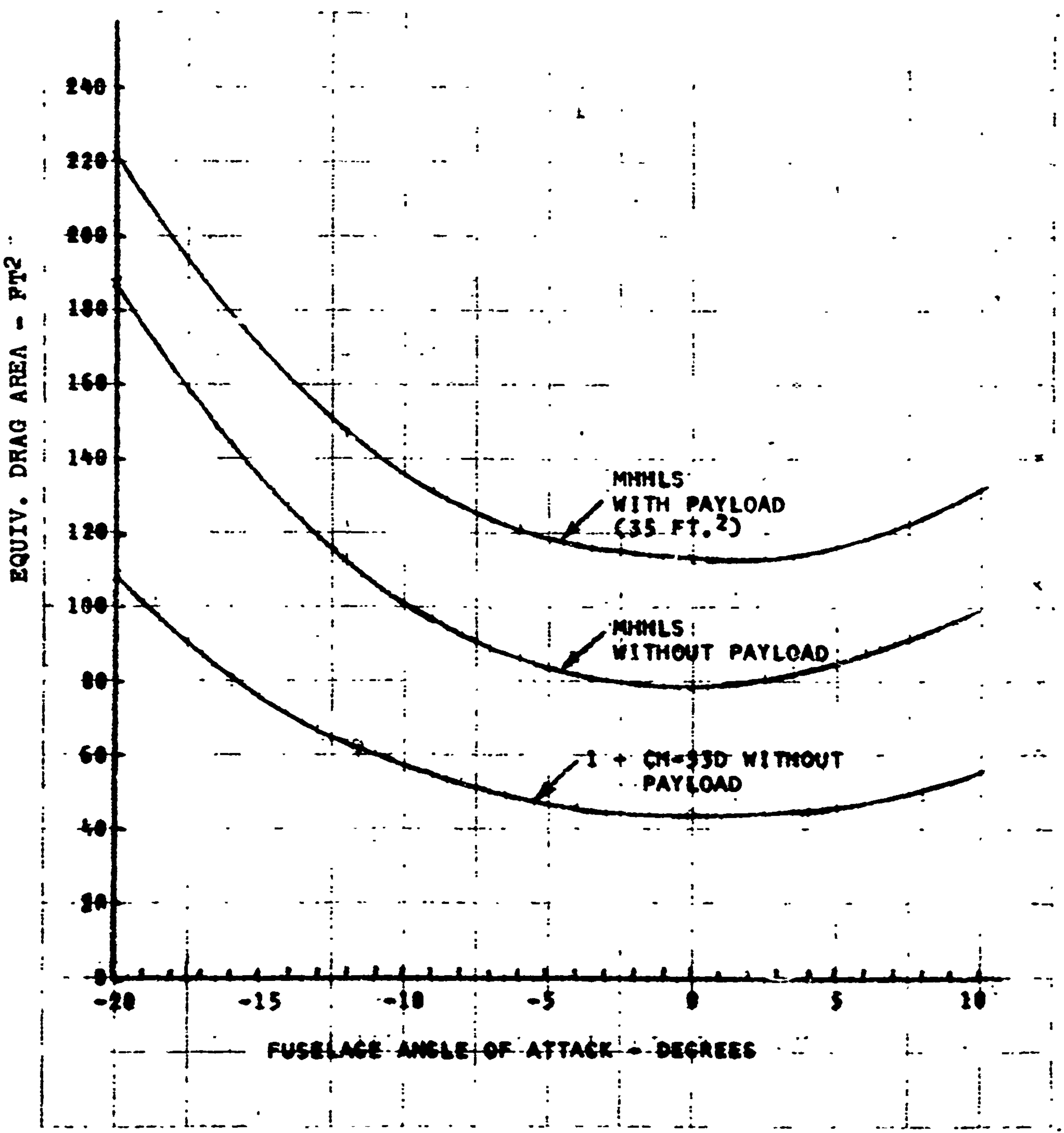


FIGURE 4-7. 2 CH-53D MULTI-HELICOPTER HEAVY LIFT
POWER VS. SPEED
H.O.G.E.
SEA LEVEL, 59°F

WITH PAYLOAD OF 35 SQ. FT. DRAG AREA EXCEPT AS NOTED

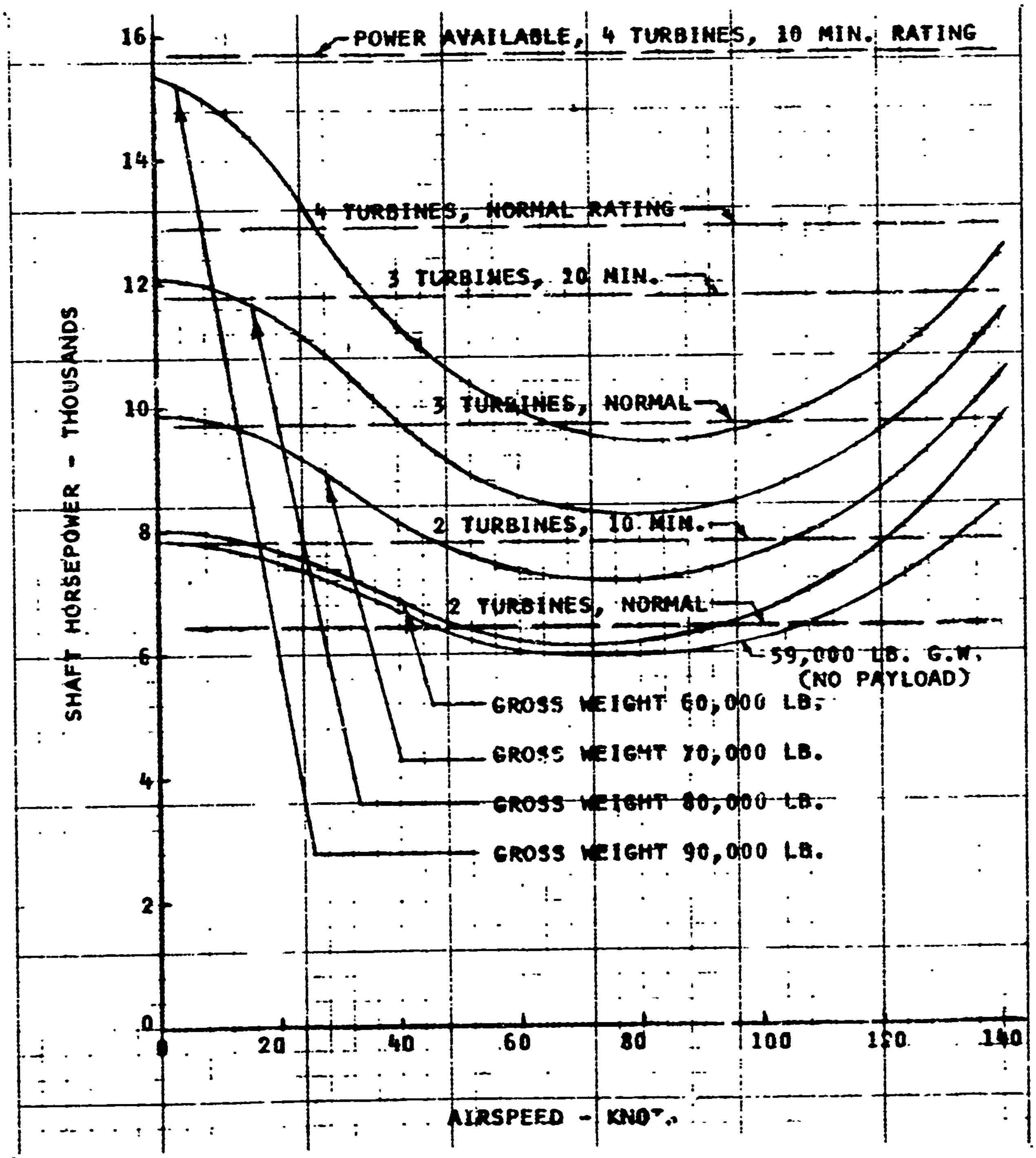


FIGURE 4-8. CH-53D MULTI-HELICOPTER HEAVY LIFT
POWER VS. SPEED
SEA LEVEL, 90°F
H.O.G.E.

WITH PAYLOAD OF 35 SQ. FT. DRAG AREA

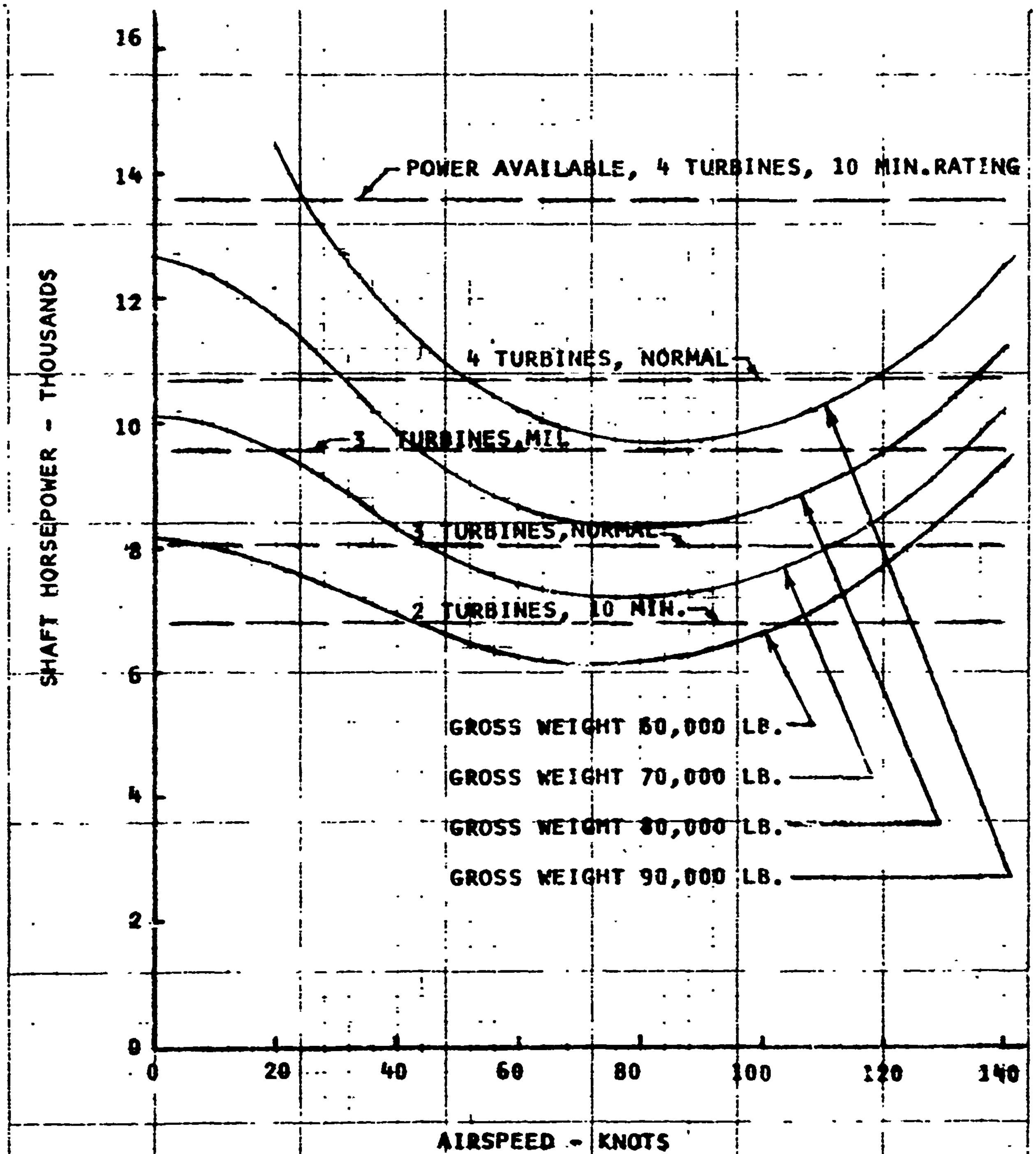
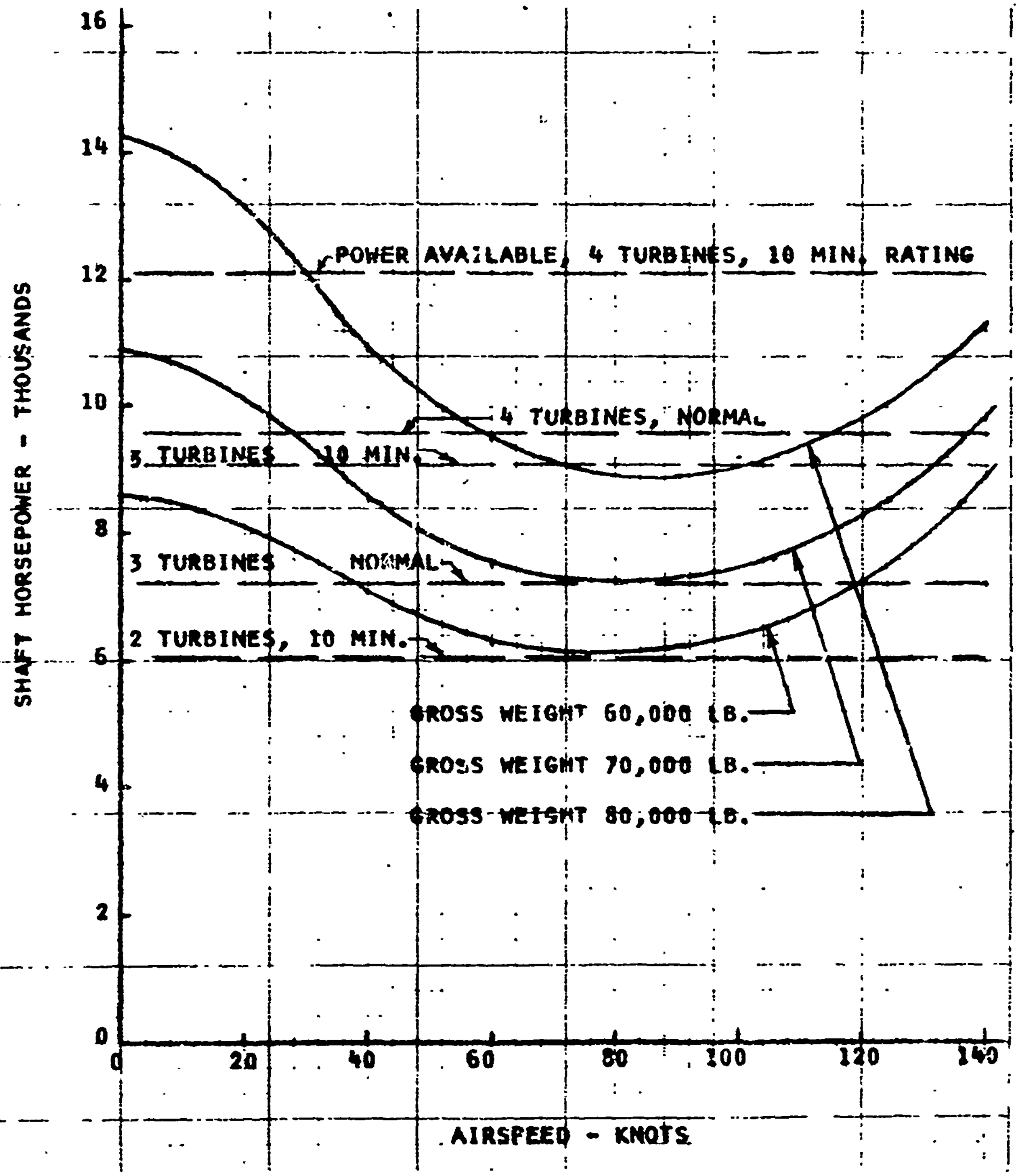


FIGURE 4-9. 2 CH-53D MULTI-HELICOPTER HEAVY LIFT
POWER VS. SPEED
3,000 FT., 91.5°F.
H.O.G.E.

WITH PAYLOAD OF 35 SQ. FT. DRAG AREA



at speeds between 45 and 110 knots using not more than normal rated power of two turbines.

Of more significance, at a gross weight of 78,500 pounds, corresponding to a 10-nautical mile payload of nearly 13 tons, the MHHLS can complete its mission with one engine out, including hover out of ground effect with payload, with the other three engines at their 10-minute rating, and can cruise at less than normal rating at speeds up to 125 knots. Even at the maximum weight studied (90,143 pounds), the MHHLS, with one engine out at sea level, 59°F, can slow down to 35 knots, a speed from which at least some types of cargo can be jettisoned from low altitude without damage.

Payload radius curves are shown in Fig. 4-10 and -11 for gross weights of the MHHLS based on the following criteria:

a. Hover out of ground effect (HOGE) at sea level, 90°F

b. Hover in ground effect (HIGE) at sea level, 90°F, 15 ft. wheel height

c. HOGE at 3,000 ft., 91.5°F

d. HIGE at 3,000 ft., 91.5°F, 50-foot wheel height

e. HOGE at 4,000 ft., 95°F

f. HIGE, one engine out, at sea level, 59°F, 15-foot wheel height

g. HIGE, one engine out, at sea level, 90°F, 15-foot wheel height

h. HIGE, one engine out, at 3,000 ft., 91.5°F, 50-foot wheel height

The mission profile for the payload-radius curves is derived from the basic Marine Corps heavy lift mission, and assumes the following:

(1) Warm-up, take-off and pick up load at the altitude and temperature noted, 5 minutes at normal rated power.

(2) Cruise out at sea level, 59°F, at 100 knots

(3) Hover out of ground effect for 5 minutes at midpoint with load

(4) Return at sea level, 59°F, at 100 knots with no load

(5) Land with 10% of initial fuel as reserve

FIGURE 4-10. MULTI-HELICOPTER HEAVY LIFT SYSTEM

PAYLOAD VS. RADIUS

H.I.G.E.

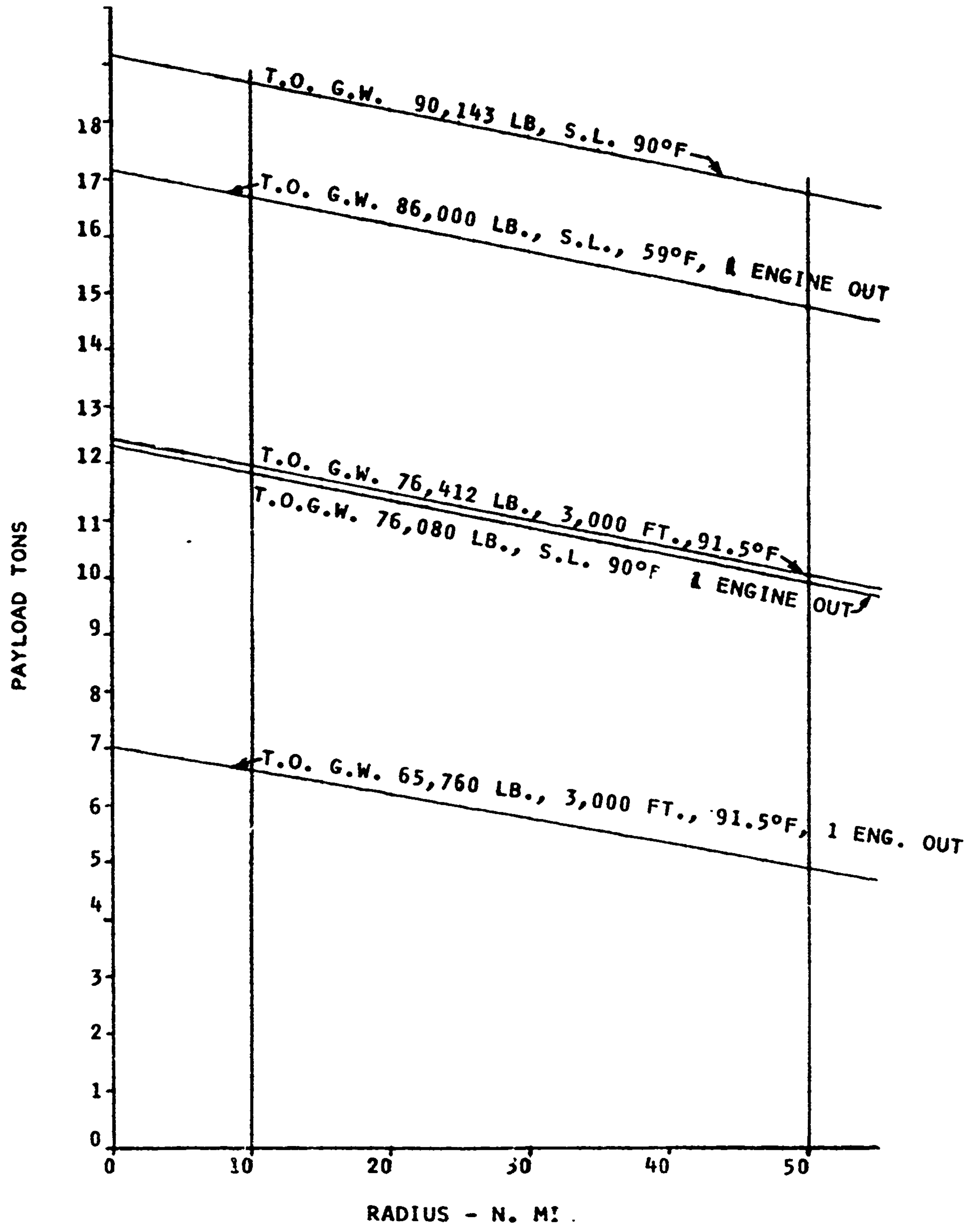
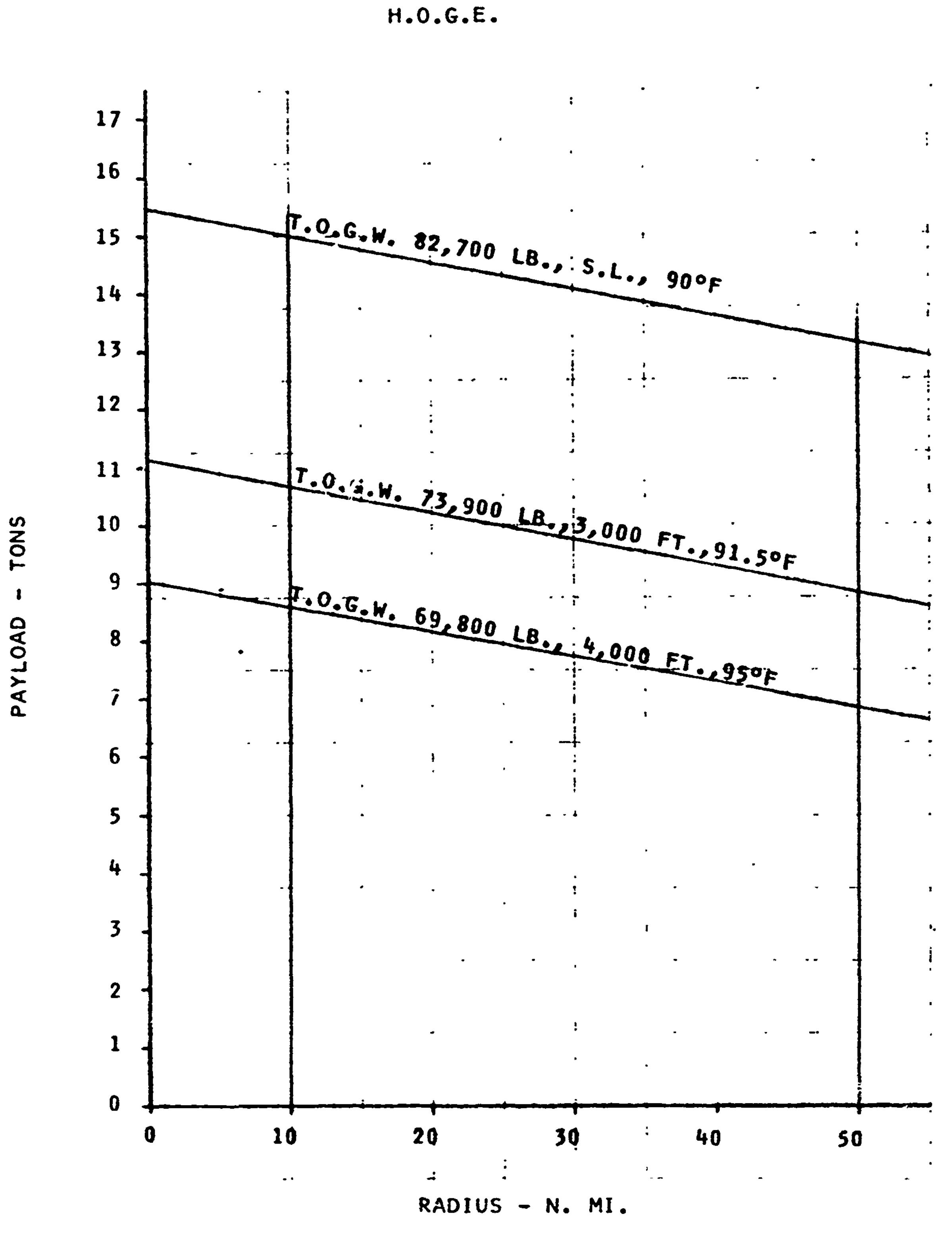


FIGURE 4-11, MULTI-HELICOPTER HEAVY LIFT SYSTEM
PAYLOAD VS. RADIUS



A summary of weights and performance is given in Table 4-2.

The latest production model turbine (T64-415) can be used in the MHHLS to provide better hot day and/or altitude performance. However, its increased power under sea level/normal temperature operation cannot be fully utilized in the CH-53D unless the main rotor collective pitch is increased. This can be rigged at the expense of increasing the lower collective pitch setting. Since the lower setting of collective pitch is used in autorotation, it is not considered good aeronautical engineering practice to compromise the autorotation performance of the aircraft. Therefore, the use of the larger powered versions of the turbine would be for hot and/or high altitude missions and the increased sea level capacity could be utilized in an MHHLS version of the CH-53 that would be designed for the larger power input.

4.2 STRUCTURE

The purpose of the structural investigation was to determine the areas of the CH-53D structure which will need reinforcing, and to determine appropriate stiffness and strength requirements for the interconnecting structure, in order to better estimate the empty weight of the MHHLS.

The MHHLS system was investigated for strength to meet structural integrity requirements and for stiffness to ascertain that the structure would not be in resonance with predominant exciting frequencies. Initially, the interconnecting structure was conservatively designed to meet the strength requirements. Based on this design, the stiffnesses and the weight distribution were established for the purpose of finding the vibratory resonant frequencies.

Using a computer program, resonant frequencies in various modes were found for the MHHLS with interconnecting structure as initially designed, and variations representing 3/4, 2 and 3 times heavier (and stiffer) interconnecting structure. For each case, the stiffnesses and the weight distributions were adjusted as required. For all cases, the basic geometry of the interconnecting structure was kept the same and the stiffnesses and weights were modified, using lighter or heavier tubing walls of the structure as required.

To avoid costly and lengthy development of any structural members of more sophisticated materials such as boron or graphite composites, beryllium, titanium, etc., in all cases, the design of the structure was based on conventional steel or aluminum alloy material.

The vibration analysis revealed that it would not be practical to build a sufficiently rigid interconnecting structure which would have its first-mode natural frequency exceeding the rotor exciting frequency of 1 per rotor revolution. However,

TABLE 4-2 WEIGHTS AND PERFORMANCE SUMMARY

		TAKE-OFF OPERATING CONDITIONS			
		HOGE		HIGE	
	UNIT	S.L. 90°F	3000' 91.5°F	S.L. 90°F	3000' 91.5°F
I WEIGHTS					
MHHLS GROSS WEIGHT (MAX.10°MIN.PWR)	LB	82,700	73,900	90,143	76,412
MHHLS WEIGHT EMPTY WITH HOOK & CABLE (100')	LB	52,163	52,163	52,163	52,163
LESS REMOVABLES WITHIN 30 MINUTES	LB	-2,515	-2,515	-2,515	-2,515
MHHLS WEIGHT EMPTY (MIN.OPERATIONAL)	LB.	49,648	49,648	49,648	49,648
CREW (3), OIL & TRAPPED FLUIDS	LB.	820	820	820	820
OPERATIONAL ZERO-FUEL WEIGHT	LB.	50,468	50,468	50,468	50,468
FUEL FOR 10 N.MI.RADIUS	LB.	2,150	2,060	2,290	2,100
FUEL FOR 50 N.MI.RADIUS	LB.	6,040	5,800	6,250	5,870
PAYLOAD FOR 10 N.MI.RAD.	LB.	30,082	21,372	37,385	23,844
PAYLOAD FOR 50 N.MI.RAD.	LB.	26,192	17,632	33,425	20,074
II PERFORMANCE (S.L./59°F)					
R_{CVERT} (MIL.POWER)	FT/MIN	1,100	1,800	300	1,100
R_{CFWD} (MIL.POWER)	FT/MIN	2,200	2,300	1,900	2,200
V_{CRUISE}	KT	100	100	100	100
V_{MIN} 1 ENGINE OUT	KT	25	0	40	0
LIMIT LOAD [illegible]	--	2.43	2.72	2.33	2.64

NOTE: FOR MISSION DEFINITION, REFER TO TEXT.

suitable stiffnesses were found which produce natural frequencies sufficiently far removed from 1 per revolution to avoid resonance.

4.2.1 Loads and Stresses

Several representative critical flight conditions were investigated in order to determine the areas of CH-53D structure which will need reinforcing and to be able to estimate the weight conditions involved. The drive system was investigated to determine the effect of interconnecting the two rotors on drive system loads, both under normal conditions and in event of an engine failure.

4.2.1.1 Fuselage Structure

Limit rotor load factors were based on the 3.0 factor used for the CH-53 at its design gross weight of 33,500 lb., reduced proportionately for increased gross weight, as shown in Table 4-3. Flight loads were calculated at a weight of 87,300 lb., corresponding approximately to the condition H.I.G.E. at sea level, 90°F. (highest weight considered in the study).

TABLE 4-3. TABLE OF LOAD FACTORS

Based on a design limit load factor for the CH-53 of 3.0 at 33,500 lb. gross weight, the limit load factor for the gross weights associated with the MHHLS payload radius curves are:

	(POUNDS) GROSS WEIGHT	(G) LOAD FACTOR
H.O.G.E. S.L. 90°F	79,200	2.54
3,000 FT., 91.5°F	71,400	2.82
H.I.G.E. S.L. 90°F	87,300	2.31
3,000 FT., 91.5°F	78,800	2.55

Note: Later refinements of performance calculations changed these gross weights, but not by more than 4.5%, which is not believed to affect any conclusions of this study.

The conditions investigated were a symmetrical pull-up to limit load factor, and an unsymmetrical rolling, yawing pull-up to limit load factor on the front rotor combined with maximum roll and yaw control. Details of these conditions are presented in the following discussion.

Critical Flight Conditions for Load Analysis

a. General - Maximum gross weight considered is 87,300 pounds (H.I.G.E., 90°F). Maximum design thrust for the CH-53 is

$$33{,}500 \text{ lb.} \times 3.00 = 100{,}500 \text{ lb.}$$

Applying this maximum design thrust to the multi-lift gives

$$N_Z = \frac{2 \times 100{,}500 \text{ lb.}}{87{,}300 \text{ lb.}} = 2.31$$

This compares with $N_Z = 2.5$ per Ref. 14 for cargo helicopters at design gross weight, and $N_Z = 2.0$ minimum at alternate gross weight. It is considered sufficient for this application, since the multi-lift system will not be maneuvered rapidly

b. Critical Symmetrical Condition - (limit loads)

$N_Z = 2.31$ (100,500 lb. at each rotor)

$N_X = 0$ (sufficient for preliminary design, since structure is not designed by fore-and-aft loads)

$N_Y = 0$ (symmetrical case)

$\dot{p} = 0$ (symmetrical case)

$\dot{q} = 0$ (symmetrical case)

$\dot{r} = 0$ (symmetrical case)

Torque at front rotor from 5,563 HP at 185 RPM

Torque at rear rotor from 17,987 HP at 185 RPM

Total HP = 3,925 HP/eng x 4 engines x 1.5 = 23,550 HP

This distribution is from trim analysis at 125 Kts.

Lateral differential cyclic pitch introduced by application of full collective pitch is $\pm 2°$.

$\therefore$ Y force = 100,500 lb. x $\frac{2°}{57.3}$ = 3,508 lb.

to left at front rotor and to right at rear rotor. Rotor torque not balanced by lateral differential cyclic pitch is reacted by tail rotor force to right and equal Y force to left at both rotors (combined with differential Y force per above).

c. Critical Unsymmetrical Condition (Limit Loads)

Rolling pull-out with limit load on front rotor, and pitching acceleration ($\mathring{q}$) from max. aft stick.

$\mathring{q}$ = 0.1 rad/sec^2/in. of stick (from stability analysis).

$\therefore$ max. $\mathring{q}$ = 0.1 x 11.54" = 1.15 rad/sec^2

This results in:

Front rotor thrust	=	100,500 lb.
Rear rotor thrust	=	7,830 lb.
TOTAL thrust	=	108,330 lb.

N_Z = $\frac{108,330 \text{ lb.}}{87,300 \text{ lb.}}$ = 1.241 (1.2446 was used in calculation)

N_X = 0 (sufficient for preliminary design since structure is not designed by fore-and-aft loads).

$\mathring{p}$ = -2,746 (same as CH-53, Sikorsky Report 65165, page 13)

Max. tail rotor force = 7,000 lb. (same as CH-53)

*Max. differential lateral cyclic pitch = $\pm 3.75°$

* This is slightly different from the final values selected (see Table 4-3), but the difference does not have significant effect on this design flight condition.

*Max roll lateral cyclic pitch = $\pm$ 5.25°

∴ Y force at fwd. rotor =

$$100{,}500 \text{ lb.} \times \frac{9.0°}{57.3} = 15{,}785 \text{ lb. to left}$$

and Y force at rear rotor =

$$7{,}830 \text{ lb} \times \frac{0.5°}{57.3} = 68 \text{ lb. to right}$$

N_y and $\dot{r}$ to balance this set of applied forces are:

$N_Y = -0.10$

$\dot{r} = -0.396$ rad/sec^2

d. Same applied loads as c. above, except combined with rotor torques per b. above.

Front rotor = 5,563 HP at [illegible] RPM

Rear rotor = 17,987 HP at [illegible] RPM

This produces torques of 157,865 lb. ft. (front)

510,442 (rear)

and reduces $\dot{r}$ to -.167 rad/sec^2

Study of Required Fuselage Reinforcements

In order to establish which structural areas of CH-53D fuselage required reinforcements, bending moment, shear and torsion diagrams were calculated for the three critical load cases discussed above.

*This is slightly different from the final values selected (see Table 4-3), but the difference does not have significant effect on this design flight condition.

The results were superimposed as limiting envelopes on corresponding diagrams of the CH-53A aircraft, and appear as Fig. 4-12, -13, -14, -15, and -16, for vertical shear, vertical bending, lateral shear, lateral bending and torsion, respectively.

These diagrams, together with additional structural analysis, indicate that some areas of the fuselage skin, mostly between Sta. 162 and Sta. 202 and between Sta. 482 and Sta. 522, will require reinforcing by stiffening with additional stringers. In addition, there will be several doublers and local stiffeners required to spread concentrated loads from interconnection fittings into the fuselage shell. These will be part of the Depot Modification Kit, and weight allowance has been made for them in the weight estimate, Table 4-1, and in the weight by which the CH-53D is increased during modification.

4.2.1.2 Drive System

Power to the rear rotor is higher than that to the front rotor at all speeds except rearward flight (including hovering because of tail-rotor power). The reason for this is that in forward flight, the rear rotor operates in the downwash of the front rotor, and its induced power is increased. If normally all four engines will be adjusted to equalize their power outputs, there will be a flow of power from the front helicopter to the rear rotor in response to the rear rotor's demand for more power than the front rotor. The critical component in the transmission system will then be the starboard bevel pinion mesh, in the rear rotor, which transmits not only the power from its own engine, but also power from the synchronizing shaft, introduced by the front engine(s). This situation can be substantially alleviated by controlling the turbines in such a way that the power in each helicopter is supplied by its own turbine. A torquemeter on the interconnecting shaft would control fuel flow differentially to the forward and aft turbines in such a way as to maintain zero torque in that shaft.

Fig. 4-17 shows the total power to each bevel pinion of the rear rotor with the engines controlled as described above. Also shown is the power normally used in a single CH-53D operated at an equivalent gross weight, with and without the drag of external cargo. Although the power in the MHHLS rear rotor is somewhat higher than the normal CH-53D throughout the expected cruise speed range, it is well within the transmission rating.

In order to balance the power used in the front and rear rotors, the centerline of the hoist cable is placed forward of the bisector centerline, mid-way between the two rotor centerlines. The minimum amount of this forward offset will be the amount to balance the power in the hovering condition in order that the front rotor power will be the same as the rear rotor (plus-tail-rotor) power (4%). An additional amount of forward offset can be made to partially compensate for the increased rear rotor power in cruise flight.

