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# A REVIEW

OF THE

# MAINTENANCE AND RELIABILITY ASPECTS

OF THE

# ARROW CONTROL SURFACE AND TRAILING EDGE COMPONENTS

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# 1.0 ABSTRACT

## 1.1 INTRODUCTION

The purpose of this report is to present a complete review of the Design and Manufacturing philosophy of the ARROW control surfaces and control boxes and the effect of this philosophy on the probable field maintenance, overhaul and inspection operations required for these components of the aircraft.

The main criticism of the design of the control surfaces and the control boxes from the maintenance point of view, is that of very limited access to the control linkages as installed in the control boxes.

In the case of the elevator control boxes, the bottom skin may be removed to permit the removal of the control mechanism. However, in the case of the aileron and rudder control boxes, the components must be removed from the aircraft to permit removal of the control mechanisms through the forward end of the box.

Since it appeared advantageous to be able to replace a "time-expired" control box with an overhauled spare component, interchangeability became an important consideration.

The criticism of the manufacturing methods employed in the assembly and installation of the control boxes, is based on the inability to guarantee interchangeability of these components.

It was felt that the best plan for reducing servicing problems was the establishment of an extensive development testing program to ensure that the reliability of the control mechanism would be such that complete removal of the control boxes would only be necessary at major overhaul periods.

This report is divided into various chapters describing the Design Consideration, Manufacturing Considerations, Functional Test Programs and the Maintenance Considerations.

## 1.2 CONCLUSIONS

To date, the test program has not reached the point where it can guarantee that the control mechanisms have sufficient reliability to preclude the removal of the control boxes for frequent periodic inspection. However, it is planned to continue the functional test program so that the equivalent flying hours attained on the B-1 rig will be far in advance of those reached by the aircraft during the development flying program.

During the flight development program, it is recommended that the control boxes be removed and components inspected at 50 hour intervals. This period will be extended when reliability is proven by the functional test and development flying programs.

This report includes all information pertaining to the ground servicing of the control boxes, including a time study and description of the control box removal procedure, a preliminary inspection schedule and a list of the required ground support equipment.

## 2.0 INTRODUCTION

The purpose of this report is to present a complete review of the Design and Manufacturing philosophy of the ARROW control surfaces and control boxes and the effect of this philosophy on the probable field maintenance, overhaul and inspection operations required for these components of the aircraft.

The control boxes, or wing and fin trailing edges as they are sometimes referred to, house the control linkage between the control surfaces and their hydraulic control jacks. This linkage consists of push-pull rods, connected to the control jacks and to bellcranks which in turn are connected by push-pull rods to the control surface.

The control boxes are attached to the rear spar of the wing torsion box and the fin torsion box by large numbers of bolts. Access holes are provided in the skins of the aileron and rudder boxes, for bearing lubrication and removal of the bellcrank pivot bolts. These holes vary from 1/2" diameter to 2-1/2" diameter. In the case of the elevator box, 2-3/4" diameter holes are provided and the bottom skin may be removed by unscrewing 480-1/4" diameter bolts. Access is, therefore, provided to the control mechanism in the elevator box by removing the bottom skin after which the complete linkage mechanism may be removed for inspection. In the case of the rudder or aileron linkage, the complete box must be removed from the aircraft and the linkage mechanisms may then be removed through the open forward end of the box.

The considerations which led to the design of this type of structure are described in detail in Chapter 3.0. The main criticism of this design from the maintenance point of view is that of very limited access to the control linkages as installed in the aircraft. This is the direct result of the need to bury a very strong and stiff linkage within the confines of a very thin and aerodynamically clean wing. The extremely high loads that must be transmitted by the control box structures prevent the provision of adequately sized access doors in the skins. It is felt that the best plan for reducing servicing problems is the establishment of an extensive development testing program to ensure that the reliability of the linkage systems is such that complete removal of the control boxes will only be necessary at major overhaul periods. A detailed description of the proposed functional test program and the results to date are described in Chapter 5.0.

Since the reliability of the control linkages including bearings could not be firmly established during the early stages of design and since access could not be provided for complete inspection, it was considered likely that the control boxes would have to be removed at predetermined intervals for inspection of the linkages and overhaul and replacement if necessary. Thus, the question of interchangeability became important. The problems associated with achieving interchangeability of the control boxes are described in some detail in Chapter 4.

