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TRANSPORTATION RESEARCH COMMAND
FORT EUSTIS, VIRGINIA

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TREC TECHNICAL REPORT 61-33

**FLIGHT EVALUATION OF REDESIGNED EXTERNAL
CARGO SWING FOR H-21 HELICOPTER**

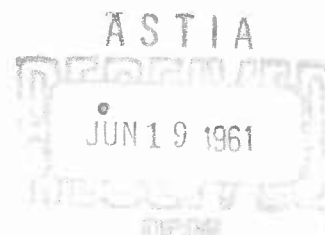
Project 9R89-02-015-14

Contract DA-44-177-TC-587

January 1961

prepared by :

VERTOL DIVISION
Boeing Airplane Company
Morton, Pa.



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Project 9R89-02-015-14

Contract DA44-177-TC-587

January 1961

FLIGHT EVALUATION OF REDESIGNED EXTERNAL
CARGO SWING FOR H-21 HELICOPTER

REPORT NO. R-232

Prepared by

Vertol Division

Boeing Airplane Company

Morton, Pennsylvania

for

U.S. Army Transportation Research Command
Fort Eustis, Virginia

FOREWORD

This report was prepared by Vertol Division - Boeing Airplane Company under U. S. Army Contract Number DA 44-177-TC-587, Modification II. The project was originated by the U. S. Army Transportation Research Command, Fort Eustis, Virginia. Mr. Robert Powell, Project Engineer, and Mr. Ralph Aiken, Assistant Project Engineer were cognizant TRECOM personnel in administering the contract.

The project was conducted through the period of May 1960 to February 1961.

The following Vertol-Boeing personnel contributed to the preparation of this report:

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SUMMARY

This report summarizes the development work on the improved external cargo sling that was developed at Vertol Division - Boeing Airplane Company. The improved sling designated the "cargo swing" was compared to the standard sling for H-21 helicopters in a previous flight test program which is reported in Vertol Report R-177. The present work was initiated to improve the "cargo swing" by modifications which now make it acceptable for potential retrofit on H-21 helicopters. However, some redesign in the interest of weight reduction and cost considerations for quantity production would be desirable if the swing is retrofitted.

The cargo swing was designed to locate the effective point of suspension of the cargo nearer the center of gravity of the helicopter. The effective point of suspension, when utilizing the swing, ranges from approximately 26 inches to 34 inches below the normal c. g. of the H-21 helicopter depending on the angle of lateral swing of the external cargo with respect to the helicopter, (Reference Figure 7). The effective point of suspension of the standard sling lies at 134 inches below the normal c.g. of the H-21 helicopter. By using the swing concept, coupling is reduced between lateral motion of the cargo and rolling motion of the helicopter.

The cargo swing pivots at 67 inches below the c.g. for longitudinal motion compared to 134 inches effective suspension point below the c.g. for the standard sling. Therefore, coupling between longitudinal motion of the load and pitch of the helicopter is also reduced with the cargo swing but to a lesser degree than for lateral motion. For tandem rotor helicopters further improvement in longitudinal stability and control is unnecessary. The primary consideration in the cargo swing design was to improve the rolling stability of the H-21 helicopter when handling external cargo.

In the program reported in Vertol Report R-177, the external cargo sling was evaluated in comparison to the standard cargo sling on an Army H-21C helicopter. The program involved flying under stabilized flight conditions from 0 to 50 knots with sling loads of 2200 lbs. and 3200 lbs. and cargo cable lengths between the hook and the cargo of 0, 5, and 10 feet. All flights were made under wind conditions of less than 15 knots. All flights comparing the cargo swing to the cargo sling, as well as flights on the current program, were made by the same pilot.

In addition to the stabilized runs mentioned above, stabilized Vmax runs of 83 knots, limited by the confines of the field, with a 2200 lb. load and cargo cable lengths of 5 ft. and 10 ft. were made utilizing the swing system. Vmax for the standard cargo sling was 65 knots for the same load and cable lengths, and was limited by excessive lateral sway and longitudinal pitching of the helicopter. Rapid accelerations and decelerations (flares), both left and right sideways flight, and both left and right extreme rolls with the various loads and cable lengths were also performed on both the cargo swing and the cargo sling. Oscillograph instrumentation records of pitch rate, roll rate, roll attitude, longitudinal stick position, lateral stick position, and air speed were taken for all of the above flight conditions on both the cargo sling and cargo swing during the original program.

The modifications to the cargo swing, that were made in the current program, consisted of redesign to improve the retraction of the swing, new fuselage attachment fittings, addition of a manual emergency cargo release system, and incorporation of a swivel at the hook to permit freedom for load rotation. A more detailed description of these modifications are as follows:

1. *Redesign to improve retraction of the swing - A trunnion was installed at the lower corners of the swing so that the apex can pivot relative to the main arms. This permits the swing apex and cargo hook boom to be retracted (nearly) parallel to the lower fuselage skin line as shown in Figure 5. A hand winch was tied into the standard H-21 sling retraction system for this program. An electrical winch is recommended if retrofit is desired.
2. The main arm fuselage attachment fittings are redesigned to provide for full swing motion to any possible combination of fore and aft and lateral angles. There is now no possibility of recurrence of the bolt failure experienced at Fort Bragg during tests conducted by the Airborne and Electronics Board.
3. A manual emergency release system has been provided which connects to the pilot's manual release handle and also the release handle located in the aft cabin area for cargo release by a crew member. The manual release handles actuate a hydraulic pump with a self-contained reservoir which pressurizes hydraulic fluid in a flexible line running down the swing arm to a hydraulic cylinder. The hydraulic cylinder is mounted on the center swinging arm which is connected to the cargo hook. When the hydraulic cylinder receives pressurized fluid, it pulls upward on a cable connected to the mechanical release on the cargo hook. This manual release system was found to function satisfactorily but requires precise adjustment. It would be advisable to provide a cylinder with a slightly larger stroke for any swings in a retrofit program.

The modifications were made on the two cargo swings from the original program and wherever possible, the old parts were used. The two modified test swings are capable of a maximum of 4000 pounds external cargo load when installed on H-21 helicopters. The installation was proof loaded to a limit load of 2.67 x 4000 pounds.

In the event it is desired to retrofit the cargo swing on H-21 helicopters, it is recommended that the material thickness of the main arms be increased to .090 inches which will make the complete installation capable of a 5000 pound external cargo load with a 2.67 limit load factor.

The testing accomplished on the current program assured the function of the swing modifications and also verified the previously reported flight test results. Additional flight tests conducted with an empty Army conex box demonstrated the effectiveness of the swing for low density loads which must be carried externally.

CONCLUSIONS

Based on the overall test program of the original cargo swing and the modified cargo swing, the following conclusions were reached:

1. Pilots report that the overall handling characteristics of the H-21 with external load are quite similar to the handling characteristics with internal cargo.
2. Pilot effort required to maneuver the helicopter carrying typical external loads is reduced to approximately one-third that required for operating with the standard sling.
3. High speed flight is now possible with externally slung loads (up to 95 knots have been achieved).
4. Offset load pickup can be made with attachment angles up to 20° with no appreciable rolling or pitching moment buildup.
5. The hovering helicopter can be rolled to angles of 20° with 3200 pounds of external cargo without exceeding safe lateral control.
6. Coordinated high speed turns carrying 3200 pounds external cargo are now possible (up to 30° bank angle and 70 knots were achieved).
7. Rolling of the helicopter, due to cargo motion, is reduced due to negligible coupling of feedback forces between external load and the helicopter.
8. More rapid accelerations and flares with external cargo are soon possible.
9. Modification of the cargo swing to improve retraction was successful (see recommendations).
10. The manual release for the cargo hook which was designed to tie into the existing H-21 manual system functioned satisfactorily (see recommendations).
11. The electrical release system for the cargo hook which is wired into the existing H-21 electrical release system functioned satisfactorily throughout the testing.
12. The redesigned fuselage attachment fittings were checked out on the ground and in flight with the load swinging well beyond any possible angle that could be achieved in normal operations. There is no possibility of a repetition of the attachment bolt failure that occurred at Fort Bragg.
13. The swivel that was incorporated in the cargo hook permits rotational freedom of the load and was completely satisfactory in operation.
14. In general it is concluded that the H-21 cargo swing is now ready for retrofit on H-21 helicopters. Some minor design changes would be required, however (see recommendations).

RECOMMENDATIONS

In the event it is desired to retrofit the cargo swings on H-21 helicopters, the following design changes are recommended:

1. For operational considerations, the manually-operated swing retraction winch should be replaced with an electric and/or hydraulic winch (controllable from the cockpit), thus eliminating the need for a cargo compartment winch operator. A cockpit indicator showing swing position (extended or retracted) should also be incorporated.
2. Some strengthening of the standard H-21 retraction system should be made since the cargo swing is heavier than the standard sling used on H-21 helicopters.
3. The hydraulic portion of the manual release system should incorporate an actuator having a cylinder with a longer stroke so that less precise adjustments would be required in the hook release mechanism.
4. The main arms should be made from .090 inch thick material so that the entire swing installation will be capable of a 5000 pound design load.
5. Some redesign is desirable in the interest of possible weight reduction and to incorporate features typical of quantity production.

INTRODUCTION

The work reported herein was contracted for under Modification II to Contract DA-44-177-TC-587. The scope of this project consisted of modifications to improve the external cargo swing for H-21 helicopters which was originally evaluated under Contract DA-44-177-TC-578 and reported in Vertol Report R-177 (Ref. 1). The design improvements were incorporated in the cargo swing and installed on an H-21 helicopter. The installation was subjected to functional test and evaluation both on the ground and in flight with external cargo.

The original cargo swing development was an outgrowth of the multilift program, Contract DA-44-177 TC-481. The cargo swing concept was initiated to fulfill a requirement to reduce the rolling moments induced in two (2) H-21 helicopters when coupled by a multilift load carrying beam. Contract DA-44-177-TC-578 was let after cancellation of the multilift project to provide for an evaluation of the swing concept when used for external cargo handling work.

The successful flight test evaluation at Vertol clearly demonstrated the value of the swing concept. Improvements were recommended since several features necessary for external cargo handling work were not required on the more specialized multilift program for which the swing was originally designed. However, it was decided to send the installation to Fort Bragg, North Carolina, for service evaluation by the Airborne and Electronics Board prior to incorporating the improvements. It was felt that experienced Army operating personnel, familiar with all types of external cargo handling problems, could determine any additional improvements that might become evident during a service evaluation.

The value of the swing concept was again demonstrated at Fort Bragg. Near the end of the evaluation a failure in one of the swing arm attachment bolts occurred. It was decided that sufficient testing had been completed so that positive recommendations for improvements could be made. As a result of the Airborne and Electronics Board recommendations at Fort Bragg, Vertol was awarded Modification II to Contract DA-44-177-TC-587 under which the current work was accomplished.

The improvements that were made under the current contract and reported herein are as follows:

- (a) Redesign at the point of attachment of the cargo swing to the helicopter fuselage to prevent repetition of the attachment bolt failure which occurred during the Fort Bragg service evaluation.
- (b) Modification of the swing so that it can be more easily retracted.

- (c) Provide a manual release for the cargo hook to tie into the existing manual release system presently used in the H-21 helicopter.
- (d) Although not specifically required by the contract, a swivel was incorporated in the cargo hook. The swivel permits the cargo to rotate freely and therefore, no torsional moments are transferred to the swing.

The objective of the present work which was accomplished under Modification II to Contract DA-44-177-TC-587 was to modify the two existing cargo swings so that it could be demonstrated that the concept would be suitable in all respects for retrofit on H-21 helicopters. Mainly this consisted of incorporating the recommendations for improvements listed above. The final proof of these changes was the functional testing both on the ground and in flight at Vertol, and a service evaluation by the Aviation Board at Fort Rucker, Alabama.

Description of Cargo Swing

A. History of Swing Development

The original H-21 cargo swing, Reference Figures 1 and 2, consisted of a parallel bar linkage hung from the two existing aft sling fitting locations. The cargo swing ship fittings were designed to permit lateral and longitudinal swing action, but it was found that under an extreme combined roll and pitch motion the bolts could be subjected to bending moments which may result in failure. The pin joints at the bottom of the assembly permitted motion of the hook boom only in the plane of the swing assembly itself. This feature was undesirable for retraction purposes since the hook and boom could not be swung forward enough to obtain ground clearance (Reference Figure 3). This swing did not have a swivel device to permit rotation of the cargo hook. The releases provided were the normal electrical release and a cable cutter for emergency release. Retraction was effected with a cable through the aft cabin door. The modification of the swing assembly aircraft fittings was also required because of a field failure of one of the ship fitting bolts during testing by the Army at Fort Bragg, North Carolina.