FIGURE 4-12. LIMIT VERTICAL SHEAR ENVELOPE; MHHLS COMPARED WITH SINGLE CH-53A

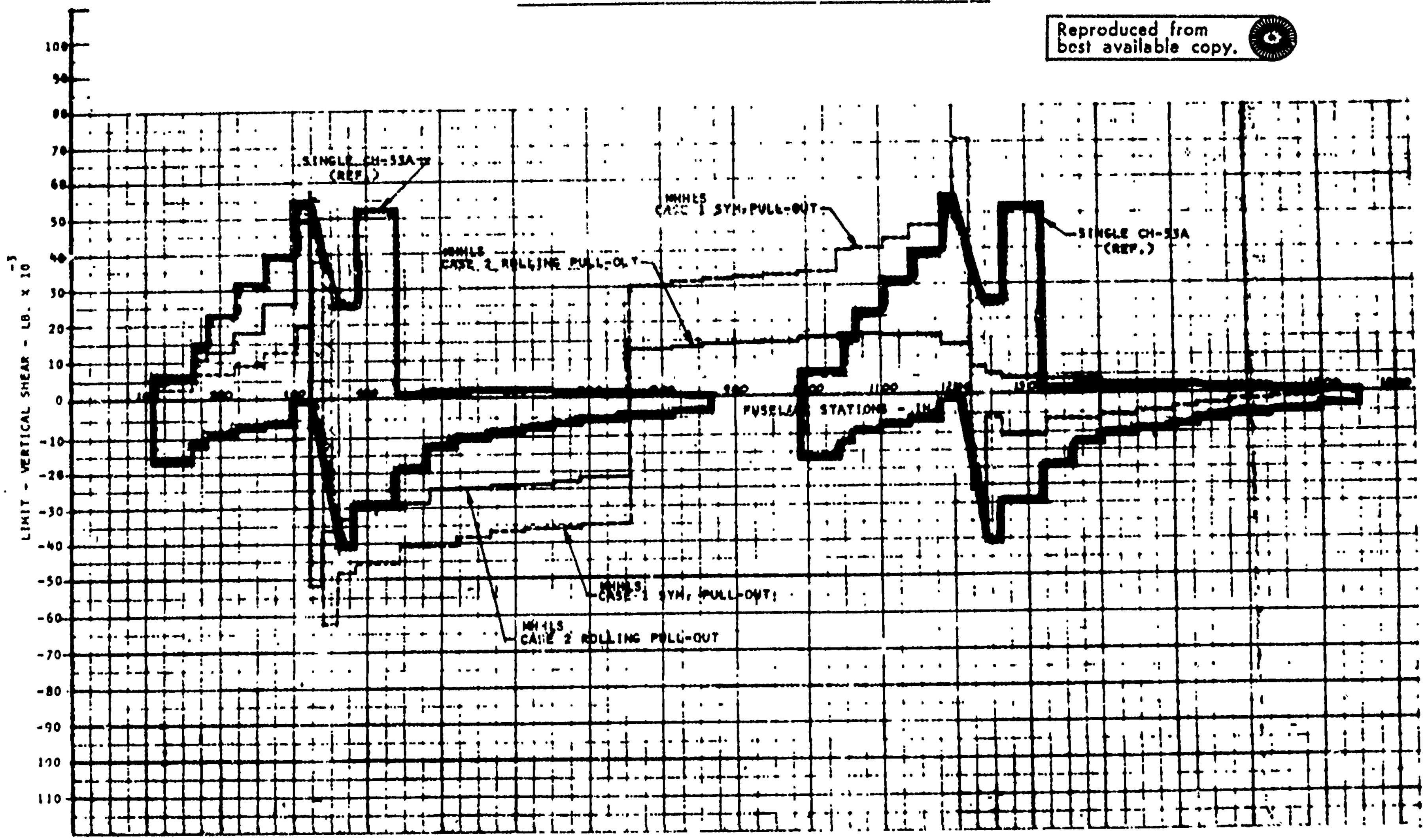


FIGURE 4-13. LIMIT VERTICAL BENDING MOMENT ENVELOPE; MHHLS COMPARED WITH SINGLE CH-53A

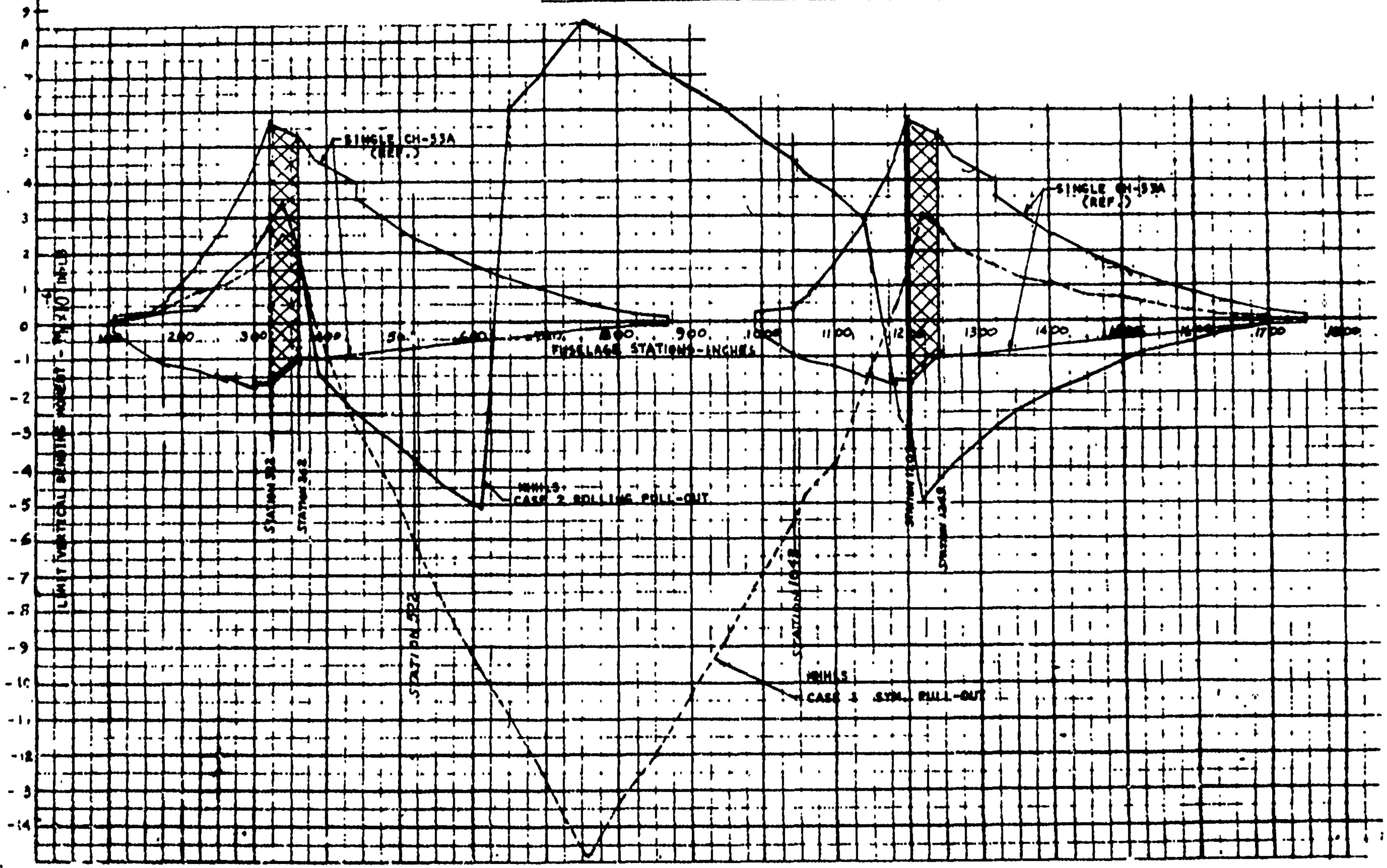


FIGURE 4-14. LIMIT LATERAL SHEAR ENVELOPE; MHHLS COMPARED WITH SINGLE CH-53A

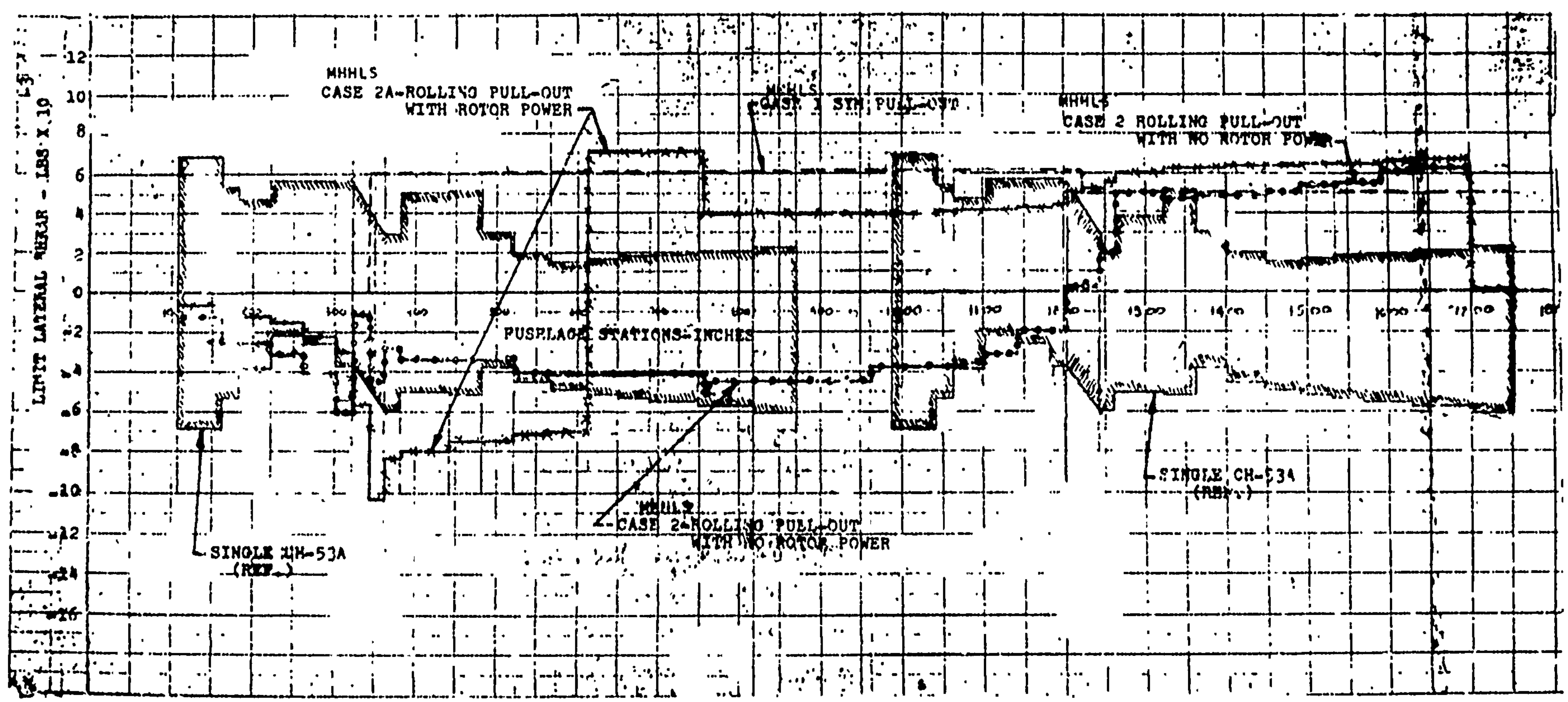


FIGURE 4-15. LIMIT LATERAL BENDING MOMENT ENVELOPE; MHHLS COMPARED WITH SINGLE CH-53A

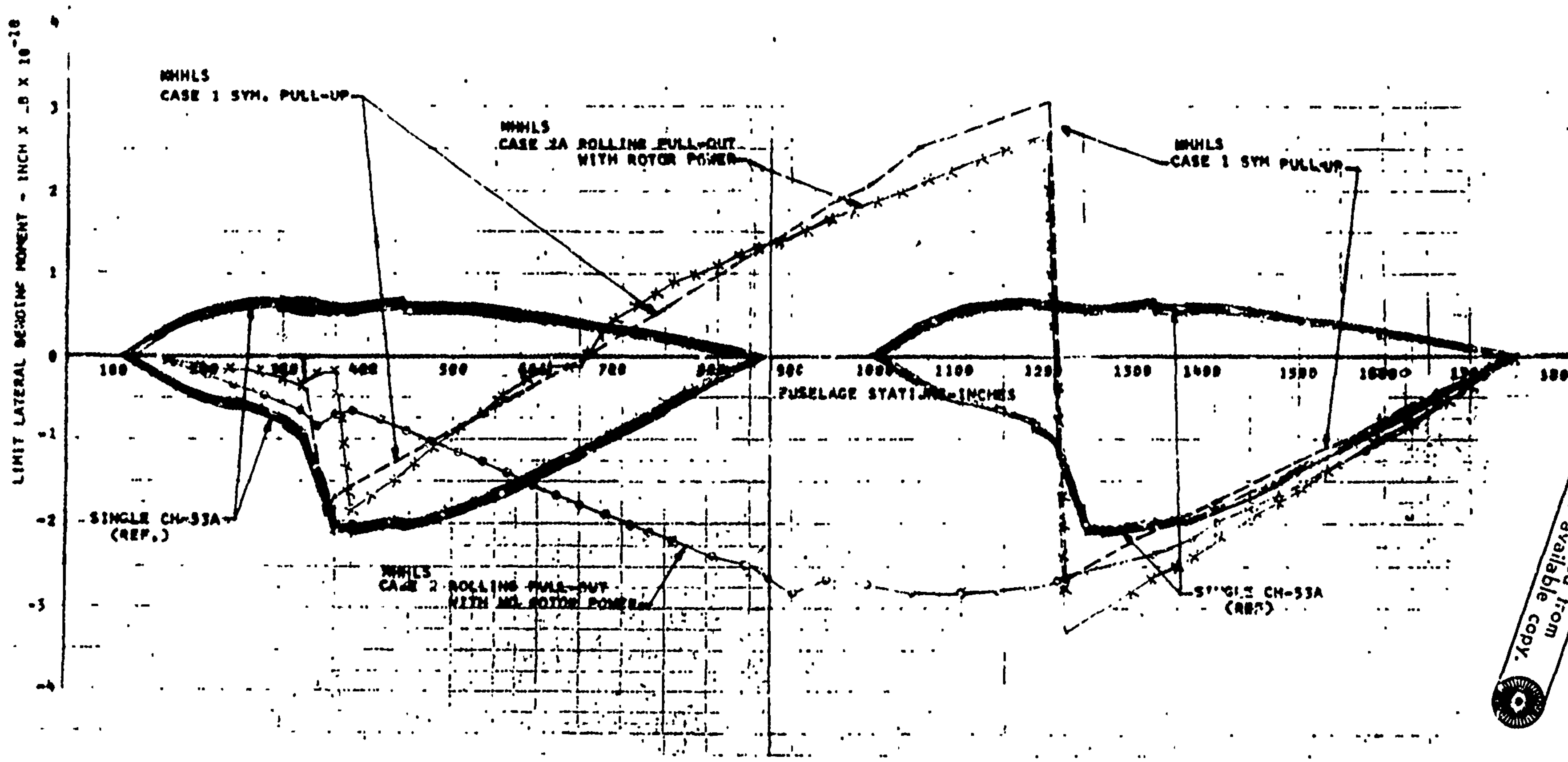


FIGURE 4-16. LIMIT FUSELAGE TORSION ENVELOPE: MHHLS COMPARED WITH CH-53D

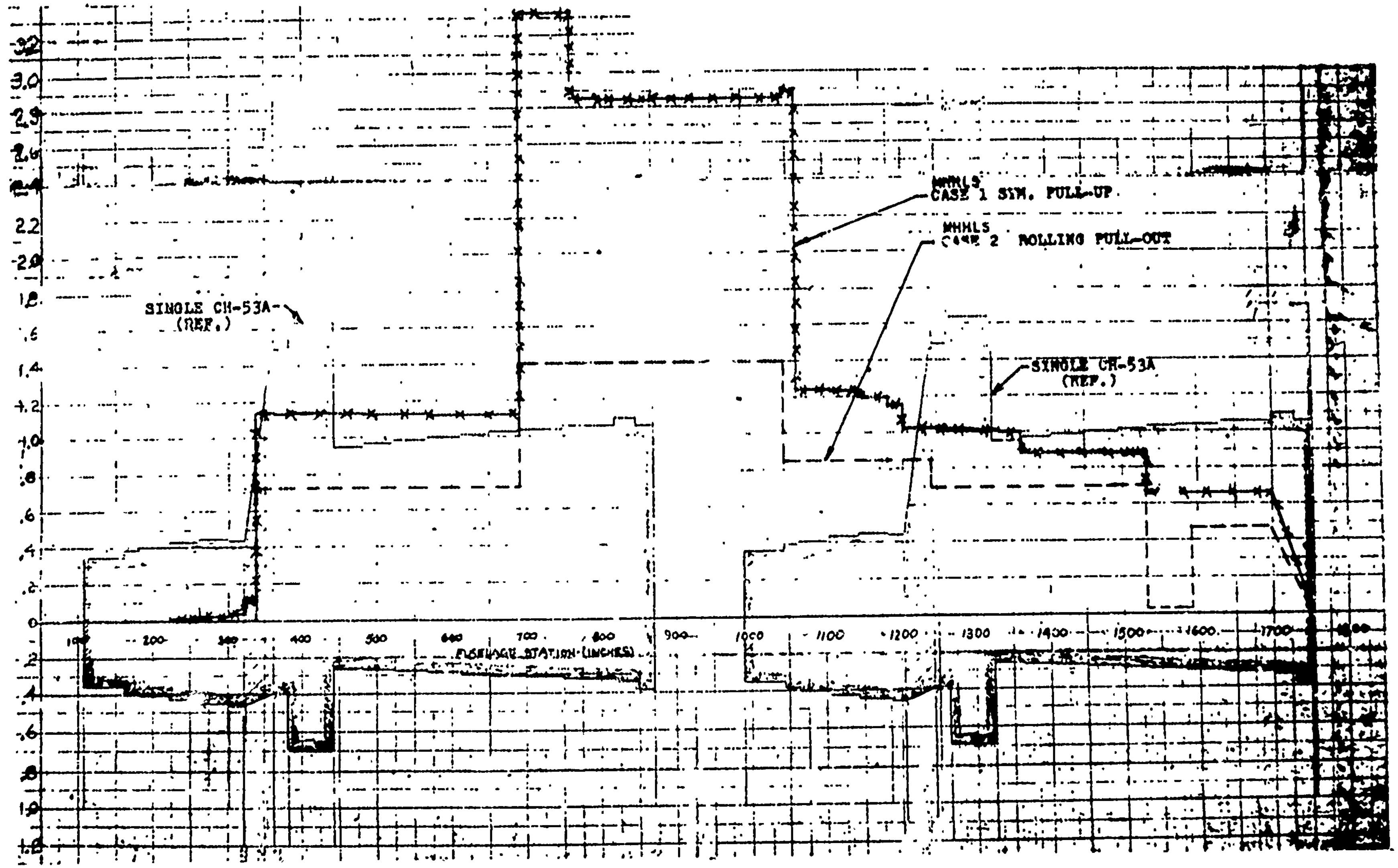


FIG. 4-17. 2 CH-53D MULTI-HELICOPTER HEAVY LIFT SYSTEM POWER TO RIGHT-SIDE BEVEL PINION, REAR ROTOR AND TAIL ROTOR (MOST CRITICAL)

GROSS WEIGHT 87,300 POUNDS
PAYLOAD OF 35 SQ. FT. DRAG AREA
SEA LEVEL, 59°F

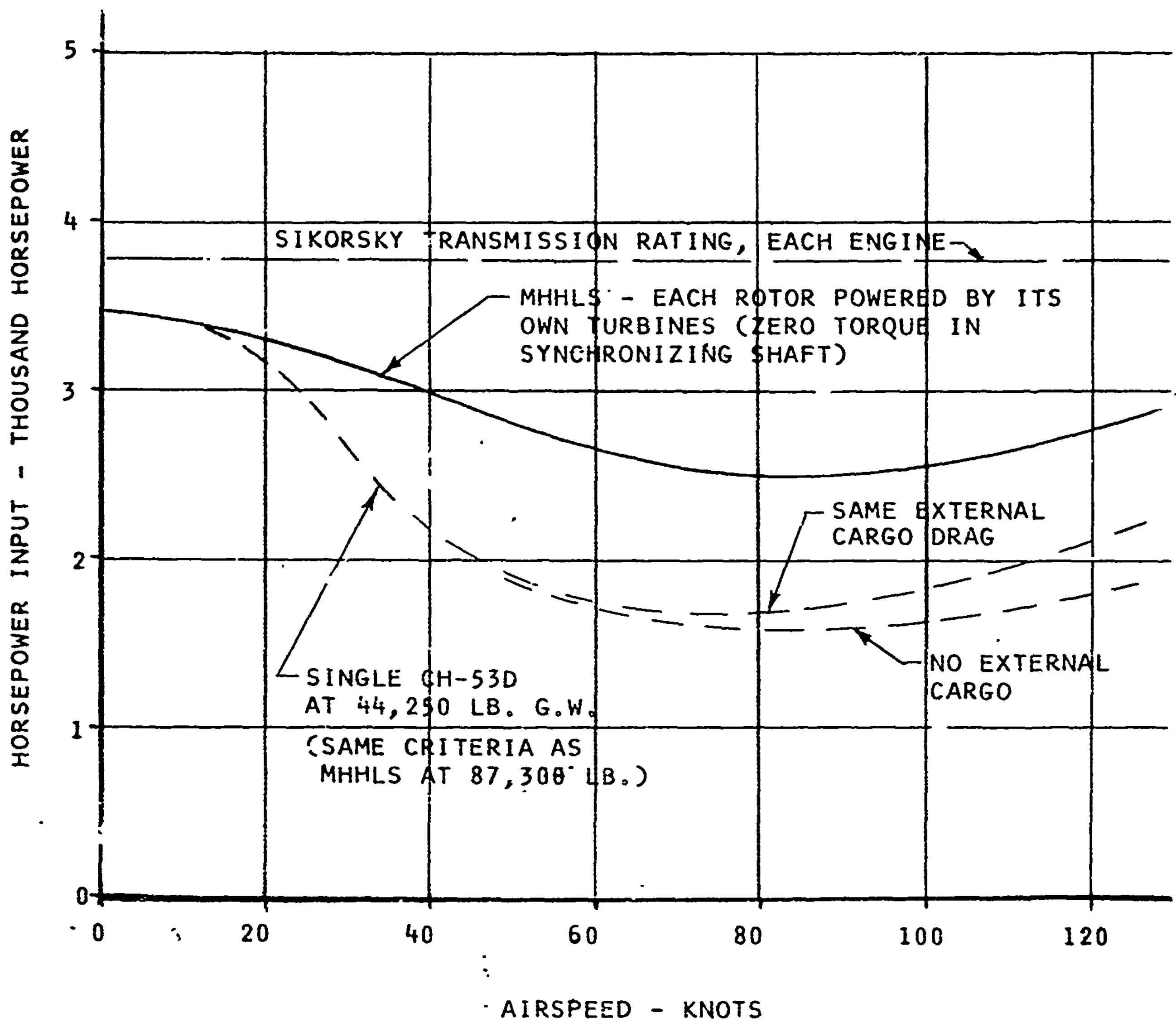


Fig. 4-18 shows the total power to the rear rotor, as a function of weight and speed. If the aft port engine should fail, all of the power to the rear rotor would have to flow through the starboard bevel pinion mesh. In this particular case of failure of the aft port engine, the power to the starboard bevel mesh would exceed the Sikorsky sing e-engine rating. An analysis of this gear mesh was made, using gear characteristics computed by the Gleason Works for teeth representative of the existing CH-53 gears and also for teeth of the same design but made from vacuum-melted steel. The line for infinite life is shown on the graph, along with lines showing limited life of 30 hours for the existing ring gear meshing with a new vacuum-melted steel pinion which is part of the modified plug. The gears have at least an 30-hour life in this emergency condition, within the speed range of 67 knots 101 knots.

4.2.2 Fuselage Vibration

Stiffness properties of the CH-53 fuselage in vertical bending, lateral bending, and torsion were taken from Sikorsky stress reports. A mathematical model was constructed of the multi-lift configuration, using the Sikorsky stiffness properties and weight distribution where applicable. The structural model consisted of 20 massless segments, each of constant stiffness, simulating the local stiffnesses of the MHHLS, and strung out along an elastic axis with bends and offsets simulating the probable locations of the local elastic axis in the MHHLS (See Fig. 4-19, -20 and -21). Suitably located in X,Y, and Z coordinates with respect to each segment were 39 "lumped" masses, along with their local mass moments of inertia about each axis, to simulate the mass distribution of the MHHLS. The interconnecting structure, which will be new, was assumed to be of constant stiffness, with three different stiffness values each, for vertical bending, lateral bending, and torsion covering a range of 4:1 for each. For each value of stiffness of the interconnecting portion a weight distribution consistent with a reasonable structure of this stiffness was used (three different weights). Table 4-4 summarizes the cases investigated.

For each assumed set of stiffnesses of interconnecting structure, a natural frequency analysis was made, using a computer program, both in vertical bending, and in lateral bending coupled with torsion. Each stiffness was investigated at minimum flying weight (zero payload and minimum fuel), and at maximum gross weight (H.I.G.E. at sea level, 90°F). The frequency range investigated was from 0.16 cycles per second (approximately 5% rotor speed) to 8 cycles per second (2.6 times rotor speed). Fig. 4-22 shows typical elastic mode shapes in vertical bending. This particular figure is for the selected value of stiffness of the interconnecting structure.

FIGURE 4-18. MHHLS TRANSMISSION LIFE UPON FAILURE OF PORT AFT ENGINE (MOST CRITICAL CASE)

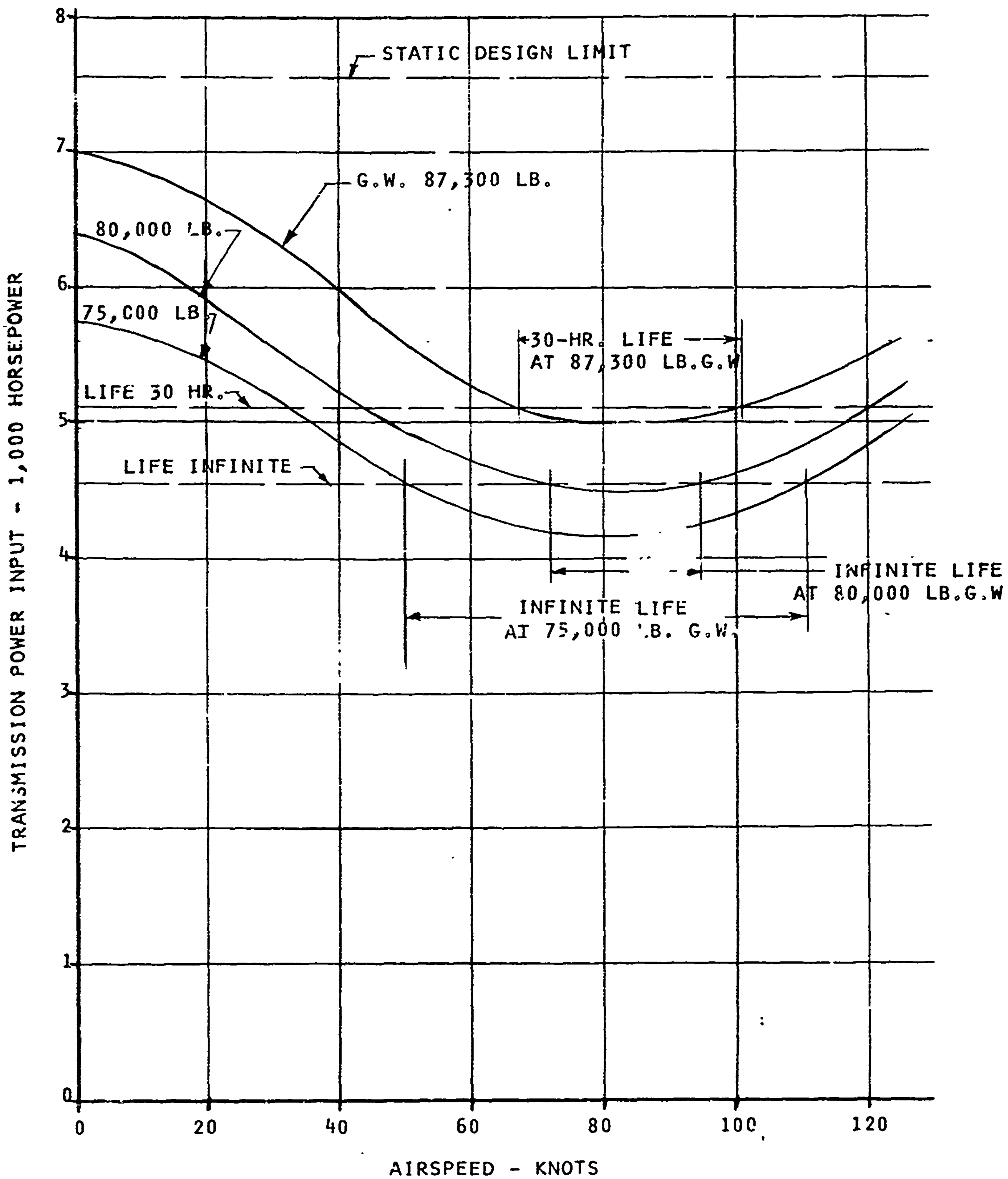


FIGURE 4-19. STRUCTURAL PROPERTIES

VERTICAL BENDING

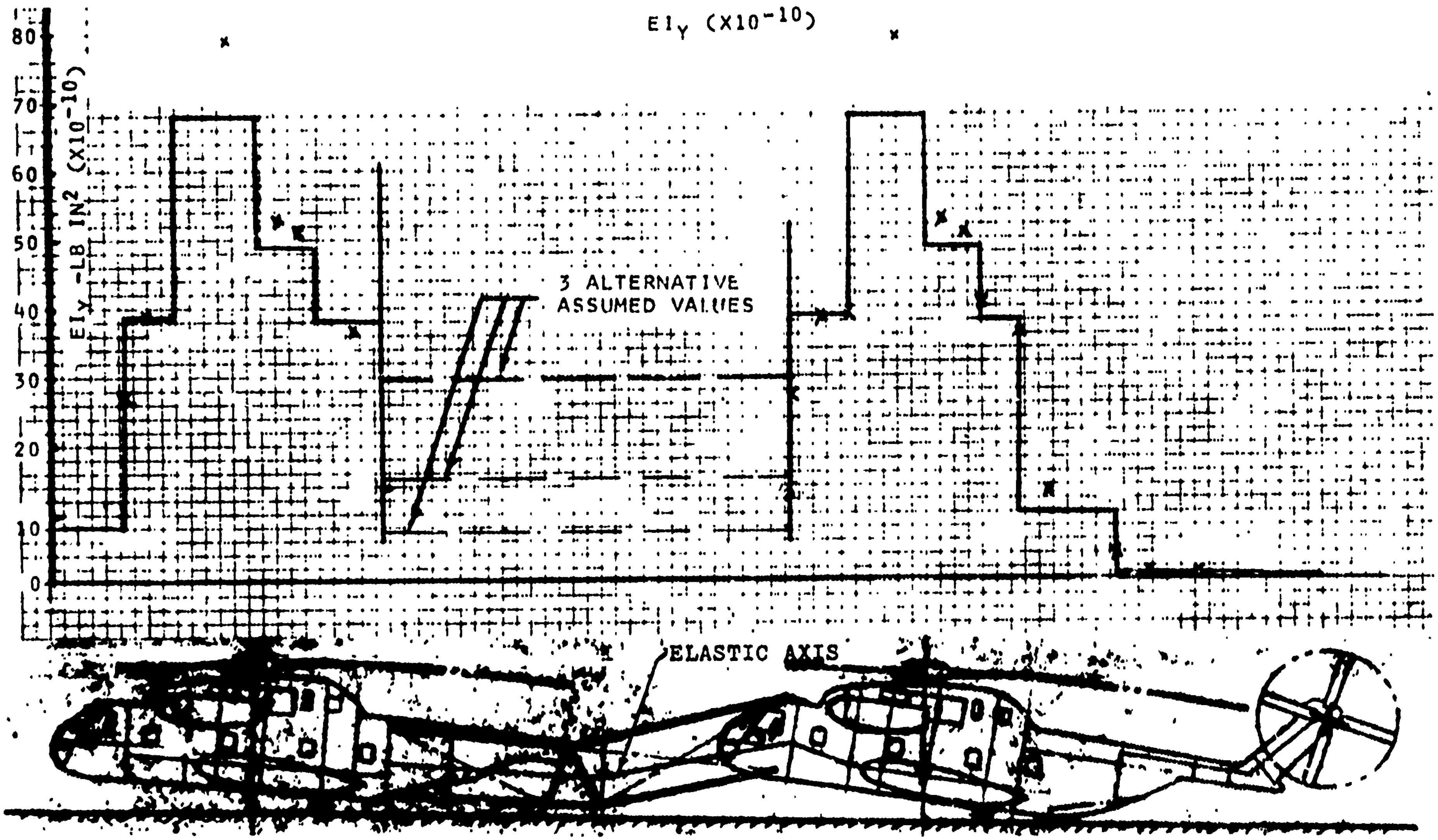


FIGURE 4-20. STRUCTURAL PROPERTIES

EI_Z (X10^{-10})

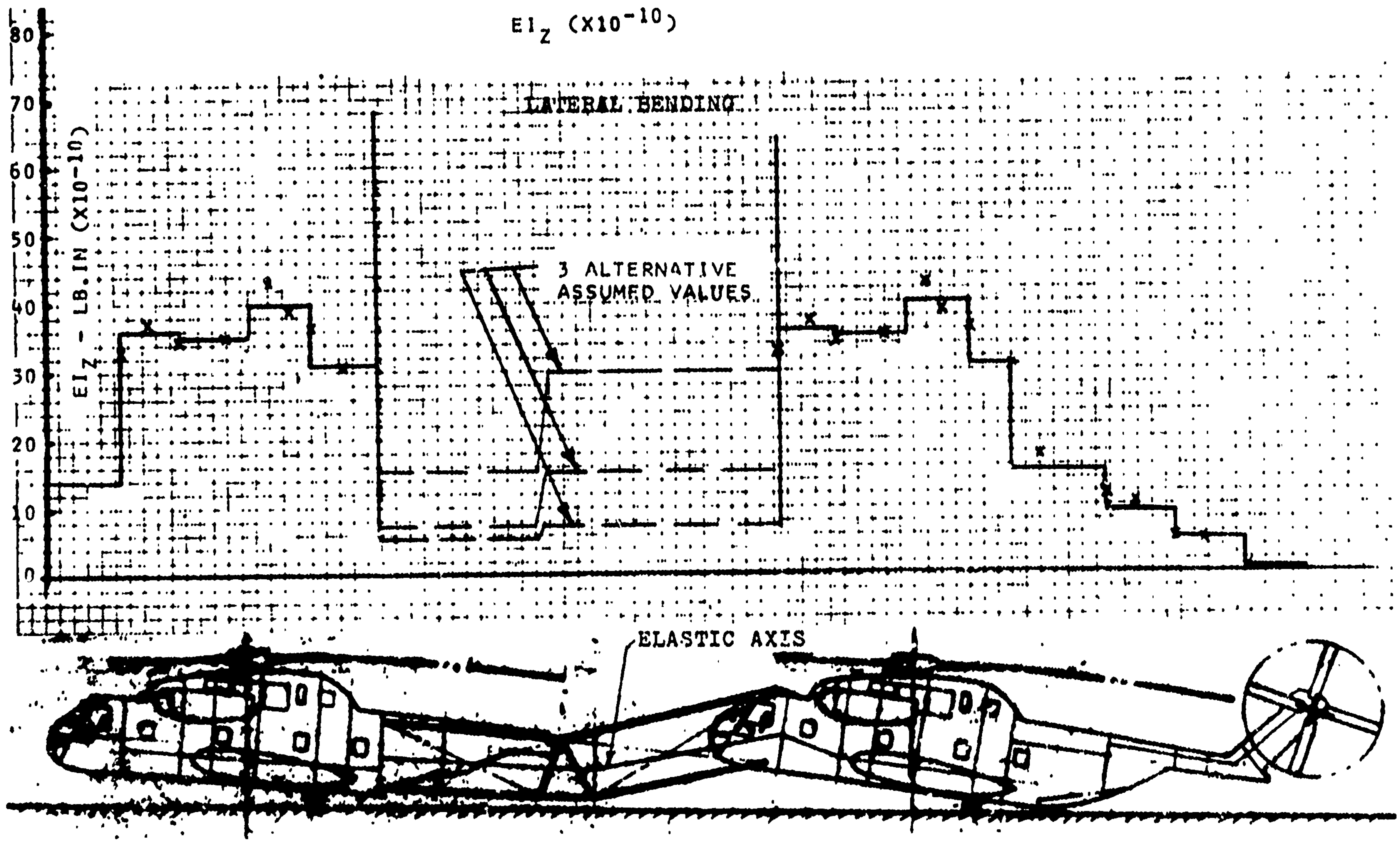
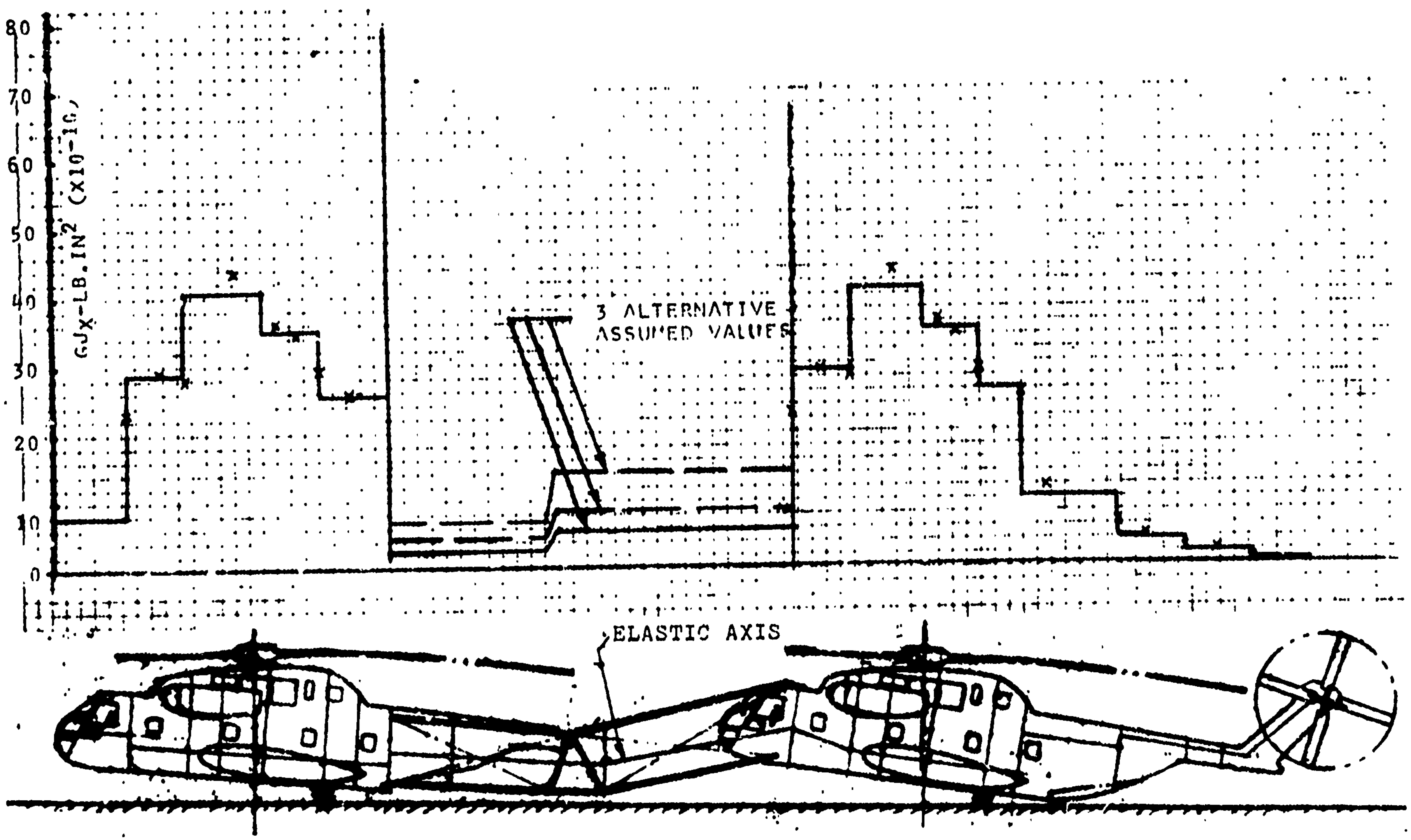