It was proposed to replace a time expired control box with an overhauled control box, to save aircraft ground time. In order to determine the actual time and manpower involved in replacing the control boxes, a special time and motion test was conducted on the metal mockup of the ARROW. The details of this test are described in Chapter 5 section 5.2.

The proposed Maintenance Instructions for the control boxes are based on facts that are presently available from the Company's test program and manufacturing methods. This maintenance philosophy is described in detail in Chapter 6.0.

# 3.0 DESIGN CONSIDERATIONS

## 3.1 DESIGN OBJECTIVES

The following were the main design objectives that established most of the important parameters affecting the detail design of the output linkages for the aileron, elevator and rudder.

(a) That the system be enclosed within the aerofoil contour as far as possible.

(b) That the system be as simple and reliable as possible.

(c) That the system handle the design loads with the minimum possible weight.

The design difficulties encountered stemmed principally from the very large loads involved and the small space available.

Elevator

The design limit hinge moment is 60,000 ft/lb per elevator.

The depth of the aerofoil is 4.72 inches at the elevator hinge line and 6.41 inches at the rear spar of the wing torque box.

Aileron

The design limit hinge moment is 25,000 ft/lb per aileron.

The total depth of the aerofoil at the hinge line is 4.66 inches (root) and 1.397 inches (tip)

The depth of the aerofoil at the rear spar of the wing torque box is 5.97 inches (root) 1.815 inches (tip)

Rudder

The design limit hinge moment is 15,000 ft/lb.

The depth of the aerofoil at the hinge line is 4.87 inches (root) 3.86 inches (tip)

The depth of the aerofoil at the rear spar of the fin torque box is 5.89 inches (root) 5.1 inches (tip)

The aerofoil depths were of course determined by the t/c ratio of 3.5% on the wing and 4% on the fin, which are necessary to enable the aircraft specification performance to be obtained. The large control surface hinge moments are necessary to meet the aircraft specification control and manoeuvreability requirements.

## 3.2 POSSIBLE SOLUTIONS

To meet objectives (a) it was obviously necessary to operate each surface by applying loads at a number of span wise points in order to get each unit of the operating linkage mechanism of small enough size to fit within the wing contour. To meet objective (b) a single actuator was favoured to reduce hydraulic complication, and a simple mechanical linkage to distribute the operating force to a large number of points, was desirable. Keeping the number of hydraulic and mechanical parts to a minimum seemed also the best way of achieving objective (c).

Only one solution, that of using a single actuator operating through a simple bellcrank linkage, for each control surface seemed to meet all the necessary objectives.

The solution adopted naturally took slightly different forms for the three control surfaces due to the different nature of the surrounding structures.

3.2.1 ELEVATOR

Due to the shallow wing structure and the desire to stay within the wing contour, a piano hinge was adopted in order to obtain the maximum possible moment arm. Even under these conditions, the limit operating load at the elevator at maximum hinge moment, elevator up, is 256,000 lb. This load is divided more or less equally among six operating linkages. The continuous hinge is of advantage here since it does an efficient job of distributing this high chordwise load fairly evenly along the full span of the elevator and from there into the wing structure. The limit load on the hydraulic actuator, for the same condition, is 71,470 lb. These very high chordwise and spanwise loads must be carried by the control box structure and from there, distributed into the main torque box of the wing structure which contains the main portion of the integral fuel tank. In addition, the very large chordwise bending moments associated with the larger elevator deflections have to be transmitted to the main wing torque box through the bolted joint at the wing rear spar.

In the interest of weight saving and also to prevent high local distortions from causing fuel tank leaks, the control box attachment to the wing was made virtually continuous by the use of large numbers of small bolts. It was recognized that this introduced fundamental difficulties in achieving interchangeability and it may be of interest to briefly examine the implications of changing to fewer local attachments.

The chordwise loads at the rear spar joint between the torque box and elevator control box are about 3700 lb. per inch of span. Assuming ribs at about 8 inch pitch attached to the torque box by tension bolts, a load of 29,500 lb. in each rib cap would result. Since the bolts must be inside the wing contour, a 5/8 inch diameter tension bolt at each rib cap would be required. A rib cap of about one square inch cross section with ends enlarged to take the tension bolt would be required. A back-up structure of similar proportions to take the loads from each rib would have to be added to the main torque box structure. The spanwise jack load would also have to be reacted, either by means of a heavy local structure or by continuous attachment to the torque box rear spar. Due to local loads at lever attachments, and the need to prevent skin buckling, it is doubtful if the control box skin gauge could be reduced very much and it would still have to be attached to the rear spar. It would therefore appear that fewer attachments between the control box and the wing would only lead to a heavier structure.