B. Swing Configuration as Modified in this Program

The modified swing assembly retained all the original basic structural frame and the kinematic configuration (Reference Figure 4). The aircraft fittings were redesigned to allow unlimited simultaneous lateral and longitudinal motion of the swing. This precludes repetition of the bolt failure experienced at Fort Bragg.

The pin joints at the bottom of the assembly were redesigned to allow the apex and cargo hook boom to rotate longitudinally out of plane with the swing assembly. This permitted the hook boom to be retracted nearly parallel to the helicopter underside, thereby allowing adequate ground clearance for the retracted swing (Reference Figure 5). A swivel was added to the hook to permit external cargo to rotate freely. The swivel design was subcontracted to the cargo hook vendor and is completely compatible with the hook.

The cable (with cable cutter) which supported the hook was eliminated and the hook and swivel are now attached directly to the two supporting channels pinned at the apex. An independent hydraulic emergency release replaced the cable cutter installation and the normal pilot's electrical release was retained, operating through slip rings in the hook swivel. The modified swing is retracted via the standard cargo sling retraction system with an additional pulley mounted on the aircraft's underside to guide the cable through the fairlead and into the normal retraction system. A hand-operated commercial winch was substituted for the bungee and handle assembly normally used to retract the standard sling assembly (Reference Figure 6).

C. Structural Design

The cargo swing was designed to criteria as shown below.

Design Load	4,000 lbs. (Test Swings)
Limit Load Factor	2.67
Limit Load	10,680 lbs.
Normal H-21 Operating Load	3,000 lbs. *
Maximum Design Load	5,000 lbs. *
Maximum Proof Load Imposed at Test	11,000 lbs.

* Stress analysis of cargo swing (Reference Appendix II) was for a 5000 pound design load. The two test swings used on this program were modified from the original cargo swings. The main support arms were originally stressed for a 4000 pound design load. Therefore, the only change required to make the complete swing assembly good for a 5000 pound design load is to change the main arm material thickness from .081 to .090 inches.

The redesigned pin joints at the bottom of the main arms as well as the aircraft fittings, swivel assembly, and swivel attachment to the hook boom were designed to a 5000 pound design load. The standard cargo sling retraction system was modified by the addition of a retraction cable guide pulley on the aircraft underside, and an additional pulley bracket and retraction winch inside the aircraft.

These components were designed to a nominal retraction load of 70 pounds with a 2.67 limit load factor. For retrofit kit installation of the swings, the standard retraction components in the system should be modified for the higher retraction loads imposed on them.

D. Aircraft Modification Required

The following modifications to the H-21 helicopter were required to install the external cargo swing.

1. The two (2) cargo swing aircraft fittings replace the original sling cable attachment eyebolts, and are attached at the two (2) aft standard sling holes. Each fitting requires an additional hole through the skin and structure for an antirotation pin.
2. For the retraction system, sheet metal brackets were installed to mount the hand winch, the winch lead-in pulley, and the lead-in pulley on the aircraft lower skin. The original sling retracting cable was removed from the cabin bulkhead.
3. For the release system, all the original release cables were removed, the actuator for the electrical release was removed, and the cable tension regulators were removed from the pilot and crew chief release lines. New cables replaced all the old cables.

4. For the emergency release system, sheet metal brackets were installed to mount the hydraulic transmitter, transmitter lever return spring, guide pulley for the cable actuating the hydraulic transmitter, and cable fairlead for the same cable. A doubler was added to a hole cut through the battery support for cable clearance. A hydraulic line was installed from the transmitter to a quick disconnect bulkhead fitting mounted at the fuselage skin. New electrical wiring was added from the original electrical release actuator plug to the cargo hook, going through a quick disconnect at the fuselage skin.

The flexible external hydraulic line and electrical wiring bundle was routed from the fuselage skin quick disconnect fitting and attached to the main arm. The bundle is routed over to the hydraulic cylinder mounted on the cargo hook boom (See Figure 5). A short length of bungee spring loads the bundle aft and prevents fouling with the swing during extreme motions.

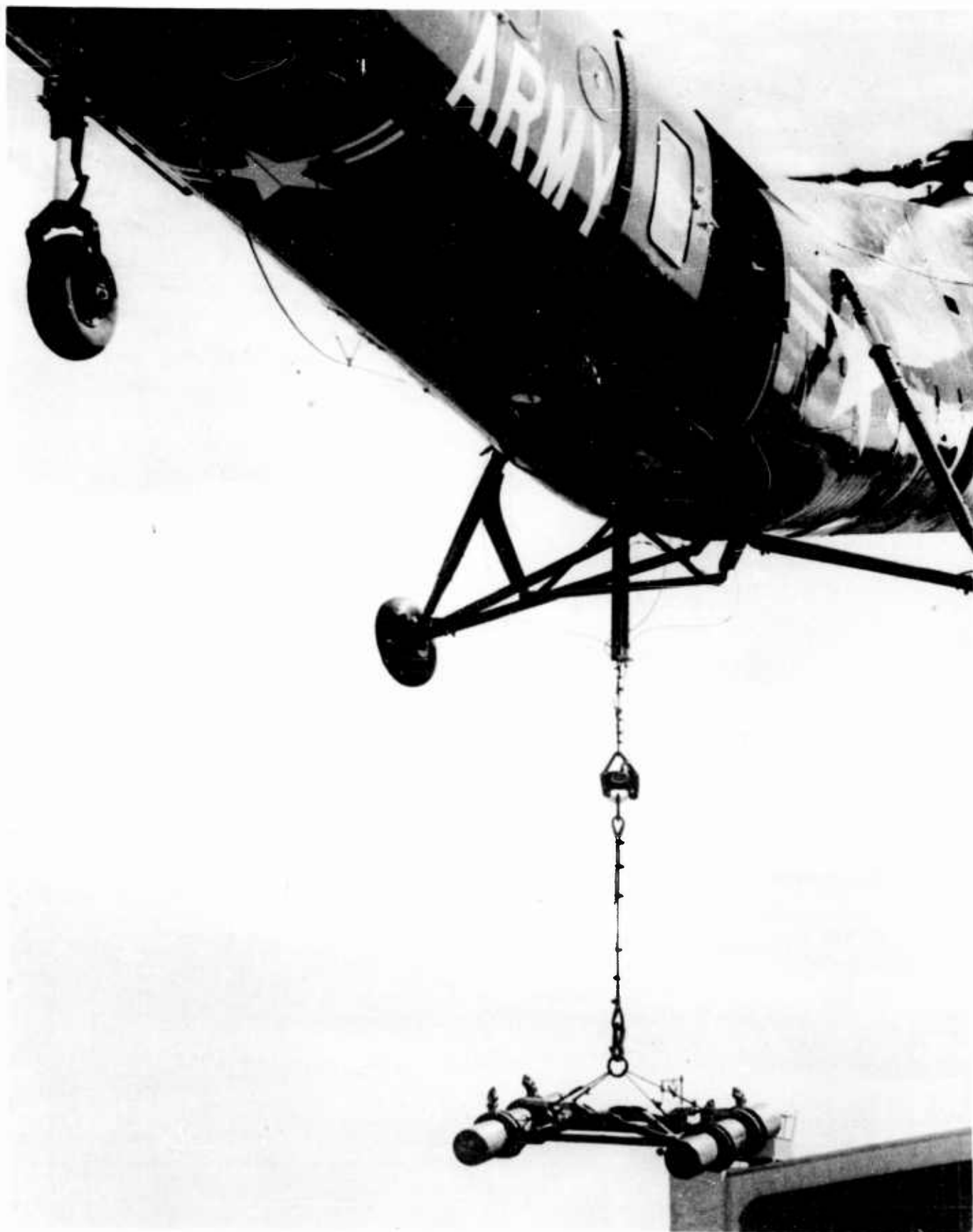


Figure 1 H-21C #317 Hovering with Original
Cargo Swing and External Cargo

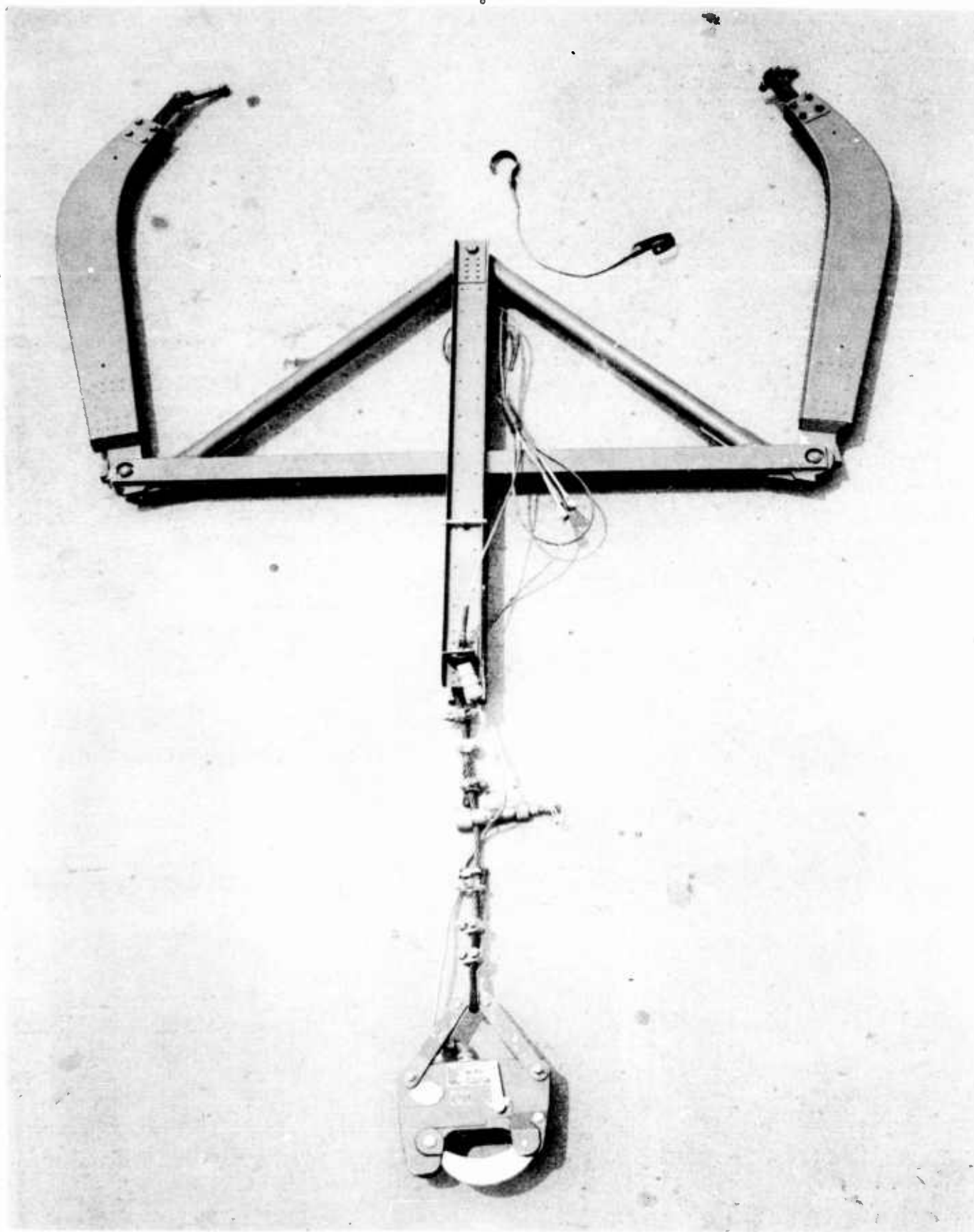


Figure 2 Original Cargo Swing with Cargo Hook and Emergency Cable Cutter Installed