FIGURE 4-21. STRUCTURAL PROPERTIES
TORSION

GJ_X ($\times 10^{-10}$)



39-X-11

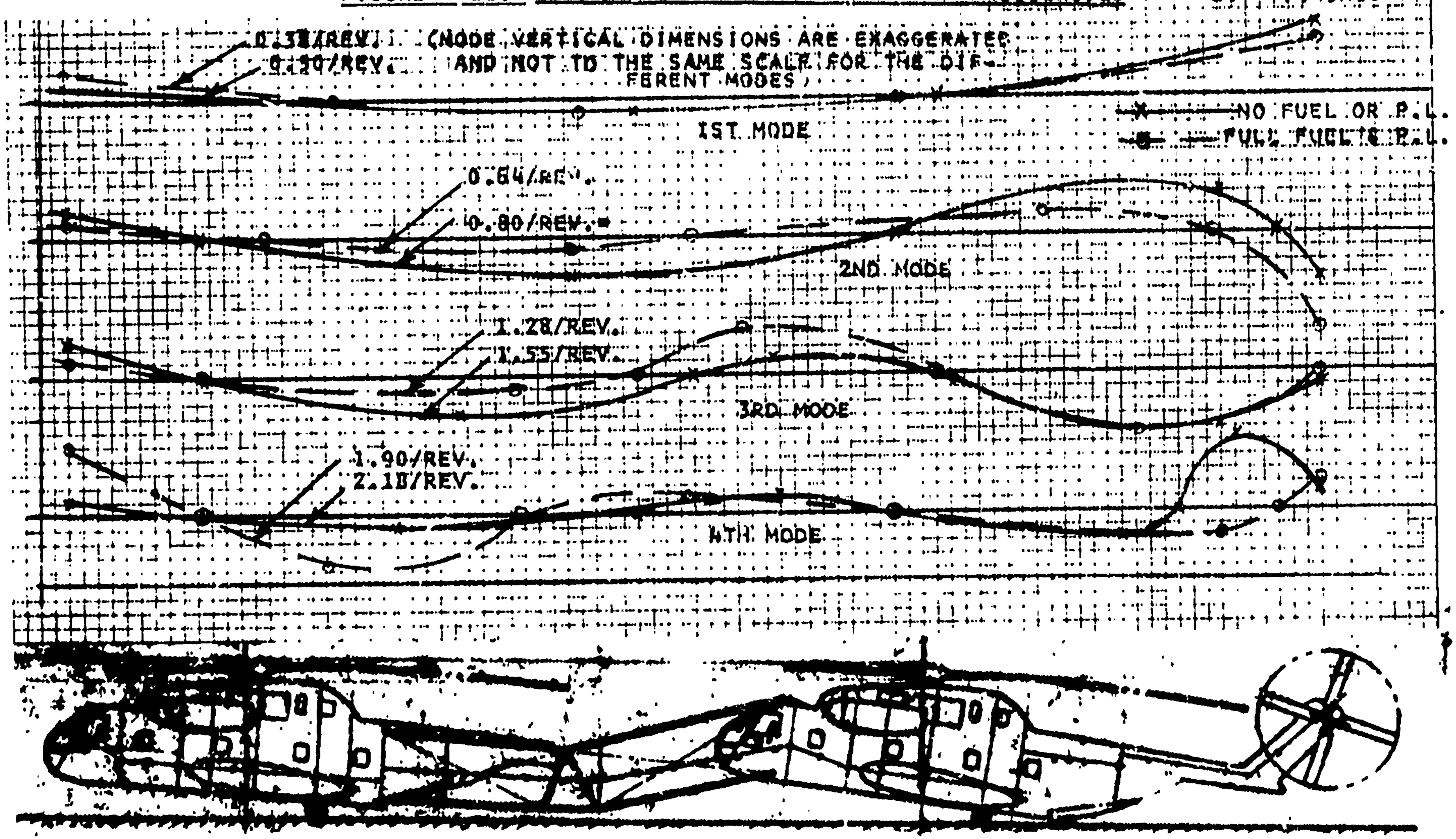
TABLE 4-4

VIBRATION ANALYSIS
MULTI-LIFT STRUCTURE

LIST OF CASES

Case No.	Type	Fuel	Payload	Stiffness
1.	Vertical Bending	0	0	7.45×10^{10} IN^{4} (EI_y)
2.	Vertical Bending	Full	Full	7.45×10^{10} IN^{4} (EI_y)
3.	Vertical Bending	0	0	14.9×10^{10} IN^{4} (EI_y)
4.	Vertical Bending	Full	Full	14.9×10^{10} IN^{4} (EI_y)
5.	Vertical Bending	0	0	29.8×10^{10} IN^{4} (EI_y)
6.	Vertical Bending	Full	Full	29.8×10^{10} IN^{4} (EI_y)
7.	Lateral Bending/Torsion	0	0	7.45×10^{10} IN^{4} (EIz)
8.	Lateral Bending/Torsion	0	Full	7.45×10^{10} IN^{4} (EIz)
9.	Lateral Bending/Torsion	Full	Full	7.45×10^{10} IN^{4} (EIz)
10.	Lateral Bending/Torsion	Full	0	7.45×10^{10} IN^{4} (EIz)
11.	Lateral Bending/Torsion	C	0	14.9×10^{10} IN^{4} (EIz)
12.	Lateral Bending/Torsion	Full	Full	14.9×10^{10} IN^{4} (EIz)
13.	Lateral Bending/Torsion	Full	Full	29.8×10^{10} IN^{4} (EIz)
14.	Lateral	0	0	29.8×10^{10} IN^{4} (EIz)

FIGURE 4-22. VERT. BENDING MODE SHAPES AND FREQUENCIES



Results are shown on Fig. 4-23, for vertical bending, and Fig. 4-24, for coupled lateral bending and torsion. From these results, suitable stiffness values for the interconnecting structure have been chosen to avoid rotor-excited resonance, as summarized on Fig. 4-25. The shaded bands in Fig. 4-23 (vertical bending) represent the shifts in natural frequency caused by different loading conditions ranging from zero fuel and payload to full fuel and payload. In the case of lateral bending (Fig. 4-24), the payload (cargo) would not be tied rigidly enough laterally to follow the relatively high-frequency lateral motions, and the hypothetical frequencies of vibration with full cargo are, therefore, shown by phantom lines. The frequency bands in this case represent the difference between zero and full fuel, regardless of the amount of cargo.

4.3 FLYING QUALITIES

The flying qualities of the MHHLS were investigated using blade motions within the limitations of the CH-53D cyclic and collective pitch ranges. Ref. 12 and particularly Ref. 13 were used as design guides. Ref. 13 defines three "levels" of flying qualities, as follows:

Level 1: Flying qualities clearly adequate for the mission Flight Phase

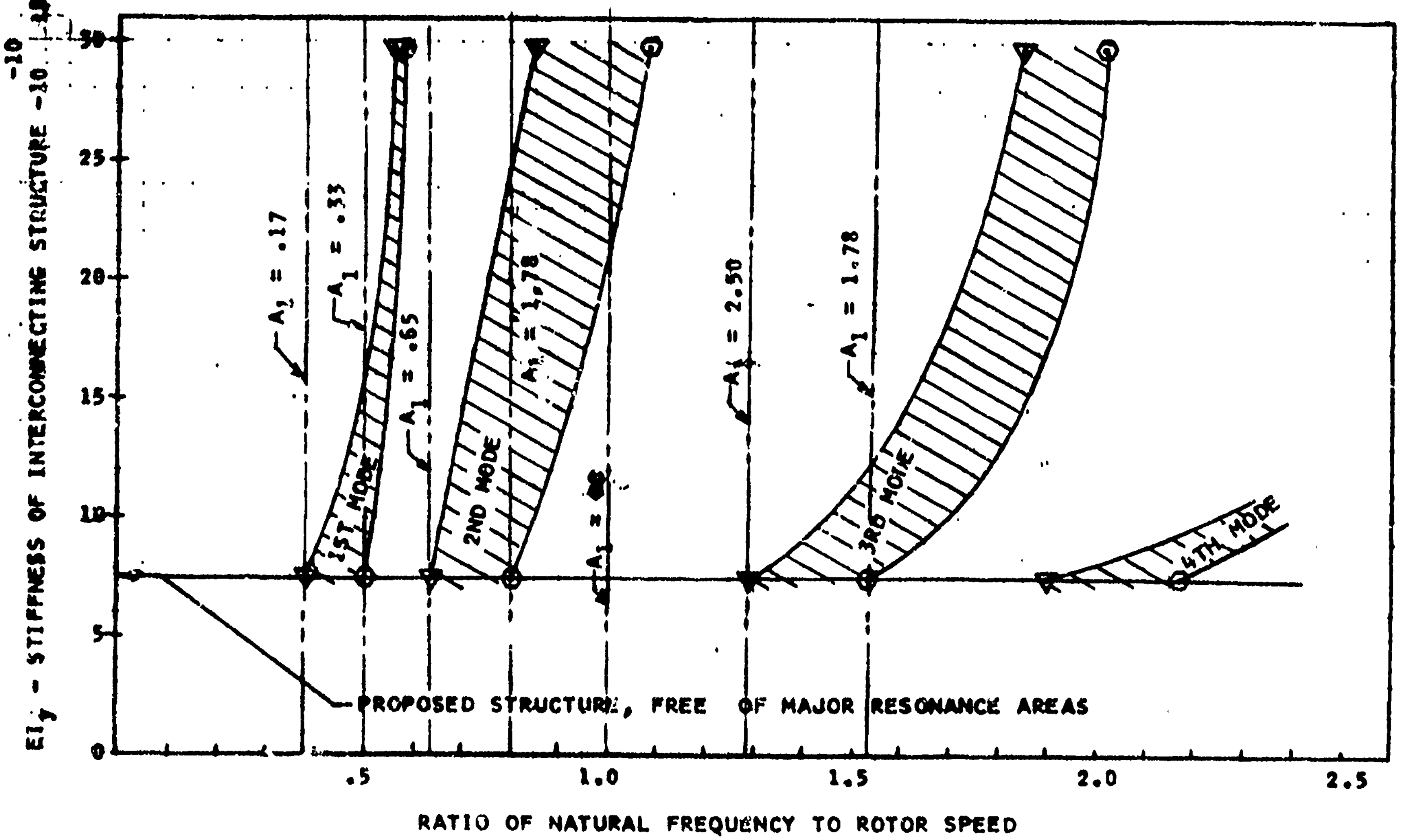
Level 2: Flying qualities adequate to accomplish the mission Flight Phase, but some increase in pilot workload or degradation in mission effectiveness, or both, exists.

Level 3: Flying qualities such that the aircraft can be controlled safely, but pilot workload is excessive or mission effectiveness is inadequate, or both. Category A Flight Phases can be terminated safely, and Category B and C Flight Phases can be completed.

Control power, control margins, and stability were investigated, with and without the CH-53 automatic flight control system (AFCS). The CH-53D is normally flown with the AFCS on, and this would also be the case for the MHHLS. Because of the reliance of the CH-53D on the use of AFCS the two critical control axes, pitch and roll, are equipped with dual AFCS channels. Yaw and collective pitch are considered manually controllable if their single AFCS channel fails. This same arrangement is used in the MHHLS, although with four channels of AFCS available for the two helicopters it would be possible to increase the AFCS fail-safe redundancy if desired.

The higher yaw inertia of the MHHLS, due to the over-hanging masses in the nose and tail, requires more yaw control power than the conventional tandem helicopter. This can be provided by increasing the lateral cyclic control. However, since it was desired not to

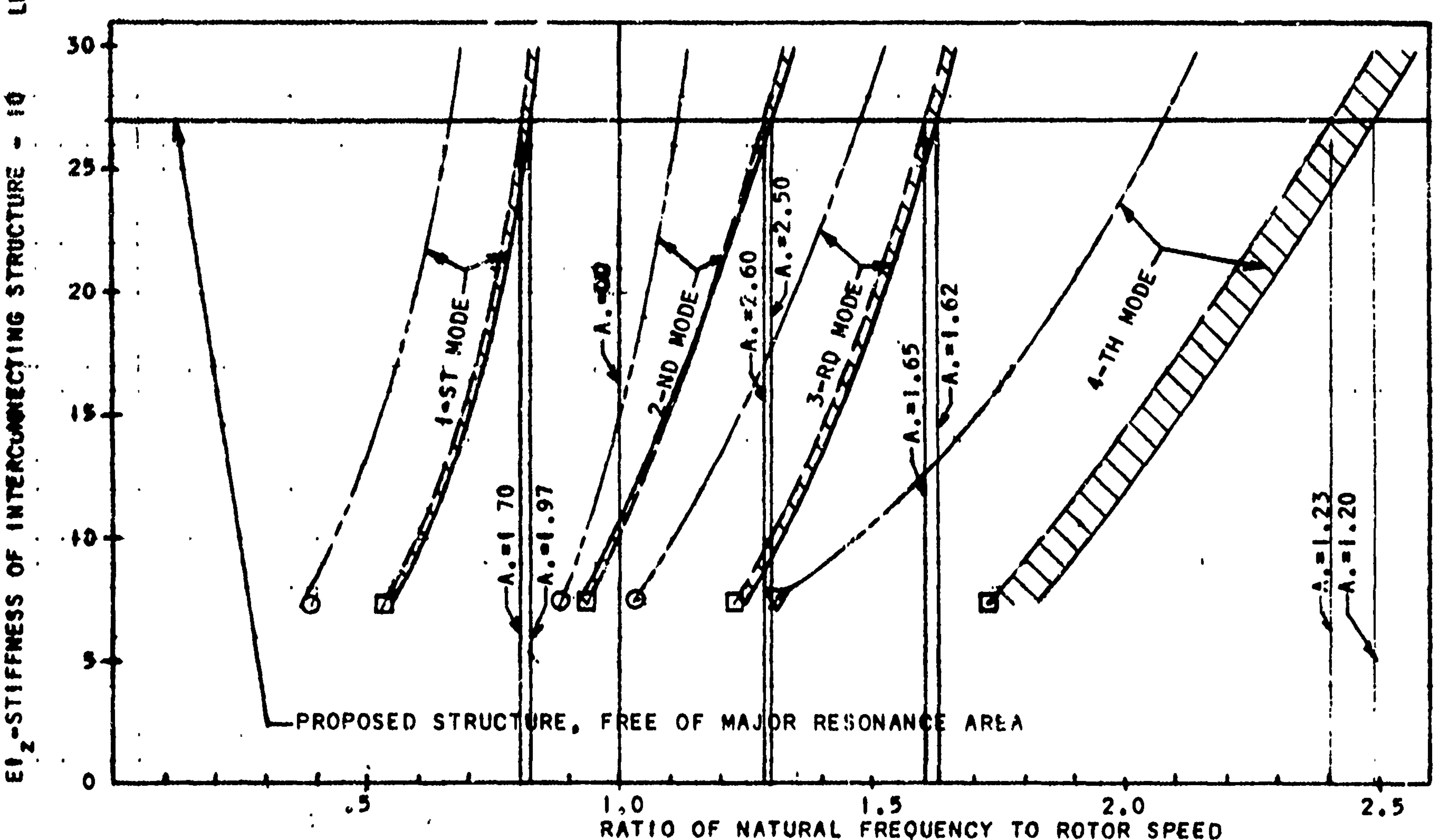
FIGURE 4-23. VERTICAL BENDING VIBRATION OF (2) CH-53D MULTI-LIFT SYSTEM



▽ FULL FUEL & FULL PAYLOAD ⊙ NO FUEL AND NO PAYLOAD

A_1 UNDAMPED AMPLIFICATION FACTOR AT EXCITING FREQ.OF ONE PER ROTOR REV.

FIGURE A-24. LATERAL BENDING/TORSIONAL VIBRATION OF (2) CH-53D MULTI-LIFT SYSTEM



○ NO FUEL-FULL PAYLOAD   □ FULL FUEL - NO PAYLOAD   ▽ FULL FUEL & FULL PAYLOAD

A. UNDAMPED AMPLIFICATION FACTOR AT EXCITING FREQ. OF ONE PER ROTOR REV.

—— – – IF PAYLOAD IS AFFIXED IN LATERAL SHEAR TO FUSELAGE

—— — ESTIMATED BORDER LINE WHEN PAYLOAD IS NOT AFFIXED TO FUSELAGE IN LATERAL SHEAR

FIGURE 4-25. MHHLS STRUCTURE AMPLIFICATION FACTOR VS. UNDAMPED NATURAL FREQUENCY RATIO

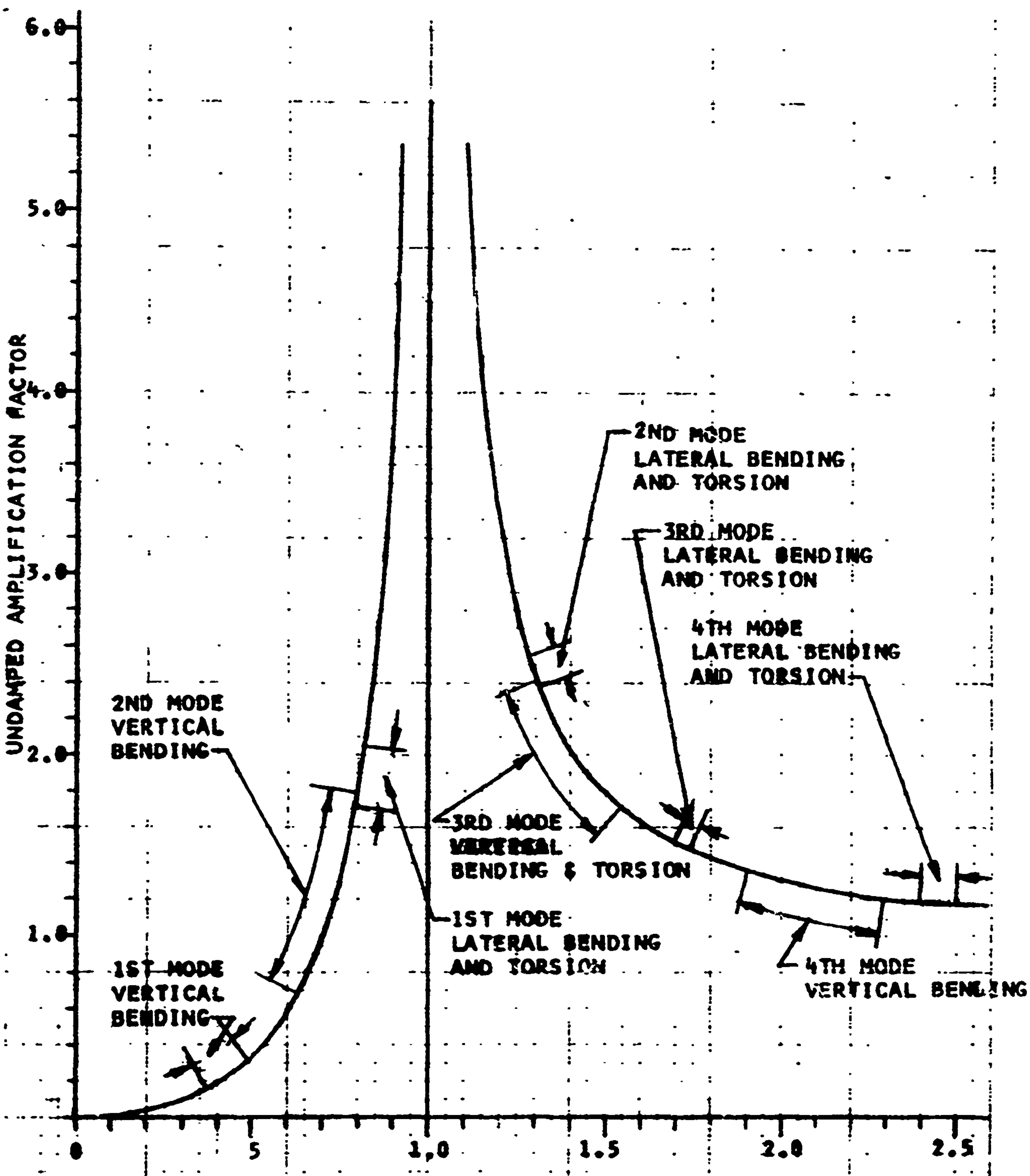


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TABLE 4-5

CONTROL MIXING FOR MHHLS COMPARED WITH SINGLE CH-53D

COCKPIT CONTROL DEFLECTION	COLL. PITCH (THRUST CONTROL)	LONGITU-D'NAL STICK	LATERAL STICK	PEDALS*
INCHES	0 to 7.44	6.77 FWD 4.77 AFT	6.76R 6.76L	2.45R 2.45L

ROTOR BLADE PITCH (DEGREES) RESULTING FROM ABOVE COCKPIT CONTROL DEFLECTIONS

		COLL. PITCH (THRUST CONTROL)	LONGITU-D'NAL STICK	LATERAL STICK	PEDALS*	TOTAL
MULTI-LIFT FRONT ROTOR	COLLECTIVE PITCH**	3.7 TO 12.4	-4.00 +2.81	-	-	-0.3 15.21
	LONGITUDINAL CYCLIC	-	12.85 FWD 9.08 AFT	-	-	12.85FWD 9.08AFT
	LATERAL CYCLIC	0 TO 2.L	-	5.25R 5.25L	1.75R 1.75L	7.00R 9.00L
MULTI-LIFT REAR ROTOR	COLLECTIVE PITCH**	3.7 TO 12.4	+4.00 -2.81	-	-	0.89 16.4
	LONGITUDINAL CYCLIC	-	12.85 FWD 9.08 AFT	-	-	12.85FWD 9.08AFT
	LATERAL CYCLIC	0 TO 2.R	-	5.25R 5.25L	1.75L 1.75R	7.00L 9.00R
	TAIL ROTOR	0 to +6	-	-	-13.0 13.0	-5 +27
SINGLE CH-53	COLLECTIVE PITCH**	0 TO 13				0 TO 13***
	LONGITUDINAL CYCLIC	-	15.3FWD 11. AFT	-	-	15.3FWD 11. AFT
	LATERAL CYCLIC	0 TO 3L	-	6.25R 6.25L	-	6.25R 9.25L
	TAIL ROTOR	0 TO 6	-	-	-13. +13.	-5 +27

*THE PEDAL CONTROLS ARE SPRING LOADED SO THAT IF THE TAIL ROTOR PITCH REACHES ITS LIMIT FROM A THRUST CONTROL INPUT, THE PEDALS CAN BE MOVED TO THEIR NORMAL STOPS, (±3.68"), BUT DO NOT PRODUCE ANY FURTHER PITCH CHANGE AT THE TAIL ROTOR.

**AT 3/4 RADIUS

***FROM RIGGING INSTRUCTIONS IN MAINTENANCE HANDBOOK, HOWEVER, 15.5° IS AVAILABLE PER SIKORSKY REPORT SER65111.

NOTE: ABOVE VALUES BASED ON RIGGING LONG. CYCLIC WITH A DIHEDRAL OF 0° WITH A -2° SHAFT DIHEDRAL RESULTING IN A -2° EFFECTIVE DIHEDRAL modify the upper control components of the CH-53D, the existing lateral cyclic limits were retained, and the additional yaw power to meet the required criteria is provided by the tail rotor of the rear helicopter.

4.3.1 Control Mixing

The chosen amounts of cyclic and collective pitch and tail rotor pitch caused by individual cockpit controls is shown on Table 4-5 together with those on the existing CH-53D. It was found that the major portion of the anti-torque need was met by the collective pitch mixing to the tail rotor of 6 degrees and to differential lateral cyclic of 2 degrees. This provided the optimum combination of lateral cyclic for lateral control and tail rotor pitch range coupled with differential lateral cyclic for directional control. Differential collective pitch satisfies the major pitch control requirements, but sufficient longitudinal cyclic control is included for precision hover tasks.

4.3.2 Trim

The MHHLS can be trimmed in steady flight for all conditions investigated.

a. Longitudinal Stick Position

The trim longitudinal stick position was computed as a function of airspeed, up to 125 knots, and is shown in Fig. 4-26. The extremes of trim stick travel allow ample control power as given in Table 4-6, which also gives the requirements of Ref. 13.

b. Lateral Directional Control Position

The trim lateral stick position, pedal displacement and roll angle have been computed for level flight speeds up to 125 knots and for sideslips up to 30°. The results are given in Fig. 4-27 for 59,486 pounds and Fig. 4-28 for 87,300 pounds gross weight.

Ref. 13 requires sideslips of 25° up to a speed of 71 knots, decreasing to 15° at 116 knots, and 14° at 125 knots. In the critical heavy weight case steady sideslips of 25° are attainable up to 85 knots before the control limits are reached, and 15° up to 100 knots, which is considered adequate for the MHHLS mission. Corresponding roll angle is only approximately 5°. A part of the pronounced left-stick position throughout the speed range is because the center of gravity is displaced to the right. As discussed in Section 3.2, the interconnecting shafting and auxiliary gearboxes are shown on the starboard side through this report. The weight of these components causes the lateral center of gravity of the MHHLS to be displaced two inches to starboard in the no-payload configuration. If the payload is considered to be centrally located, then the fully loaded center

FIGURE 4-26. MHHLS LONGITUDINAL TRIM STICK POSITION
AFCS OFF, S.L. STD. ATMOS., FLIGHT STRAIGHT AND LEVEL

G.W. 87,300 POUNDS

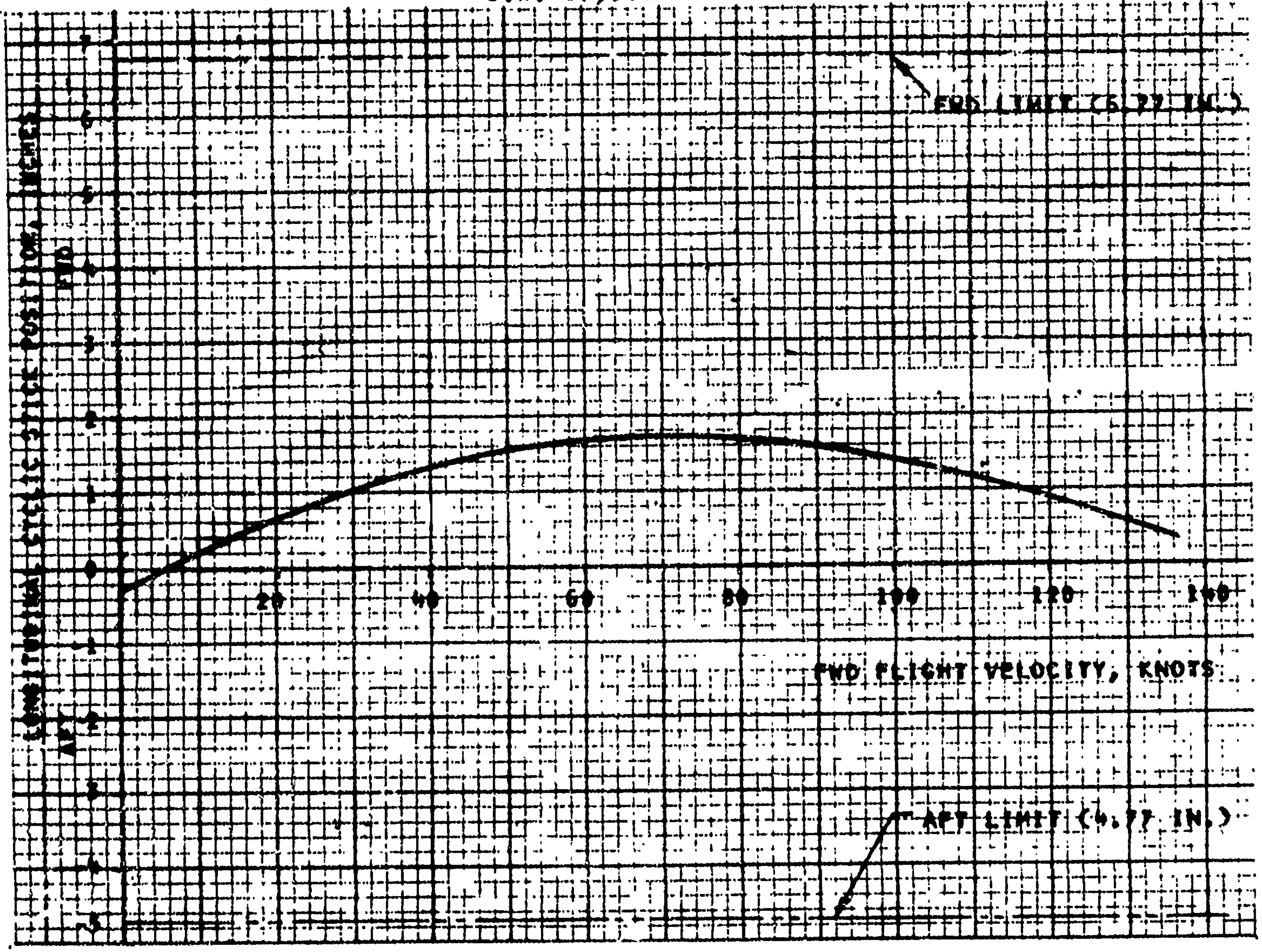


TABLE 4-6. MHHLS CONTROL RESPONSE, AFCS OFF

(WITH CONTROL REMAINING AFTER TRIM)

HOVER AND LOW SPEED

	DEGREES ATTITUDE CHANGE IN ONE SEC.									ACCEL. - "G"		
	PITCH			ROLL			YAW			VERTICAL (COLL.PITCH)		
MIL-F-83300 LEVEL	1	2	3	1	2	3	1	2	3	1	2	3
REQUIREMENT	±3.	±2.	±2.	±4.	±2.5	±2.	±6.	±3.	±2.	0.1	0.05	-
FLIGHT CONDITION												
HOVER (ONE) CH-53D	32.3			66.8			70.5					
ROTOR DIHEDRAL -2°												
87,300 LB.G.W.												
HOVER	11.8			19.4				3.9		.100		
35 KT. FWD	14.5			16.4				4.0		.186		
59,486 LB.G.W.												
HOVER	12.0			21.9				4.0		.591		
35 KT. FWD	13.8			19.6				3.3		.714		

FIGURE 4-27. MHHLS LATERAL-DIRECTIONAL TRIM
G.W. = 59,486 LB., S.L. 59°F.

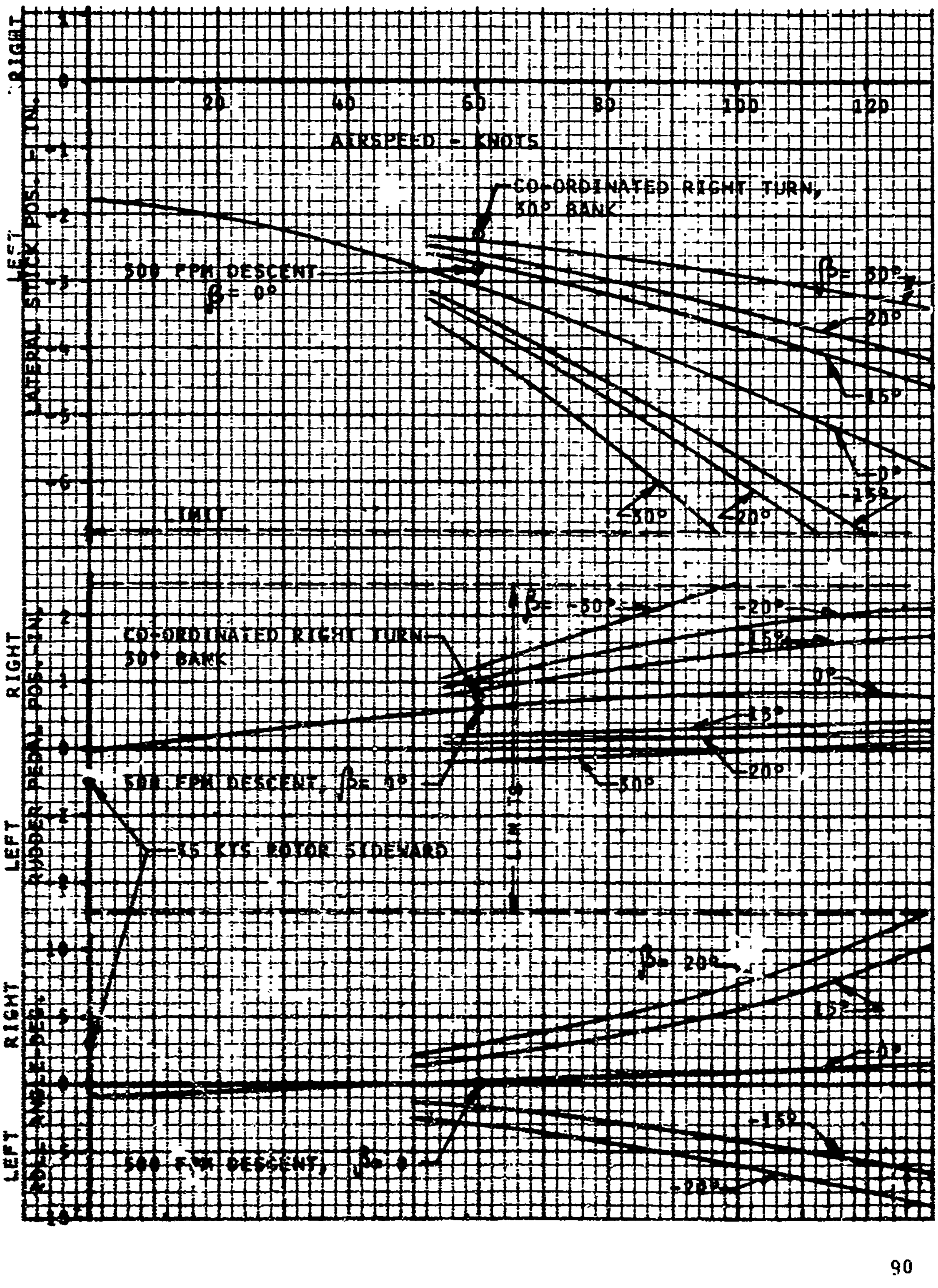
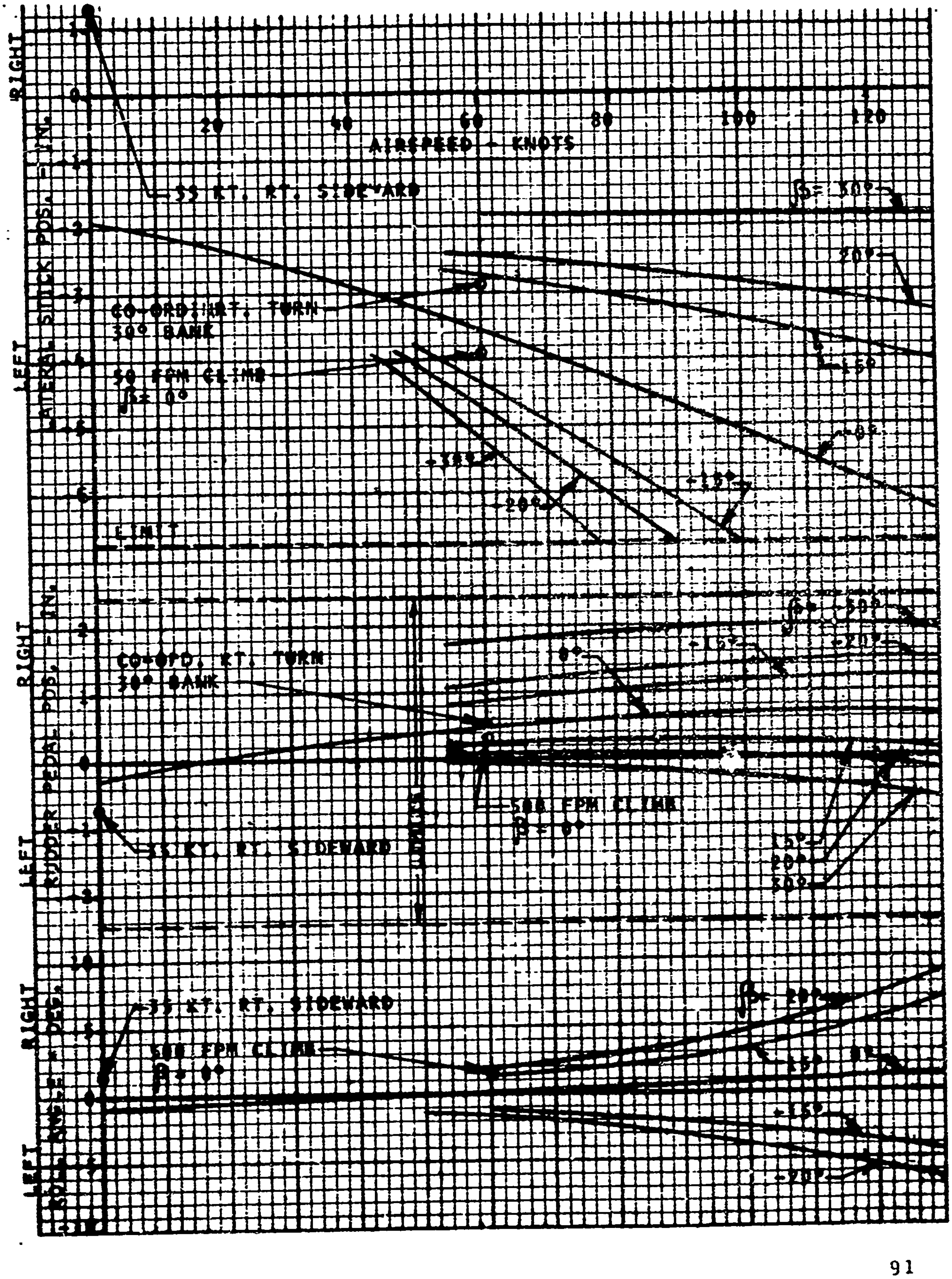


FIGURE 4-28. MHHLS LATERAL-DIRECTIONAL TRIM
G.W. = 87,300 LB., S.L., 59°F.



of gravity is 1.36 inches to starboard. Since the lateral stick trim position tends to move to the left with increasing airspeed because of lateral rotor-blade flapping, this condition is aggravated by also having to overcome a starboard center of gravity, and at 125 knots, Fig. 4-28 shows that the stick is within .72 inch of the left stop. The stick would remain more nearly centered by about 1.2 inches if the interconnecting drive system were located on the port side instead, and the required sideslip angle could probably be attained out to 125 knots.