In the early stages of design, the possibility of excessive wear on the piano hinge was recognized and a test was carried out to check this. A hinge was oscillated under loads producing bearing stresses equivalent to those obtained on the ARROW elevator, and acceptable rates of wear were achieved.

A careful study of available bearings was made and self-aligning roller bearings were chosen, which are now installed in the system. At the same time an extensive bearing evaluation program was put under way and this is still continuing. Comparative evaluation of various types of bearings is carried out on a machine designed for this purpose and the performance of the bearings initially selected is checked on the flying controls test rig under conditions which duplicate service life as closely as possible.

All bearings in the elevator system can be lubricated in situ after removal of small access doors. The various items of the control system, with the exception of the spanwise push rod, can be removed for inspection and maintenance by removing the lower skin of the elevator control box. The elevator is removable by un-bolting the front portion of the piano hinge from the control box and is interchangeable by using the old front portion of the hinge in conjunction with a new elevator. This, of course, involves removal and replacement of the hinge pin after the elevator assembly has been removed from the wing.

3.2.2. AILERON

The average depth of the wing structure in this area is far less than for the elevator and although the loads are lower, the space problem was far more critical. A piano hinge was again adopted to obtain maximum moment arm; even so, for the ~~four~~ FIVE outboard operating links it was impossible to keep all the mechanism within the aerofoil contour. External fairings cover these ~~four~~ FIVE links. The total limit operating load on the aileron is 149,580 lb. which is divided unequally between seven operating links. The limit load in the hydraulic actuator for the same condition is 38,800 lb.

The transmission of these loads into the outer wing main torque box was again achieved by distributed loading, for reasons of structural efficiency. The ultimate chordwise loads at the rear spar of the torque box vary from about 4,000 lb. per inch of span to a peak value of about 4,500 lb. per inch. Because of the very sharp taper on the outer wing structure, it is necessary to use the aileron control box to contribute to the wing torsional stiffness for a good proportion of the outer wing span. To meet the exacting torsional stiffness requirements demanded by the high design speeds it was necessary to use both torque boxes as efficiently as possible. This made a continuous attachment of control box to rear spar absolutely mandatory.

As in the case of the elevator, access doors are provided for lubrication of all bearings, but a removable skin panel could not be incorporated. In some regions, space was so critical that anchor nuts could not be used and the crowded conditions would have made it impossible to do useful maintenance or inspection even if a skin panel were detached. The entire control box must therefore be removed in order to get at the control linkage. The aileron is interchangeable by means of removal of the piano hinge pin. This is achieved by spinning the pin in or out at the wing tip.

The testing of the various units of the control linkage is being handled in the same way as for the elevator controls. The aileron system will be added to the flying controls test rig for environmental testing.

### 3.2.3 RUDDER

In the case of the rudder control box, the loads are relatively lower and considerable more space exists for the installation of the control linkage.

There are five separate hinges, one at each of the five operating links. A needle bearing is used in each hinge. Otherwise, the control linkage is similar in design to that used on the elevator and aileron. The total limit operating load at the rudder is 82,000 lb. which is divided among the five operating links and the load in the hydraulic actuator is 30,200 lb. The control box is attached to the rear spar of the fin in a similar manner to that employed for the elevator and aileron control boxes with the exception that spigots are used to transmit rib shear loads. As in the case of the outer wing, the rudder control box must be used to assist in providing bending and torsional strength and stiffness to the fin. This necessitates continuous attachments to provide a structurally economical joint, especially at the base of the fin where the loads are very high.

The bearings in the control linkage can be lubricated through access openings in the skin panels but, as with the aileron, the control box must be removed from the fin in order to remove any of the control linkage parts. The rudder is removable by pulling out the hinge pins and control link pins and is an interchangeable assembly.

# 4.0 MANUFACTURING CONSIDERATIONS

## 4.1 INTERCHANGEABILITY

During the development of a new aircraft, it is customery to achieve interchangeability after the initial manufacturing problems have been resolved. At some point during the early production program, it is usually possible to establish that all major components are interchangeable. Where permanent type tooling is used, it is possible to achieve main component interchangeability on the first aircraft.