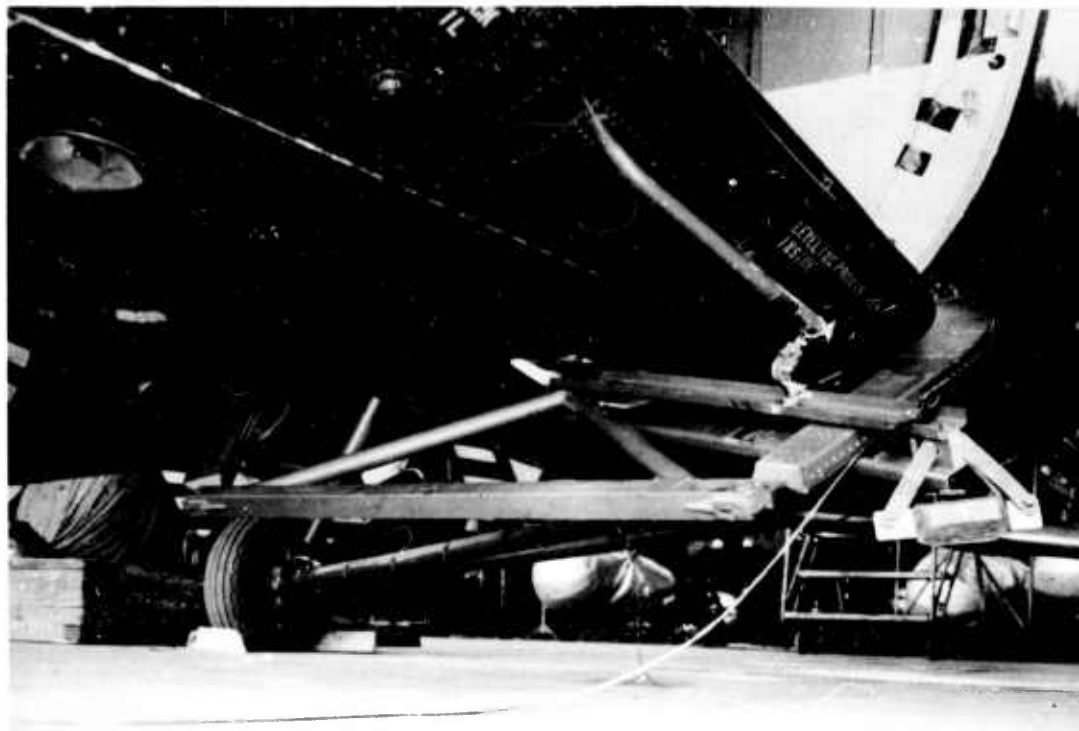


Figure 3 Original Cargo Swing Shown Retracted



Figure 4 H-21C Hovering with Modified Improved Cargo Swing and External Load



Figure 5 Modified Improved Cargo Swing
Shown in Retracted Position

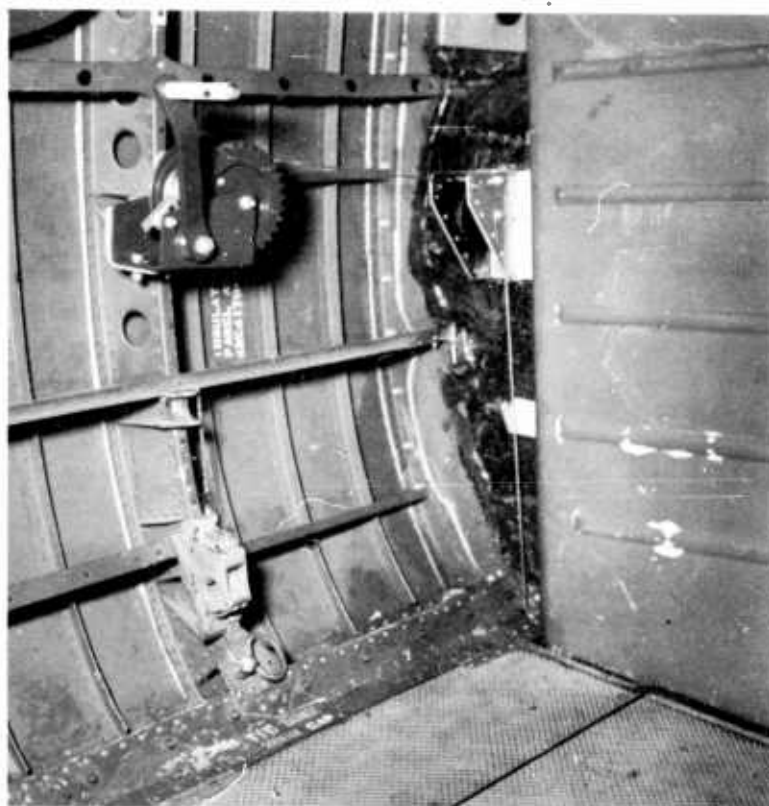
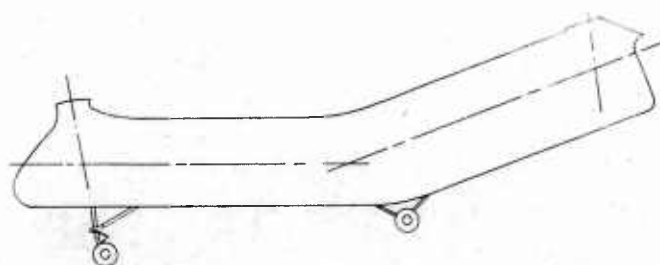
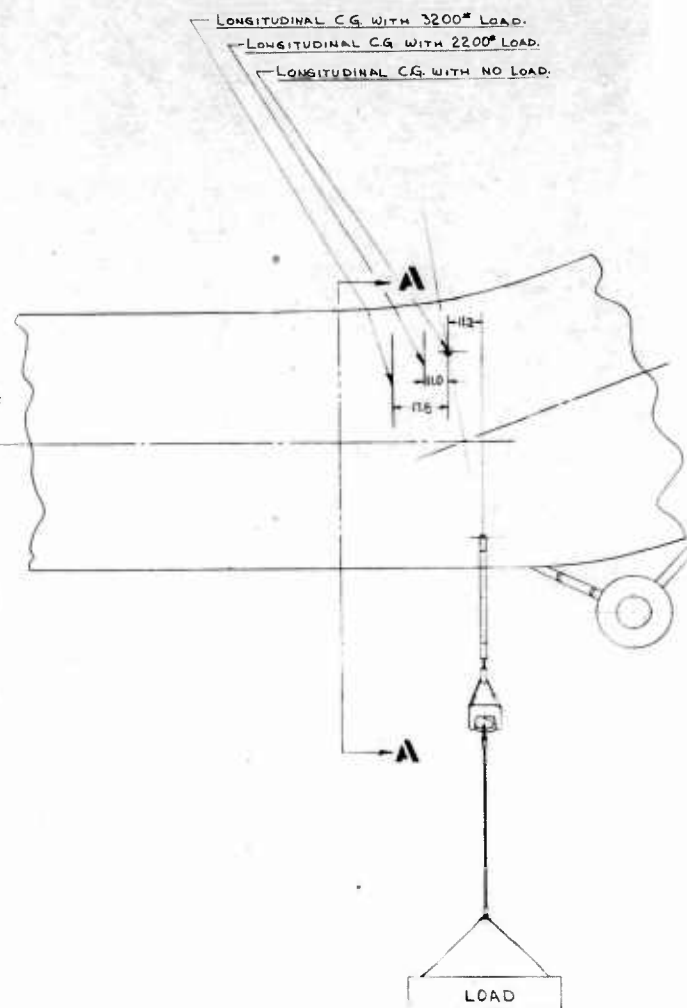
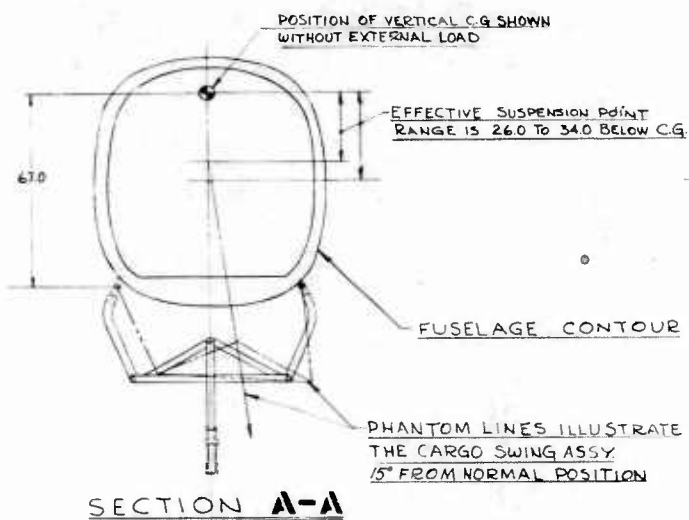


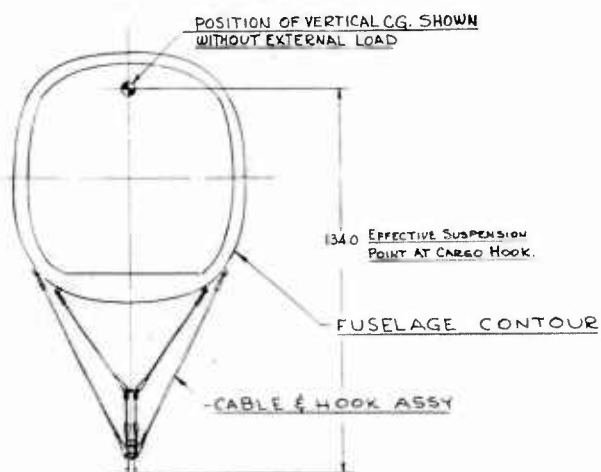
Figure 6 Retraction Winch Installation



NOTES:

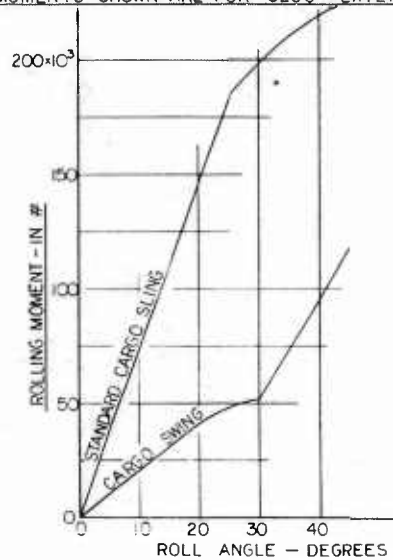
- 1- CARGO SWING INSTALLED AT EXISTING AFT FITTING FOR SLING
- 2- WEIGHT OF SWING ASSY. 45.8* (NO HOOK)

1

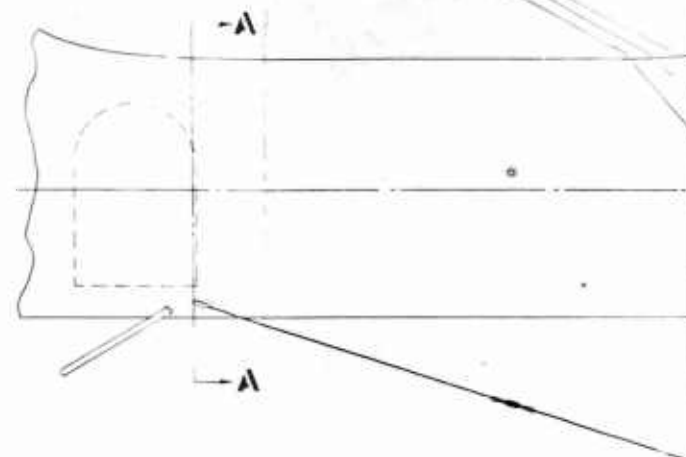


SECTION A-A

ROLLING MOMENT INDUCED IN THE HELICOPTER
vs
ROLL ANGLE OF HELICOPTER (WITH RESPECT TO EXTERNAL LOAD LINE)
MOMENTS SHOWN ARE FOR 3200# EXTERNAL LOAD

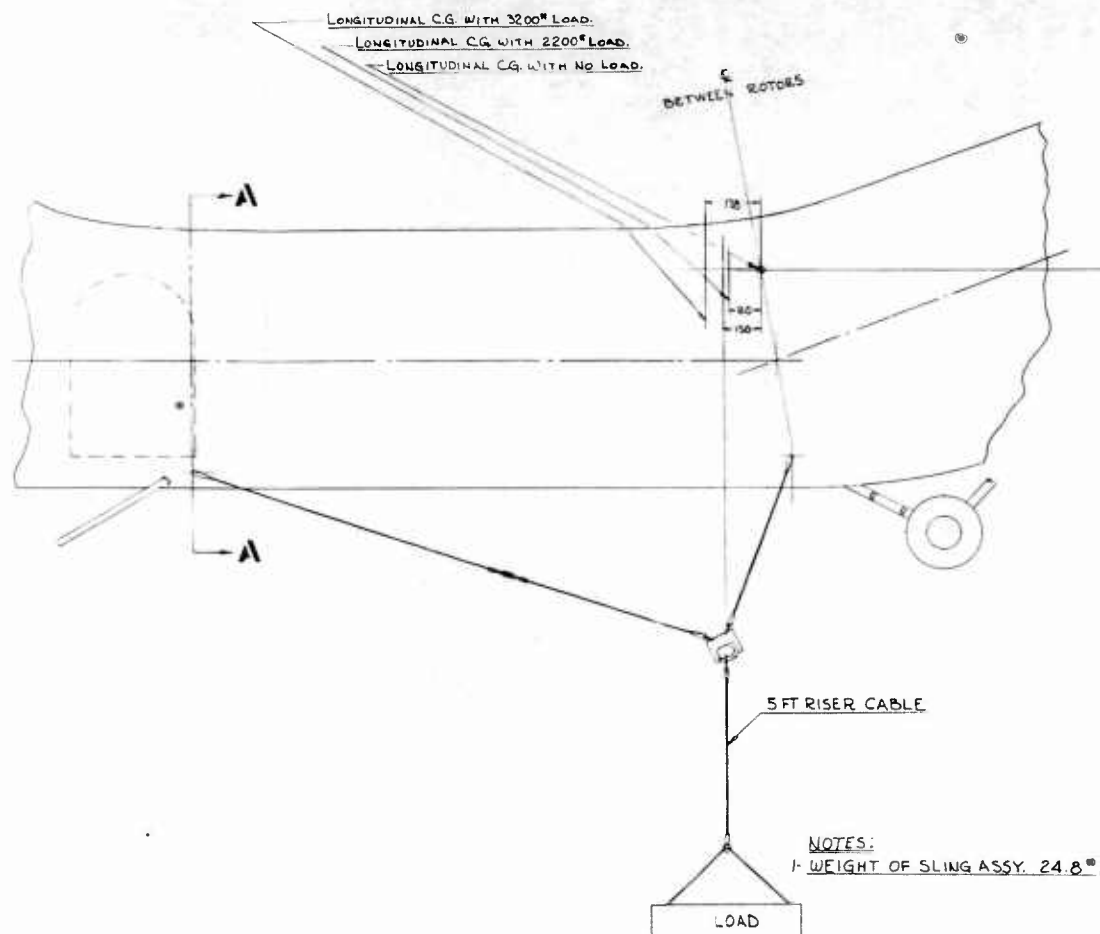


LONGITUDINAL CG. WITH 3200# LOAD.
LONGITUDINAL CG. WITH 2200# LOAD.
LONGITUDINAL CG. WITH NO LOAD.