4.3.3 Control Power

Control power AFCS off is shown in Table 4-6 and 4-7 including control available from trim, and attitude change for this amount of control, compared to the requirements of Ref. 13.

Table 4-6 for hover and low speed, indicates that the attitude change in one second, using maximum control from trim, is more than required for level 1 of Ref. 13 in pitch, roll and height control, and meets level 2 for yaw control. In forward flight, (Table 4-7), roll control power meets level 1 for speeds up to at least 100 knots. At 125 knots, the lateral stick position is only .72 inches from the left stop, and control power in this direction falls 19% below level 2. If the lateral center of gravity were shifted to the left instead of the right, as mentioned in section 4.3.2, the lateral stick position would be 2 inches from the left stop, and the control power would be well within level 1. Yaw control power meets level 2 in hover and low speed (Table 4-6) and for speeds up to 125 knots (Table 4-7). Although it would be desirable for the yaw control to meet level 1, as does all the other controls, this is precluded by the limitations on allowable control motions in the existing CH-53D. However, since the MHHLS is not expected to be maneuvered rapidly, its yaw control should be adequate. If the CH-53D swashplate motions were modified to increase the lateral tilt available, the aft tail rotor could be removed, or the yaw control power could be made to meet level 1.

An investigation was made to determine the effects of AFCS operation on the critical yaw response case which was found to be 60 knots. The yaw response for a full pedal displacement from trim is shown in Fig. 4-29. This response is greater than that with AFCS off because, in the lateral-directional dynamics, only the roll channel is provided with displacement and rate augmentation, and no yaw augmentation has been considered. With a moderate amount of gain in the yaw channel, the yaw response will be reduced, but not to an extent which would make it less than the AFCS-off value of 3.6° in one second.

4.3.4 Stability

4.3.4.1 Static Stability

a. Static Longitudinal Stability - AFCS off

The local slopes of stick position change with respect

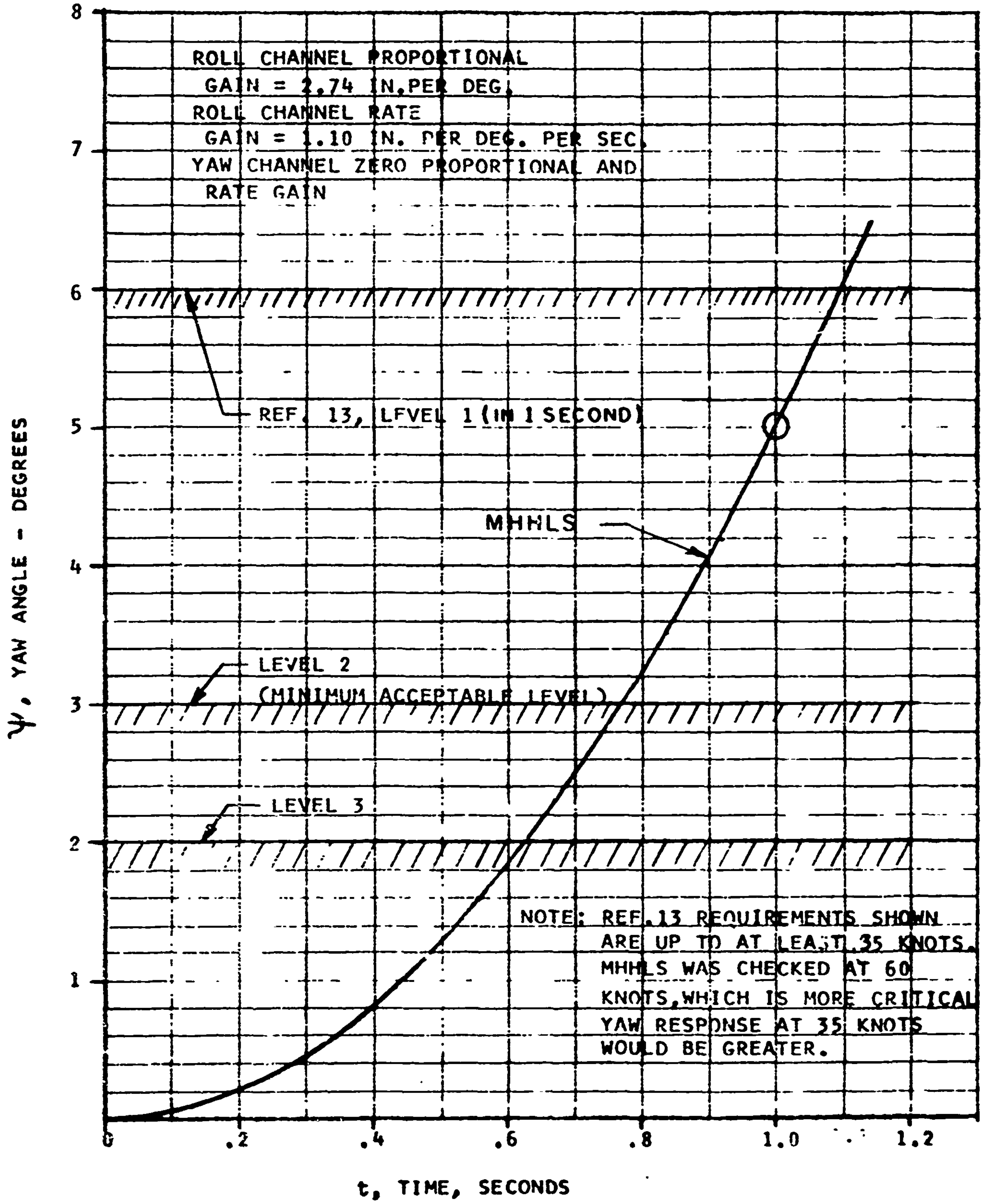
TABLE 4-7

MHHLS LATERAL/DIRECTIONAL CONTROL RESPONSE IN FORWARD FLIGHT, AFCS OFF

	ROLL			YAW		
MIL-F-83300 - LEVEL	1	2	3	1	2	3
REQ'T AT SPEEDS ABOVE 35 KNOTS	MAX. TIME TO ROLL 30 DEG. (SEC)			MIN. ATTITUDE CHANGE IN 1 SEC. (DEG.)		
(NO LONG. OR VERT.REQTS)	2.5	3.2	4.0	6.0	3.0	1.0
GROSS WEIGHT 87,300 LB.						
35 KT. STRAIGHT & LEVEL	1.6				4.0	
60 KT. STRAIGHT & LEVEL	1.8				3.6	
60 KT., 500 FPM CLIMB	1.9				3.8	
60 KT., 500 FPM DESCENT	1.7				3.4	
100 KT. STRAIGHT & LEVEL	2.4				3.6	
125 KT. STRAIGHT & LEVEL			3.8*		3.8	
GROSS WEIGHT 59,486 LB.						
35 KT. STRAIGHT & LEVEL	1.5				3.3	
60 KT. STRAIGHT & LEVEL	1.6				3.0	
60 KT. 500 FPM CLIMB	1.7				3.0	
60 KT. 500 FPM DESCENT	1.6				3.0	
100 KT. STRAIGHT & LEVEL	2.1				3.0	
125 KT. STRAIGHT & LEVEL		2.9*			3.3	

*IF LATERAL CENTER OF GRAVITY WERE SHIFTED TO THE LEFT INSTEAD OF THE RIGHT, AS DISCUSSED IN SECTION 5.3.3.1, THE CHANGE IN TRIM STICK POSITION WOULD SHIFT THE ROLL RESPONSE AT 125 KNOTS WELL WITHIN LEVEL 1.

FIGURE 4-29. YAW ANGLE TIME RESPONSE FOR FULL CONTROL INPUT FROM TRIM POSITION AFCS ON; G.W. 87,300 LB.



to speed at constant collective pitch, were calculated for 87,700 pounds gross weight, and are shown in Table 4-8.

TABLE 4-8

LOCAL SLOPE OF LONGITUDINAL STICK POSITION VS. SPEED AFCS OFF

87,300 POUNDS

SPEED (KNOTS)	0	35	60	125
STICK POSITION SLOPE (INCHES PER KNOT)	.039	.045	-.004	-.012

Ref. 13 permits an unstable (negative) local slope of up to -.025 inch per knot (one-half inch in 20 knots) for level 2 - VFR. For level 1, or for Level 2, - IFR, the slope must be positive or zero. It begins to fall below Level 1 at approximately 60 knots. It remains well within level 2 - VFR up to 125 knots. These results are consistent with the results from the computer trim and stability program, AFCS off. This program gives as output the roots of the characteristic equations, which are a direct indicator of stability (see Table 8-2 in the appendix). At zero and 35 knots, all real roots are negative, indicating static stability. However, at 60 and 125 knots, there is a positive real root, indicating static instability. The basic CH-53D AFCS, with minor modification of gains, is able to provide excellent dynamic stability, as discussed below.

b. Static Lateral-Directional Stability

Satisfactory lateral static stability characteristics dictate that the slope of lateral stick position and roll angle versus sideslip angle shall be positive (positive dihedral effect) and that the slope of pedal displacement versus sideslip angle shall be negative (positive weathercock or static directional stability) The lateral-directional trim curve cross plots contained in Fig 4-30 (for 59,486 pounds) and Fig. 4-31 (for 87,300 pounds) indicates this requirement is satisfied, with AFCS-off, over a sideslip range in excess of ±30° and in the entire forward flight speed range

c. Vertical Flight Damping

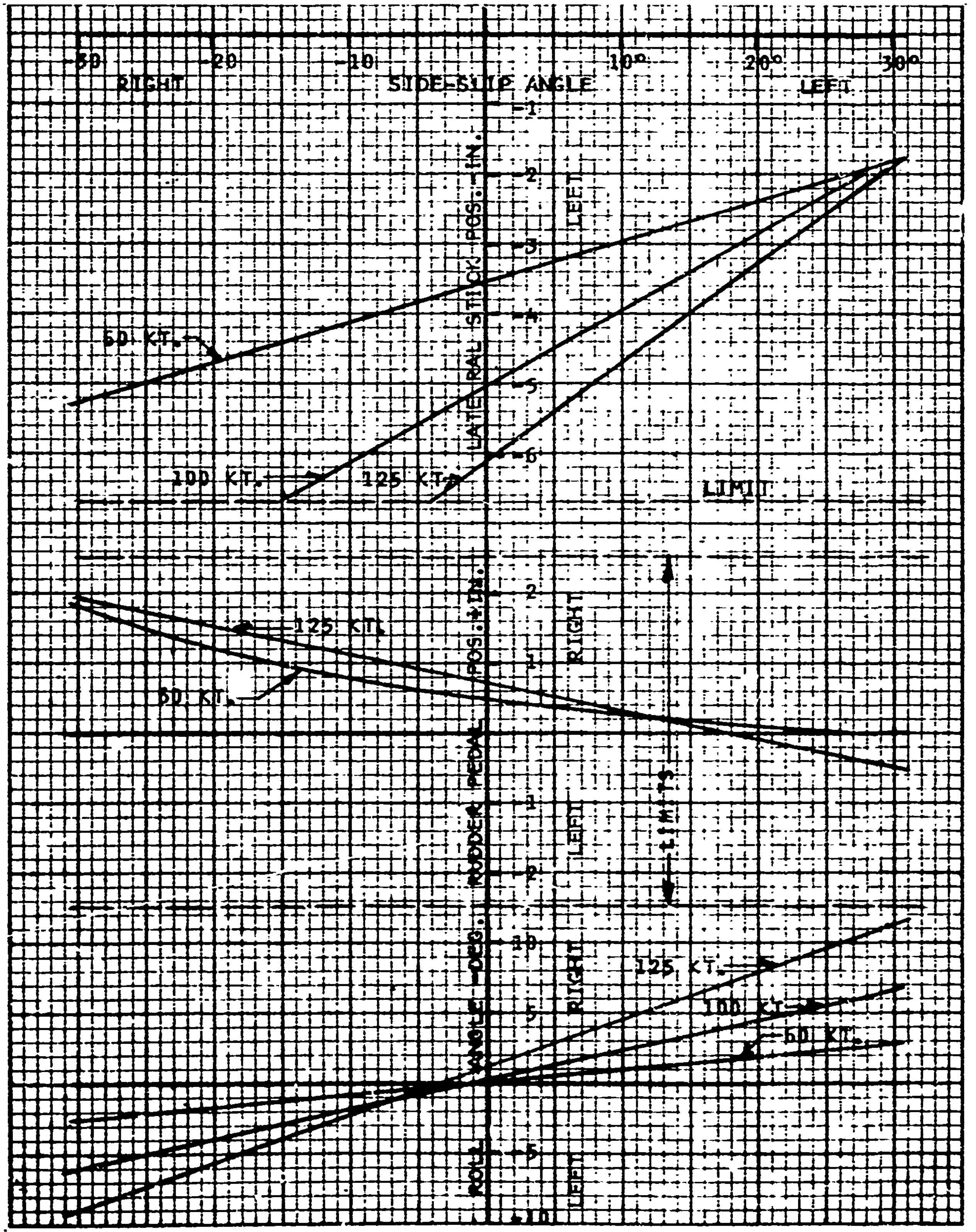
The specification of MIL-F-83300 (Ref 13) for vertical flight or translational height damping requires that vertical force change with vertical velocity shall not be in the unstable sense. Computer-derived computations of vertical damping indicate this

FIGURE 4-30. MHHLS LATERAL-DIRECTIONAL STATIC STABILITY
G.W. = 59,486 LB., S.L.,59°F.

AUTOPILOT FLIGHT CONTROL SYSTEM OFF

FIGURE 4-31. MHHLS LATERAL-DIRECTIONAL STATIC STABILITY
G.W. = 87,300 LB., S.L. 59°F.

AUTOPILOT FLIGHT CONTROL SYSTEM OFF



derivative is stable under all flight conditions with magnitudes between .007 g per ft./sec. and .029 g per ft./sec.

4.3.4.2 Dynamic Stability

a. AFCS Off. Longitudinally, at speeds below about 50 knots, the MHHLS is statically stable (no aperiodic instability) but dynamically unstable (oscillations with increasing amplitude with stick fixed). At speeds above about 50 knots, the MHHLS is also statically unstable, typical of tandem helicopters without stability augmentation. All oscillatory modes have relatively long periods (greater than 15 seconds). Root locus plots for longitudinal dynamics, AFCS off are given in Fig. 4-32. These characteristics are obtained from the longitudinal stability roots given in the Appendix., Table 8-2.

Lateral-directional dynamics are characterized by a well-damped roll mode (maximum time constant of 1.3 second) and a spiral mode (both meeting the requirements of Ref. 13) with an undamped Dutch-roll mode typical of the unaugmented tandem helicopter. These characteristics are obtained from the lateral-directional stability roots given in the Appendix, Table 8-3.

Root locus plots for lateral-directional dynamics, AFCS off, are given in Fig. 4-33.

All instabilities, both longitudinal and lateral-directional, are made stable by the CH-53D automatic flight control system (AFCS), as discussed below.

b. AFCS On. The CH-53 AFCS system redesign for the purpose of stability augmentation of the MHHLS consists of selection of the optimum feedback-loop amplifier gain (provided by the removable gain capsules). The feedback transfer function is:

$$K\ (S + K_1)$$

where K is the amplifier gain and K_1 is the ratio of proportional to rate gain. Fixed values of K_1 equal to those in the present AFCS system have been used, as the root locus analyses indicate these are near optimum for the MHHLS, and redesign for these parameters is not necessary. In the pitch channel K_1 is 2 sec^{-1} and in the roll channel K_1 is 2.5 sec^{-1}.

In the root locus plots for the pitch and roll channels (Figs. 4-34,-35, -36, the design selection has been based on the indicated (by triangle symbols) location of the well-damped, high-frequency (undamped natural frequency) closed-loop poles. Additional damped, aperiodic, closed-loop poles are shown as well in the pitch and roll channel loci. These real roots are much smaller than the oscillatory ones but do not contribute to the closed-loop dynamics because they are essentially cancelled by the adjacent zeros which

FIGURE 4-32. LONGITUDINAL DYNAMICS, PITCH AXIS ROOT LOCUS, AFCS OFF

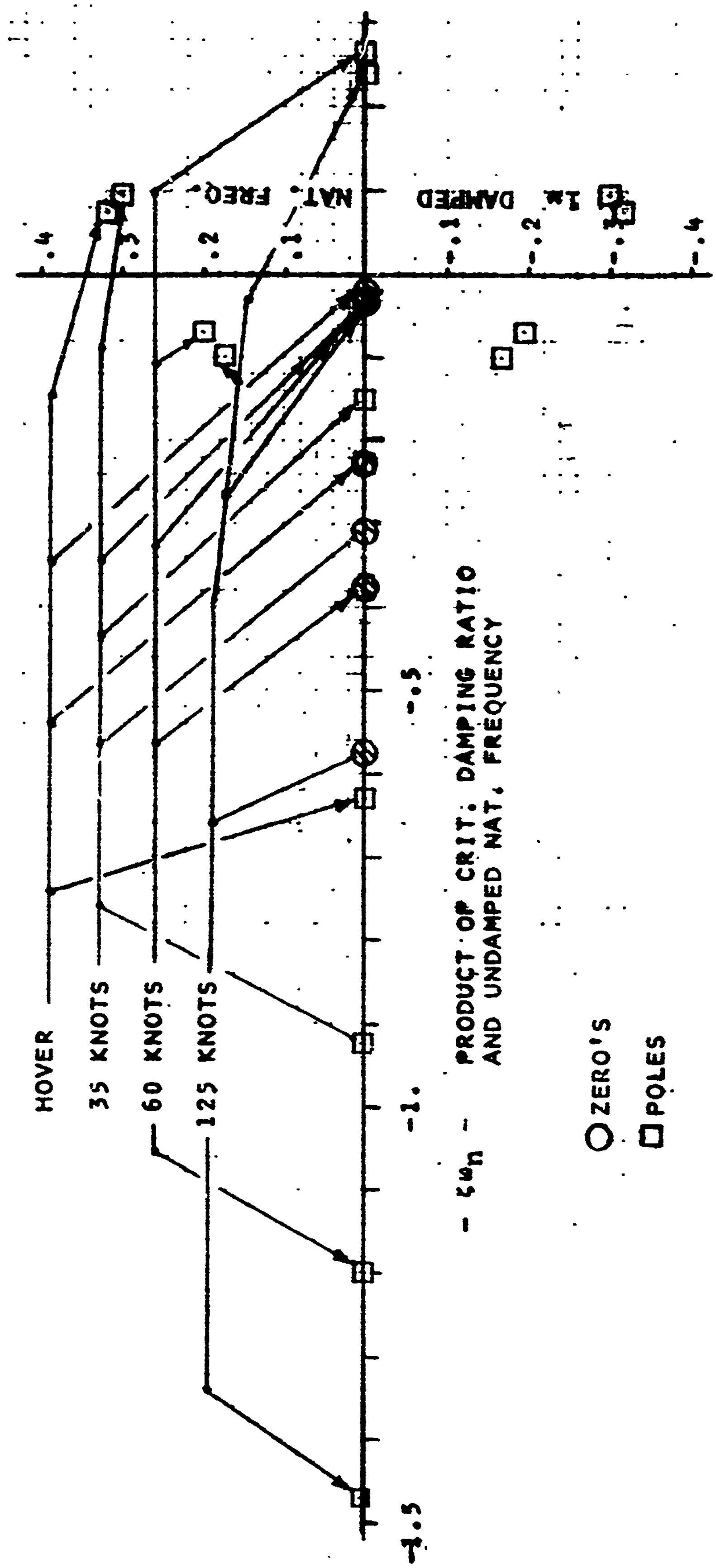


FIGURE 4-33. LATERAL DIRECTIONAL DYNAMICS, ROOT LOCUS, A.F.C.S. OFF STRAIGHT AND LEVEL

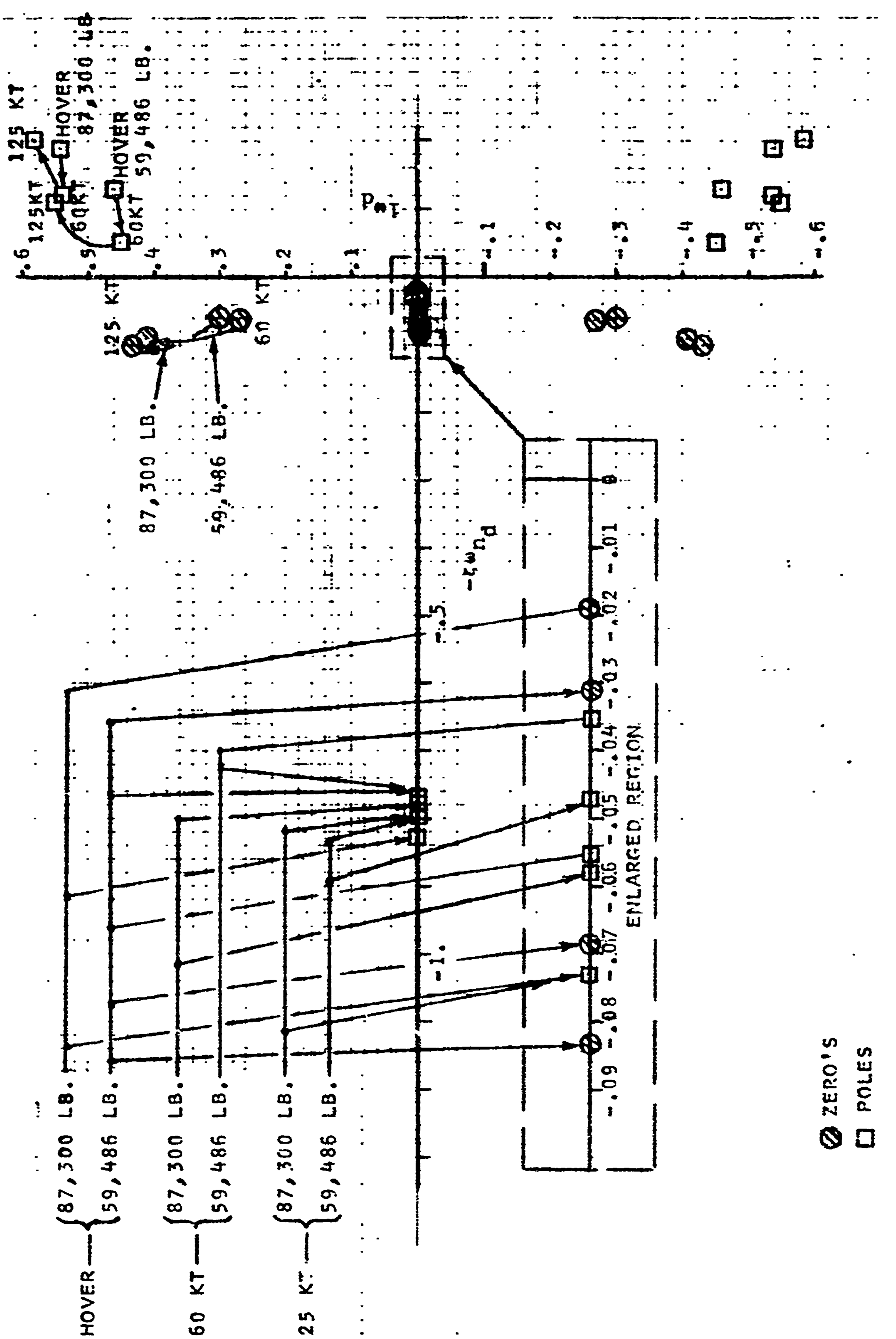


FIG. 4-34. MHHLH LONGITUDINAL DYNAMICS (AFCS ON) PITCH CHANNEL ROOT LOCUS

60 KTS., STRAIGHT AND LEVEL, G.W. = 87,300 LB., 59°F., S.L.

K_θ , PROPORTIONAL GAIN = 0.827 IN. STICK/DEG.PITCH

$K_{\dot\theta}$, RATE GAIN = 0.414 IN. STICK/DEG./SEC.

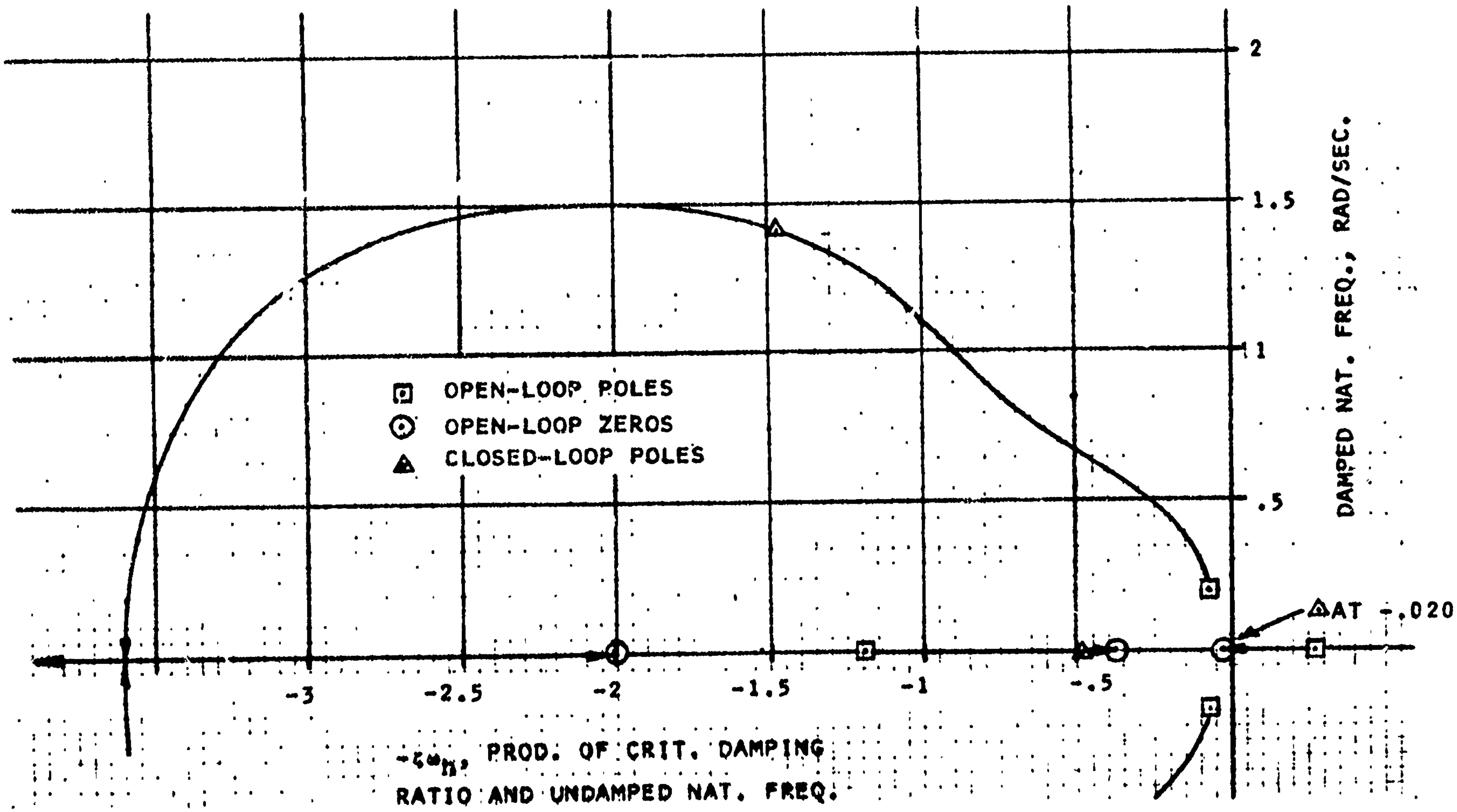


FIGURE 4-35
MMHLS LATERAL DIRECTIONAL DYNAMICS
ROLL CHANNEL ROOT LOCUS, HOVER, 87,300 LB., AFCS ON

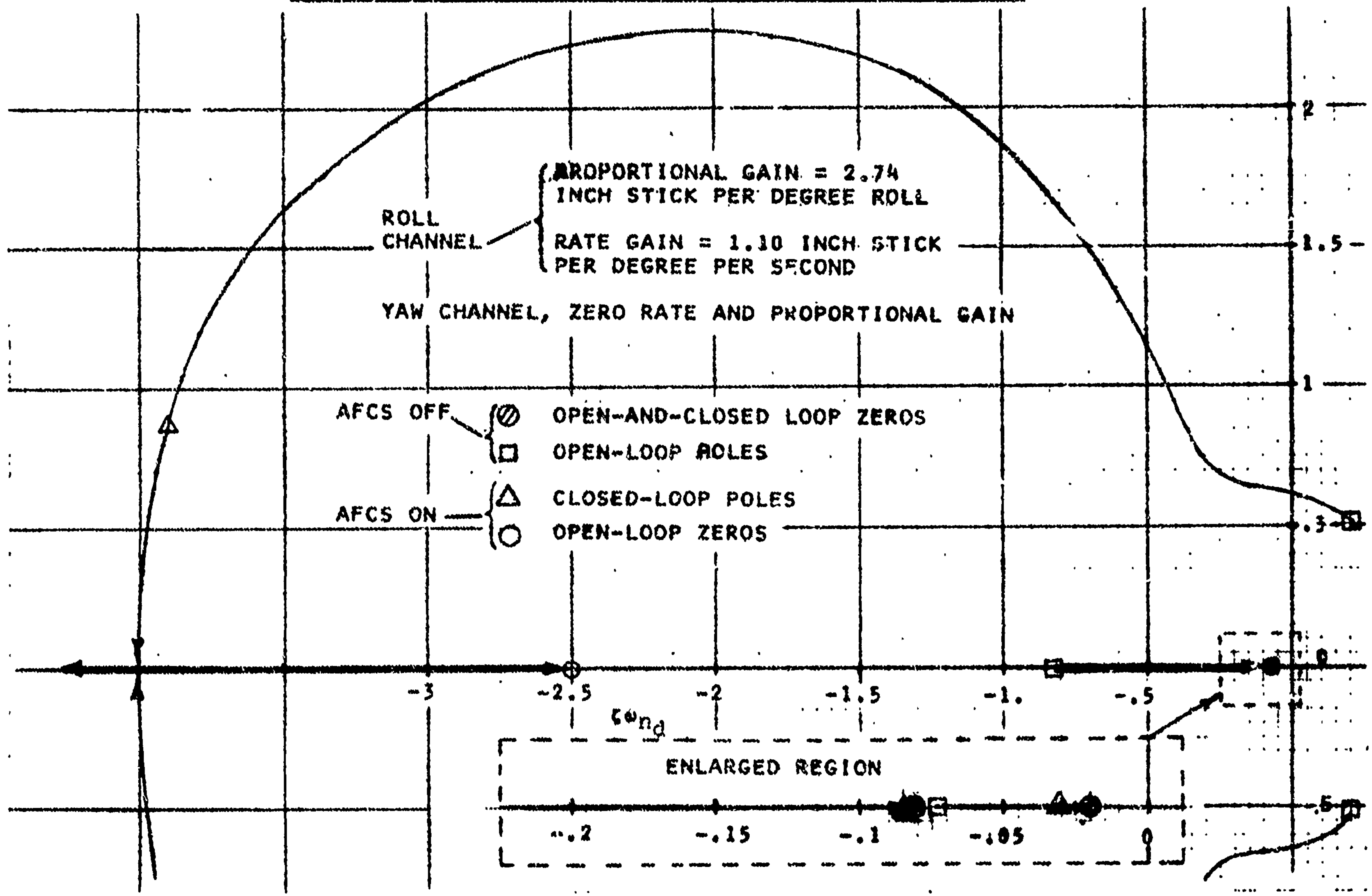
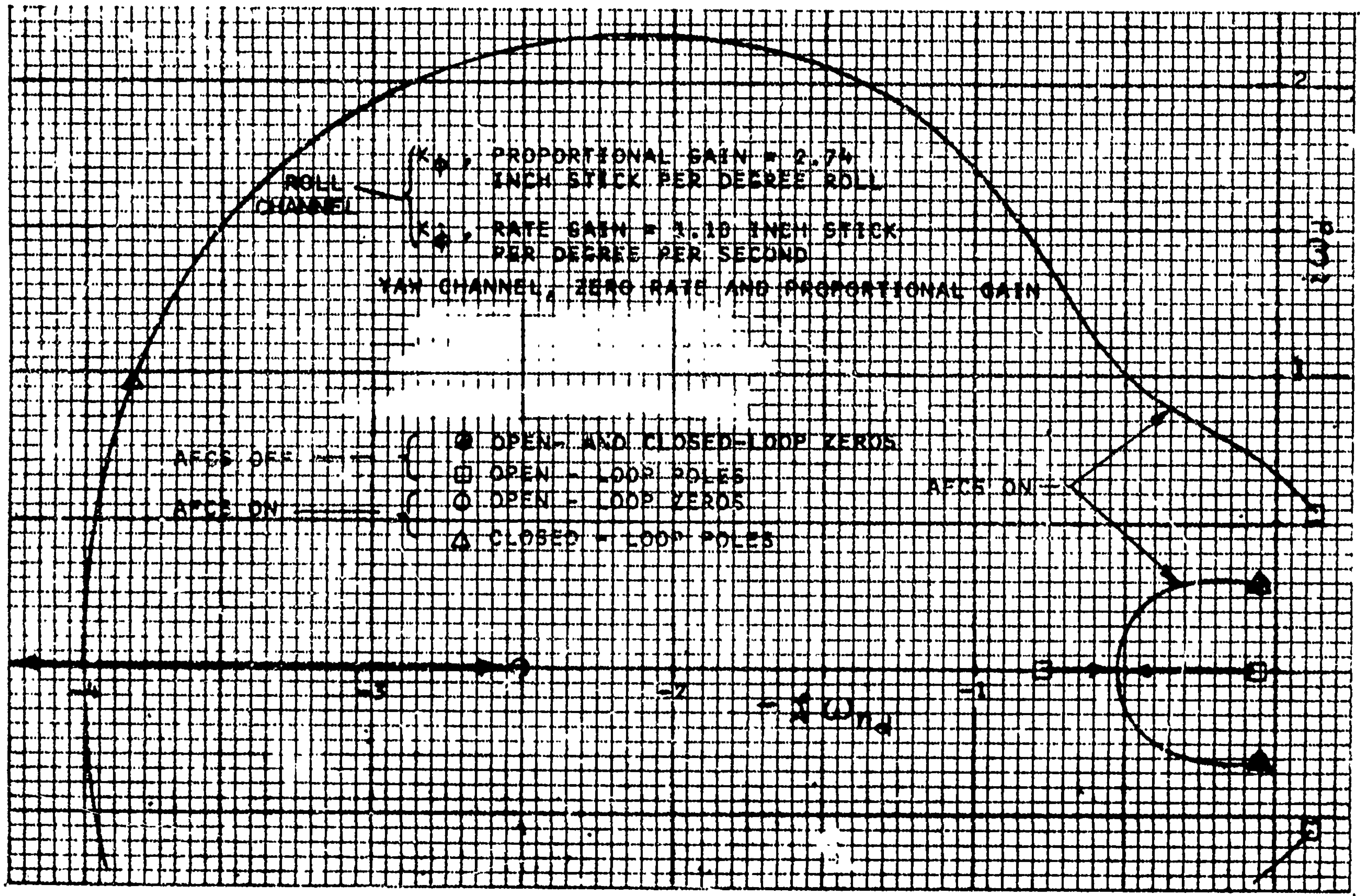


FIGURE 4-36. MHHLS LATERAL DIRECTIONAL DYNAMICS ROLL CHANNEL ROOT LOCUS

60 KNOTS, 87,300 LB. GROSS WEIGHT, S.L., 59°F



are not only the open-loop zeros, but also are closed-loop zeros in each system.

The AFCS pitch channel design root-locus is shown in Fig. 4-34. Although the design root-locus is for 60 knots, it is evident from the clustered points in Fig. 4-32 that the 60-knot condition is typical and representative of the others. The resultant closed-loop characteristics (indicated by the remaining closed-loop poles) are of high frequency and well damped. Figure 4-37 compares the MHHLS longitudinal dynamics with the requirements of Ref. 13 and is plotted on the same format as the corresponding figure in Ref. 13. Based on the 60-knot condition, with AFCS on, the Level 1 - IFR requirement for the short period damping and frequency is satisfied with a sufficient margin to ensure satisfactory dynamics at all other flight conditions, considering the close grouping of the poles and zeros. A longitudinal response to a stick pulse has been calculated for the AFCS on at 60 knots, 87,300 lbs. This is shown in Fig. 4-38 in comparison with the CH-53A response at 170 knots. It is evident that the resultant damping is near optimum with negligible overshoot and the response is essentially that of pure displacement-control to stick motion.

Utilizing the AFCS roll channel, only, for stability augmentation, the Dutch-roll mode characteristics satisfy the Level 1 requirement of Ref. 13. The design roll channel root locus is given in Fig. 4-35 as based on the critical hover, heavy weight case. It is evident from the clustered location of the poles and zeros in Fig. 4-33 that the augmentation will be equally effective at all flight conditions. The 87,300-pound hover Dutch-roll mode, with AFCS on, is well damped and of sufficient frequency to place the roots well within the Level 1 requirements region of Ref. 13 (as shown in Fig. 4-39, which is plotted in the same format as the corresponding figure from Ref. 13).

An additional AFCS root locus for the roll channel based on the same gains, has been constructed for 60 knots, 87,300 pounds. This is shown in Fig. 4-36. The purpose in obtaining this information was to determine the closed-loop characteristics required to compute the yaw-response control-power available with AFCS on, for the critical yaw-control condition. The closed-loop Dutch-roll mode characteristics are almost identical to those for the hover case using the same design gains.

With the lateral stick trim position coming close to the left stop at 125 knots, as shown in Fig. 4-28, the Dutch-roll stability could be troublesome at this speed. However, as pointed outin Section 4.3.2 (TRIM) this condition can be greatly alleviated by moving the interconnecting transmission system from the starboard side to the port side.