On the CF-100 program, for example, interchangeability was established and proven on the first ten aircraft. On the ARROW program, planning for interchangeability was started early and the view was held that it would be achieved on the first aircraft. The complexity and difficulties only became known in detail at a later date.

At meetings held in February and April 1955 between Avro Aircraft and the Royal Canadian Air Force, it was agreed that full specifications requirements regarding interchangeability were not expected on the first aircraft and that the development program must take precedence over interchangeability when there was a conflict of interest, providing the Royal Canadian Air Force was satisfied that the interests of interchangeability had been fully examined. In certain areas, proof of interchangeability can only be ascertained by demonstration and this requires two aircraft with spare components.

Interchangeability of control boxes became increasingly important when it was felt that these components might have to be removed quite frequently due to the lack of access to the control linkages.

## 4.2 DEFINITION OF INTERCHANGEABILITY AND REPLACEABILITY

### (a) Interchangeability

Interchangeable assemblies, components and parts shall be capable of being readily installed, removed or replaced without alteration, misalignment or damage to parts being installed on adjoining parts. No fabricating operations such as cutting, drilling, reaming, hammering, bending, prying, or forcing shall be required. Only those tools generally available to aircraft mechanics shall be required for installation procedure. This is not intended to preclude the use of special tools, fixtures and other shop aids during original assembly of the parts into the article. All check installations of equipment shall provide for the maximum outline-dimensional requirements of the particular equipment involved, as set forth in the applicable specifications or drawings. Jacking or other force applications using conventional equipment is allowable only to the extent necessary to position components for installation and shall not be used for forcing alignment when such forcing causes permanent deformation or distortion, or tearing, shearing, bending, or harm to the parts being checked or installed or to any matching parts or other parts of the component assembly or article upon which physical check for fit is being conducted. When assemblies contain controls, wiring, hydraulic lines, etc., interchangeability shall be provided at the attachments of these items to their next assembly as well as for the structural attachments of the assembly.

Controlled items, if detachable, shall have interchangeability with respect to any equivalent item conforming to the engineering data, information and other control media established by the prime design contractor.

(b) Replaceability

Replaceability applies to parts, the installation of which may require work or operations additional to the application of the attaching means. In general such operations include drilling, reaming, cutting, filing, trimming, shimming or other means normally associated with original assembly into the aircraft. Many instances may require match drilling or reaming from the original part or portion of the item. Replaceable parts shall be designed to permit replacement under field maintenance conditions.

4.3 INTERCHANGEABILITY OF CONTROL SURFACE AND CONTROL BOXES

Production Engineering have reviewed the planning and tooling of the control surfaces and control boxes in conjunction with the interchangeability problem. The following table depicts the interchangeability status of the components in question at the present time.

| ITEM | INTERCHANGEABLE | REPLACEABLE |
|---|---|---|
| Elevator Control Surface | x | |
| Elevator Control Box | x (*) | |
| Aileron Control Surface | x | |
| Aileron Control Box | x (*) | |
| Rudder Control Surface | x | |
| Rudder Control Box | x (*) | |

NOTE - Items marked * are still in doubt, pending interchangeability trials.

## 4.4 PROBLEMS IN ACHIEVING INTERCHANGEABILITY

The control boxes are attached to the rear spars of the main surfaces by means of large numbers of bolts. In the case of the aileron box, 400-1/4 inch diameter bolts are employed; for the rudder, 372-3/16 inch diameter bolts; for the elevator 400-1/4 inch diameter bolts.

The allowable design hole tolerance is ± .002 inch while the minimum manufacturing build tolerance is approximately ± .0075 inch.

A certain amount of difficulty is anticipated in maintaining the proper angular match at the mating surface.

All the control boxes will be drilled together with their mating structures "in situ" using a clam shell type drill jig locating on the control box hinge.

Figure I shows the fin assembly jig with the space provided for the later installation of the rudder control box. Figure 2 shows the holding jig in which the fin is mounted while the rudder control box is being installed. The rudder control box is mounted in the clam shell drill jig and moved under the fin and lifted into position. The attachment holes in the control box and the fin are drilled together.

In principle, the same procedure is used for drilling off the attachment holes for the aileron and elevator control boxes.