H21 EXTERIOR CARGO SLING

2



H21 EXTERIOR CARGO SLING

PRINT REDUCED
ONE-THIRD
INDICATED SCALE

3

FIG 7

DESIGNED BY E. H. GORDON	DATE 3-6-53	COMPARISON OF H21 CARGO SLING & CARGO SWING.		VERTOL BOSTON, PENNSYLVANIA	
STANDARD PROG. 88	WEIGHT 24.8	NAT. PROJ. DHS APP	SCALE 1:20	DWG. NO. SK-4752	REV
STAFF CURT	CURT	SCALE 1:20	REV	SHEET 1 OF 1	

DISCUSSION OF RESULTS

A. Proof Load Static Test

Prior to flight testing of the modified cargo swing it was statically loaded while installed on the H-21 helicopter. The load was applied with a hydraulic ram and measured with a load cell as shown (Reference Figure 8). Test results are as follows:

<u>Load (Pounds)</u>	<u>Longitudinal Angle (Degrees)</u>	<u>Lateral Angle (Degrees)</u>
11,000	6 fwd	0
11,000	24 aft	0
11,000	0	20

The operation of the new hydraulic pilot and crew chief hook release and the manual pilot electrical release was checked out satisfactorily at a 4500 pound loading.

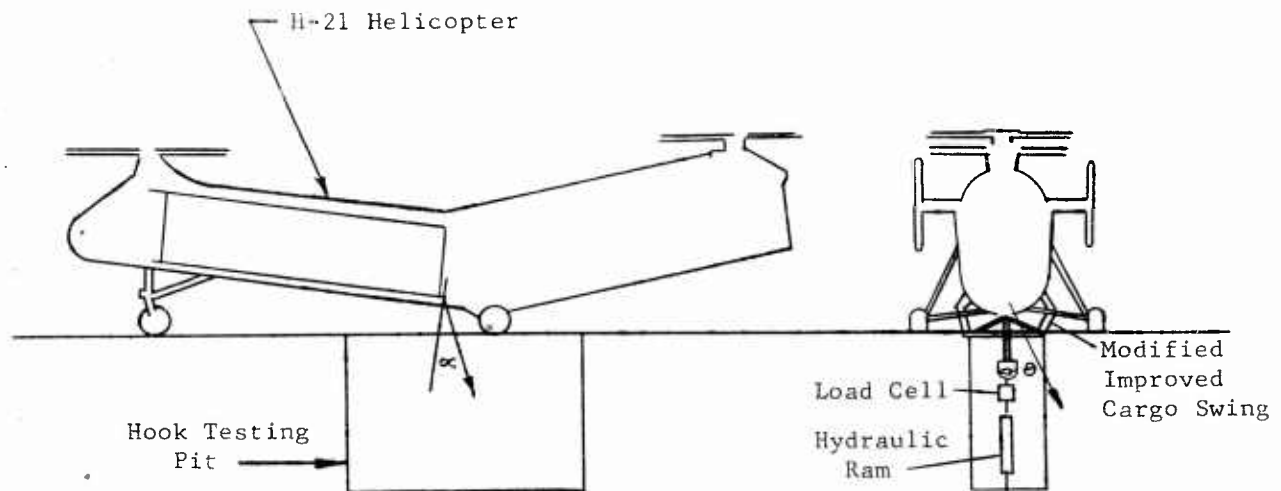


FIGURE 8

*SCHEMATIC SHOWING DIRECTION OF STATIC PROOF LOADING AND PROOF LOAD SET UP

B. Flight Test Program

During the flight test program the swing was retracted and extended in flight, the electrical and manual hook release systems were checked out, and flights were made with various loads to reconfirm the operating characteristics of the swing principle. These flights are described below. The initial load was a 400 pound concrete-filled five gallon container. The second was a 3200 pound high density load, which consisted of two concrete filled steel pipes approximately twelve inches in diameter and four feet long. The normal and emergency release mechanisms were checked with these loads. A 1600 pound empty Conex box was then lifted and flown to forward speeds of 70 knots. This box is cube shaped with dimensions of each side approximately 6'. This shape presents a dynamic problem in forward flight and lateral oscillations up to 30° from the vertical were experienced during this flight. This motion, coupled with simultaneous rotation of the box due to windloading, presented no pilot control problem. Vmax was limited to 70 knots by the confines of the airfield. With this load, 30° banks were executed at the 70 knot airspeeds.

No instrumentation was installed for this program. Oscillograph records of pitch rate, roll rate, roll attitude, longitudinal stick position, lateral stick attitude, longitudinal stick position, lateral stick position, and airspeed were taken during the testing of the original swing and are presented in Appendix C of report No. R-177 (Reference 1). These results are valid for the modified cargo swing also.

C. Results

During flight testing of the modified swing assembly the method of retraction was proven to be satisfactory for a military evaluation of the swing, although the pilot recommended the use of a powered winch for pilot control of retracting and extending the swing. The redesigned pin joints at the bottom of the parallel beams allowed adequate ground clearance upon retraction of the swing. Normal and emergency release systems functioned perfectly under loads from 400 to 3200 pounds.

The H-21 helicopter pitch and roll stability were excellent with the modified improved cargo swing carrying the 1600 pound Conex box. The redesigned fuselage fittings functioned as required at Vmax runs of 70 knots with lateral oscillations of the box to 30° from the vertical being encountered. During this rotation and oscillation of the box the new hook swivel proved to be an important addition to the unit. The swivel feature eliminates torsional moments induced on the cargo hook arm by the yawing motion of the cargo.

In testing of the original swing configuration (Reference 1) a 2200 pound high density load was carried with zero, five, and ten foot riser cable lengths on the swing. In stabilized flights to 50 knots, rapid acceleration and deceleration, sideward flight and quick rolls in both directions, a maximum of 25% of available lateral control authority was required. In direct comparison tests by the same pilot, as much as 75% of available authority was required for similar maneuvers with the standard sling configuration. A similar flight sequence was conducted in original testing using a 3200 pound high density load and riser cable lengths as above. The cargo swing maneuvers required a maximum of 35% of control authority; the same maneuvers using the standard sling required to 80% of available authority. Longer riser cable lengths presented increasing control problems for the standard sling, but did not affect the operating characteristics of the cargo swing.

During a high speed run of 70 knots on the current program the Conex box was unintentionally dropped. This was due to a cable in the emergency release being adjusted too short. After proper adjustment, no unintentional hook releases were experienced.

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APPENDIX I

PILOT COMMENTS

A. Flight No's. C10-X329 (8/27/60) and X330 (8/29/60)

G.W.: 10,400#
C.G.: 10" F C.G.
Fuel: 500 lbs.

Purpose of Flights

Hover check on cargo swing sling retraction mechanism.

Comments

The swing sling was retracted and extended three times successfully.

The aircraft was set up for load-carrying capabilities.

B. Flight No. C10-X331 (8/30/60)

G.W.: 10,400#
C.G.: 10" F C.G.
Fuel: 500 lbs.

Purpose of Flight

Flight evaluation of H-21 cargo swing sling and retracting mechanism.

Comments

A 400 lb. load was picked up and released electrically and manually.

A 3,200 lb. load was picked up and released successfully, electrically and manually. A 1,600 lb. Conex box was lifted and flown to 70 knots forward speed, accompanied by changes in attitude up to 30° left and right. During this latter maneuver the load was inadvertently released. It was found that the cable releasing mechanism was too short. Adjustments were made, and preparations were initiated for flight #332.

C. Flight No. C10-X332 (8/31/60)

G.W.: 10,400#
C.G.: 10" F C.G.
Fuel: 500 lbs.

C. Flight No. C10-X332 (Continued)

Purpose of Flight

Evaluation of H-21 cargo swing sling and retracting mechanism.

Comments

1. A 400 lb. weight was picked up, and radical rolling inputs to the left and right were applied to check the hold ability of the hook. Following this, two passes were made over the photographer at 60 knots, one with the swing extended and one with the swing retracted. Upon completion of this maneuver, a Conex box (1600 lbs.) was lifted. Flights up to 70 knots forward speed, accompanied by banks to 30°, were accomplished for the photographer. Following this, a 3200 lb. load was picked up and electrical and manual releases accomplished satisfactorily.

D. Flight No. C10-X333 (8/31/60)

G.W.: 10,400#
C.G.: 10" F C.G.
Fuel: 500 lbs.

Purpose of Flight

Flight demonstration of cargo swing sling and retraction system for Ft. Eustis personnel.

Comments

1. A 400 lb. load was lifted and radical inputs applied to the left and right to demonstrate hook holding capabilities in extreme attitudes. The extension and retraction of the swing was demonstrated at 60 knots forward speed. A 1,600 lb. Conex box was lifted and flown to 65 knots forward speed, accompanied by coordinated turns to the left and right. Following this, radical directional inputs to the left and right were demonstrated to check the swinging characteristics of the Conex box. Directional inputs were applied to both stops, left and right. The TRECOM personnel that viewed the demonstration were Captain McGuire, Lt. Kellogg, and Mr. R. Aiken.

D. Flight No. C10-X333 (8/31/60) (Continued)

Comments (Cont'd.)

2. The cargo swing sling was evaluated previously; and comments, as far as handling characteristics, are the same as listed previously. At no time during the radical lateral inputs did we exceed 25% of available control authority. The retraction mechanism is satisfactory for a military evaluation in the present configuration. In the event that we are to do any further testing, it is suggested that an electric winch be installed and a light system be installed on the console so that the pilot may be able to read swing position (up or down), accompanied by a switch so that the pilot could retract or extend the swing himself. This would eliminate the need for another man in the aircraft.

A. Temple
Experimental Test Pilot

APPENDIX II

STRESS ANALYSIS OF H-21

CARGO SWING

R-205

**VERTOL DIVISION
BOEING AIRPLANE COMPANY**

CODE IDENT. NO. 77272

PREPARED BY <i>J.C.L. Bryant</i>	J.C.L. Bryant	REPORT NO. R-205	NO. OF PAGES 21
CHECKED BY <i>W.B.P.</i>	W.B. Peck	MODEL	
APPROVED BY <i>W.B. Peck</i>	W.B. Peck	CONTRACT NO. DA-177-TC-587 Modification 2	ITEM NO.
APPROVED BY <i>K.T. Waters</i>	K.T. Waters	DATE 27 July 1960	
REVISIONS			
DATE	PAGES AFFECTED	REMARKS	

PREPARED BY: JBryant
CHECKED BY:
DATE: 7/27/60

VERTOL DIVISION
BOEING AIRPLANE COMPANY

PAGE NO. 1
REPORT NO. R-205
MODEL NO. H-21 Cargo Swing

INTRODUCTION

In order to reduce the rolling and pitching moments imposed on the H-21 Helicopter by externally slung cargo, the subject cargo swing was designed. The cargo swing is designed to locate the effective point of suspension of the cargo nearer the center of gravity of the helicopter. The effective point of suspension, when utilizing the swing, ranges from approximately 26 inches to 34 inches below the normal c.g. of the H-21 Helicopter depending on the angle of lateral swing of the external cargo with respect to the helicopter. The effective point of suspension of the standard sling lies at approximately 134 inches below the normal c.g. of the H-21 Helicopter. By using the swing concept, coupling is reduced between lateral motion of the cargo and rolling motion of the helicopter.