FIGURE 4-37. MHHLS SHORT TERM LONGITUDINAL RESPONSE CHARACTERISTICS
(REQUIREMENTS PER MIL-F-83300)

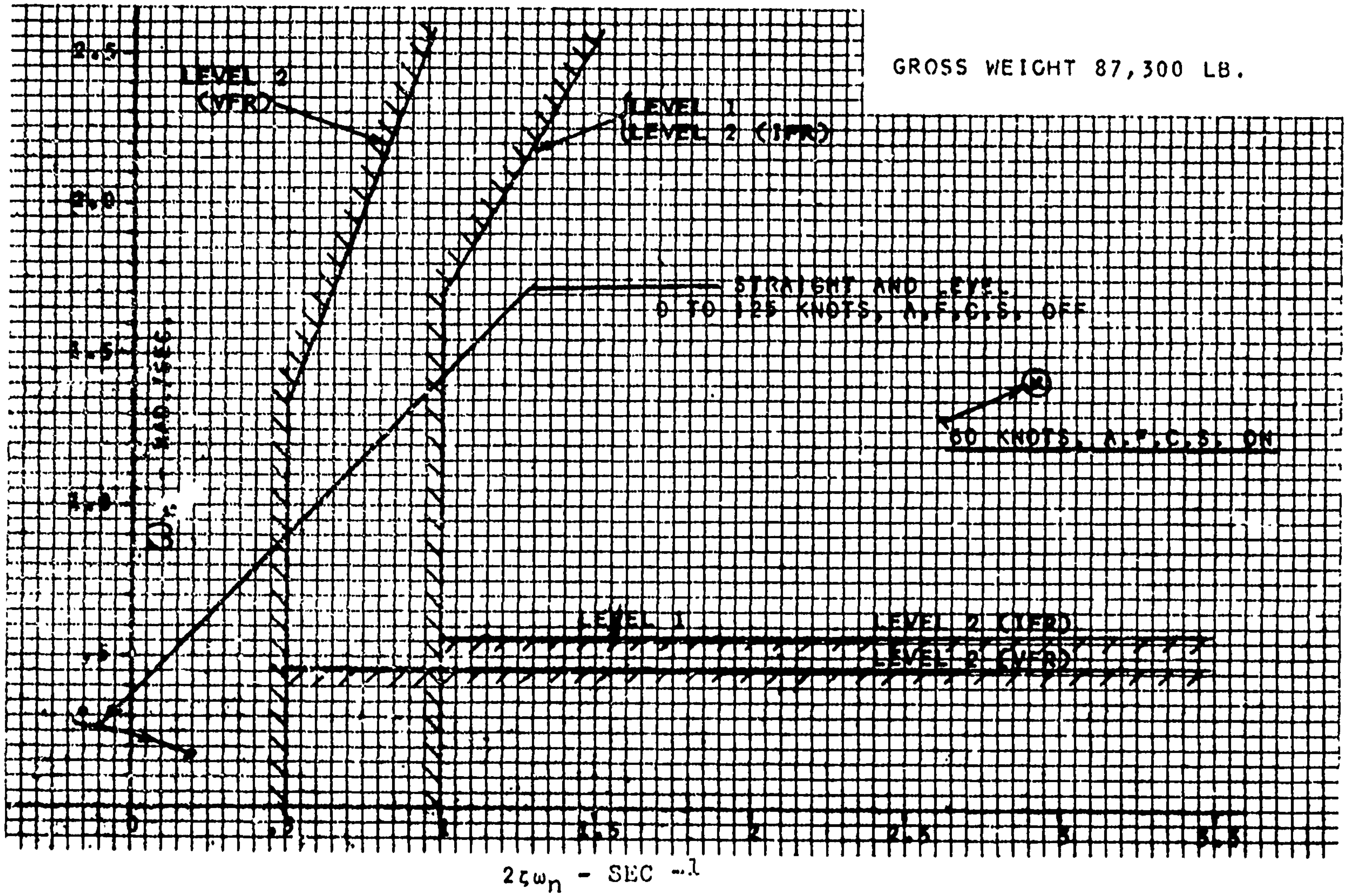


FIGURE 4-38. MHHLS LONG. STICK PULSE RESPONSE

60 KTS., 87,300 LB., 59°F, S.L., AFCS ON

K_{θ} = .827 IN. STICK/DEG. PITCH

$K_{\dot{\theta}}$ = 0.414 IN. STICK/DEG./SEC.PITCH

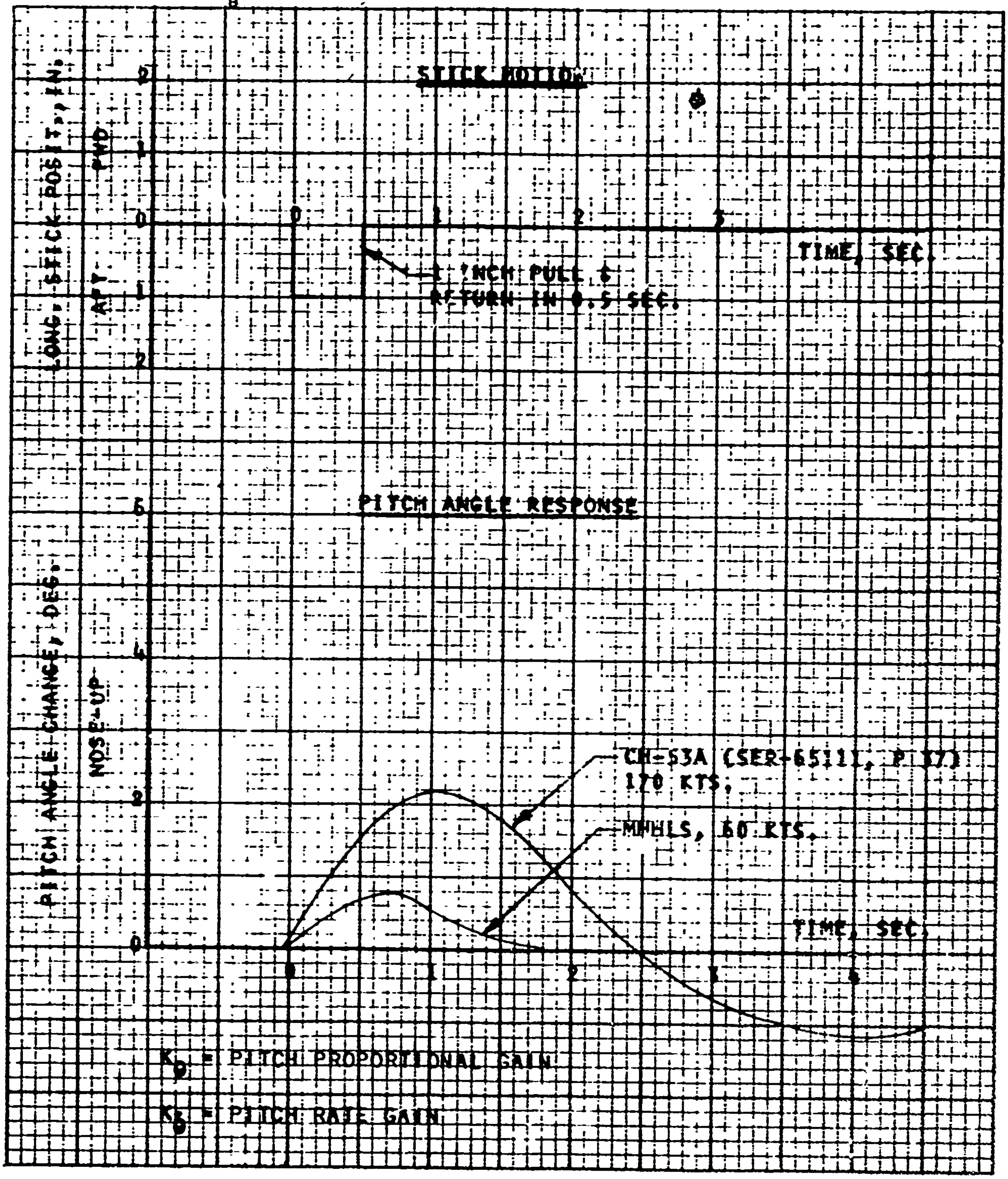
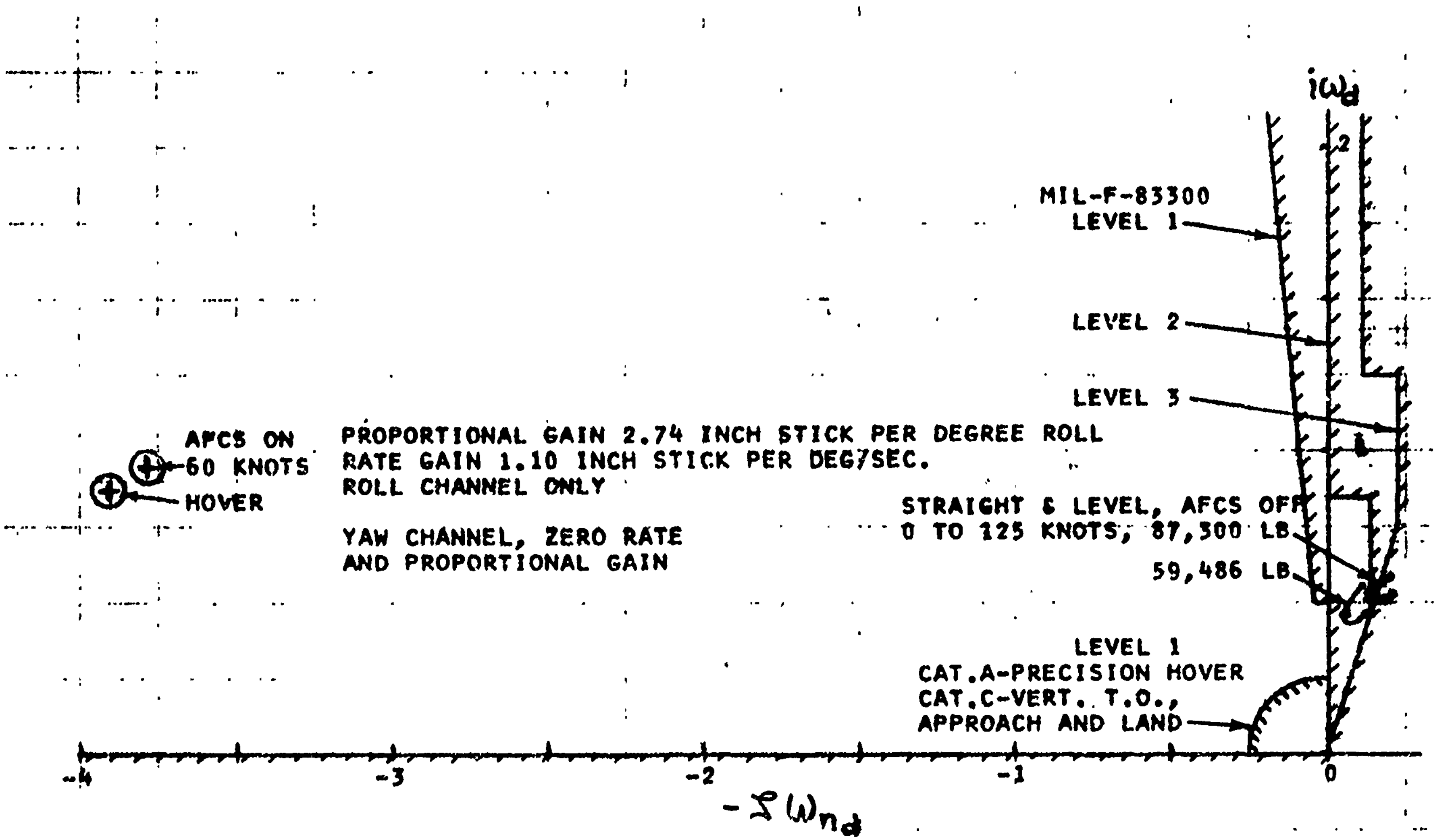


FIGURE 4-39. MHHLS LATERAL-DIRECTIONAL OSCILLATORY CHARACTERISTICS (DUTCH ROLL)

S. L., 59°F.



4.3.5 Autorotation

In the event of complete power failure (all four engines), the MHHLS would have to release its external payload, since it is not designed to land with it. An analysis was made of the longitudinal trim and control power in autorotation at 59,486 pounds (full fuel and zero payload) at 60 knots airspeed.

With full-down collective pitch, the rate of descent is 2319 ft. per minute at sea level, 59°F. Stick position is 1.56 inches forward. Longitudinal control power with full forward displacement from trim (most critical) is 10.5° in one second. Incremental vertical acceleration from full collective pitch application is 0.88-g, which is sufficient to reduce the rate of descent to zero in a height of less than 30 feet.

4.4 RELIABILITY AND AVAILABILITY

4.4.1 Reliability

The two largest single causes of mishaps in single-rotor helicopters are failure of some portion of the powerplant system and malfunction of or damage to the tail rotor. In both of these aspects, the MHHLS can be expected to show greater mission reliability than the two CH-53D's of which it is comprised.

a. Powerplant redundancy: as discussed in section 4.1 (WEIGHTS AND PERFORMANCE), the MHHLS can successfully complete probably the majority of its missions after the failure of one turbine, including hover out-of-ground-effect for pickup and discharge of cargo.

b. Tail Rotors: The MHHLS dispenses with one entire tail rotor system. In the event of failure of the tail rotor which is retained, yaw control is not fully lost. The differential lateral cyclic is sufficient to provide the anti-torque couple and approximately one-third of the original yaw control power remains for maneuvering.

Although not contemplated in this study, the MHHLS also affords the possibility of having a quadruple-redundant electrical system and AFCS. Since both of these systems are already dual on each CH-53D, tying them together to form integrated quadruple systems would not entail a great deal of extra complexity. However, their already dual redundancy should afford sufficient reliability.

A possible cause for decreased reliability is the introduction of new components into the rotor drive system (the interconnecting gears and shafting). A shaft failure would not be catastrophic, since each rotor could still be driven by its own pair of turbines, and the blades are not overlapped, permitting a safe landing. However, because of the effect on reliability of these added components, the entire MHHLS rotor drive system, including interconnecting gears and shafts, should be subjected to the design and qualification testing requirements of Ref. 16. Tandem helicopter experience, with both enclosed and open interconnected shaft systems, have shown good operational reliability. A cover over the open shaft can be installed, but has not been included in the design weight.

"Murphy's Law" states that if it is possible to do something wrong, sooner or later it will be done wrong. Since the assembly and disassembly of the two CH-53D's into the MHHLS requires numerous connections to be made or broken, the design of each connection must be such that it cannot be assembled incorrectly, and that all attaching hardware is "captive" and cannot be misplaced. For example, the structural interconnection is a simple truss with pin-ended members. The number of pins is reduced by the use of end fittings that permit the individual members to be joined to each other prior to their assembly to the aircraft. Thus, the amount of time and the operations required to make the final field joint of the aircraft are reduced. Self-lockable expanding pins are used for quick installation. Thus, precision positioning is not needed to insure final precision alignment after assembly. These pins "Expando-Grip" are standard items. Drive system interconnection utilizes face type couplings to transmit torque in each of the shaft connection joints, thus eliminating the need for careful alignment of splines. The teeth on these couplings are formed on standard gear-cutting equipment.

Considering the various aspects discussed above on an overall basis, it seems likely that the overall reliability of the MHHLS can be at least as high as that of the CH-53D's.

4.4.2 Availability

It might be argued that, since two CH-53D's are needed to carry out one MHHLS mission, the overall aircraft availability will be poorer than when each CH-53D can fly its own mission. This argument, however, overlooks the point that in the time frame contemplated, no other helicopter in the free world can perform the heavy-lift missions, for which the availability without MHHLS is zero. From this viewpoint, therefore, one can only conclude that overall mission availability is considerably increased.

4.5 COST OF CONVERSION

The cost of conversion of two CH-53D helicopters into one MHHLS consists principally of the following elements.

a. Furnishing to the Government of kits for:

1. Modifying the basic CH-53D helicopters with components making them adaptable to being connected together at a later stage, but still able to be operated as individual

aircraft. These modifications are a one-time changeover, and would be performed in an overhaul depot.

2. Installation of those items of interconnection which would not normally be left on the helicopters when they are operated individually, and which are installed at the time of actual assembly of the MHHLS.

b. Actual modification of the CH-53D's at an overhaul depot, using the kit supplied as described above. Actual connection in the field of the modified CH-53D's is described in Section 4.6, OPERATIONAL ASPECTS. The "cost" of this field operation involves only 86 man hours of mechanics' labor, and is a negligible element of cost.

4.5.1 Depot Modifications

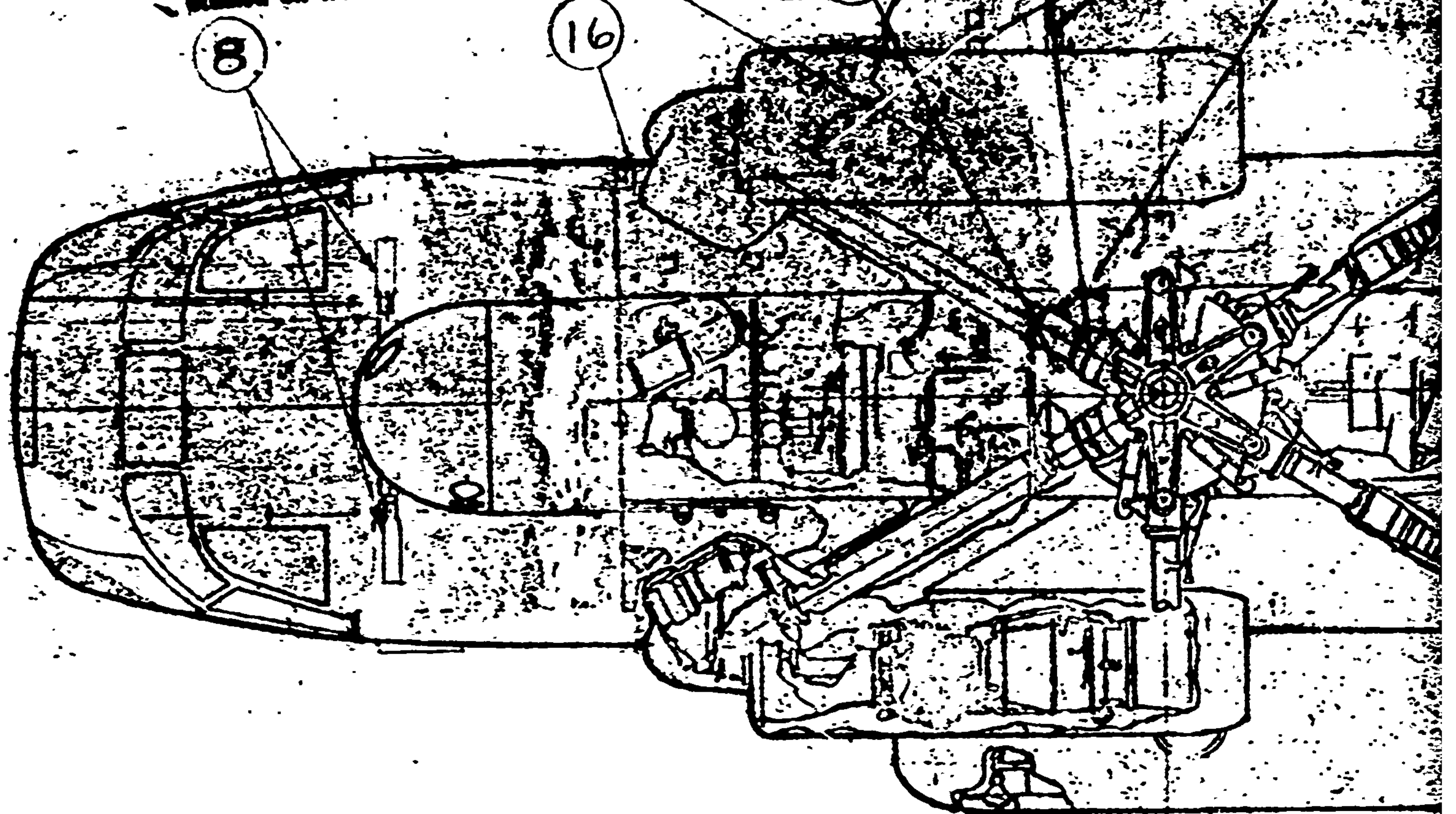
The portions of the helicopter requiring modification are shown on Fig. 4-40 and its continuation, which is a list of items furnished in the kit. Table 1 in the upper right-hand corner of Fig. 4-40 is a list of the items which are removed from the CH-53D, and replaced by items from the kit. A removed item is identified on the drawing itself by a numeral enclosed in a square. An item added, from the kit, is shown by a numeral enclosed in a circle.

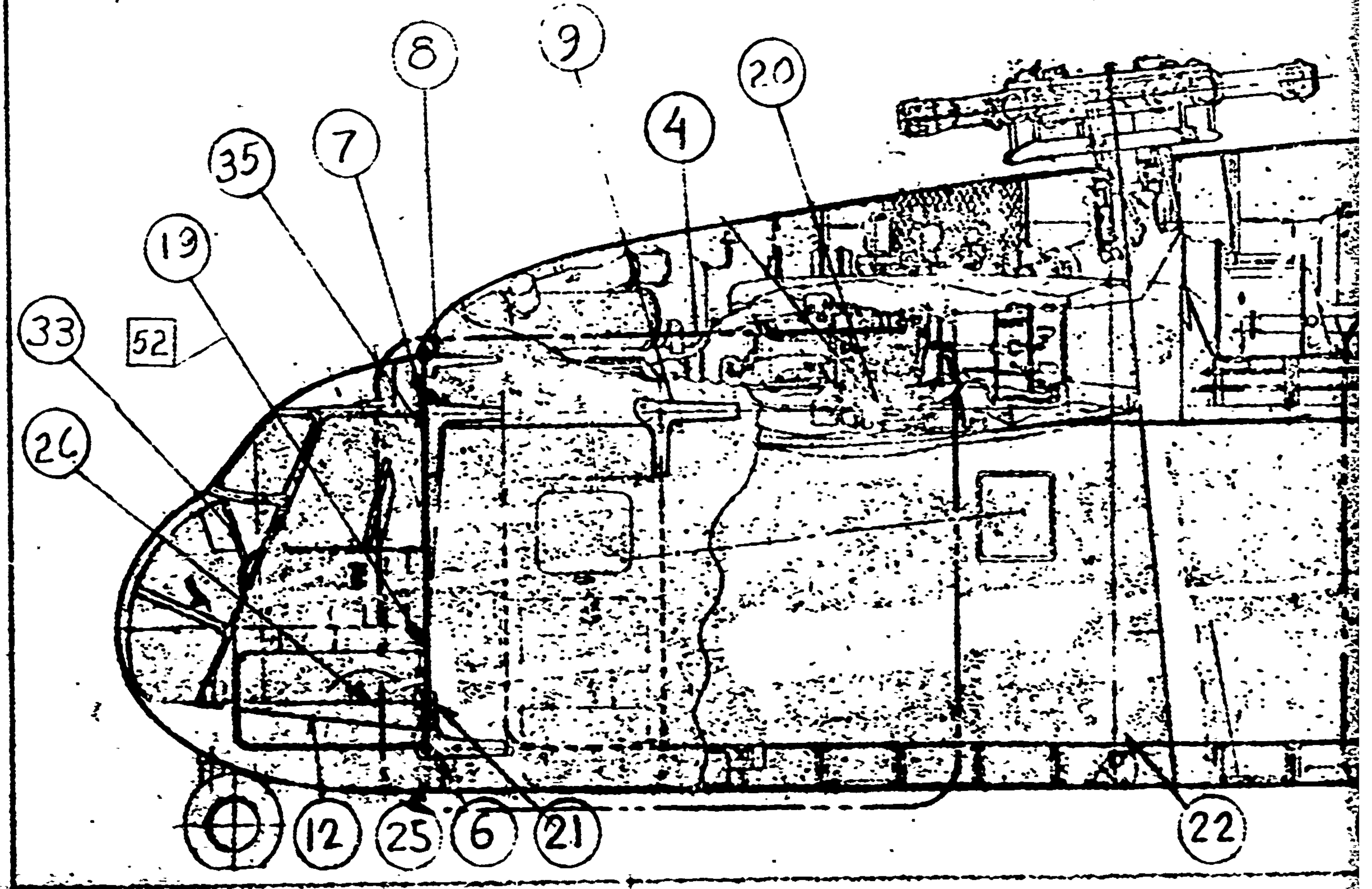
Structure

Items 4 and 5 are distributed reinforcements of the CH-53D fuselage structure to enable it to carry the increased loads discussed in Section 4.2. Items 6 through 11 are local provisions on the CH-53D structure for later attachment of the interconnecting structure. The electrical equipment door (item 12) would be prevented from opening on the MHHLS by interference with the interconnecting structure, so it is modified to open in two halves.

Drive System

Item 13 is a rotor gear box with the new input-bevel plug described in Section 3.2. The gear box removed, item 50, can be either rebuilt into a modified one or placed in the regular CH-53D spares inventory. Items 14, the new drive shaft, is identical to the old one (item 51 which it replaces), except for length. It is approximately twelve inches shorter because the new input plug protrudes that much further from the gear box. Items 15, 16 and 17 are mounting provisions for later installation of the synchronizing drive shaft supports and the intermediate gear box described in Section 3.2. The transmission cowl, item 18, is modified only by providing a clearance hole for the shaft between the rotor gear box and the added intermediate gear box.





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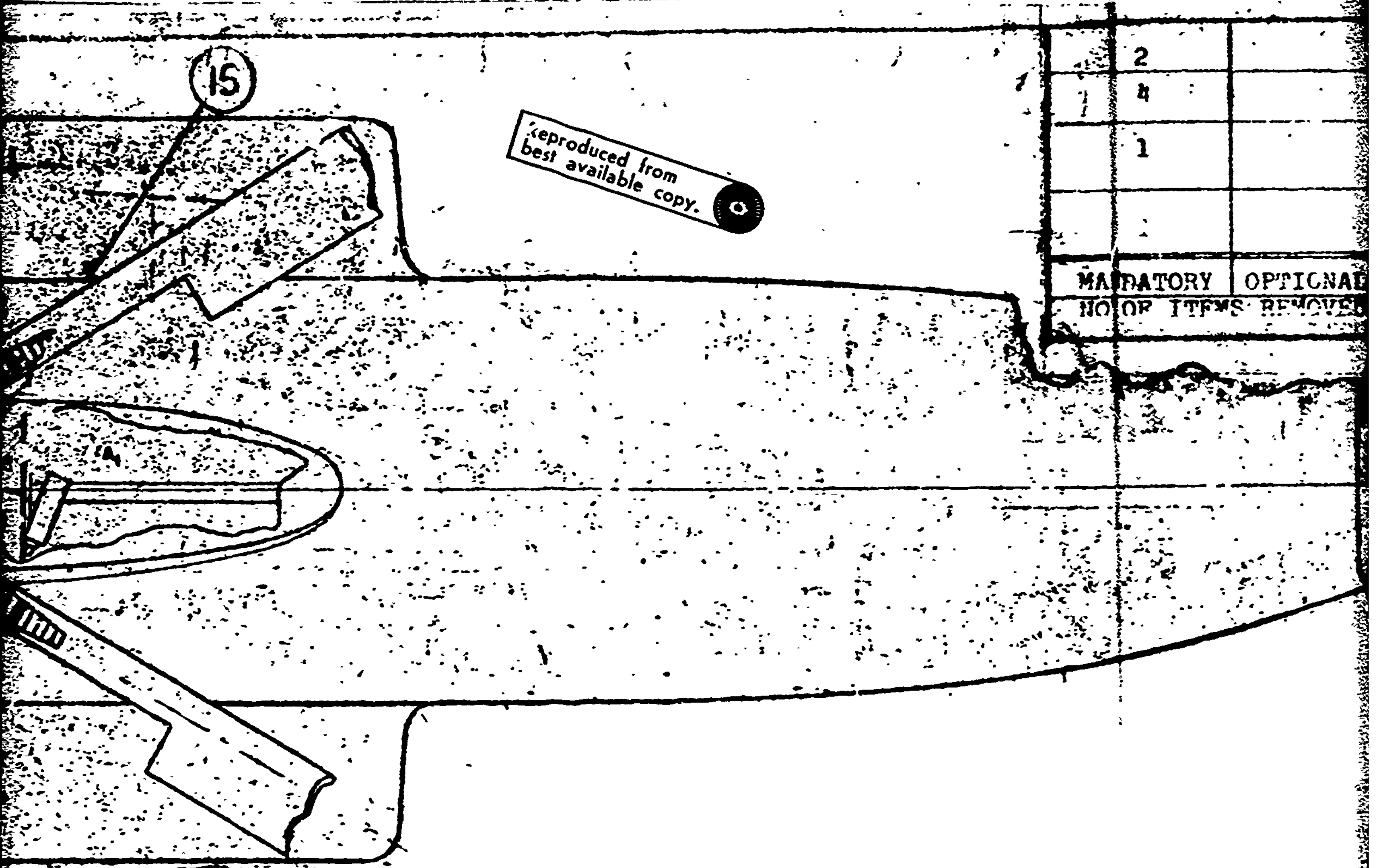
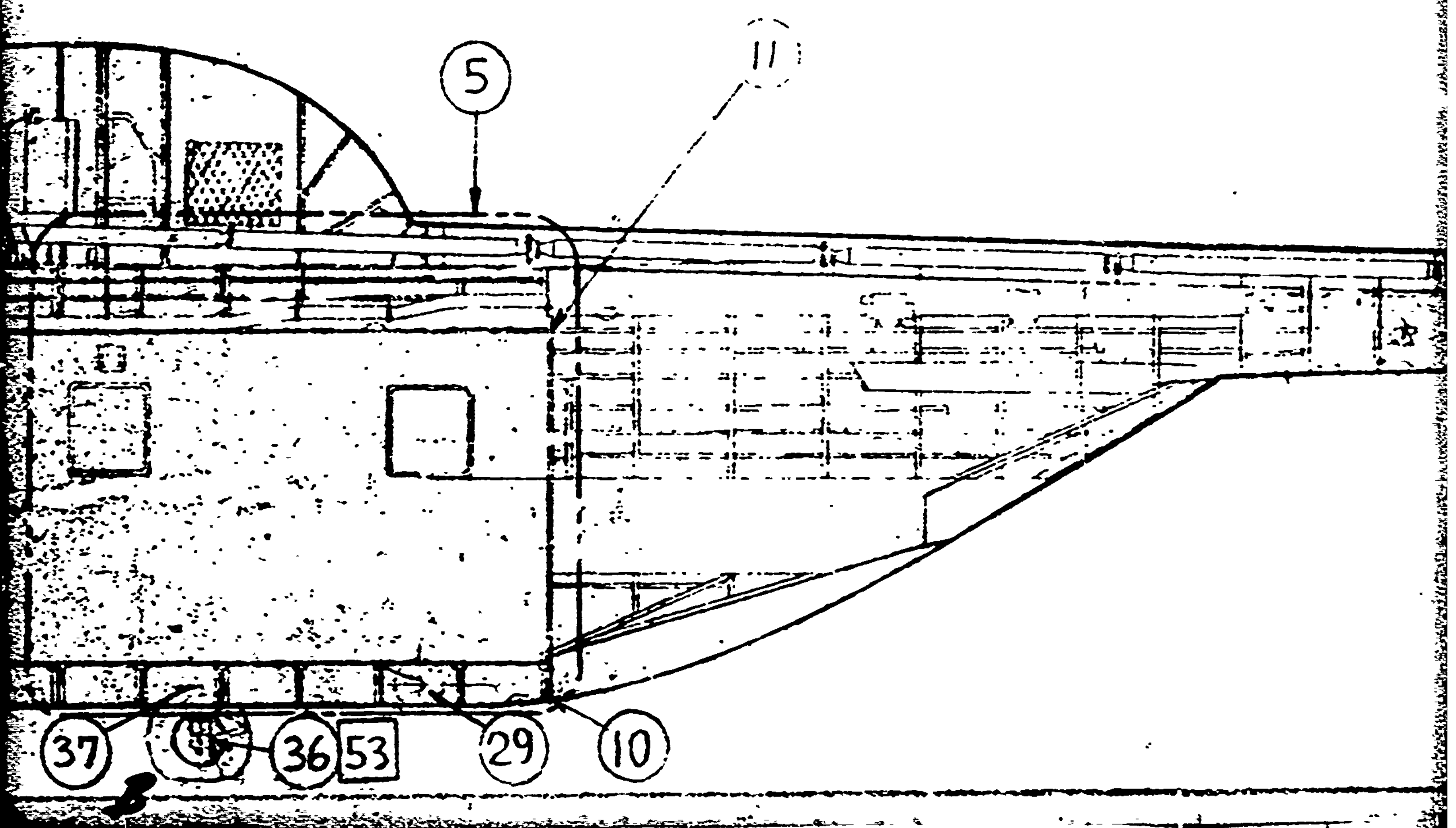
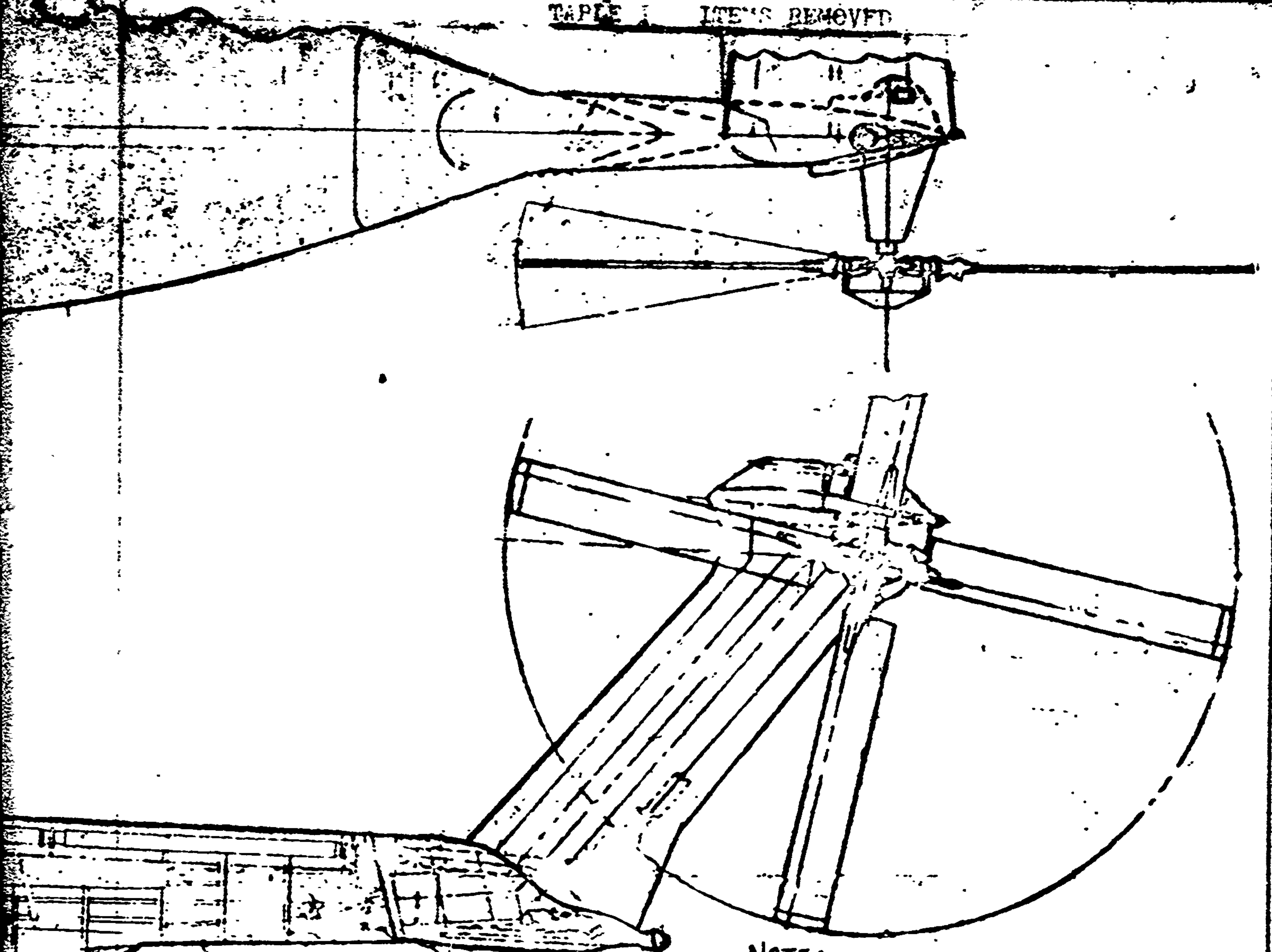

15
2
4
1
MANDATORY
OPTIONAL
NO OF ITEMS REMOVED


5
11
37
8
36
53
29
10

MANDATORY NO. OF ITEMS REMOVED	OPTIONAL	DESCRIPTION OF ITEMS REMOVED	ITEM NO.
2		MAIN LANDING GEAR ASSY	53
4		CONTROL BELLCRANK, STA 162 W.T. 127	52
1		DRIVE SHAFT, BETWEEN STBD ENGINE NOSE GEAR BOX AND TRANSMISSION	51
1		MAIN ROTOR TRANSMISSION	50

TABLE I ITEMS REMOVED



NOTES

1. FOR LIST OF MAT'L SEE FIG. 4-40 (CONT'D)
2. TABLE I SHOWS ITEMS WHICH ARE TO BE REMOVED

CH-53D
DEPOT MODIFIED
FOR INTERCONNECTION

FIG. 4-40

FIGURE 4-40 (cont'd)

-3			PART NO.	DESCRIPTION	SPECIFICATION	[illegible]	[illegible]
1			39L-1002-1	[illegible] CONTROLS, MAIN L/G SWIVELING			37
1			39L-1001-1	[illegible] TYPE (LOCKABLE) MAIN L/G			36
				LANDING GEAR			
							35
1			39Q-1002-1	(PROVISIONS FOR (WIRING, AFT A/C ENGINE INSTRUMENTS			34
1			39Q-1001-1	(PROVISIONS FOR (AFT A/C ENGINE INSTRUMENTS IN FWD A/C			33
1			39E-1003-1	(PROVISIONS FOR (WIRING, ENGINE CONTROL, FWD A/C			32
1			39E-1002-1	(PROVISIONS FOR (WIRING, ENGINE CONTROL, AFT A/C			31
1			39E-1001-1	MODIF'N, STBD ENGINE COWL			30
1			39H-1003-1	PULLEY BRACKET, A/C TO RAMP			29
1			39F-1002-1	PROVISIONS FOR WIRING, AFT/FWD INTERCOM SYSTEM			28
1			39F-1001-1	PROVISIONS FOR WIRING, AFT/FWD INTERCOM SYSTEM			27
				EQUIPMENT, INSTRUMENTATION, COMMUNICATION, ETC.			
1			39C-1019-1	MODIF'N,ELEC.COMP.SHELF			26
1			39C-1018-1	COVER, CONTROL ROD HOLE, STA 162			25
1			39C-1017-1	PROVISIONS FOR WIRING, FOR AFCS, AFT A/C			24
1			39C-1016-1	PROVISIONS FOR WIRING FOR AFCS, FWD A/C			23
1			39C-1015-1	PROVISIONS FOR FITTINGS, SUPPORT, CONTROL CONDUIT			22
1			39C-1014-1	PROVISIONS FOR FITTINGS, CONTROL CONDUIT SUPPORTS			21
1			39C-1013-1	PROVISIONS, CONTROL MIXING ADAPTER			20
1			39C-1012-1	MODIFIED CONTROL BELCRANKS, STA 162			19
				CONTROL			
1			39D-1010-1	MODIF'N. TRANSMISSION COWL			18
1			39D-1009-1	PROVISIONS FOR FITTINGS, BEVEL GEAR BOX			17
1			39D-1008-1	PROVISIONS FOR FITTINGS, DRIVE SHAFT SUPP., STA.222			16
1			39D-1007-1	PROVISIONS FOR FITTINGS, DRIVE SHAFT SUPP., STA. 322			15
1			39D-1006-1	DRIVE SHAFT, [illegible] ENGINE TO TRANS.			14
1			39D-1005-1	MODIFICATION, ROTOR TRANSMISSION			13
				DRIVE			
			39S-1041-1	MODIF. DOOR, ELECTRICAL COMP.			12
1			39S-1040-1	(PROVISIONS FOR (UPPER INTERCONNECTING FITTINGS STA 522			11
1			39S-1039-1	(PROVISIONS FOR (LOWER INTERCONNECTING FITTINGS STA 522			10
1			39S-1038-1	(PROVISIONS FOR (UPPER INTERCONNECTING FITTINGS STA 222			9
1			39S-1037-1	(PROVISIONS FOR (ROOF INTERCONNECTING FITTINGS STA 162			8
1			39S-1036-1	(PROVISIONS FOR (UPPER INTERCONNECTING FITTINGS STA162			7
1			39S-1035-1	(PROVISIONS FOR (LOWER INTERCONNECTING FITTINGS STA162			6
1			39S-1034-1	FUSELAGE STRUCTURAL REINFORCEMENTS			5
1			39S-1032-1	FUSELAGE STRUCTURAL REINFORCEMENTS			4
				STRUCTURE			
			-3	CH-53D DEPOT MODIF'D TO MCH-53D			3
							2
							1

Controls

The bell cranks at station 162 (item 19) are modified for later attachment of the MHHLS controls interconnection as described in Section 3.3.1. They replace item 52. Item 20 comprises provisions for later replacement of the mixing unit with a modified one as described in Sections 3.3 and 3.3.2. Items 21 and 22 are mounting provisions for later installation of the interconnecting controls conduit (Section 3.3.1). Items 23 and 24 are wiring provisions for later interconnection of the electrical portions of the automatic flight control systems. Items 25 and 26 are minor, non-structural, modifications in the electrical compartment to eliminate spacial interference with the interconnecting controls.