The same jigs will be used to drill spare components full size on the attachment holes concerned. Spare components would be shipped with all attachment holes drilled to full size. On assembly of a spare box, the procedure would be to fit the box to the aircraft with as many nominal sized bolts as possible. Any holes not within tolerance would then be reamed through control box skin and spar 1/64 (.015 inch) oversize. Permission has been granted by the design department to open holes from nominal, 3 times (.015 inch each time).

This would mean that 2 additional control boxes could be fitted to any one aircraft, assuming Avro used the first oversize stage on a small percentage of holes during manufacturing. Special bolts would be required and would consist of a special oversized shank with a standard thread and countersunk head, so that the original skin countersinks and anchor nuts could be used.

It should be noted that any control box, once installed on an aircraft, can be removed for inspection and for servicing of the control linkage and replaced without opening up the attachment holes.

In the case of the elevator control box, a .020 inch shim allowance has been granted from the design office, between the control box rib face and spar attachment angle. This shim allowance should greatly assist in aligning spar attachment holes on spare components.

In the case of the aileron box, a .020 inch shim allowance has been granted for the spar attachment angle to closing rib between aileron and elevator. This shim allowance will allow a greater percentage of holes to line up without using oversize bolts.

The joint between the aileron and elevator control boxes occurs at the aileron inboard rib. This joint has received special attention from an interchangeability standpoint. It was recommended that a spare aileron control box be supplied complete with a separate spare inboard rib. The inboard flange of the rib would be left blank and drilled on assembly.

The following circumstances are listed as affecting the interchangeability of the aileron control box inboard rib:

4.4.1 REPLACEMENT OF AN OUTER WING (Refer to Figure 3)

In order to replace an outer wing, the elevator control box must be removed to provide access for reaming the rear spar joint attachment holes.

The replacement outer wing will be provided with an aileron control box in the following conditions:

(a) The aileron control box will contain the inboard rib. The top and bottom flange of the rib will be left blank so that the holes may be located and drilled from drill jig. 7-4200-1-DJ-38/39 to match the hole pattern in the elevator control box.

(b) The holes in the end rib which pick up the angle attaching the elevator hinge spar to the end rib will be left blank. The holes will be located and drilled off from the angle on the elevator hinge spar when the outer wing is installed.

(c) The top and bottom spar flanges of the outer wing rear spar, inboard of the aileron control box, will be left blank to permit the locating and drilling of the holes from drill jig 7-4200-1-DJ-38/39 to match the hole pattern in the elevator control box. When the elevator control box is installed on the wing, the holes will be checked for alignment. If the holes do not line up, they may be drilled 1/64 inch oversize. An allowance of .030 inch for trimming has been made on the aileron control box access door and the filler strip in order to maintain the correct skin gap on assembly.

4.4.2 <u>REPLACEMENT OF AN AILERON CONTROL BOX</u>

There are two methods of replacing an aileron control box:

The aileron control box could be supplied complete with the inboard rib,

OR

The aileron control box could be supplied without the inboard rib. (The inboard rib might be left installed on the outboard end of the elevator control box).

Each possibility is now discussed in detail.

4.4.2.1

If the aileron control box is provided complete with the inboard rib, the rib will be in the following condition:

(a) The outer wing spar attachment angle will be left blank and the attachment holes will be located and drilled from the wing spar.

(b) The top and bottom flange of the inboard rib will be left blank and located and drilled from drill jig 7-4200-1-AJ-38/39.

(c) The holes in the inboard rib aileron hinge spar attachment angle which line up with the elevator hinge spar attachment angle are left blank. These will be located and drilled from the elevator hinge spar attachment angle when the elevator control box is installed.

4.4.2.2

If the aileron control box is supplied without the inboard rib, the control box will be in the following condition:

(a) The holes in the control box skin, where it is attached to the inboard rib, will be drilled full size. They may be opened up 1/64 inch if there is any misalignment.

(b) The holes in the flange of the intercostal where it is attached to the inboard rib will be drilled full size.