The cargo swing pivots at 67 inches below the c.g. for longitudinal motion compared to 134 inches effective suspension point below the c.g. for the standard sling. Therefore, coupling between longitudinal motion of the load and pitch of the helicopter is also reduced with the cargo swing but to a lesser degree than for lateral motion. The primary consideration in the cargo swing design was to improve the rolling stability of the H-21 Helicopter when handling external cargo.

CRITERIA

The ultimate load is assumed acting anywhere within a cone, whose internal angle is 60° and whose apex is 30" below the c.g. The axis of this cone is normal to the aircraft water line plane and passes through the c.g.

The design load shall be:

5,000# cargo @ 2.67 g (limit)

or

5,000 x 2.67 x 1.5 = 20,000# (ultimate)

All symbols and material properties are in accordance with MIL-HDBK-5 (March 1959) and Vertol Structural Design Manual as noted on Page 11.

REV

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JBryant

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DATE:

7/27/60

**VERTOL DIVISION
BOEING AIRPLANE COMPANY**

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REPORT NO.

R-205

MODEL NO.

H-21 Cargo Swing

SYMBOLS

A	Area (*)
D, d, t, w	Lug Dimensions, as noted
F	Allowable Stress (*)
f	Applied Stress (*)
K	Concentration Factor (*)
M	Bending Moment
P	Allowable Load (*)
R	Stress Ratio (*), Reaction
V	Direct Shear
τ	Torsional Moment

(*) Used with Subscript

Subscripts

ALL	Allowable
B, b	Bending
br	Bearing
c	Compression, Column
cr	Crippling
s	Shear
T, t	Tension
u	Ultimate
y	Yield
τ	Torsion

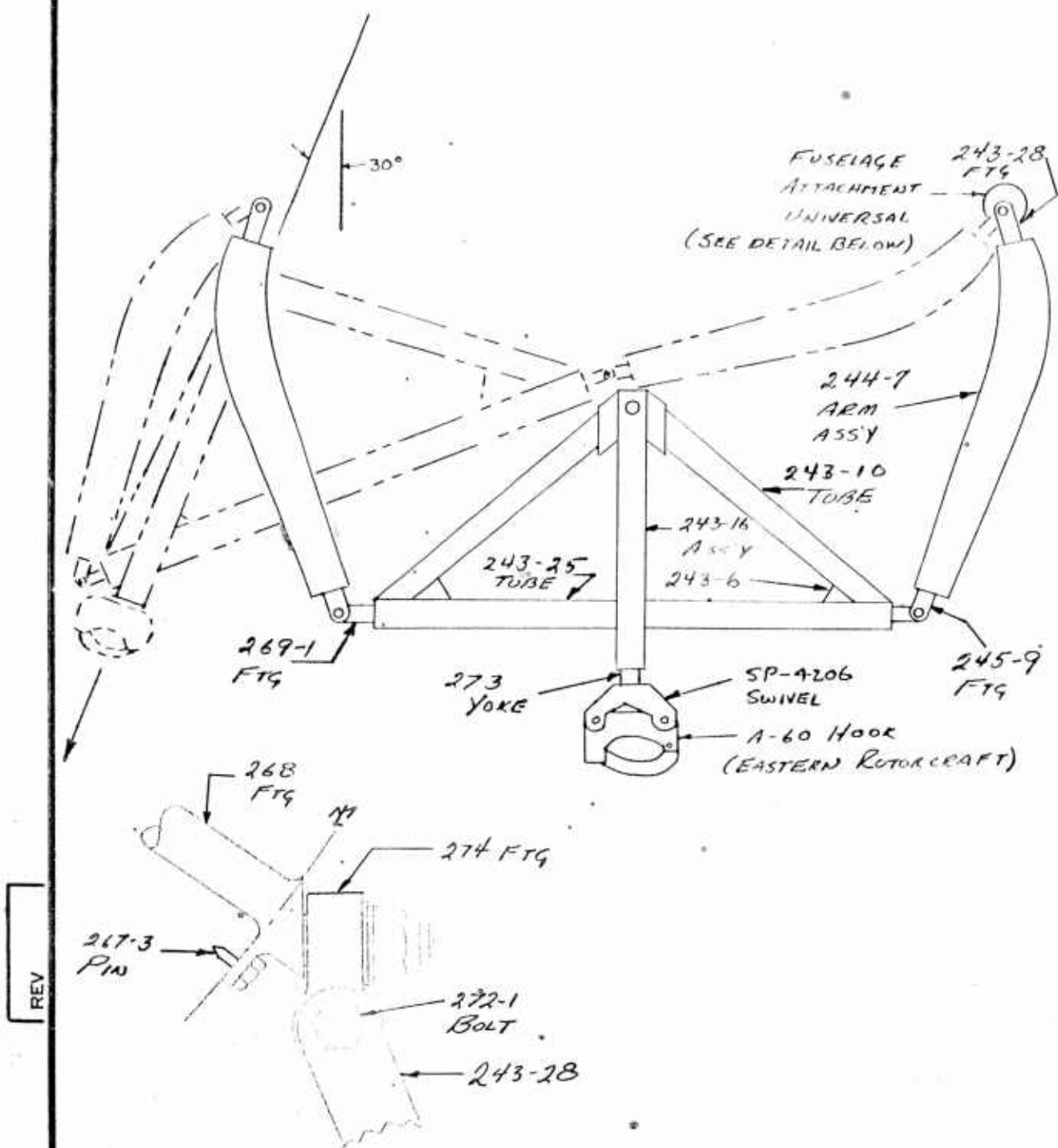
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BOEING AIRPLANE COMPANY

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MODEL NO. H-21 SWING

GENERAL CONFIGURATION

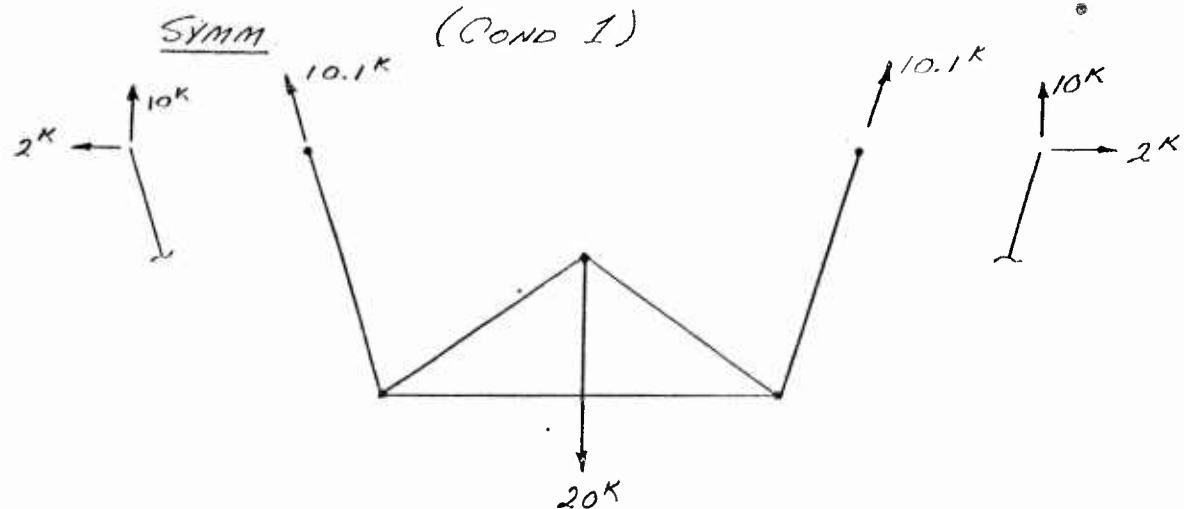


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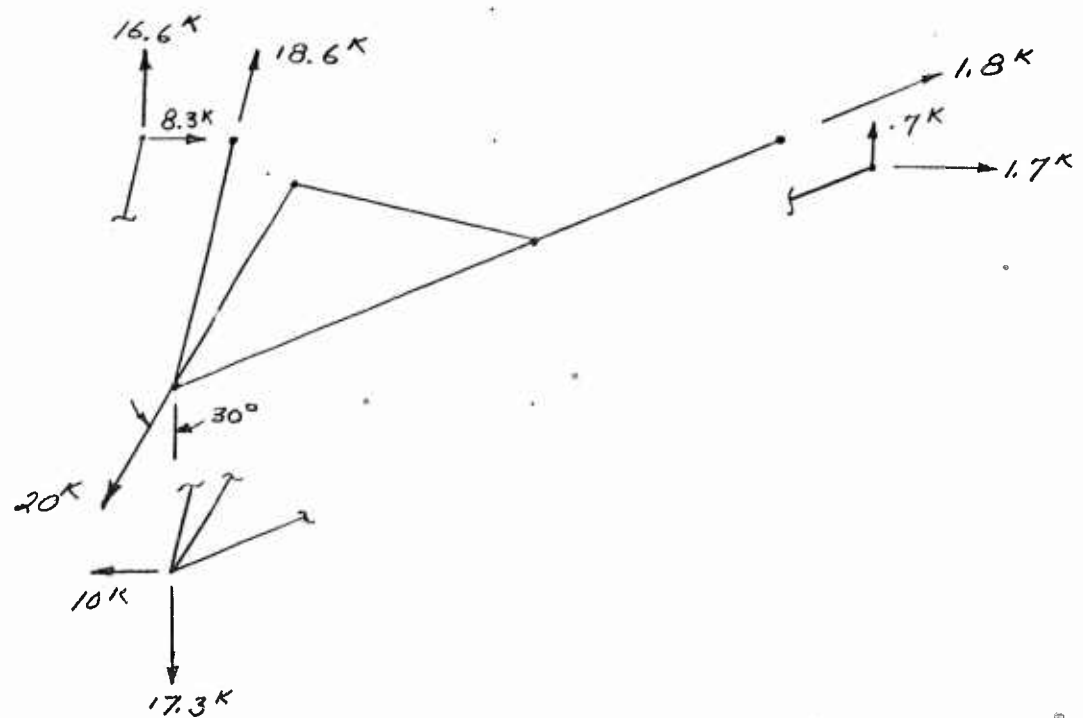
VERTOL DIVISION
 BOEING AIRPLANE COMPANY

PAGE NO. *2*
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 MODEL NO. *H-21 SWING*

DESIGN LOADS $P = 5000 \times 2.67g \times 1.5 = 20^k$



30° SIDE SWAY (COND 2)



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VERTOL DIVISION
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 REPORT NO. R-205
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273-1 YOKE

2024-T4 BAR UTS = 64 KSI

ATTACHMENT TO SWIVEL

3 - AN5 BOLTS

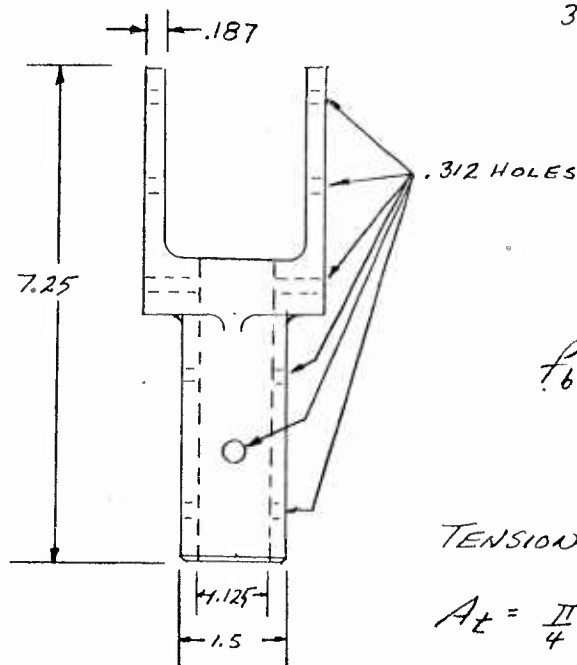
$$P_{ALL} = 6 \times 5750 = 34500 \#$$

$$M.S. = \frac{34500}{20000} - 1 = \underline{+.72}$$

$$WALL \ t = \frac{1.50 - 1.125}{2} = .188$$

$$P_{br} = \frac{20000}{6 \times .188 \times .312} = 57000 \text{ PSI}$$

$$M.S. = \frac{96000}{57000} - 1 = \underline{+.68}$$



TENSION IN TUBE:

$$A_t = \frac{\pi}{4} (1.5^2 - 1.125^2) - 2 \times .312 \times .188$$

$$= .665 \text{ in}^2$$

$$P_t = \frac{20000}{.665} = 30,000 \text{ PSI}$$

$$M.S. = \frac{64}{30} - 1 = \underline{+.13}$$

TENSION IN FORK:

$$A_t = .187 \times 1.5 = .28 \text{ in}^2$$

$$P_t = \frac{10000}{.28} = 35800 \text{ PSI (CONSERVATIVE)}$$

$$M.S. = \frac{64}{35.8} - 1 = \underline{+.79}$$

ATTACHMENT TO SWING ARM:

3 - AN5 BOLTS

SAME AS ABOVE

$$MIN \ M.S. = \underline{+.68}$$

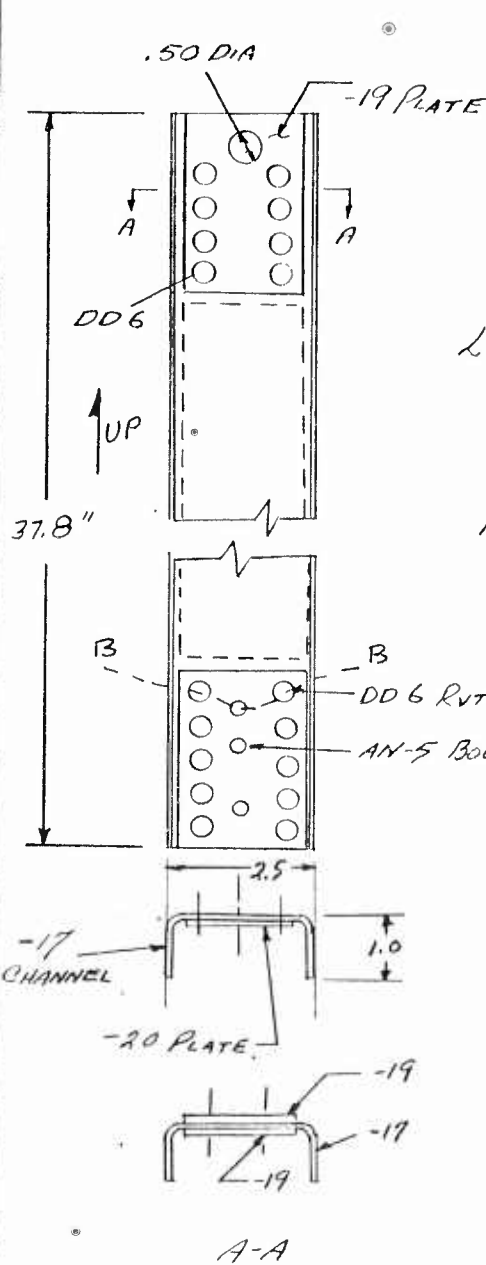
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 MODEL NO. H-21 SWING

243-16 SWING ARM



ARM IS MADE UP OF TWO (2) -16 ASS'YS.

CLAD
 -17 .071 2024-T4 UTS 58 KSI
 -20 .071 D₀
 -19 .071 D₀

LOAD/ASSY = 10^K

LWR BOLTS

$$P_{br} = \frac{10000}{3 \times 2 \times .071 \times .312} = 75,000 \text{ PSI}$$

$$F_{bru} = 112,000 \text{ PSI}$$

$$M.S. = \frac{112}{75} - 1 = +.50$$

LWR RVTs (10 @ DD6)

MUST TRANSFER 5000[#]

$$\frac{5000}{10} = 500 \text{ #/RVT}$$

$$P_{ALL} = 1180 \text{ #} \quad M.S. = \frac{1180}{500} - 1 = +1.36$$

UPPER RVTs (8 @ DD6)

EACH ELEMENT AT A-A (2 @ -19, 1 @ -17) BEARS $\frac{10,000}{3} \approx 3340 \text{ #}$

$$\frac{3340}{8} = 418 \text{ # (BRG LOAD/RVT IN -19)}$$

$$BRG \text{ LOAD/RVT IN -17} = 2 \times 418 = 836 \text{ #}$$

$$M.S._{-17, BRG} = \frac{1192}{836} - 1 = +.43$$

243-16 ARM (CON'T)

UPPER RVTs (CON'T)

$$\text{DOUBLE SHEAR LOAD/RVT} = 836 \#$$

$$P_{ALL} = 1180 \times 2 \times .857 = 2020 \#$$

$$M.S. = \frac{2020}{836} - 1 = \underline{\underline{+1.42}}$$

UPPER BOLT

$$f_{br} = \frac{10000}{3 \times .071 \times .50} = 94000 \text{ PSI}$$

$$M.S. = \frac{112}{94} - 1 = \underline{\underline{+.19}}$$

TENSION IN -17, (THRU RVT HOLES), B-B

$$A_T \approx 4.5 \times .071 - 2 \times .188 \times .071 - .312 \times .071$$

$$\approx .27 \text{ IN}^2$$

$$f_t = \frac{10000}{.27} = 37000 \text{ PSI}$$

$$M.S. = \frac{58}{37} - 1 = \underline{\underline{+.57}}$$

APEX BOLT

AN-8

$$\text{SINGLE SHEAR } P_{ALL} = 14700 \#$$

$$V = 10K$$

$$M.S. = \frac{14.7}{10} - 1 = \underline{\underline{+.47}}$$

REV

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VERTOL DIVISION
BOEING AIRPLANE COMPANY

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MODEL NO. H-21 SWING

243-10 TUBE

1.75 X .058 WALL 4130 STL, UTS = 90^{KSI}

LENGTH = 26" A = .3083 P = .599

P_c (COND 2) = 20^K

$$f_c = \frac{20000}{.3083} = 64800 \text{ PSI}$$

$$4/p = \frac{26}{.599} = 43.5$$

F_c = 66^{KSI} (MIL-HDBK-5, P₉ 57)

$$M.S. = \frac{66}{64.8} - 1 = \underline{\underline{+.02}}$$

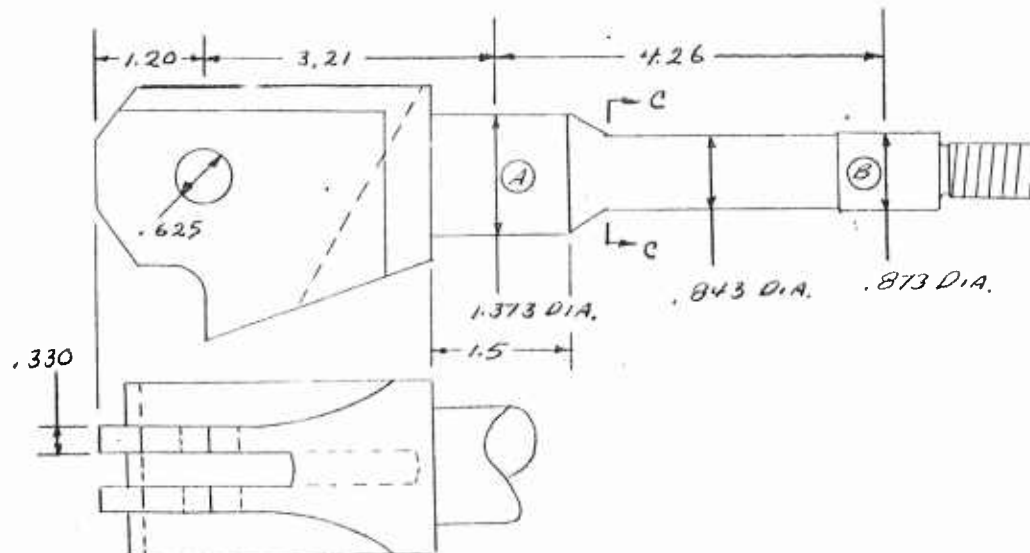
WELD TO 243-6 FITTING TO -10 TUBE

12" OF 3/16 WELD

$$f_s = \frac{20,000}{12 \times .058} = 28900 \text{ PSI}; F_{su} = 55^{\text{KSI}}$$

$$M.S. = \frac{55}{28.9} - 1 = \underline{\underline{+.90}}$$

269-1 FITTING 17-4 PH STL UTS = 180^{KSI}

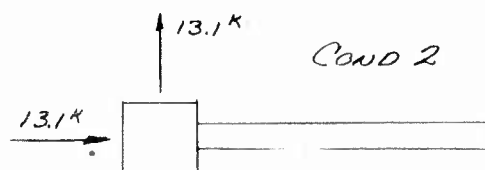
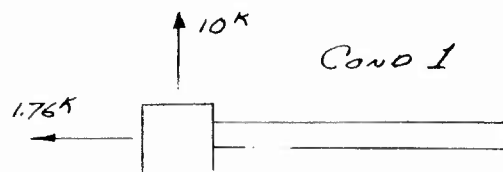


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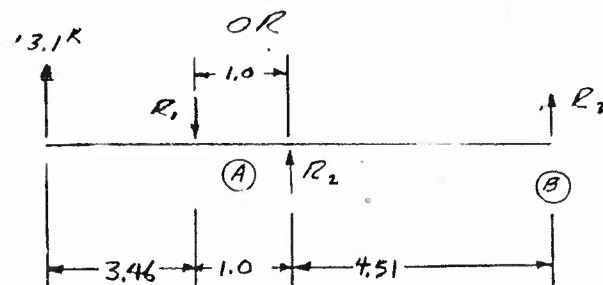
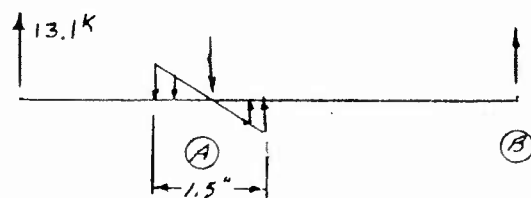
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269-1 Fig (CON'T)



COND 2 IS THE CRITICAL
 CONDITION, BY INSPECTION.

THE APPLIED LOAD IS REACTED BY SOCKET ACTION ACROSS
 THE 1.373 DIA ϕ BY COUPLE ACTION (AT (A) & (B))



I	.174	.025
l	1.0	4.51
$K = \frac{I}{l^3}$	.174	.00555
$C = \frac{K}{\epsilon K}$	.97	.03

REV

269-1 FTG (CON'T)

EXAMINATION OF THE MOMENT DISTRIBUTION FACTORS (C) INDICATE THAT THE APPLIED LOAD IS REACTED ALMOST ENTIRELY AS SOCKET ACTION. IN THE INTERESTS OF STRUCTURAL INTEGRITY, THE FOLLOWING CONSERVATIVE, OVERLAPPING ASSUMPTIONS WILL BE MADE:

- 1) 100% DESIGN LOAD REACTED AS SOCKET ACTION AT (A)
- 2) 33% DESIGN LOAD REACTED AS A COUPLE AT (A) & (B)

PER ASSUMPTION 1)

$$M_{MAX} = 3.21 \times 13.1 \text{ K} = 42 \text{ K}''$$

$$d = 1.373, \quad f_s = \frac{32M}{\pi d^3} = \frac{32 \times 42}{\pi \times 1.373^3} = 164 \text{ KSI}$$

$$N.S. = \frac{180}{164} - 1 = \underline{\underline{+1.10}}$$

SOCKET BEARING PRESSURE

$$p = \frac{13.1 \text{ K}}{1.5''} + \frac{13.1 \text{ K} \times 3.21''}{\frac{1}{2} \times .75 \times \frac{2}{3} \times 1.5} = 8.75 \text{ K/IN} + 112 \text{ K/IN}$$

$$= 120.75 \text{ K/IN}$$

$$f_{br} = \frac{120.75 \text{ K/IN}}{1.373''} = 88 \text{ KSI}$$

$$N.S. = \frac{265}{88} - 1 = \underline{\underline{+2.00}}$$

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269-1 FTG (CON'T)

PER ASSUMPTION 2)

$$M_{c-c} = \frac{.33 \times 13.1^K \times 321''}{4.26''} \times 3.2'' = 10.4^K$$

$$d = .843 \quad f_b = \frac{32 \times 10.4}{\pi \times .843^3} = 177^{KSI}$$

$$M.S. = \frac{180}{177} - 1 = \underline{\underline{+1.02}}$$

LOGS

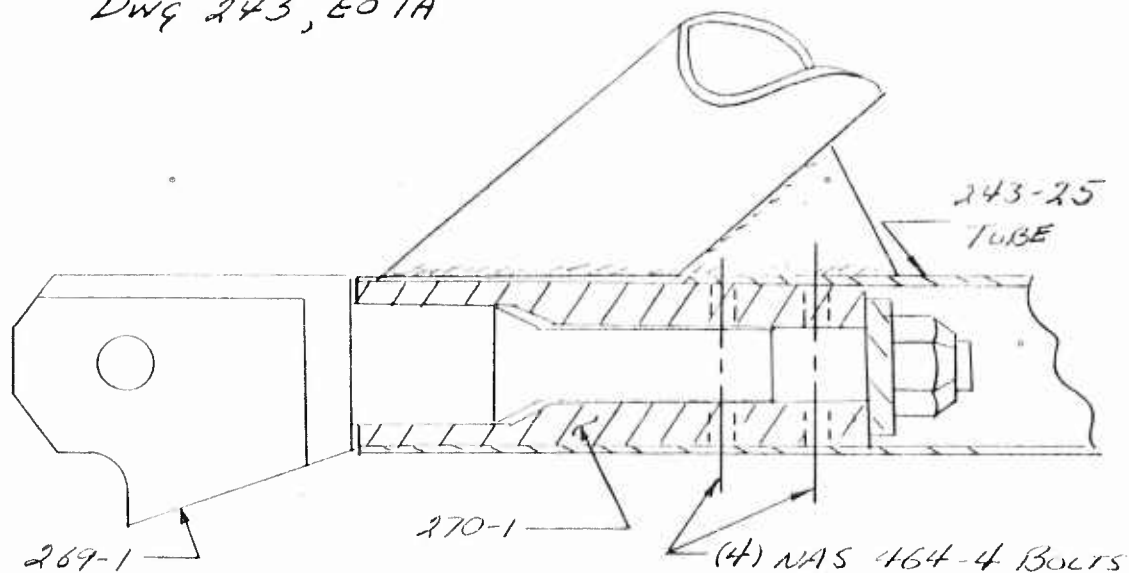
LOGS ARE NOT SUBJECTED TO TENSION LOADS

$$f_{br} = \frac{18.6^K}{2 \times .625 \times .330} = 45^{KSI}$$

NOT CRITICAL

BEAM END ASS'Y

DWG 243, EO 1A



MAX SHEAR ON BOLTS = 13.1^K

$$V/BOLT = \frac{13.1}{8} = 1640^{\#} \quad M.S. = \frac{4650}{1640} - 1 = \underline{\underline{+1.84}}$$