Equipment

Items 27, 28, 31, 32 and 34 are provisions for later electrically interconnecting various subsystems. The pulley bracket (item 29) is installed so that the CH-53D can be positioned on the assembly ramp during assembly into the MHHLS by use of its own cargo-handling winch (see Section 4.6). The engine cowl (item 30) requires clearance holes for the drive shaft between the rotor gear box and the new intermediate gear box.

Landing Gear

As described in Section 3.1, the main landing gear of the forward helicopter of the MHHLS becomes the nose gear of the combined system, and must be swivelling for ground maneuverability. Thus the main landing gear assembly (item 53) is replaced with a modified assembly (item 36) which is locked to prevent swivelling when used in the normal CH-53D configuration, but which can be unlocked for the MHHLS. Item 37 comprises the locking controls.

4.5.2 Kits for Field Interconnection

Assembly of two CH-53D's modified as in Section 4.5.1 into the MHHLS is accomplished with three field installation kits:

a. Components to be installed in the forward helicopter of the pair.

b. Components to be installed in the aft helicopter.

c. The interconnecting section which joins the two helicopters.

The items in the kits are shown on Figures 4-41, -42, and -43, respectively.

4.5.2.1 Forward Aircraft Field Modification Kit (See Fig. 4-41)

This kit contains the fittings (items 15 and 16) to be installed just forward of the cargo-loading ramp for joining to the interconnecting structure, the sections of synchronizing shafting and their supports which are mounted on the forward helicopter (items 3 through 6), the intermediate bevel gear box (item 7), and the push-pull rods for interconnecting the controls (item 8), the functions of all of which are self-evident. The modified control mixing unit (item 9) replaces item 55 which is removed, as described in Section 3.3.2. The control conduit assemblies (items 10 and 11) are the portions of the conduit described in Section 3.3.1 which are supported from the forward helicopter. Item 12, which replaces item 65, causes the AFCS servo units in both helicopters to operate as a single system with the proper gains adapted to the MHHLS'S flight characteristics. Item 17 comprises duplicate instruments to display to the master pilot information on essential systems in the aft helicopter. A list of these instruments is given in Table 4-9. Item 18 comprises the various wiring harnesses to be installed in the forward helicopter for interconnection to the appropriate systems in the aft helicopter.

4.5.2.2 Aft Aircraft Field Modification Kit (see Fig. 4-42)

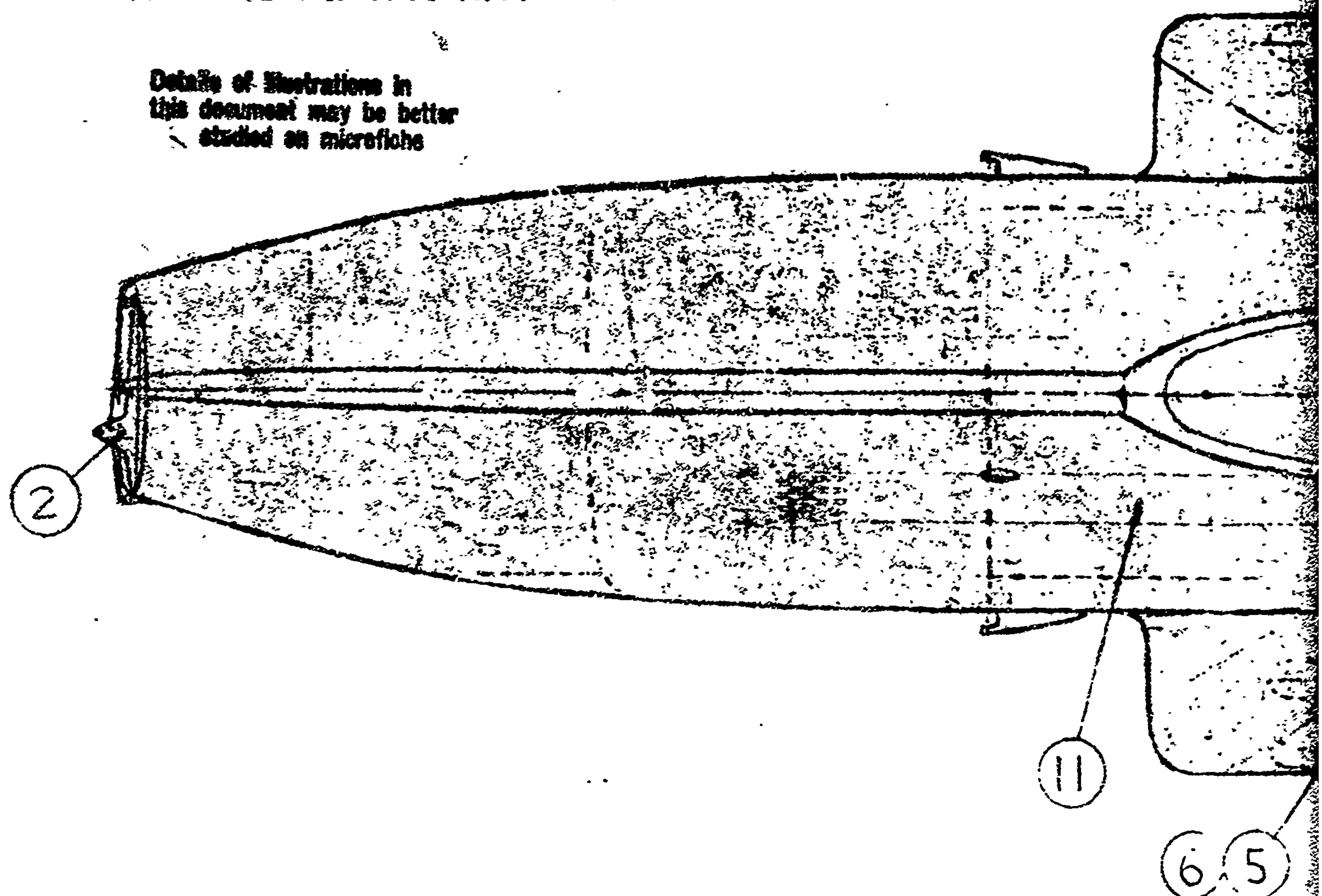
This kit contains the brackets and fittings (items 2, 3, and 14 through 17) to be installed just aft of the cockpit for joining to the interconnecting structure, the sections of synchronizing shafting and their supports (items 4 through 7) which are mounted on the aft helicopter, the intermediate bevel gear box (item 8) which is identical to item 7 of Fig. 4-41, the controls push-pull rods (item 9), the modified controls mixing unit (item 10 which replaces item 53), and item 15 comprising the wiring harnesses to be installed in the aft aircraft.

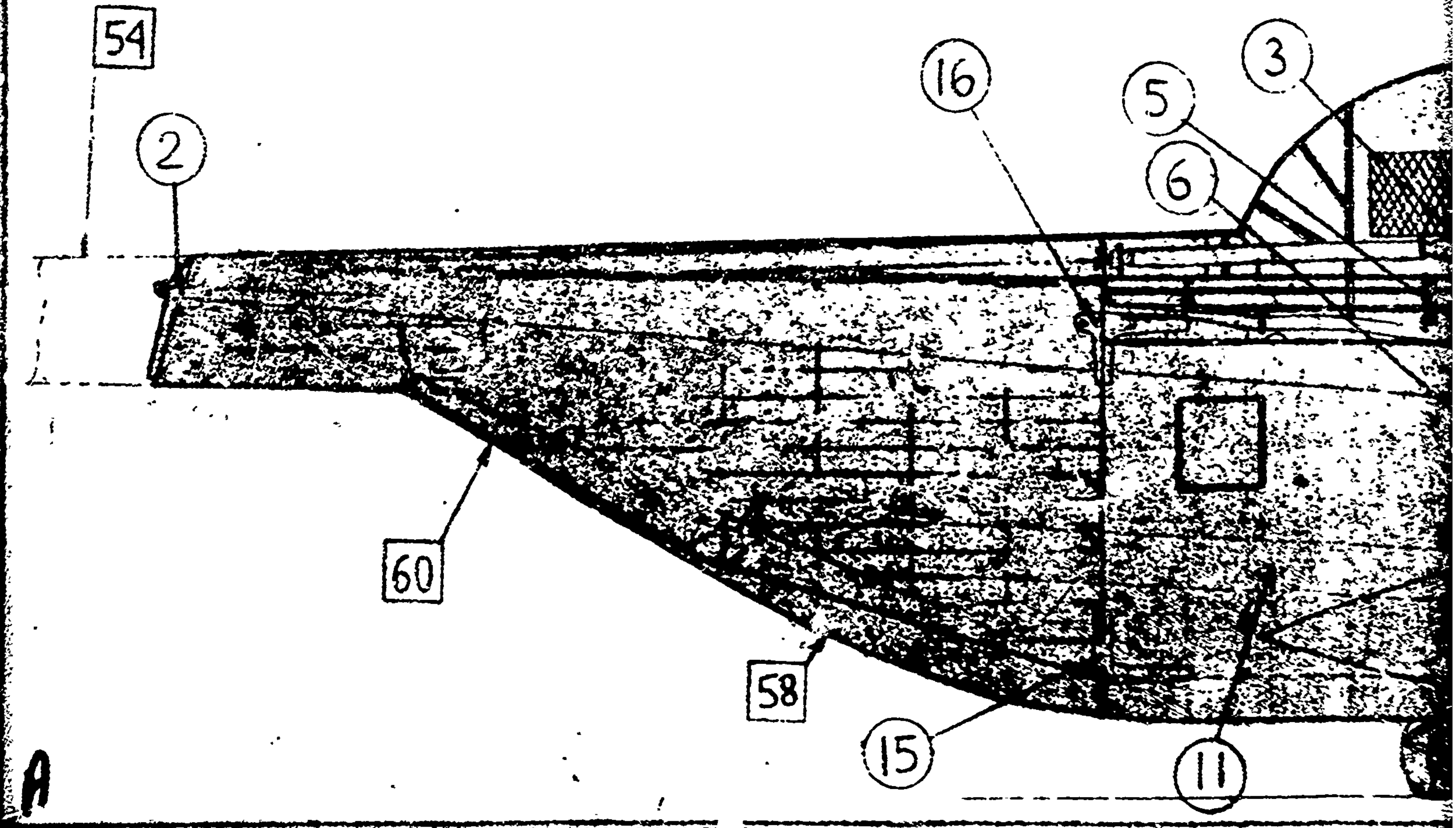
4.5.2.3 Interconnecting Section Field Kit (see Fig. 4-43)

This kit comprises the components of structure, drive shafting, controls, and electrical cables which join the forward helicopter to the aft one. These components can be assembled into a sub-assembly, as shown in Fig. 4-44, which can be left intact, and need not be taken apart each time the MHHLS is returned into two CH-53D'S. The assembly dolly shown on Fig. 4-44 does not remain with the sub-assembly, but is used for ground handling during assembly of the MHHLS.

4.5.3 Cost of Modification

Table 4-10 summarizes the estimated cost of material in dollars and labor in man-hours to supply the four kits required, and the man-hours expended in depot and field installations of the kits to assemble one MHHLS, based on a procurement of 20 system sets. All


2
11
6
5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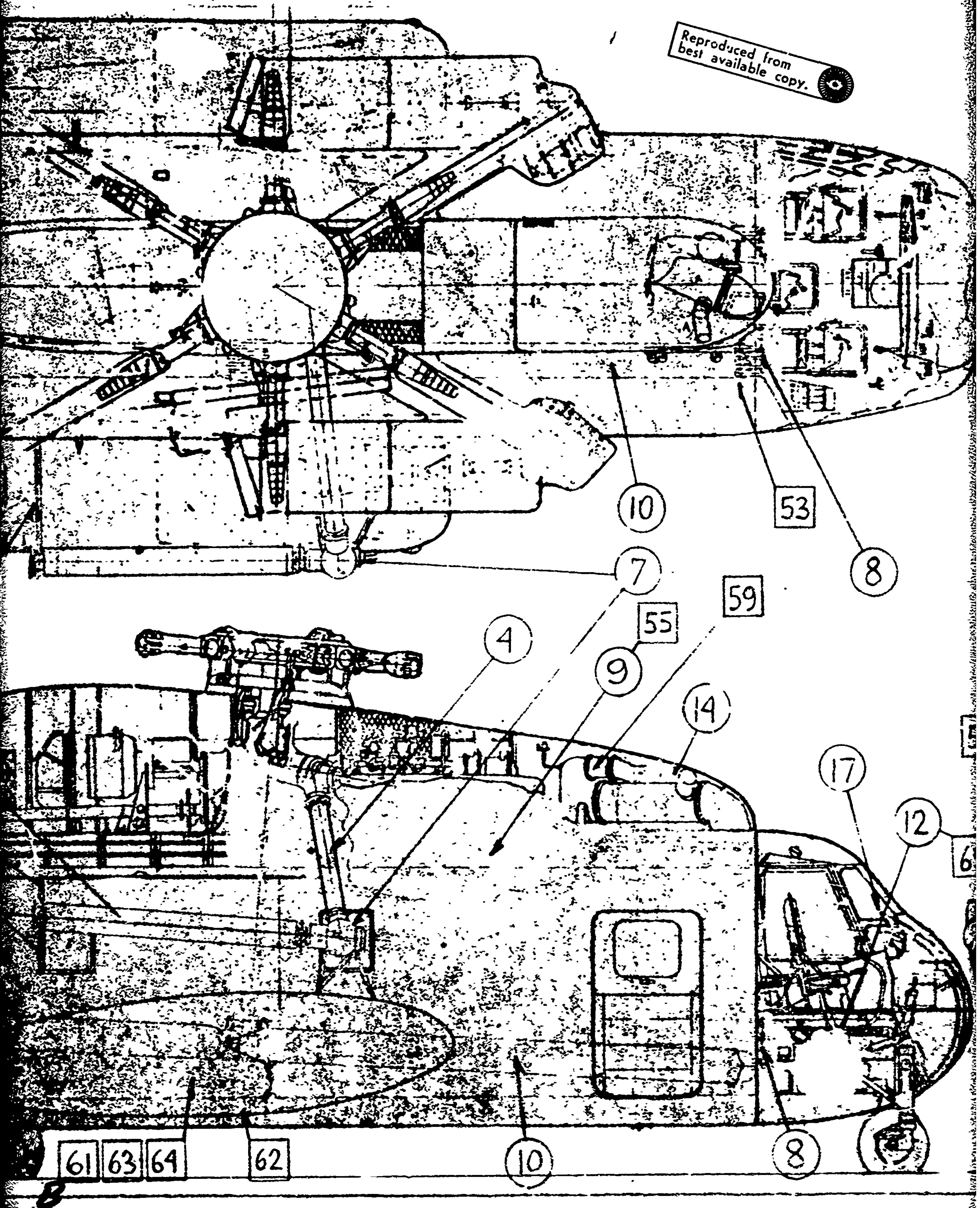
10
53
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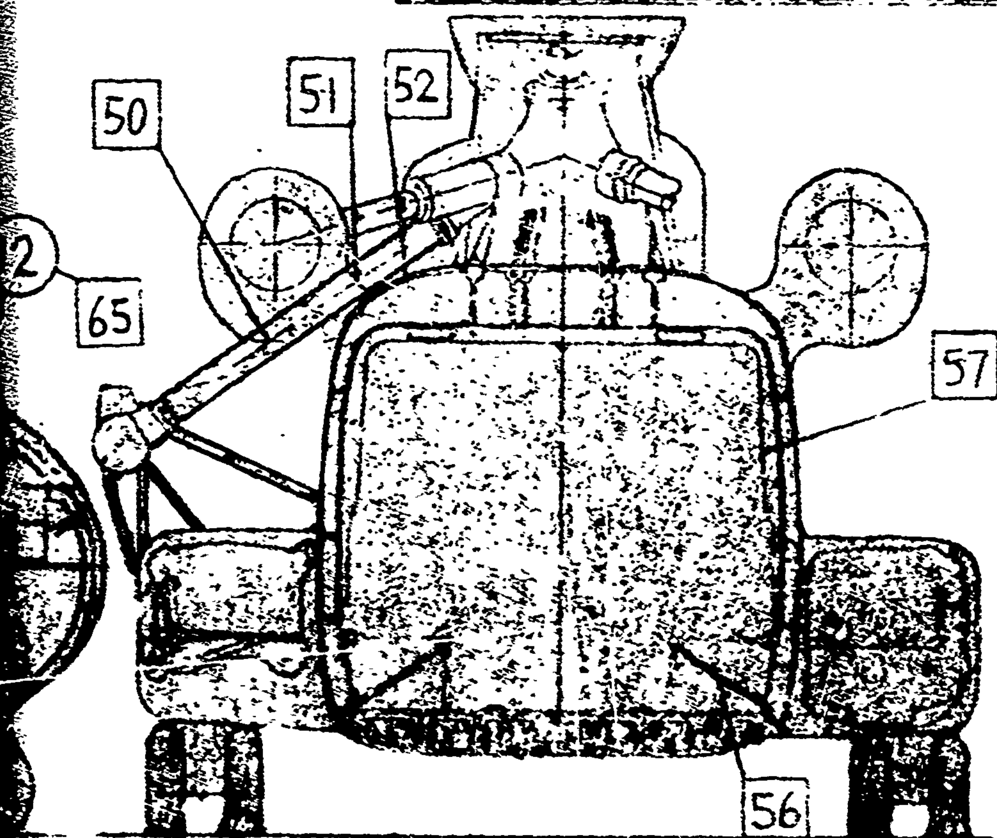
7
59
55
4
9
14
17
12
8
10
61
63
64
62

MANDATORY	OPTIONAL	DESCRIPTION OF REMOVED ITEM
1		AFCS "BLACK BOX"
	SET	GUIDE RAILS
	SET	CARGO HANDLING EQUIPMENT
	SET	CARGO SLING
	SET	SNATCH BLOCKS & BRACE
	SET	UPPER AFT DOOR
	1	HEATER
	1	RAMP ASSY (WITH SEAL & NON-SKID LINER)
	ALL	SOUNDPROOFING SET
	ALL	SEATS AND SEAT BELTS
1		CONTROL MIXING UNIT
1		TAIL ROTOR PYLON (WITH ENTIRE TAIL GROUP
1		WINCH ASSY, UTILITY, STBD
1		HOLE COVER, FWD XMSN ENCLOSURE
1		HOLE COVER, ENGINE COWLING, UPPER
1		HOLE COVER, ENGINE COWLING, LOWER
NO. OF ITEMS REMOVED		

TABLE I. ITEMS REMOVED



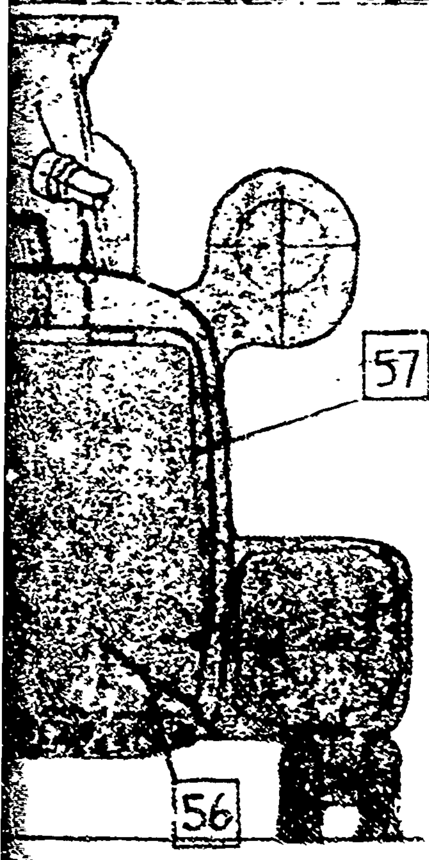
NOTES:

1. ITEMS LISTED IN TABLE
TO BE REMOVED AND T
OPTIONAL SHOULD ALSO
TIME PERMITS, TO RED
2. FOR ITEMS TO BE ADD

39-X-11

OPTIONAL ITEMS REMOVED	DESCRIPTION OF REMOVED ITEM	ITEM NO.
	AFCS "BLACK BOX"	65
SET	GUIDE RAILS	64
SET	CARGO HANDLING EQUIPMENT	63
SET	CARGO SLING	62
SET	SNATCH BLOCKS & BRACE	61
SET	UPPER AFT DOOR	60
1	HEATER	59
1	RAMP ASSY (WITH SEAL & NON-SKID LINER)	58
ALL	SOUNDPROOFING SET	57
ALL	SEATS AND SEAT BELTS	56
	CONTROL MIXING UNIT	55
	TAIL ROTOR PYLON (WITH ENTIRE TAIL GROUP)	54
	WINCH ASSY, UTILITY, STBD	53
	HOLE COVER, RTR XMSN ENCLOSURE	52
	HOLE COVER, ENGINE COWLING, UPPER	51
	HOLE COVER, ENGINE COWLING, LOWER	50

TABLE I ITEMS REMOVED



NOTES :

1. ITEMS LISTED IN TABLE I AS MANDATORY TO BE REMOVED AND THOSE LISTED AS OPTIONAL SHOULD ALSO BE REMOVED IF TIME PERMITS, TO REDUCE WEIGHT.
2. FOR ITEMS TO BE ADDED, SEE FIG 4-41 (CONT'D)

FIG. 4-41

FIGURE 4-41 (cont'd)

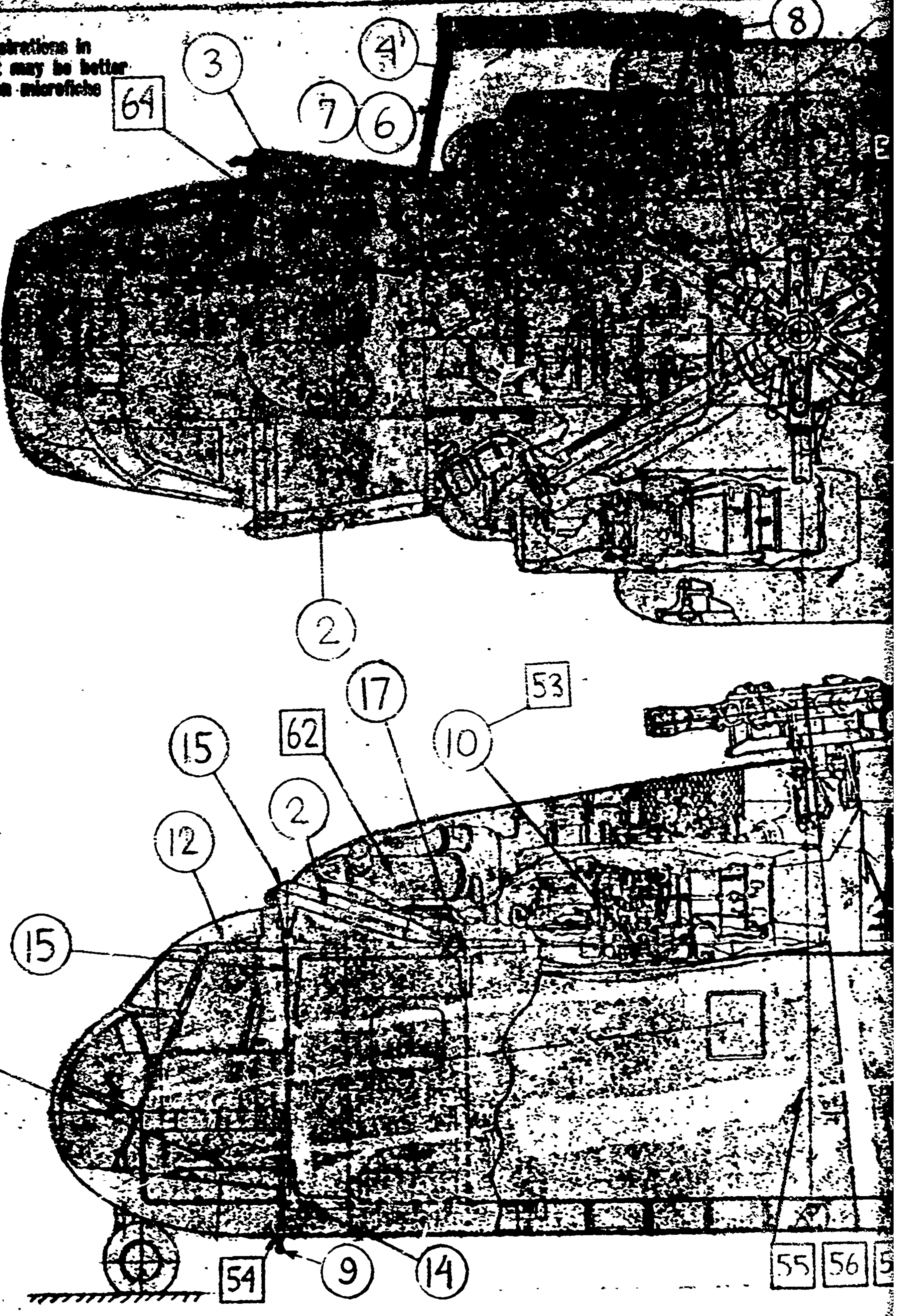
-1	PART NO.	DESCRIPTION	SPECIFICATION	NOTE	ITEM
1	39X-0040-3	CH-53D, DEPOT MODIF'D			14
		ELECTRIC WIRING ASSEMBLIES			13
		(DUPLICATE INSTRUMENTS FOR DISPLAY (FROM AFT AIRCRAFT			17
					13
		EQUIPMENT			
1	39C-1004-1	MODIFIED AFCS "BLACK BOX"			12
1	39C-1003-2	CONTROL CONDUIT ASSEM. CENTER			11
1	39C-1003-1	CONTROL CONDUIT ASSEM. FWD.			10
1	39S-1002-1	MODIFIED CONTROL MIXING UNIT			9
4	39C-0002-1	PUSH/PULL RODS, INTERCONNECTING CONTROLS			8
		CONTROL			
1	39D-5000-1	BEVEL GEARBOX WITH MOUNT			7
1	39D-1019-1	STRUT. ASSEM. SHAFT SUPPORT			6
1	39D-1018-1	STRUT. ASSEM. SHAFT SUPPORT			5
1	39D-1004-2	DRIVE SHAFT ASSEM.			4
1	39D-1002-1	DRIVE SHAFT ASSEM.			3
		DRIVE			
1	39S-1040-2	UPPER INTERCONNECTING FITTINGS STA 522			16
1	39S-1030-2	LOWER INTERCONNECTING FITTINGS STA 522			15
1	39S-1031-1	ADAPTER ASSEM., INTERCONNECTING STRUCTURE			2
		STRUCTURE			
	39X-0041-1	FWD CH-53D, FIELD MODIF'D FOR INTERCONNECTION			1

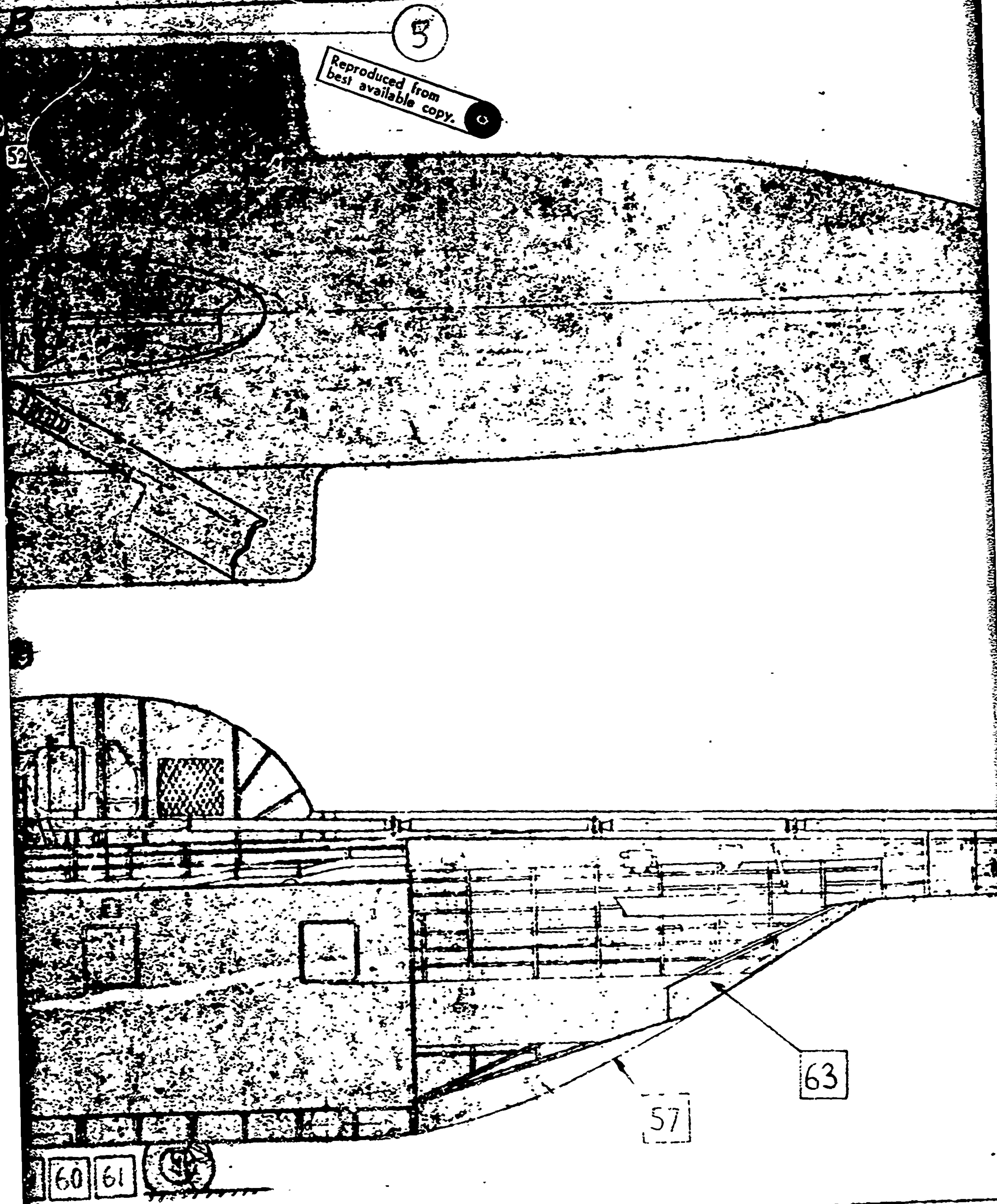
TABLE 4-9

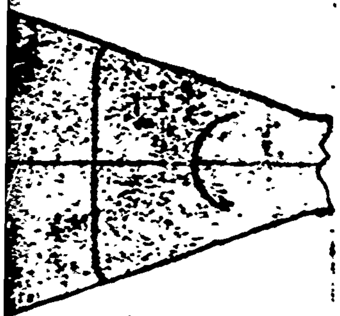
INSTRUMENTS ON AUXILIARY PANEL FOR FRONT AIRCRAFT FOR DISPLAY OF AFT AIRCRAFT SYSTEM STATES

ITEM NO FROM FIG.2-8 OF REF. 15	NAME
28	NO. 1 ENGINE GAS GENERATOR TACHOMETER
29	NO. 2 ENGINE GAS GENERATOR TACHOMETER
30	NO. 1 ENGINE POWER TURBINE INLET TEMPERATURE INDICATOR
31	NO. 2 ENGINE POWER TURBINE INLET TEMPERATURE INDICATOR
32	NO. 1 ENGINE FUEL FLOWMETER INDICATOR
33	NO. 2 ENGINE FUEL FLOWMETER INDICATOR
34	NO. 1 ENGINE OIL TEMPERATURE GAGE
35	NO. 2 ENGINE OIL TEMPERATURE GAGE
36	NO. 1 NOSE GEAR BOX OIL TEMPERATURE GAGE
37	NO. 2 NOSE GEAR BOX OIL TEMPERATURE GAGE
38	MAIN GEAR BOX OIL PRESSURE GAGE
39	MAIN GEAR BOX OIL TEMPERATURE GAGE
40	1ST STAGE FLIGHT CONTROL SYSTEM HYDRAULIC PRESSURE GAGE
41	2ND STAGE FLIGHT CONTROL SYSTEM HYDRAULIC PRESSURE GAGE
42	UTILITY HYDRAULIC SYSTEM PRESSURE GAGE
45	CHIP LOCATOR PANEL
49	MASTER FIRE WARNING LIGHT
51	PILOT'S TORQUEMETER INDICATOR
52	PILOT'S TRIPLE TACHOMETER
54	MASTER CAUTION LIGHT

Details of illustrations in this document may be better studied on microfiche

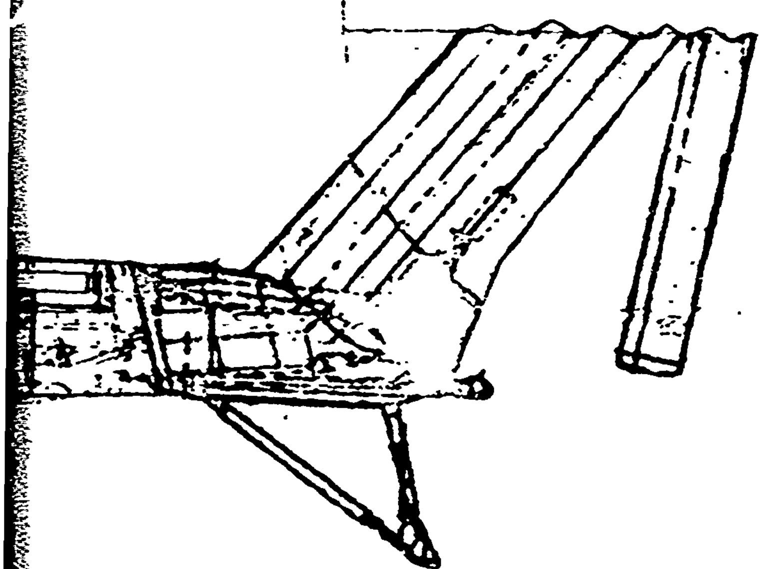



5
52
63
57
60
61



MANDATORY	OPTIONAL	DESCRIPTION OF REMOVED ITEM
	1	UTILITY WINCH, STBD.
	SET	UPPER AFT DOOR
	1	HEATER
	SET	GUIDE RAILS
	SET	CARGO HANDLING EQUIPMENT
	SET	CARGO SLING
	SET	SNATCH BLOCK & BRACE
		RAMP ASSY (WITH SEAL & NON-SKID LINER)
	ALL	SOUNDPROOFING SET
	ALL	SEATS AND SEAT BELTS
1		HOLE COVER, CONTROL PUSH/PULL RODS
1		CONTROL MIXING UNIT
1		HOLE COVER, RTR XMSN ENCLOSURE
1		HOLE COVER, EN[illegible]E COWLING, UPPER
1		HOLE COVER, ENGINE COWLING, LOWER
NO. OF ITEMS REMOVED		

TABLE [illegible] ITEMS REMOVED



NOTES

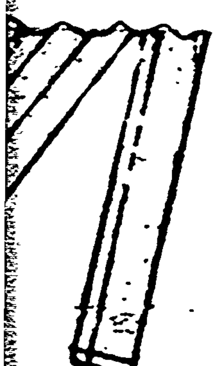
1. ITEMS LISTED IN TABLE
TO BE REMOVED AND [illegible]
[illegible] SHOULD [illegible]
TIME PERMITS TO REDUC
2. FOR ITEMS TO BE ADDE

UNLESS OTHERWISE SPECIFIED TOLERANCES ARE	TITLE
DRAWN E. KORSAK DATE	AFT CH-53D
CHECKED	FIELD MODIFIED
APPROVED	FOR INTERCONNECTION

39-X-11

OPTIONAL ITEMS REMOVED	DESCRIPTION OF REMOVED ITEM	ITEM NO.
1	UTILITY WINCH, STBD.	64
SET	UPPER AFT DOOR	63
1	HEATER	62
SET	GUIDE RAILS	61
SET	CARGO HANDLING EQUIPMENT	60
SET	CARGO SLING	59
SET	SNATCH BLOCK & BRACE	58
1	RAMP ASSY (WITH SEAL & NON-SKID LINER)	57
ALL	SOUNDPROOFING SET	56
ALL	SEATS AND SEAT BELTS	55
	HOLE COVER, CONTROL PUSH/PULL RODS	54
	CONTROL MIXING UNIT	53
	HOLE COVER, RTR XMSN ENCLOSURE	52
	HOLE COVER, ENGINE COWLING, UPPER	51
	HOLE COVER, ENGINE COWLING, LOWER	50

TABLE I ITEMS REMOVED



NOTES

1. ITEMS LISTED IN TABLE I AS MANDATORY TO BE REMOVED AND THOSE LISTED AS OPTIONAL SHOULD ALSO BE REMOVED IF TIME PERMITS TO REDUCE WEIGHT.
2. FOR ITEMS TO BE ADDED SEE FIG.4-42(CONTD)

LIST OF MATERIAL

TITLE AFT CH-53D FIELD MODIFIED FOR INTERCONNECTION

PIASECKI AIRCRAFT CORP.

FIG. 4-42

FIGURE 4-42 (cont'd)

1		ELECTRIC WIRING ASSEMBLIES			18
					13
1	39X-0040-3	CH-53D, DEPOT MODIFIED			12
					11
		EQUIPMENT			
1	39C-1002-2	MODIFIED CONTROL MIXING UNIT			10
8	39C-0002-2	PUSH/PULL RODS, INTERCONNECTING CONTROLS			9
		CONTROL			
1	39D-5000-1	BEVEL GEARBOX WITH MOUNT			8
1	39D-0017-1	STRUT.ASSEM.SHAFT SUPPORT			7
1	39D-0016-1	STRUT.ASSEM.SHAFT SUPPORT			6
1	39D-1004-2	DRIVE SHAFT ASSEM.			5
1	39D-1002-2	DRIVE SHAFT ASSEM.			4
		DRIVE			
	39S-1038-2	UPPER INTERCONNECTING FITTINGS STA222			17
	39S-1037-2	ROOF INTERCONNECTING FITTINGS STA162			16
	39S-1036-2	UPPER INTERCONNECTING FITTINGS STA162			15
	39S-1035-2	LOWER INTERCONNECTING FITTINGS STA162			14
1	39S-1030-1	BRACKET ASSEM., INTERCONNECTING STRUCTURE, STBD.			3
1	39S-1029-1	BRACKET ASSEM., INTERCONNECTING STRUCTURE, PORT			2
		STRUCTURE			
	39X-0042-1	AFT CH-53D, FIELD MODIFIED			1
-1	PART NO.	DESCRIPTION	SPECIFICATION	NOTE	ITEM

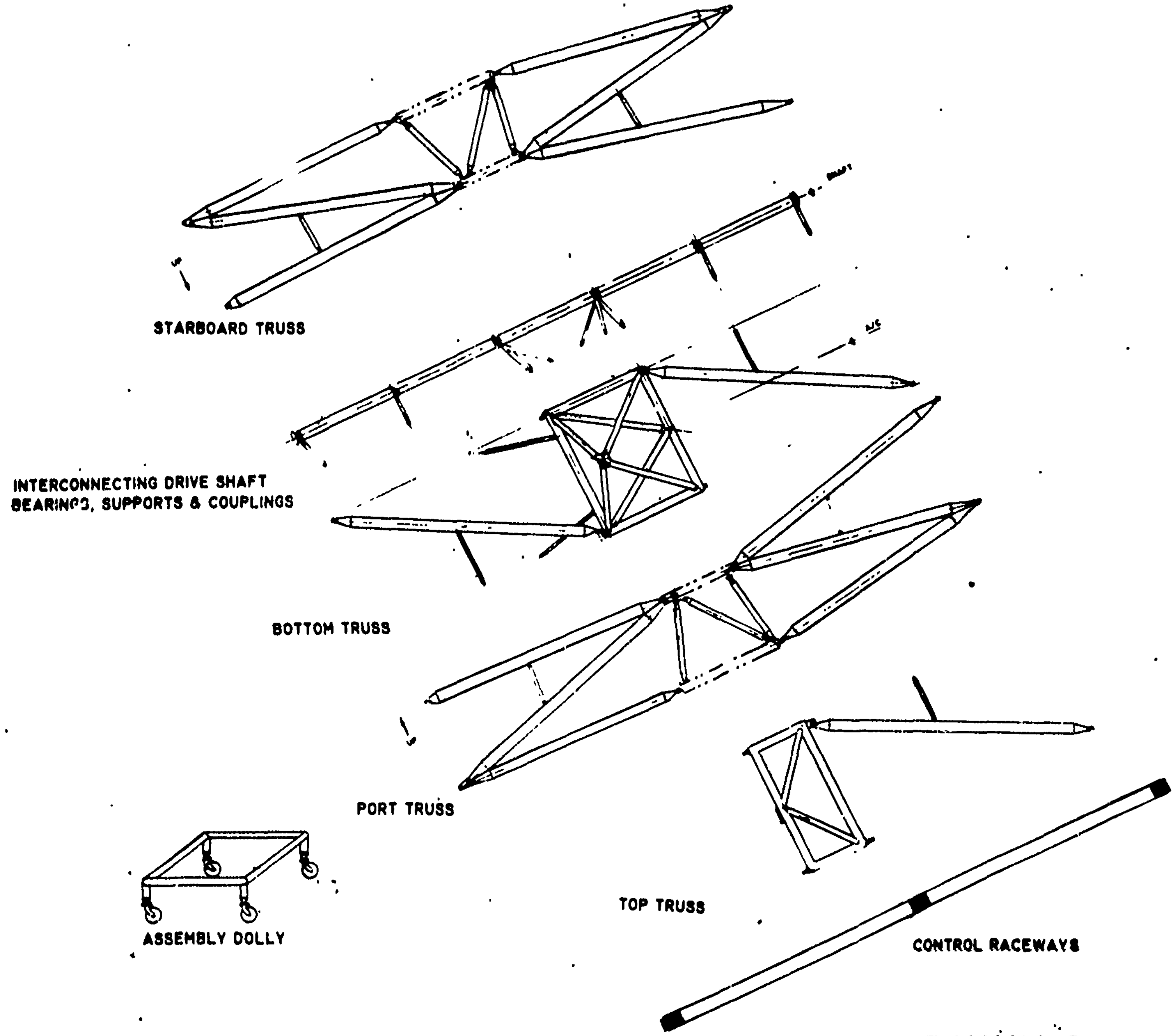


FIG. 4-43 **COMPONENTS OF INTERCONNECTING SECTION KIT MHHLS**
EXPLODED VIEW

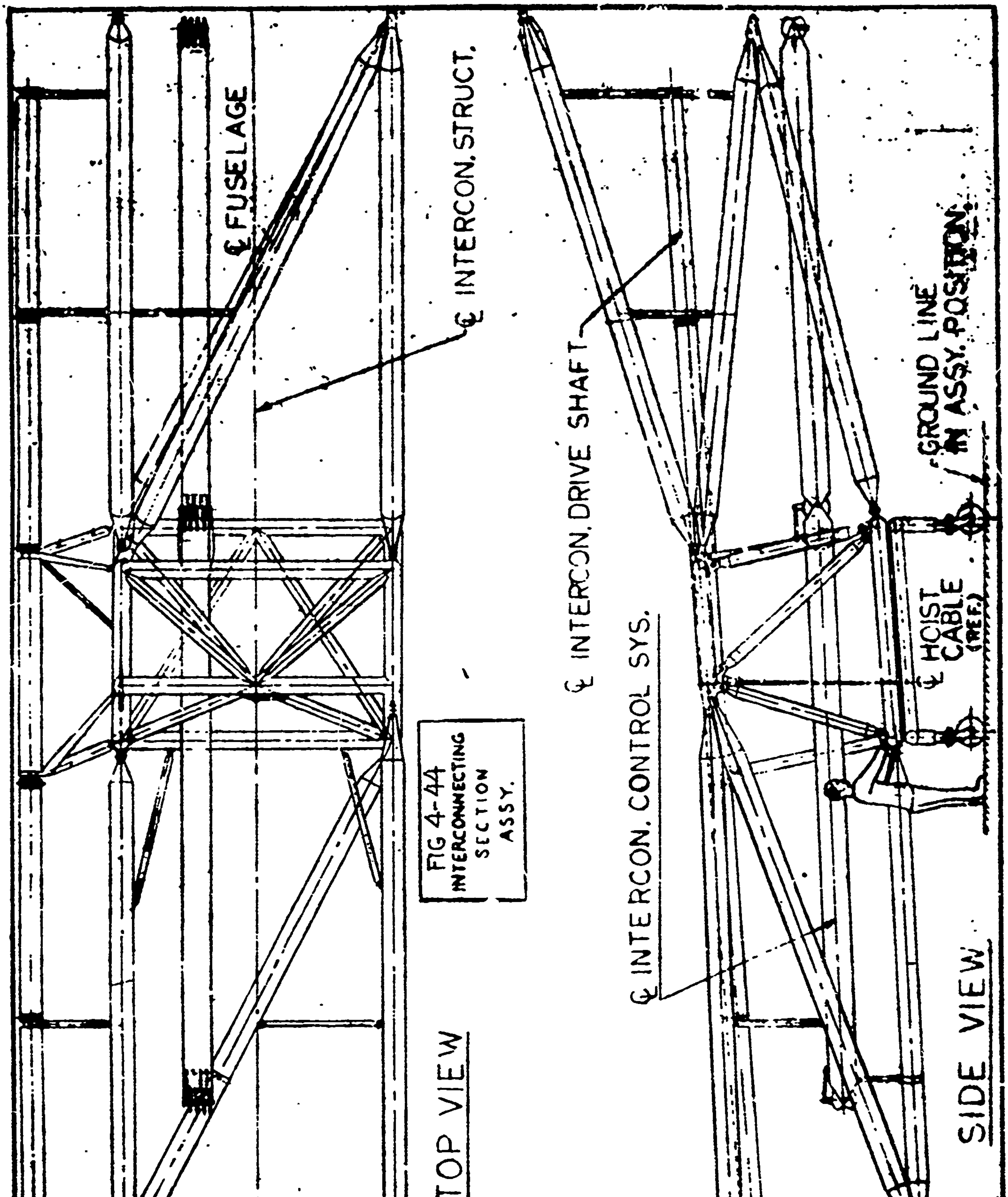


FIG 4-44 INTERCONNECTING SECTION ASSY.

TABLE 4-10 MAN-HOURS AND PARTS COST REQUIRED FOR ASSEMBLY OF ONE MHHLS SYSTEM

AIRCRAFT SYSTEM	DEPOT* OVERHAUL FIG. 4-49		KITS							
			DEPOT*		FWD A/C, FIELD		AFT A/C, FIELD		INTERCONNECTING SECTION	
	MAN HRS	MAT. $	MAN HRS	MAT. $	MAN HRS	MAT. $	MAN HRS	MAT. $	MAN HRS	MAT. $
STRUCTURE	3,676.8	306.	4,136.5	350.	164.4	219.	328.4	274.	45,380.	4,104.
DRIVE	175.7	-0-	0 0	30,640	1,437.9	31,238	1,208.1	31,192	5,753	1,149
CONTROL	394 0	-0-	819 6	29,398.	982 7	2,317	655.5	1,544.	1,640	3,860
EQUIPMENT INSTRUMENTATION & COMMUNICATION	525 3	-0-	2,519.1	5,515	0.0	109	0.0	109.	0.0	-0-
LANDING GEAR	878 2	-0-	5,254.8	5,515.	0 0	-0-	0 0	-0-	0 0	-0-
SPECIAL TOOLS	-	-	-	-	-	-	-	-	1,135.	1,707.
TOTAL	5,650.0	306.	12,730	71,418	2,585 0	33,883.	2,192	33,119	53,908.	10,820.

*BASED ON TWO (2) AIRCRAFT MODIFIED TO THE STANDARD MODIFIED CH-53D (DEPOT MOD) WHICH CAN BE USED FOR EITHER FWD OR AFT UNIT OF MHHLS

TABLE 4-10 (CONT'D)

AIRCRAFT SYSTEM	FIELD PRE-ASSEMBLY: INTER'CON STR FIG 4-43		FIELD PRE-ASSEMBLY: FWD A/C FIG 4-41**		FIELD PRE-ASSEMBLY: AFT A/C FIG 4-42**		FINAL FIELD ASSEMBLY MHHLS** FIG 4-45	
	MAN HRS	MAT $	MAN HRS	MAT $	MAN HRS	MAT $	MAN HRS	MAT $
STRUCTURE	11 0	-0-	6 6	-0-	4 6	-0-	7 0	-0-
DRIVE	3 0	-0-	3 0	-0-	1 6	-0-	2 0	-0-
CONTROL	5.0	-0-	6 5	-0-	1.5	-0-	6.0	-0-
EQUIPMENT INSTRUMENTATION & COMMUNICATION	0 0	-0-	7 0	-0-	7 8	-0-	2.0	-0-
LANDING GEAR	0 0	-0-	-0-	-0-	-0-	-0-	0.0	-0-
SPECIAL TOOLS	-	-	-	-	-	-	-	-
TOTAL	19 0	-0-	23.1	-0-	15.5	-0-	17.0	-0-

** FIGURES GIVEN CONSIDER THE REMOVAL OF MANDATORY ITEMS OF EQUIPMENT ONLY. IF THE OPTIONAL ITEMS OF EQUIPMENT ARE TO BE REMOVED, ADD 11.2 HRS PER AIRCRAFT BASED ON (20) SYSTEM SETS PROCUREMENT AND DOES NOT INCLUDE GOVT.FURN.EQUIP. (SEE SEPARATE LIST) dollar figures are 1971 dollars. The cost of acquiring all four kits is $149,240. worth of material plus expenditure of 71,415 man hours of labor. Cost of installation of the depot modification kit is $306. of material plus expenditure of 5,650 man hours of installation labor. In addition, Table 4-11 lists the components assumed to be available from G.F.P. for conversion of two CH-53D's into one MHHLS. Hence, the total cost of having two CH-53D's modified and ready for conversion is $149,546. of material plus 77,065 man hours of labor.

TABLE 4-11

LIST OF GOVERNMENT FURNISHED PROPERTY FOR MHHLS

2	each	CH-53D's Complete with Winches, Blade Folding, etc.
1	each	Sling and Cable for 18 Ton Lift
1	set	Powerplant and Drive System Operating Instruments, CH-53D
2	each	Flight Control Assemblies, #65404-03000-011, CH-53D
4	each	Nose Landing Gear Assemblies, CH-53D
1	each	Interconnecting Shaft Torquemeter and Indicator

Cost of actual assembly of components in the field is minimal. No materials are required other than furnished in the kits. The two modified CH-53D's and the components of the three field kits can be assembled in an estimated 74.6 man hours. Removal of the optional weight-saving items, removable within thirty minutes, requires an additional 11.2 man hours.

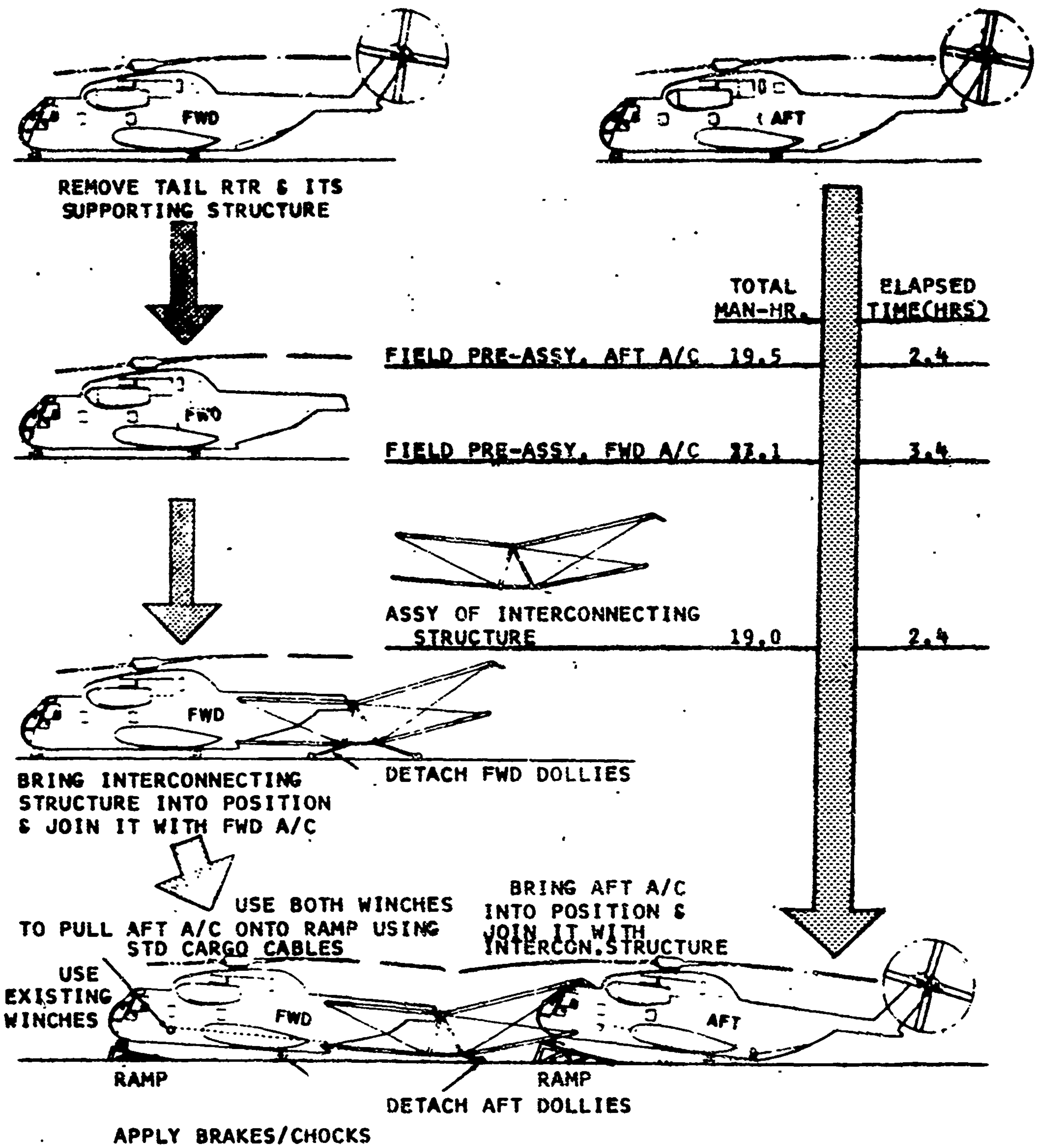
4.6 OPERATIONAL ASPECTS

4.6.1 Assembly and Disassembly

Field assembly procedures for the MHHLS, illustrated on Fig. 4-45, divide into three major areas of effort; first, the field preparation of the two depot modified CH-53's as a forward or aft vehicle by the installation of the respective field kit, second, the preassembly of the interconnecting structure preparatory to joining the two aircraft; and last, the joining together of the three elements, forward aircraft, aft aircraft and interconnecting structure into the complete MHHLS system.

Fig. 4-41 shows the field modifications required for the forward aircraft, and Fig. 4-42 for the aft aircraft. These figures were discussed in Section 4.5, COST OF CONVERSION.

FIGURE 4-46
ASSEMBLY SEQUENCE DIAGRAM
WITH TOTAL MAN-HOUR AND ELAPSED TIME
(BASED ON 8 MAN CREW & INCLUDES TIME TO REMOVE 30 MIN. REMOVAL ITEMS)



	TOTAL MAN-HR.	ELAPSED TIME(HRS)
FIELD PRE-ASSY. AFT A/C	19.5	2.4
FIELD PRE-ASSY. FWD A/C	27.1	3.4
ASSY OF INTERCONNECTING STRUCTURE	19.0	2.4
FINAL ASSEMBLY, MHHLS	20.2	2.5
GRAND TOTAL	85.8	10.7

The first step of the procedure involves the removal of dynamic and structural components and equipment that will not be required in the MHHLS configuration from each of the CH-53's. This is probably more significant in the forward vehicle since the tail rotor is removed. The second step in the procedure involves the removal of optional items of equipment that are removed mainly for the purpose of saving weight in the final configuration. A list of items which Navy tests have shown can be removed within thirty minutes is given in Table 4-12.

TABLE 4-12

ITEMS REMOVABLE WITHIN 30 MINUTES

ITEM	WEIGHT (POUNDS) FWD HELICOPTER	AFT HELICOPTER
UPPER AFT DOOR	44.8	44.8
CARGO RAMP AND SEAL	303.9	303.9
TROOP SEATS	120.	120.
CREW CHIEF'S SEAT	10.9	10.9
LITTER SUPPORTS	13.4	13.4
GUIDE RAILS	124.1	124.1
SOUNDPROOFING	194.	194.
CARGO HANDLING EQUIPMENT (CONVEYORS)	145.7	145.7
*CARGO WINCHES	42	84.
SNATCH BLOCKS AND BRACE	11.	11.
EXTERNAL CARGO SLING	65.5	65.5
CARGO TIE-DOWN FITTINGS	49.6	49.6
HEATER	111.5	111.5
	1236.4	1278.4

* REMOVAL OF ONE WINCH IN FORWARD HELICOPTER IS MANDATORY TO PROVIDE CLEARANCE FOR CONTROLS.

The next step requires the addition of items to the drive system, control system and instrument system of the two vehicles, from the field modification kit and prepares the vehicles for their role in the MHHLS system. In this step, the added angle gear boxes are installed on the sponsons as well as the shafts connecting them to the main rotor transmission plugs. Modified Control Mixing Units are installed and the control conduit assemblies are installed in the forward aircraft and control connections are made. The aft vehicle is equipped with port and starboard fittings on the fuselage top to accept the interconnecting section. The plug-in connections to the instrument packages and communications packages are made with the cable packs in the control conduit assembly. Table 4-9 shows the additional instruments in the front cockpit to display required information on the state of systems in the rear aircraft.

Prior to, or in parallel with this, the interconnecting section is prepared for mating up of the system (see Figures 4-43 and -44). For handling on the ground, and as the platform on which it is built up, this structure utilizes a dolly. The lower welded truss assembly is installed on fittings provided on the ground handling dolly, and the diagonal and vertical tubular members are added, erector set fashion, mating up with the upper welded truss assembly, thus forming a central unit to which the remaining struts of the interconnecting structure are then attached. In order to stabilize some members of the interconnecting truss assembly prior to mating this assembly with forward and aft aircraft, additional stabilizing struts are added. Interconnecting drive shaft assemblies and their bracketry, and control conduit assemblies complete the pre-assembly of the interconnecting section. Maximum use is made of erector set type assembly utilizing quick disconnect fasteners having no loose pieces of hardware.

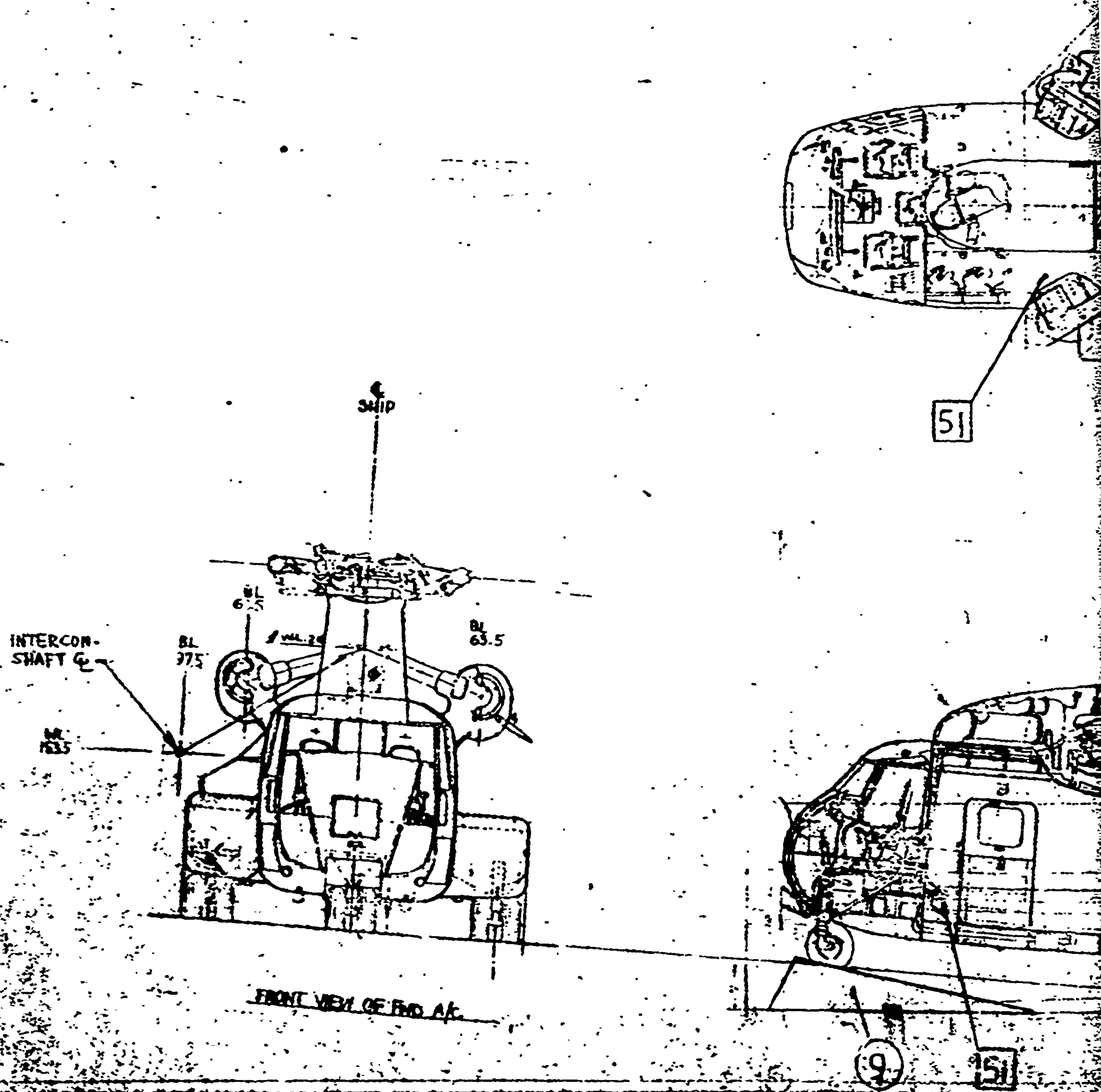
Final assembly of the complete system is accomplished by locating the forward aircraft in proper position and bringing the interconnecting section on its ground handling dolly into position behind it. Accurate positioning of the interconnecting section in relationship to the mating points on the forward aircraft is accomplished through vernier adjustments built into the ground handling dolly The interconnecting section is then attached to the forward aircraft by means of quick disconnect fasteners. The connections to the drive shafts, the control raceway assemblies and the cable pack contained therein is made, completing the mating of the forward aircraft and the interconnecting section. The ground handling dolly is removed from under the interconnecting section, the forward aircraft is positioned on its nose wheel ramp and the sub-assembly is ready to receive the aft aircraft.

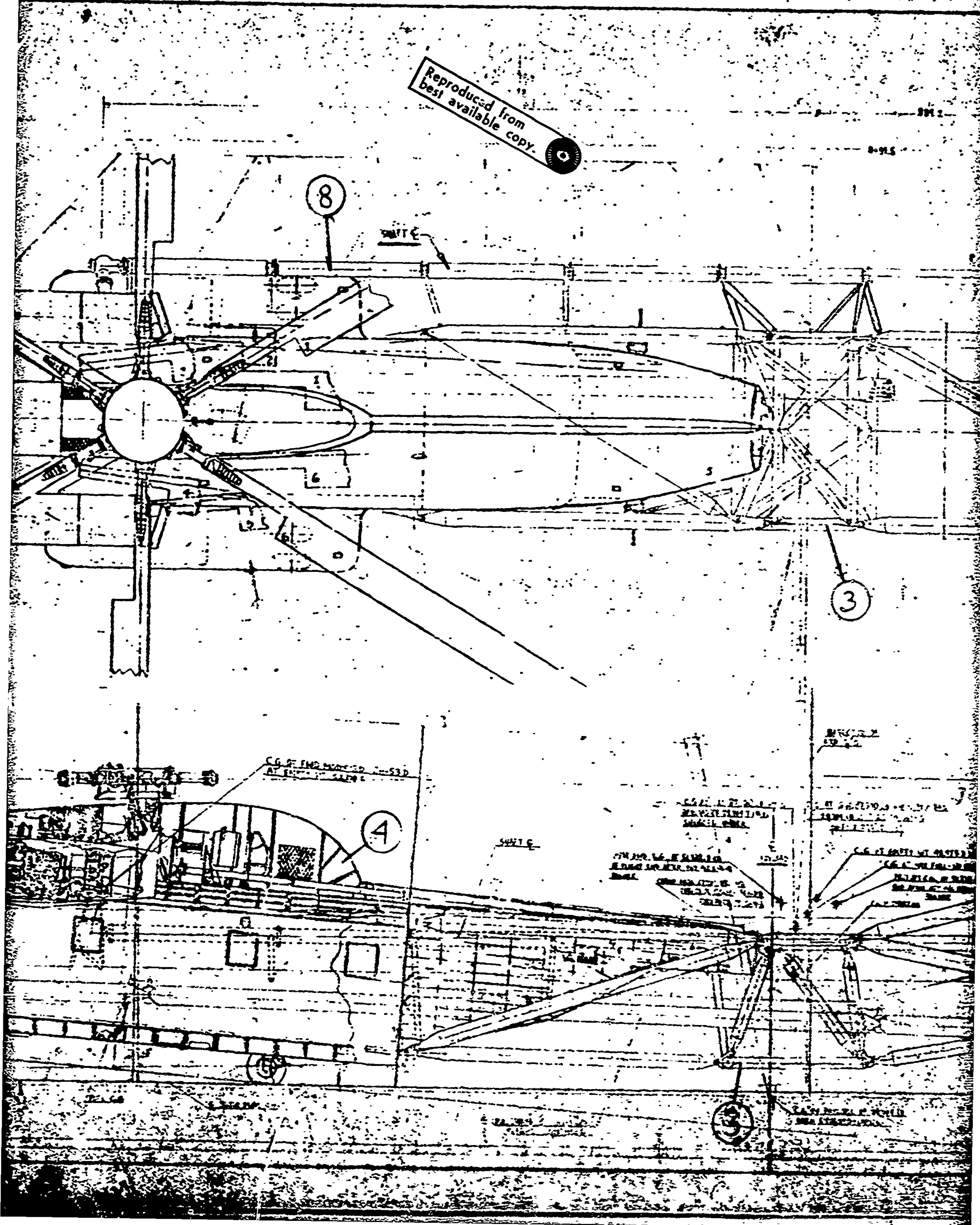
The aft aircraft is brought into position behind the above sub-assembly and positioned on its nose wheel ramp.

Positioning both aircraft on their nose wheel ramps is accomplished by attaching the aircraft's winch cable to fittings provided on the ramp and using the winch to draw the aircraft up on its ramp. This accomplished, the aft aircraft is joined to the interconnecting section using quick disconnect fasteners. The drive shaft interconnection is made, the control interconnection is made and the cable pack connect is made. The final assembled MHHLS is shown on drawing Fig. 4-46.

Inspection of the MHHLS would be arranged as a progressive step function incorporating permanent records of the step performed

Details of illustrations in this document may be better studied on microfiche

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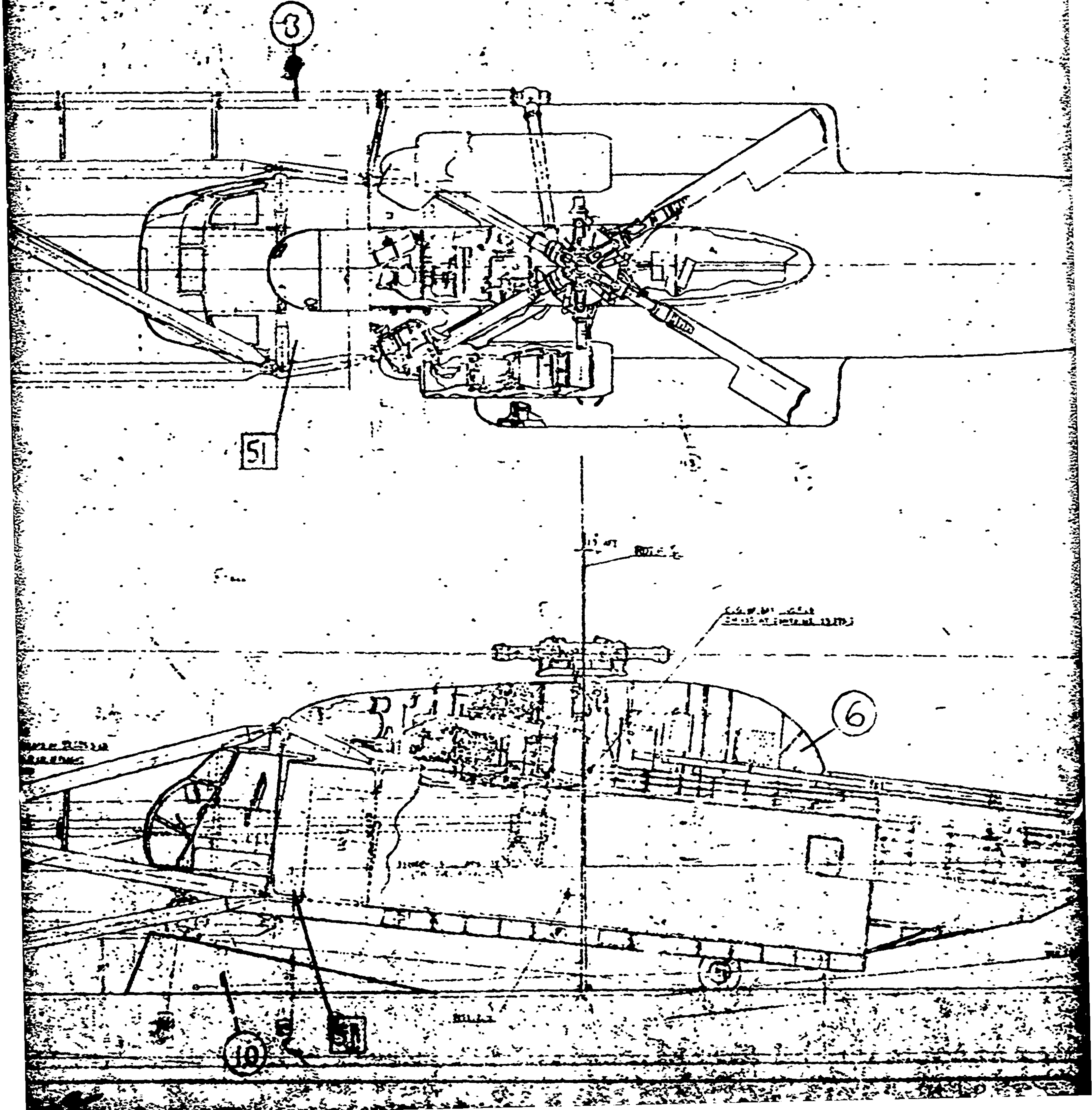

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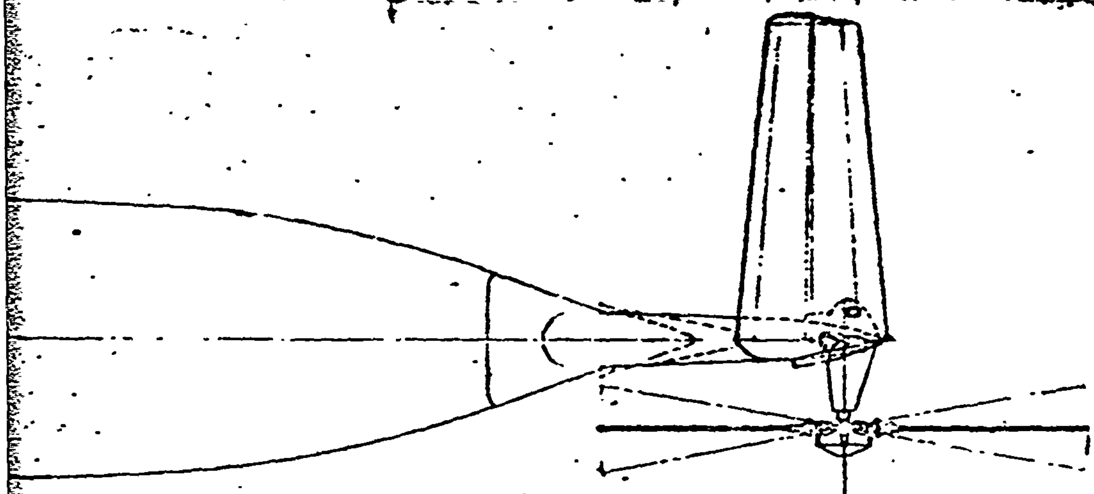
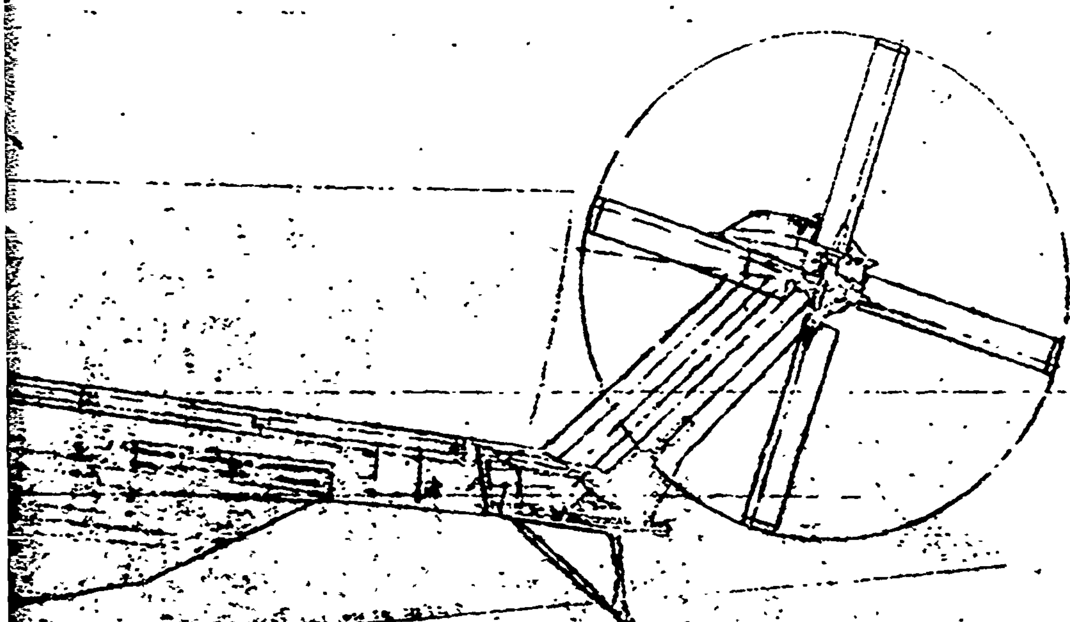
MANDATORY NO. OF ITEMS REMOVED	OPTIONAL	DESCRIPTION OF REMOVED ITEM
	2	UTILITY WINCH

TABLE I ITEMS REMOVED





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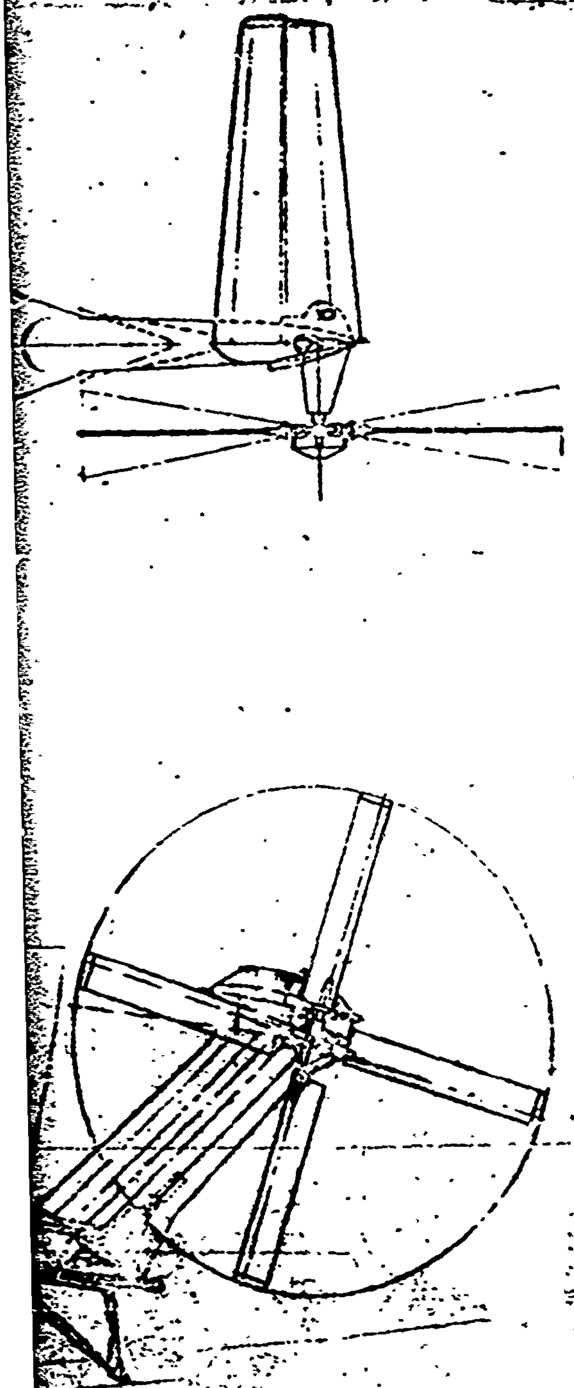
NOTES

1. FOR LIST OF MA
   FIGURE 4-46
2. TABLE I SHOWS
   WHICH SHOULD BE
   TIME PERMITS, FO

...TORY ITEMS REMOVED	OPTIONAL	DESCRIPTION OF REMOVED ITEM	ITEM NO.
	2	UTILITY WINCH	51

TABLE I ITEMS REMOVED



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NOTES

1. FOR LIST OF MATERIALS SEE FIGURE 4-46 (CONT'D).
2. TABLE I SHOWS OPTIONAL ITEMS WHICH SHOULD BE REMOVED IF TIME PERMITS, FOR WEIGHT SAVING.