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VERTOL AIRCRAFT CORPORATION

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MODEL NO. *H-21 SCORING*

BEAM END ASS'Y (Cont'd)

Brg on -25 TUBE 4130 STL UTS = 90^{ksi}

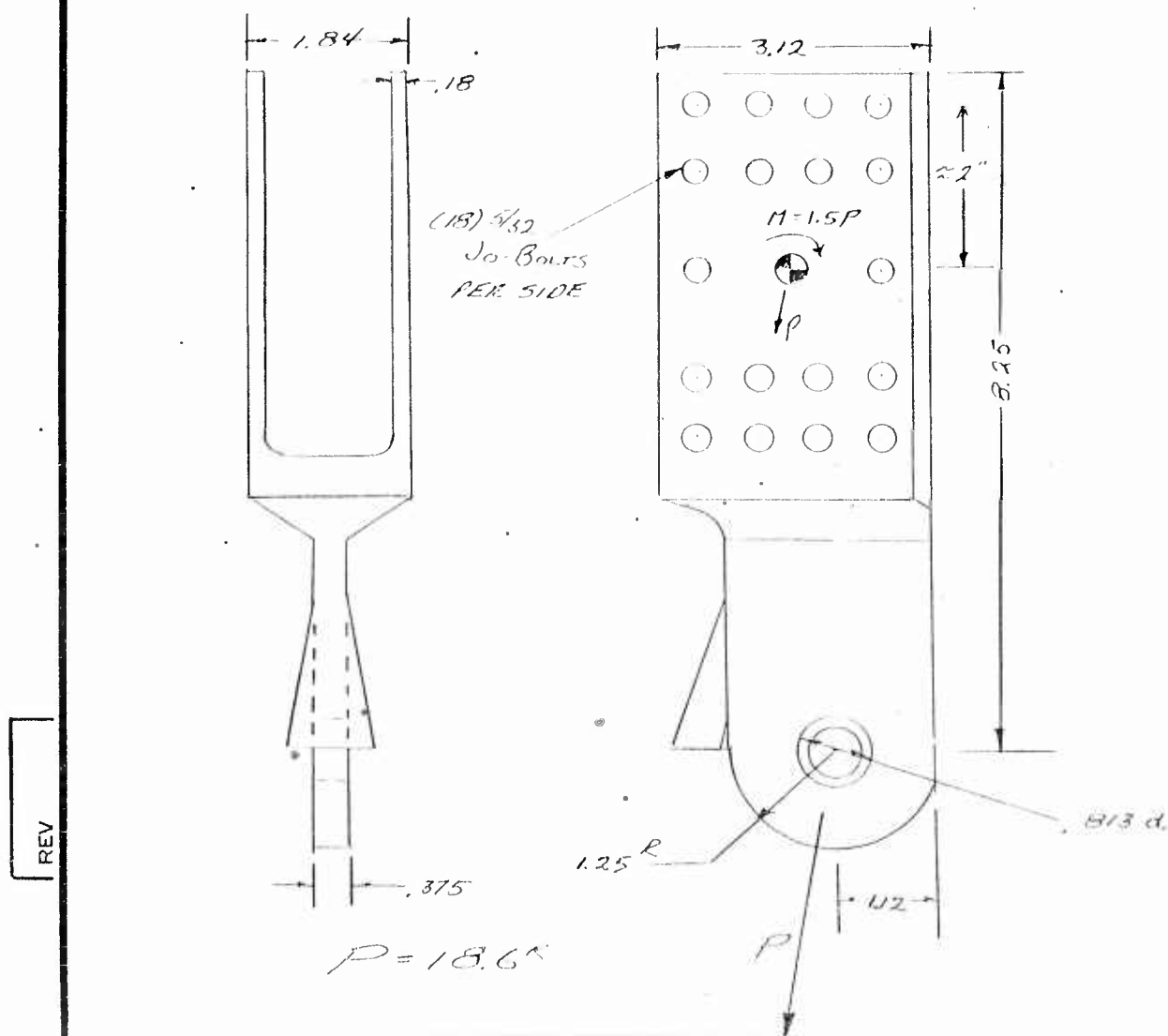
$$t = .062$$

$$f_{br} = \frac{1640}{.35 \times .062} = 106^{ksi}$$

$$M.S. = \frac{140}{106} - 1 = \underline{+ .32}$$

245-9 FITTING

2024-T4 Al Al UTS = 58 ksi



245-9 FTG (Cont)

- ASSUME MOMENT REACTED BY 24 JO-BOLTS @ 2" RAD.

$$P_{\text{MOMENT}} = \frac{18600 \times 1.5''}{24 \times 2''} = 580 \#$$

$$P_{\text{DIRECT}} = \frac{18600}{36} = 520 \#$$

$$P = 580 + 520 = 775 \#$$

$$P_{br} = \frac{775}{.18 \times .156} = 27600 \text{ PSI} \quad \text{NOT CRITICAL}$$

$$P'_s = 1680 \#$$

$$M.S. = \frac{1680}{775} - 1 = \underline{\underline{+1.16}}$$

LUGS

$$\text{LOAD/LUG} = 9.3 \text{ K}$$

$$\text{TENS: } w/D = \frac{2 \times 1.12}{.813} = 2.75 \quad K = .82$$

$$A_T = .375 \times (2.24 \times .813) = .535 \text{ in}^2$$

$$P'_{t_n} = .82 \times .535 \times 58 \text{ KSI} = 25.4 \text{ K}$$

$$\text{SHR-BRG: } w/D = \frac{1.25}{.813} = 1.54 \quad P/t = \frac{.813}{.375} = 2.16$$

$$K = 1.42$$

$$P'_{brn} = 1.42 \times .813 \times .375 \times 58 \text{ KSI} = 25.1 \text{ K}$$

$$M.S. = \frac{25.1}{9.3} - 1 = \underline{\underline{+1.70}}$$

REV

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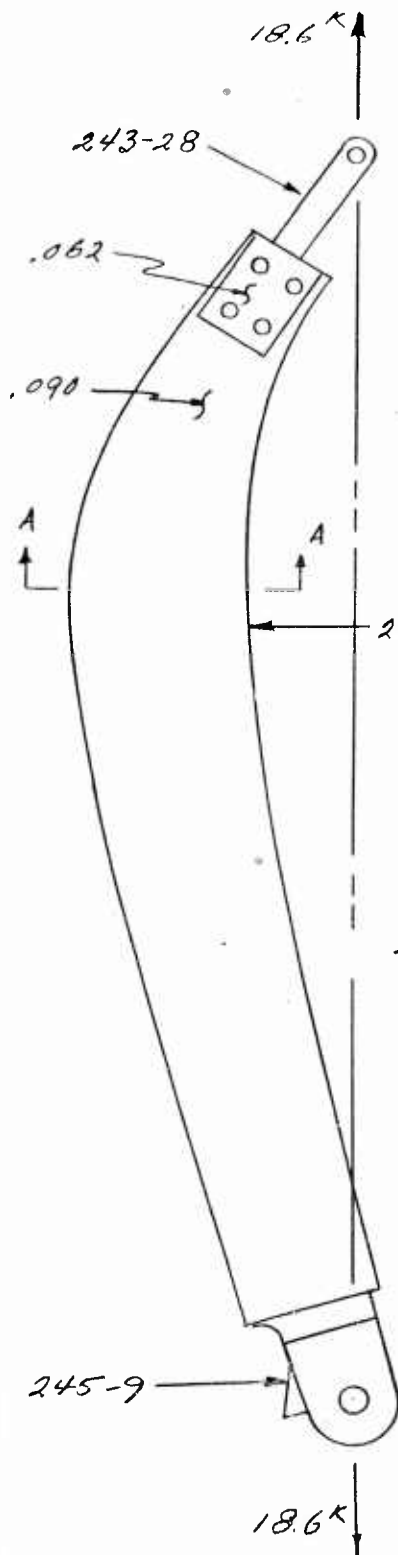
**VERTOL DIVISION
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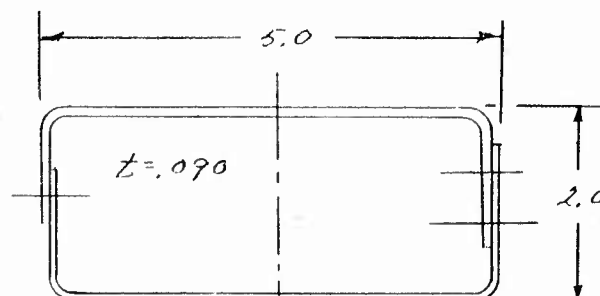
REPORT NO. R-205

MODEL NO. H-21 SWING

244-7 ARM



ALL MTL 2024-T42 ALCLAD
(NEW DESIGNATION FOR OLD
2024-T4 H.T. BY USER)
UTS = 59 KSI



A-A

AT A-A



$$\begin{aligned} T &= 18.6 \text{ K} \\ V &= 0 \\ M &= 100.5 \text{ "K} \end{aligned}$$

SECTION PROPERTIES

	A	Z	AZ	AZ ²	I _o
1	.153	.045	.007	≈ 0	—
2	.450	2.50	1.125	2.820	.937
3	.135	4.955	.670	3.320	—
	<u>.738</u>		<u>1.802</u>	<u>6.140</u>	<u>.937</u>
	$\bar{Z} = 2.44" \quad I_{xx} = 2.677 \text{ in}^4$				

1.4"	③
5.0"	②
1.7"	①

PER ASS'Y

$$A = 1.476 \text{ in}^2 \quad \frac{I}{c} = \frac{2 \times 2.677}{2.44} = 2.19 \text{ in}^3$$

$$\begin{aligned} f_t &= \frac{100.5}{2.19} + \frac{18.6}{1.476} \\ &= 45.9 + 12.6 = 58.5 \text{ KSI} \end{aligned}$$

$$M.S. = \frac{59}{58.5} - 1 = \underline{\underline{+.01}}$$

REV

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VERTOL DIVISION
BOEING AIRPLANE COMPANY

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MODEL NO. H-21 SUMMG

244-7 ARM (CON'T)

IN ITS ORIGINAL DESIGN, THIS ARM WAS CONSTRUCTED OF .081 MTL. SINCE I & A ARE DIRECT FUNCTIONS OF t , THE ALLOWABLE LOAD ON THE ORIGINAL IS

$$5000 \# \times \frac{.081}{.090} \times 1.01 = 4550 \# \text{ CARGO AT } 4g \text{ ULT.}$$

UPPER ATTACHMENTS

(4) AN-5 BOLTS

$$\text{LOAD / SHEAR SURFACE} = \frac{18.6 \#}{2 \times 4} = 2330 \#$$

$$P'_5 = 5750 \#$$

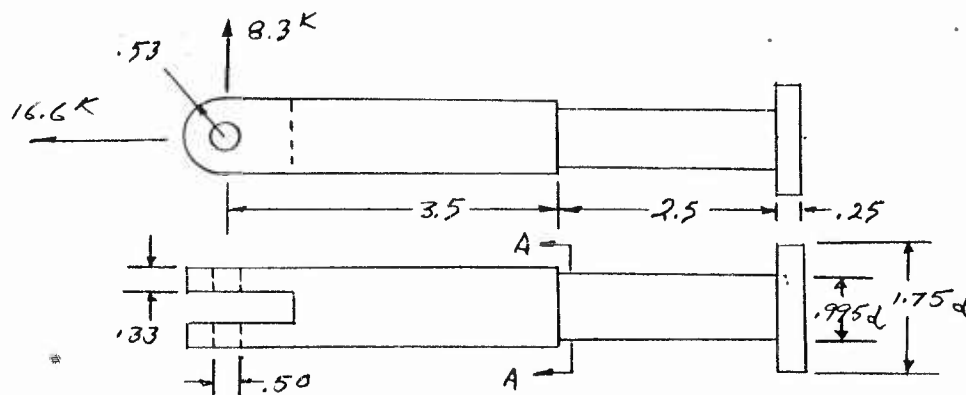
$$M.S. = \frac{5750}{2330} - 1 = \underline{\underline{+1.46}}$$

$$P_{br} = \frac{2330 \#}{.312 (.090 + .062)} = 49 \text{ KSI}$$

$$M.S. = \frac{112}{49} - 1 = \underline{\underline{+1.29}}$$

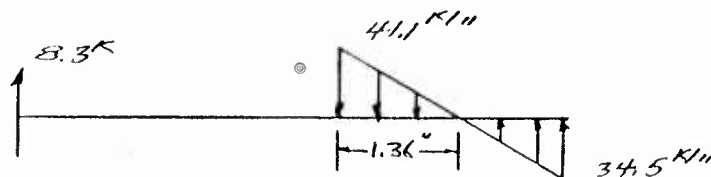
243-28 FITTING

17.4 PH STL UTS = 215 KSI

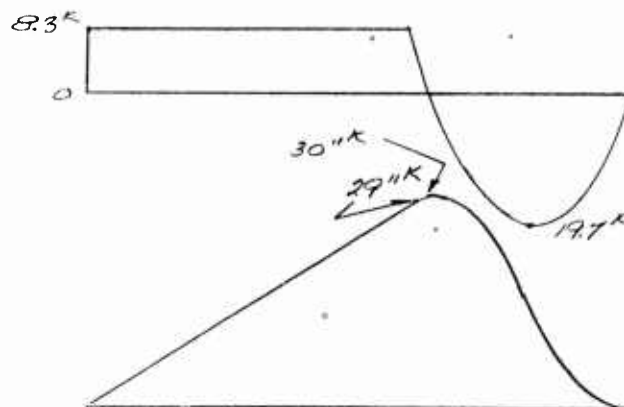


REV

243-28 FTG (CON'T)



LOADING



SHEAR

MOMENT

At A-A:

$$d = .995 \quad f_b = \frac{32M}{\pi d^3} = \frac{32 \times 30}{\pi \times .995^3} = 306 \text{ KSI}$$

$$F_B = 1.7 \times 215 = 365 \text{ KSI}$$

$$R_B = \frac{306}{365} = .84$$

$$f_t = \frac{16.6}{\pi \times .995^2} = 21.2 \text{ KSI}$$

$$F_{T0} = 215 \text{ KSI}$$

$$R_T = \frac{21.2}{215} = .099$$

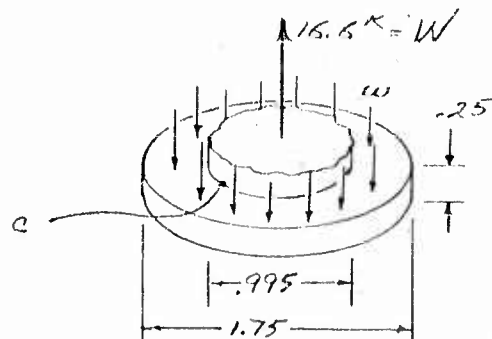
$$R_B + R_T = .939$$

$$M.S. = \frac{1}{.939} - 1 = \underline{\underline{+.065}}$$

REV

243-2B Ftg (Cont)

At "B"



At "C"

$$S = \frac{3w}{4t^2} \left[\frac{4a^2(m+1) \log \frac{a}{b} - a^4(m+3)}{a^2(m+1) + b^2(m-1)} + \frac{b^4(m-1) + 4a^2b^2}{a^2(m+1) + b^2(m-1)} \right] *$$

WHERE:

$$S = \text{STRESS}; w = \frac{W}{\pi(a^2 - b^2)}$$

$$t = .25; a = \frac{1.75}{2}; b = \frac{.995}{2}; m = \frac{\text{POISSON RATIO}}{1} = 3.0$$

SOLN OF THE ABOVE YIELDS

$$S = 144.5 \text{ KSI}$$

$$M.S. = \frac{215}{144.5} - 1 = \underline{\underline{+1.49}}$$

LUGS

$$\text{LOAD} / L_{09} = 9.3K$$

$$\text{TENSION: } w/D = \frac{1.06}{.5} = 2.12 \quad K_T = .96$$

$$P'_{T_0} = .96 \times 215 \text{ KSI} \times .56 \times .33 = 38.2K$$

$$\text{SHR-BRG: } a/D = 1.06 \quad D/t = \frac{.50}{.33} = 1.51 \quad K_{br} = .83$$

$$P'_{br_4} = .83 \times 215 \text{ KSI} \times .33 \times .50 = 29.4K$$

$$M.S. = \frac{29.4}{9.3} - 1 = \underline{\underline{+2.16}}$$

REV

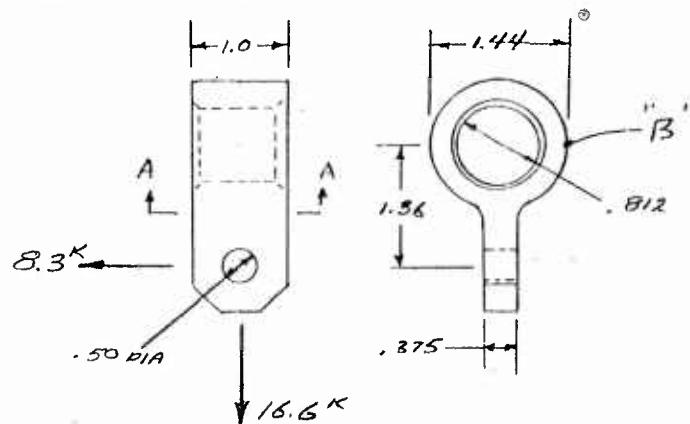
* REF: KOENIG, "FORMULAS FOR STRESS & STRAIN", Pg 100, ITEM 21

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 CHECKED BY:
 DATE: 7/15/60

VERTOL AIRCRAFT CORPORATION

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274-1 FITTING 17-4 PH STL UTS = 180 KSI



LUG TENSION: $w/d = 1/.5 = 2, K_t = .96$

$$P'_{tu} = .96 \times 180 \text{ KSI} \times .5 \times .375 = 32.4 \text{ K}$$

SHR. BRG: $w/d = 1.0, D/t = 1.375 = 1.33, K_{br} = .82$

$$P'_{brg} = .82 \times 180 \text{ KSI} \times .5 \times .375 = 27.8 \text{ K}$$

$$M.S. = \frac{27.8}{18.6} - 1 = \underline{\underline{+.49}}$$

AT A-A

$$M = 8.3 \text{ K} \times .7 = 5.81 \text{ K} \quad T = 16.6 \text{ K}$$

$$f_t = \frac{6 \times 5.81}{.375 \times 1.0^2} + \frac{16.6}{.375 \times 1.0} = 93.0 + 44.4 = 137.4 \text{ KSI}$$

$$M.S. = \frac{180}{137.4} - 1 = \underline{\underline{+.31}}$$

HOOP TENSION AT "B"

$$p = \text{BEARING PRESSURE} = \frac{16.6}{1.0} + \frac{8.3 \times 1.36}{2/3 \times 1.0 \times \frac{1}{2} \times .5} = 84.3 \text{ KSI MAX}$$

$$1.44 - .812 = .628 \text{ "}$$

$$P = p t \quad P = \frac{84.3 \text{ KSI}}{.628 \text{ "}} = 134 \text{ KSI} \quad M.S. = \frac{180}{134} - 1 = \underline{\underline{+.34}}$$

$$A = .628 t$$

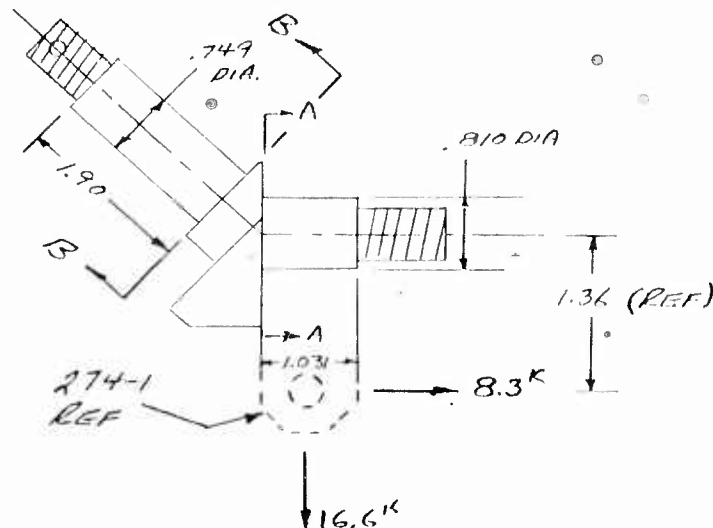
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268-1 FITTING 17-4 PH STL UTS = 190 KSI



FOR SIDE SWAY (COND 2, SHOWN)

AT CENTROID OF A-A

$$M = 1.36 \times 8.3^K - .5 \times 16.6^K = 3.7^K$$

$$T = 8.3^K$$

$$V = 16.6^K \downarrow$$

FOR SYMM (COND 1)

$$M = 1.36 \times 2^K + .5 \times 10^K = 7.72^K$$

$$T = -2^K \text{ (COMP)}$$

$$V = 10^K \downarrow$$

BOTH CONDITIONS WILL BE INVESTIGATED.

$$A = \frac{\pi d^2}{4} = \frac{\pi \times .810^2}{4} = .515 \text{ in}^2; f = \frac{P}{A} = 1.96 P$$

$$f_b = \frac{32M}{\pi d^3} = \frac{32M}{\pi \times .81^3} = 15.5 M$$

REV

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VERTOL DIVISION
 BOEING AIRPLANE COMPANY

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26B-1 FTG (CON'T)

COND 1

$$\left. \begin{aligned} f_b &= 15.5 \times 7.72''^K = 120^{KSI} \\ f_t &= 1.96 \times 2^K = 3.92^{KSI} \end{aligned} \right\} R_T = \frac{123.92}{190} = .652$$

$$f_s = 1.96 \times 10^K = 19.6^{KSI} \quad R_s = \frac{19.6}{120} = .163$$

$$R_T + R_s = .672$$

COND 2

$$\left. \begin{aligned} f_b &= 15.5 \times 3.7''^K = 57.4^{KSI} \\ f_t &= 1.96 \times 8.3^K = 16.3^{KSI} \end{aligned} \right\} R_T = \frac{73.7}{190} = .388$$

$$f_s = 1.96 \times 16.6^K = 32.5^{KSI} \quad R_s = \frac{32.5}{120} = .271$$

$$R_T + R_s = .474$$

$$M.S. (COND 1) = \frac{1}{.672} - 1 = \underline{\underline{+.49}}$$

AT B-B

COND 1

$$M = 10.1^K \times 1.21 = 12.2''^K$$

$$T = 5.4^K$$

$$V = 8.4^K$$

COND 2

$$M = 0$$

$$T = 17.4^K$$

$$V = 6.4^K$$

$$d = .749$$

$$f = \frac{P}{A} = \frac{4P}{\pi d^2} = 2.27P$$

$$f_b = \frac{32M}{\pi d^3} = 14.2M$$

REV

268-1 FTG (CON'T)

COND I IS CRITICAL BY INSPECTION

$$f_b = 24.2 \times 12.2''^K = 295^{KSI} \quad R_B = \frac{295}{321} = .920$$

$$f_t = 2.27 \times 5.4''^K = 12.3^{KSI} \quad R_T = \frac{12.3}{190} = .065$$

$$f_s = 2.27 \times 8.4''^K = 19.1^{KSI} \quad R_S = \frac{19.1}{120} = .159$$

$$(R_B + R_T) + R_S = .996$$

$$M.S. = \frac{1}{.996} - 1 = \underline{\underline{+.003}}$$

YIELD ANALYSIS OF THE ABOVE

$$f_{by} = \frac{295}{1.5} = 196.5^{KSI} \quad R_B = \frac{196.5}{216} = .910$$

$$f_{ty} = \frac{12.3}{1.5} = 8.2^{KSI} \quad R_T = \frac{8.2}{170} = .048$$

$$f_{sy} = \frac{19.1}{1.5} = 12.7^{KSI} \quad R_S = \frac{12.7}{107} = .119$$

$$(R_B + R_T) + R_S = .966$$

$$M.S. \text{ YIELD} = \frac{1}{.966} - 1 = \underline{\underline{+.035}}$$

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