GEN ARRANGEMENT CH-53 MULTI-LIFT SYSTEM - NOSE TO TAIL.

FIG. 4-46

FIGURE 4-46 (cont'd)

	THESE ITEMS ARE NOT PART OF ASSEM'S			(		1	39D-0102-1	RAMP, AUX.LANDING GEAR, AFT A/C			10
				(		[illegible]	39D-0101-1	RAMP, AUX.LANDING GEAR, FWD A/C			9
								SPECIAL TOOL			
						2	39D-1004-1	DRIVE SHAFT ASSEM., INTERCON.SYS.			8
								DRIVE			
											7
						1	39X-0042-1	AFT CH-53D FIELD MODIFIED			6
											5
						1	39X-0041-1	FWD CH-53D FIELD MODIFIED			4
						1	39X-0039-1	INTERCONNECTING SECTION SUB ASSEM.			3
											2
							39X-0032-1	CH-53 "MULTI-LIFT SYSTEM"			1
						-1	PART NO.	DESCRIPTION	SPECIFICATION	NOTE	ITEM

in the aircraft's log books. Each kit would contain a permanent record check-off list to be signed off by the mechanic performing the work and counter-signed by the assigned inspection mechanic signifying the completion and acceptance of each task.

The Interconnecting Section Kit would provide a log book as a permanent accompanying record of compliance with specified assembly and check-off procedures, and the persons performing the task.

The overall MHHLS system will have its master log book to which the (2) CH-53D aircraft logs and the interconnect section will be sub logs. This procedure will require performing specific non-powered and powered functional checks of each system of the MHHLS, through a ground run-up and hover lift-off

Upon completion of these procedures and approvals, the MHHLS is ready for operation.

4.6.2 Shipboard Compatibility

The MHHLS system as proposed herein has a high compatibility with ships, since it can hoist from hover or slow forward flight, with high operational reliability, and it can be refueled while flying along a ship under way. Utilizing its full payload capacity in the form of auxiliary tanks, the MHHLS system can have an endurance of approximately 10 hours or a range of approximately 900 miles, thereby giving it somewhat the characteristics of an airship It is capable of other missions such as wider or deeper minesweeping, towing vessels, sleds, etc. or it can be returned to the basic CH-53D functions by separating the MHHLS system into its components.

The various modes of ship-based operations considered were:

(1) Deployable (Intermediate Maintenance Support)

(2) Operable (Minimal or No Maintenance Support)

(3) Transportable (Temporary Parking/Storage on Board)

The determination as to whether a specific aircraft is deployable, operable, or transportable from a specific ship must be based on an overall assessment of the physical compatibility of that aircraft with ship characteristics, together with the operational impact of that aircraft on the normal operation of ship's equipment or other aircraft in the ship's complement The overall size and weight of any aircraft tends to be the governing factor, in that the operational constraints imposed on the ship are usually directly related to either aircraft weight or size.

The physical constraints are imposed by:

a. Landing Area

b. Deck Capacity

c. Hangar capacity

d. Hangar height and elevator capacity

e. Hangar deck area

From Ref. (2), Page E-2, the selected candidate ship classes are:

Aviation Ships	Amphibious Warfare Ships
CVA-59	LSD-28
CVA-41	LSD-36
CVA-19	LST-1179
CVS-9	LKA-113
LHA-1	LPD-1
LPH-2	

The dimensional and load limits of these ships were taken from Ref. (2) and the MHHLS characteristics applied thereto Since the landing and below deck clearances were critical, two of the smallest ships were chosen; the LPD-1, an amphibious warfare ship, and the LPH-2, the smallest of the aviation ships. The MHHLS on deck, elevator and hangar storage positions is shown on Figures 4-47 and -48 for the LPD-1 and LPH-2 respectively.

Since the MHHLS can be reduced in size to be within the basic CH-53D, any elevator-hangar deck that can accommodate the CH-53D can take the MHHLS. With regard to the wheel loads on the deck, the MHHLS, less payload, has wheel loads less than the CH-53D fully loaded. In flight configuration, it operates on a four point alighting gear, but when returned to separate units, it returns to the original three point alighting gear configuration per unit.

Deck Handling

The basic concept of the MHHLS is to keep the two CH-53D helicopters as close to their standard fleet configuration as possible at all times, in order to permit their use in smaller capacity

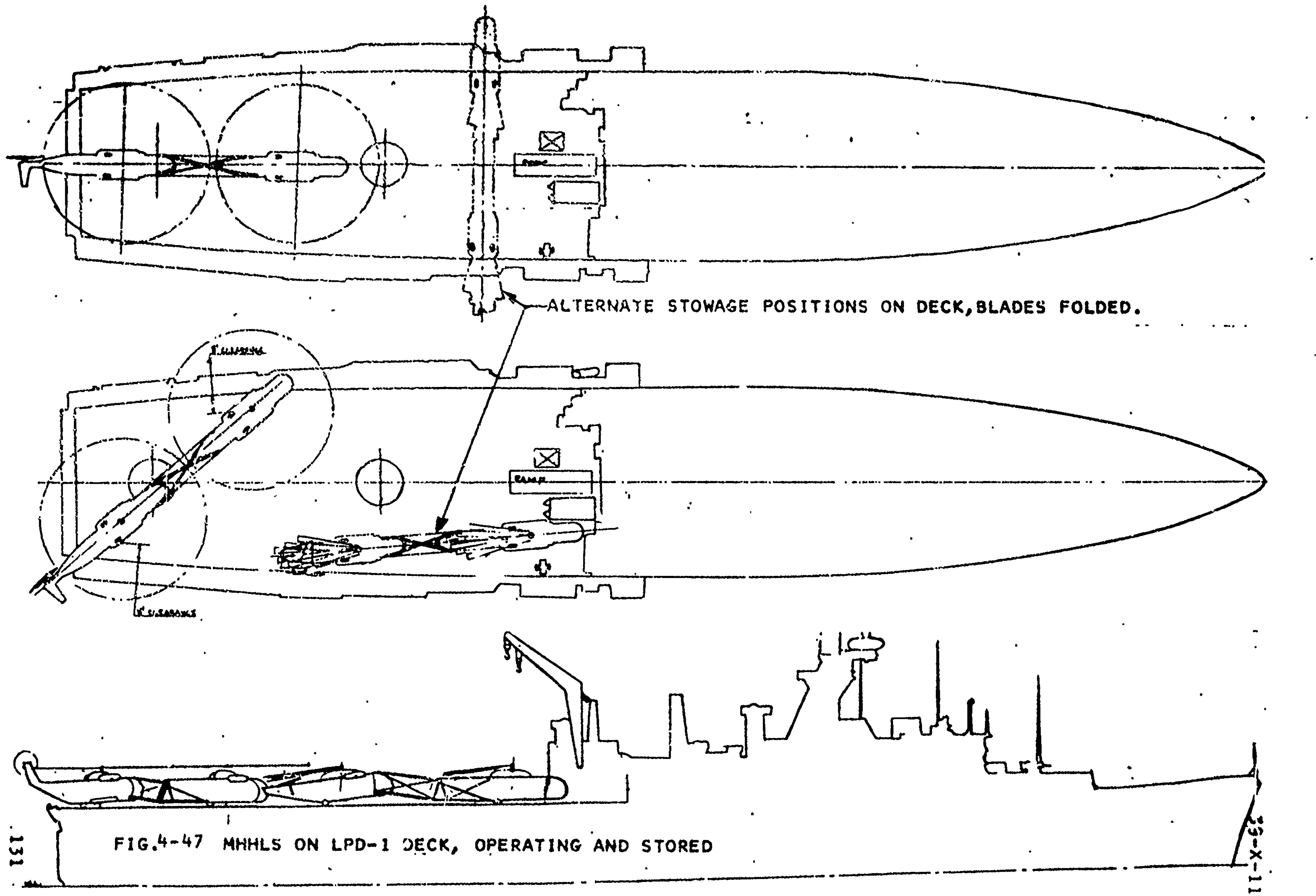
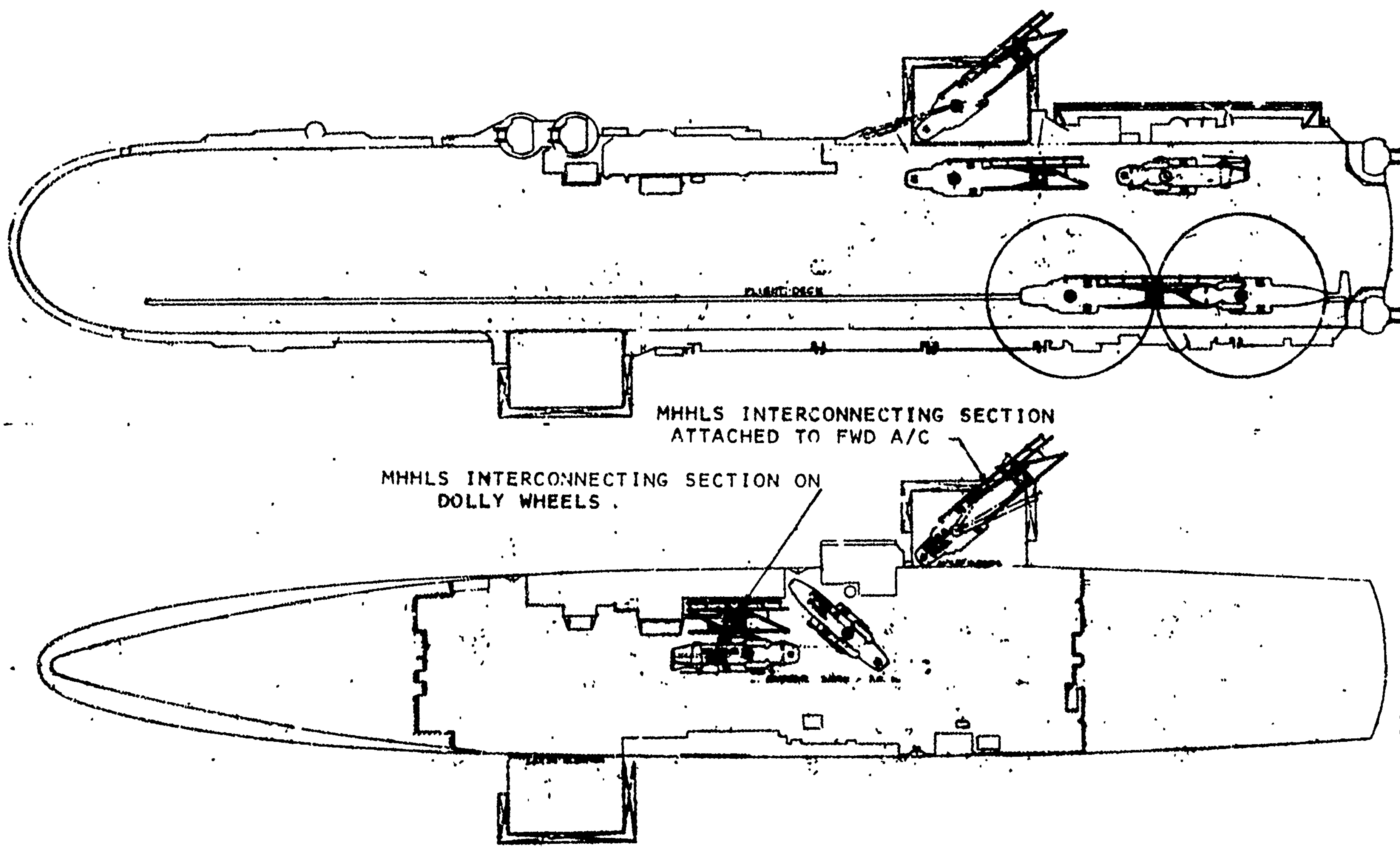


FIG.4-47 MHHLS ON LPD-1 DECK, OPERATING AND STORED

FIGURE 4-48. MHHLS COMPATIBILITY WITH LPH-2

APPROX. SCALE 1" = 59'



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missions. In attaining this, however, of the two aircraft used to make a system, the aft is favored wherever possible to have the least number of changes, so it could be reverted back into single-aircraft operation in the minimum of time.

The illustrations in Section 4.6.1 show the preparation and assembly procedures of the two aircraft being accomplished on deck or other surface, long enough to support the wheel points of the two aircraft.

On an LPH, the stowage of the MHHLS, with blades folded, (normal CH-53 power fold systems) along one side of the deck allows the continuation of normal helicopter deck operations, as shown on Fig. 4-48.

If MHHLS operations are expected to be frequent, but intermittent, the forward aircraft and the interconnected structure can remain attached, with the aft aircraft released for other operations when not active in MHHLS. This materially reduces the time required to reach the MHHLS configuration. The time to split the MHHLS into two units, with the interconnecting section remaining attached to the forward unit, is 35 minutes, utilizing eight men. To separate it into three units for stowage below decks, the time is 75 minutes with eight men.

Piloting Techniques

Crew stations, conforming to accepted human engineering criteria, are provided for the following crew members:

(1)	Master Pilot Co-Pilot]--	Occupying the existing side-by-side seats in the cockpit of the forward aircraft.
(3)	Cargo Pick-Up Pilot	Pilot occupying the existing pilot's seat in the cockpit of the aft aircraft.

The cargo pick-up pilot also acts as a Flight Engineer.

The cargo pick-up pilot is provided with the standard full authority flight controls. He uses the existing cockpit visibility of the aircraft pilot's station for viewing the loading and the unloading operations and for observation of the stability of the load in forward flight. Each of the three pilots is provided with emergency load release switches. Switching of the flight controls from one pilot to another is controlled by the master pilot. His instrumentation provides a visual indication as to who is at the controls. All the other operating controls and instrumentation of each of the helicopters remain.

The hoist-cable-hook system has not been specified herein since it is not critical to this system. Upon prototype testing, separate tests on the optimum hook, hoist and load stabilization system can be determined utilizing the latest techniques now under development.

The landing gear is basically the same as the CH-53D. Thus, there is little space under the structure on the hook-up centerline to attach loads directly to the structure, unless they are of low height. The hook/cable is supported on the top of the structure, allowing the hook to be raised above the bottom of the interconnecting structure. Landing and taking off from the deck will be without suspended load.

In forward flight, since the centerline of the cable attachment to the structure is 21 ft. ahead of the aft pilot station, his view of the cable and the load below is excellent (53° below the horizon with a 15 ft. cable). The forward pilot has an unobstructed view from the CH-53D standard cockpit, an important feature in busy traffic shuttles using the MHHLS.

Thus, the MHHLS, comprised of two CH-53D's, does not appear to have any serious limitations for being based on Navy aviation ships.

5. CONCLUSIONS

From results of the work performed under this contract, the following conclusions are set forth:

For a permanent weight penalty of 580 lbs. per aircraft, existing fleet CH-53D helicopters may be modified to provide a multi-lift capability in the field on demand. When two CH-53D's are combined to form an MHHLS, a 100% improvement in maximum payload capability occurs. Thus, a substantial improvement in payload-range capability results without developing a new helicopter with new dynamic components.

To convert from two CH-53D's in flight-ready status to one MHHLS is estimated to take eight men 10.7 hours, including assembly of the interconnecting structure from its components. If this structure is already pre-assembled, the conversion time is reduced to 8.3 hours.

The rigid interconnection proposed herein offers a reasonable HLH flight envelope and performance capability without the economic burden of a dedicated HLH aircraft. Its operational disadvantages are felt to be acceptable and limited shipboard operations feasible. The single airframe multi-lift concept with its compact size relative to a loose interconnection system has an obvious advantage in constrained airspace around ships, forests, etc. and under IFR conditions.

Application of the MHHLS concept to the next generation of heavy lift helicopters may further increase the payload-range capabilities of future helicopters. Since many of the constraints present in the CH-53D multi-lift design problem will be absent, application of the multi-lift concept to a new design may ameliorate the operational disadvantages of an MHHLS and reduce the design modifications necessary to provide an MHHLS capability.

6. RECOMMENDATIONS

6.1 Continue the development of this technology and construct and test a prototype to demonstrate and determine objectively the fleet suitability of the flying qualities, the assembly and disassembly procedures and times, and the reliability of the assembled interconnections.

6.2 Evaluate the feasibility and performance of applying MHHLS technology to advanced versions of the CH-53D such as the RH-53D, as well as other large helicopters.

7. REFERENCES

NO.	REPORT NO.	CO. OR AGENCY	TITLE	AUTHOR	DATE
1.	55-X-3 Vol. 1	Piasecki Aircraft Corp.	"Parametric Design Study of Flying Crane Helicopters"	Ciolkosz Somerson Daland Mamrol Piasecki	31 Jan. 57
2.	OP-96/Jg	U. S. Navy	"Navy Heavy Lift Helicopter (HLH) Requirements Study"	CNO	1 Jul. 70
3.	RFQ-DAAJ01-71-Q-0274	U. S. Army	"Advanced Technology Component Program, Heavy Lift Helicopter	USA AVSCOM	9 Oct. 70
4.	SER.64460	Sikorsky Aircraft Corp.	"Preliminary Multi-Lift Feasibility Study"	Maciolek Kenigsberg Monteleone	16 May 69
5.	AIR-2145A: RAM:B/S	U.S.Navy	General Requirements H.L.H.	NAVAIR	29 OCT 69
6.	39-K-1A	Piasecki Aircraft Corp	"Weight & Balance - CH-53 Multi-Lift System"	K. Korsak	11 NOV.71
7.	39-A-1	Piasecki Aircraft Corp.	"Performance & Flying Qualities"		
8.	39-S-1	Piasecki Aircraft Corp.	"Structural Analysis, Multi-Helicopter Heavy Lift System" (2 CH-53D)	P. Kubicki K. Korsak	24 NOV. 71

NO.	REPORT NO.	CO. OR AGENCY	TITLE	AUTHOR	DATE
9.	65583	Sikorsky	Substantiating Data for Standard Aircraft Characteristics and Performance Charts for CH-53D Helicopter	J. Turkis	1 June 70
10.		U.S.Army Aviation Systems Test Activity, Edwards AFB, Calif.	Army Preliminary Evaluation III and IV, YCH-47C Medium Transport Helicopter	Jester and Forsythe	OCTOBER 1970
11.	651012	Sikorsky	Actual Weight and Balance Report, 99th Production Helicopter, CH-53D	G.J. Setescak	11 FEB 70
12.	MIL-H-8501 A	Dept.of Defense	Helicopter Flying and Ground Handling Qualities; General Requirement for		
13.	MIL-F-83300	U.S.A.F. (proposed)	Flying Qualities of Piloted V/STOL Aircraft		31 Dec.70
14.	MIL-S-8698	U.S.A.F. and U.S.Navy	Structural Design Requirements Helicopters		28 Feb.58
15.	NAVAIR 01-230HMA-1	NASC	NATOPS Flight Manual, Navy Model CH-53A/D Helicopters		15 Apr.69
16.	MIL-T-59556	D.O.D.	Transmission Systems,VSTOL-STOL, General Requirements for		17 Sep.70

8. APPENDIX

METHOD OF FLYING QUALITIES ANALYSIS

Twenty-one flight conditions which might prove critical with regard to flying qualities were investigated. They are listed in Table 8-1.

The longitudinal trim and stability (static and dynamic)have been obtained utilizing an existing tandem configuration computer program. The important influence of rotor down-wash interference effects have thereby been included as they would apply to the MHHLS. The basic assumptions underlying the program consider articulated inelastic rotors with flapping only, steady-state aerodynamics, and a rigid fuselage, as well as uniform induced velocity. These are not considered limitations for purposes of flying qualities investigations. Modifications required for applicability to the MHHLS design that have been included are the representation of the actual fuselage-plus-downwash aerodynamics with the horizontal tail surface as an integral part. No other corrections were required, as the direction of rotor rotation is immaterial in the longitudinal phase.

The lateral-directional trim was computed based on the rotor force and moment results as given in the longitudinal computer program output, taking into account the actual rotor directions of rotation. The fuselage aerodynamics, including vertical fin, were estimated and included in the force and moment balance equations, as were the tail rotor force and moment contributions. The important effects of tail rotor's δ_3 angle were also included.

The static stability and control derivatives were obtained for the dynamic analysis from the lateral-directional trim results. The angular rate damping derivatives were calculated in a separate analysis.

Utilizing the principal body axis as the body fixed system, the lateral directional equations of motion in dimensional form are:

Side Force:

$$(ms - Y_v)v-[(Y_{\dot{\phi}}+m\alpha V)s+mg]\phi +(mV-Y_{\dot{\psi}})\dot{\psi} = Y_{\delta_S}\delta_S+Y_{\delta_R}\delta_R$$

$$(s-\frac{Y_v}{m})v-[(\frac{Y_{\dot{\phi}}}{m}+\alpha V)s+g]\phi+(V-\frac{Y_{\dot{\psi}}}{m})\dot{\psi} = \frac{Y_{\delta_S}}{m}\delta_S + \frac{Y_{\delta_R}}{m}\delta_R \qquad (1)$$

TABLE 8-1. CONDITIONS FOR FLYING QUALITIES ANALYSIS

No.	Representative Flight Phase	SPEED Fwd Knots	SPEED Side Knots	Vertical (fpm)	Nominal Bank Angle	Loading Conditions Fuel	Loading Conditions Payload
1.	Vertical take-off	0	0	300	0	full	0
2.	Vertical Landing	0	0	-300	0	full	0
3.	Climb	60	0	500	0	full	full
4.	Cruise, straight and Level	60	0	0	0	full	0
5.	Cruise, straight and Level	60	0	0	0	full	full
6.	Cruise, coordinated turn	60	0	0	30	full	0
7.	Cruise, coordinated turn	60	0	0	30	full	full
8.	Descent	60	0	-500	0	0	0
9.	Cruise, straight and Level	125	0	0	0	full	0
10.	Cruise, straight and Level	125	0	0	0	full	full
11.	Hover	0	0	0	0	full	0
12.	Hover	0	0	0	0	full	full
13.	Slow fwd. flight	35	0	0	0	full	0
14.	Slow fwd. flight	35	0	0	0	full	full
15.	Rearward flight	-35	0	0	0	full	0
16.	Rearward flight	-35	0	0	0	full	full
17.	Sideward flight	0	35	0	as req'd	full	0
18.	Sideward flight	0	35	0	" "	full	full
19.	Cruise	125	0	0	0	1/2 fwd	0
20.	Cruise	125	0	0	0	1/2 rear	0
21.	Autorotation Descent	60	0	-2500	0	full	0

Rolling Moment:

$$-L_v v+(I_{XX}s-L_{\dot\phi})s\phi -(I_{XX}\alpha s+L_{\dot\psi})\dot\psi = L_{\delta_S}\delta_S + L_{\delta_R}\delta_R$$

$$-\frac{L_v}{I_{XX}} v+(s-\frac{L_{\dot\phi}}{I_{XX}})s\phi -(\alpha s+\frac{L_{\dot\psi}}{I_{XX}})\dot\psi = \frac{L_{\delta_S}}{I_{XX}}\delta_S + \frac{L_{\delta_R}}{I_{XX}}\delta_R \quad (2)$$

Yawing Moment:

$$-N_v v-N_{\dot\phi}s\phi + (I_{ZZ}s-N_{\dot\psi})\dot\psi = N_{\delta_S}\delta_S + N_{\delta_R}\delta_R$$

$$-\frac{N_v}{I_{ZZ}} v-\frac{N_{\dot\phi}}{I_{ZZ}} s\phi + (s-\frac{N_{\dot\psi}}{I_{ZZ}})\dot\psi = \frac{N_{\delta_S}}{I_{ZZ}}\delta_S + \frac{N_{\delta_R}}{I_{ZZ}}\delta_R \quad (3)$$

It should be noted that all rate coupling and control coupling items are included. An expansion of the determinant matrix yielded the characteristic equation roots from which the roll, spiral, and Dutch-roll mode characteristics were obtained. In addition, the lateral-stick-deflection roll-angle response was determined from these equations of motion for the analysis and design of the AFCS roll channel. The yaw channel was not investigated since satisfactory flying qualities were obtainable with the roll feed-backs alone. Additional yaw static stability and damping is available with moderate gains of the same magnitude as provided in the current AFCS.

All pertinent calculated control and stability derivatives and the characteristic equation roots are given in Tables 8-2 (longitudinal), and 8-3 (lateral-directional).

Static speed stability was determined by finding the derivative of stick position with respect to speed at constant trim. This was calculated from the relation:

$$\frac{d\delta_B}{dV} = \frac{-\frac{\partial M}{\partial V} - \frac{M}{\partial \alpha} \times \frac{\partial \alpha}{\partial V}}{\frac{\partial M}{\partial \delta_B}} = \frac{-\frac{1}{I_{YY}} \times \frac{\partial M}{\partial V} - \frac{1}{I_{YY}} \times \frac{\partial M}{\partial \alpha} \times \frac{\partial \alpha}{\partial V}}{\frac{1}{I_{YY}} \times \frac{\partial M}{\partial \delta_B}}$$

The partial derivatives $\frac{\partial M}{\partial V}$ and $\frac{\partial M}{\partial \alpha}$ (pitching moment with respect to speed and angle of attack, respectively) are computer outputs found in Table 8-2. The partial derivative $\partial\alpha/\partial V$ (angle of attack with respect to speed) is found by obtaining the slopes of the curves plotted in Fig. 8-1 at the appropriate points.

TABLE 8-2 LONGITUDINAL CONTROL AND STABILITY DERIVATIVES AND ROOTS OF CHARACTERISTIC EQUATION STRAIGHT AND LEVEL FLIGHT, 83,700 POUNDS G. W.

AIRSPEED (KNOTS)		0	35	60	125
X_{δ_B}/m	$ft/sec^2/inch$	-.046	-.046	-.047	-.097
Z_{δ_B}/m	$ft/sec^2/inch$	-.002	-.162	-.346	-.330
M_{δ_B}/I_{YY}	$rad/sec^2/inch$	-.091	-.000	-.099	-.124
X_u/m	$ft/sec^2/ft/sec$	-.019	-.032	-.026	-.047
Z_u/m	$ft/sec^2/ft/sec$	-.002	-.123	-.103	-.082
M_u/I_{YY}	$rad/sec^2/ft/sec$	.0021	.002	.0000	-.000
X_w/m	$ft/sec^2/ft/sec$	-.002	.0010	.0083	-.032
Z_w/m	$ft/sec^2/ft/sec$	-.229	-.302	-.364	-.563
M_w/I_{YY}	$rad/sec^2/ft/sec$	-.000	.0026	.0043	.0030
X_α/m	$ft/sec^2/rad$	-.005	.0566	.8448	-6.63
Z_α/m	$ft/sec^2/rad$	-.729	-17.9	-36.9	-117.
M_α/I_{YY}	$rad/sec^2/rad$	-.000	.1557	.4349	.6182
X_q/m	$ft/sec^2/rad/sec$	.472	.4231	.6219	-.238
Z_q/m	$ft/sec^2/rad/sec$	-.290	-2.09	-3.43	-3.85
M_q/I_{YY}	$rad/sec^2/rad/sec$	-.460	-.565	-.685	-.823
CHARACTERISTIC EQUATION:					
REAL ROOT		-.229	-.150	.2638	.2397
REAL ROOT		-.634	-.923	-1.20	-1.47
REAL ROOT		.0776	.0872	-.070	-.099
IMAGINARY PART		.3163	.2960	.1959	.1710
NUMERATOR EQUATION:					
REAL ROOT		-.0199	-.0339	-.0283	-.0413
REAL ROOT		-.2291	-.3065	-.3775	-.5759

TABLE 8-3 LATERAL-DIRECTIONAL CONTROL AND STABILITY DERIVATIVES AND ROOTS OF CHARACTERISTIC EQUATION STRAIGHT AND LEVEL FLIGHT

GROSS WEIGHT (POUNDS)			59,486			87,300	
AIRSPEED (KNOTS)		0	60	125	0	60	125
$Y_{\delta S}/m$	ft./sec.^{2}/inch	.3505	.3570	.3635	.3510	.3605	.3650
$Y_{\delta R}/m$		-.8900	-.8250	-1.1420	-.5980	-.5530	-.7740
$L_{\delta S}/I_{XX}$		.1251	.1263	.1277	.1123	.1143	.1153
$L_{\delta R}/I_{XX}$		-.0872	-.0803	-.1114	-.0856	-.0856	-.1198
$N_{\delta S}/I_{ZZ}$	rad./sec^2/inch	-.00007	.00002	-.00002	-.00014	-.00003	-.00015
$N_{\delta R}/I_{ZY}$		.0515	.0494	.0627	.0584	.0566	.0699
Y_v/m	ft./sec^2/ft./sec.	-.0574	-.0633	-.1075	-.0480	-.0524	-.0764
L_v/I_{XX}		-.00555	-.00366	-.00528	-.00836	-.00606	-.00752
N_v/I_{ZZ}	rad./sec^2/ft./sec.	.000455	.000734	.000808	.000404	.000933	.000907
Y_p/m		-.4144	-1.0949	-.5810	-.7844	-1.0528	-.4762
Y_r/m	ft./sec^2/rad./sec.	.8786	1.3089	-1.4958	.6501	.8608	.9098
L_p/I_{XX}		-.4532	-.5715	-.4242	-.3976	-.4505	-.2915
L_r/I_{XX}	rad./sec^2/rad./sec.	.0994	.1220	.1254	.1151	.1298	.1274
N_p/I_{ZZ}		.00146	-.01455	.00138	-.01505	.01505	-.01550
N_r/I_{ZZ}		-.05832	-.07275	-.08896	-.07971	-.09125	-.10670
CHARACTERISTIC EQUATION							
SPIRAL MODE ROOT		-.0555	-.0355	-.0473	-.0732	-.0580	-.0730
ROLL MODE ROOT		-.7735	-.7745	-.7987	-.8288	-.7800	-.8050
DUTCH ROLL REAL PART		.1303	.0511	.1132	.1884	.1220	.2028
DUTCH ROLL IMAGINARY PART		.461	.453	.550	.540	.543	.584
NUMERATOR EQUATION:							
REAL ROOT		-.0688	-	-	-.0835	-	-
REAL ROOT		-.0314	-	-	-.0192	-	-
REAL PART		-	-.0629	-.0906	-	-.0623	-.0985
IMAGINARY PART		-	.2732	.4121	-	.3054	.4328

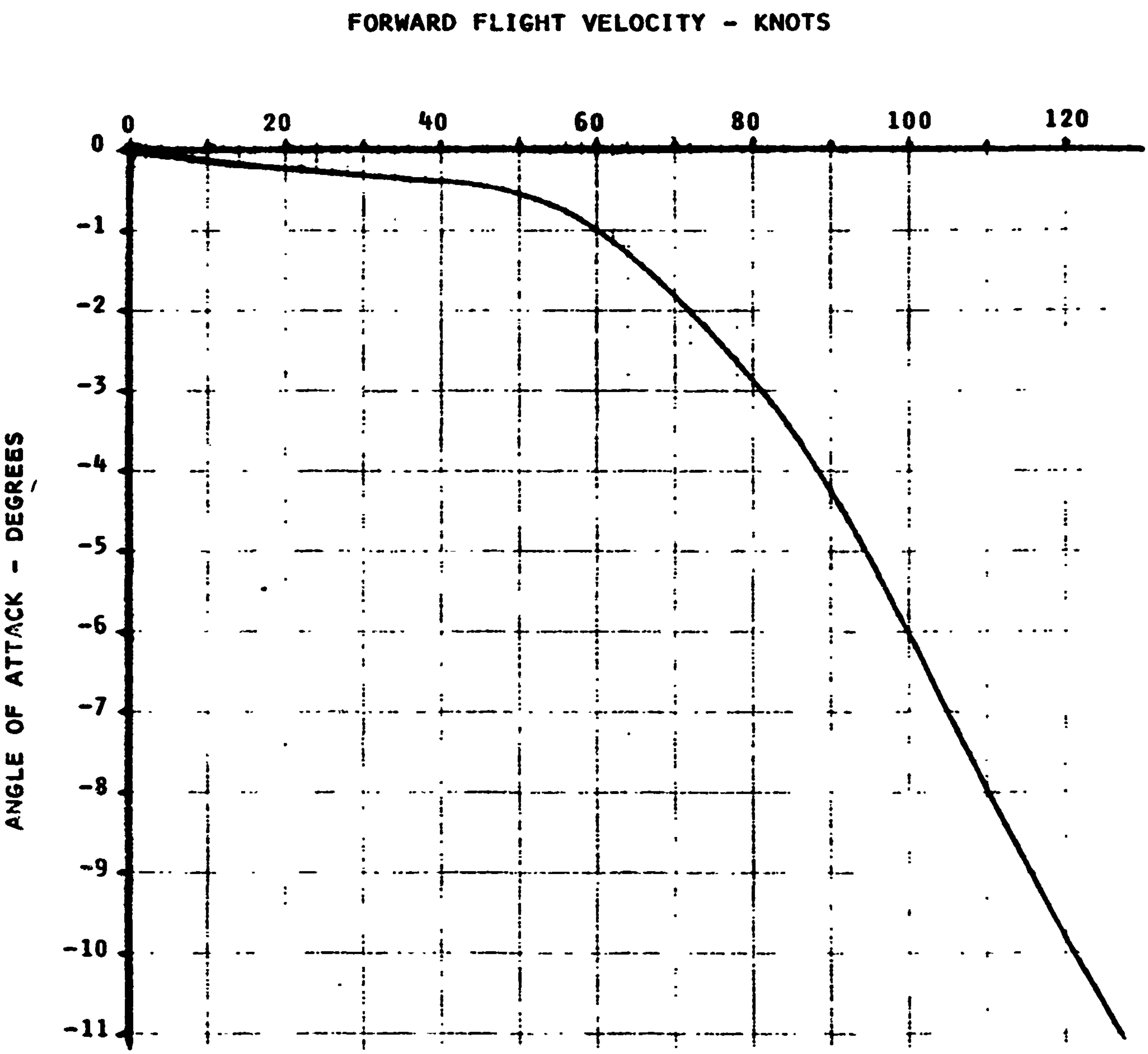

FIGURE 8-1. MHHLS TRIM FUSELAGE ANGLE OF ATTACK