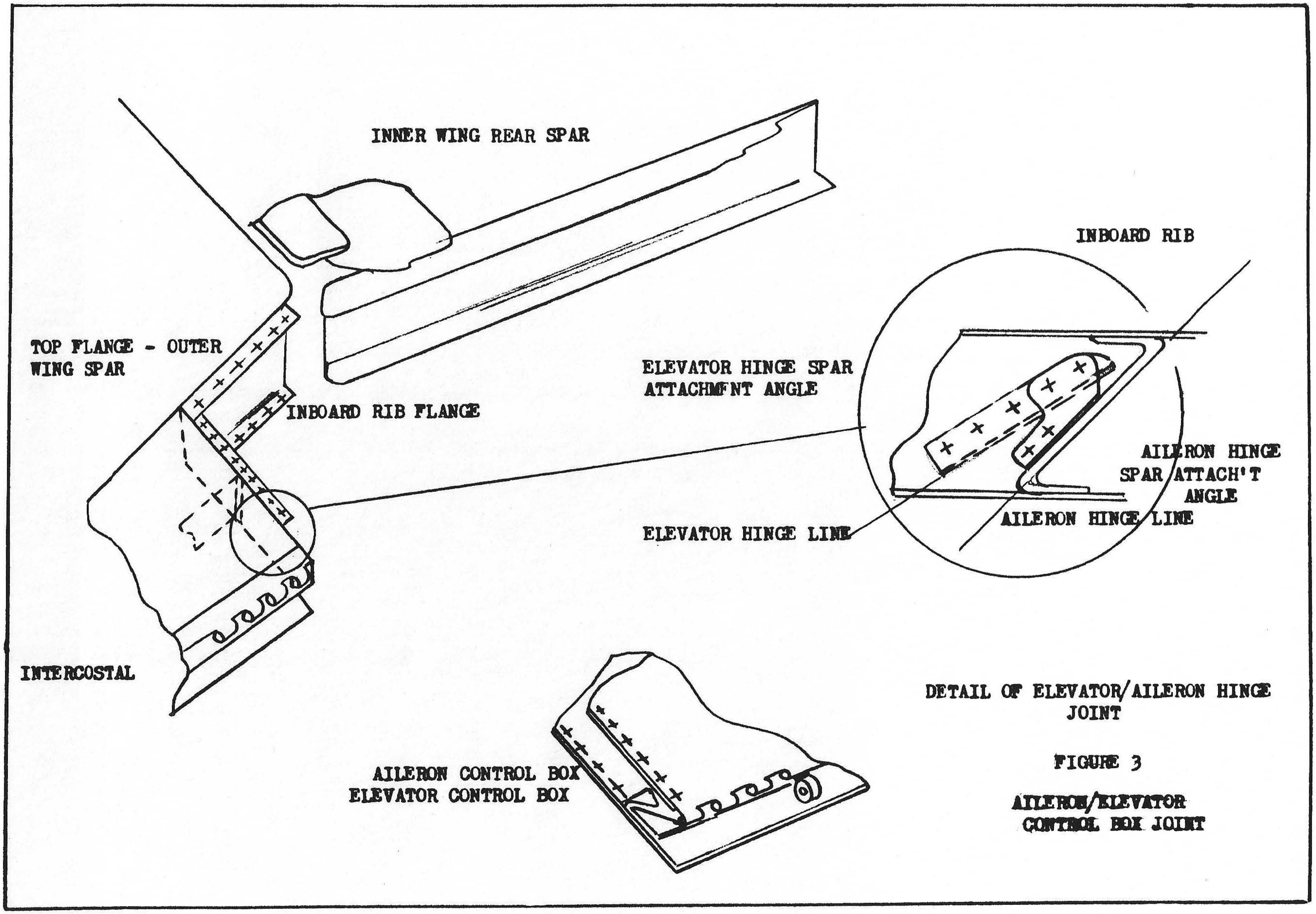
(c) The holes in the aileron hinge spar attachment angle where it picks up the inboard rib and elevator hinge spar attachment angle will be left blank. The holes will be located and drilled from the elevator hinge spar attachment angle.

(d) The holes in the aileron hinge spar attachment angle which attach the angle to the end rib will be drilled full size.

4.4.2.3 Replacement of An Elevator Control Box

The replacement elevator control box will be offered up to the wing and the attachment holes checked for alignment. The attachment holes in the elevator control box will be full size and if they do not line up properly with the aileron control box inboard rib, the rib should be replaced in order to permit the maximum number of changes of the elevator control box.

The attachment angle between the elevator hinge spar and the aileron control box inboard rib will be left blank and the holes will be located and drilled from the aileron control box inboard rib.




DETAIL OF ELEVATOR/AILERON HINGE JOINT

FIGURE 3

AILERON/ELEVATOR CONTROL BOX JOINT

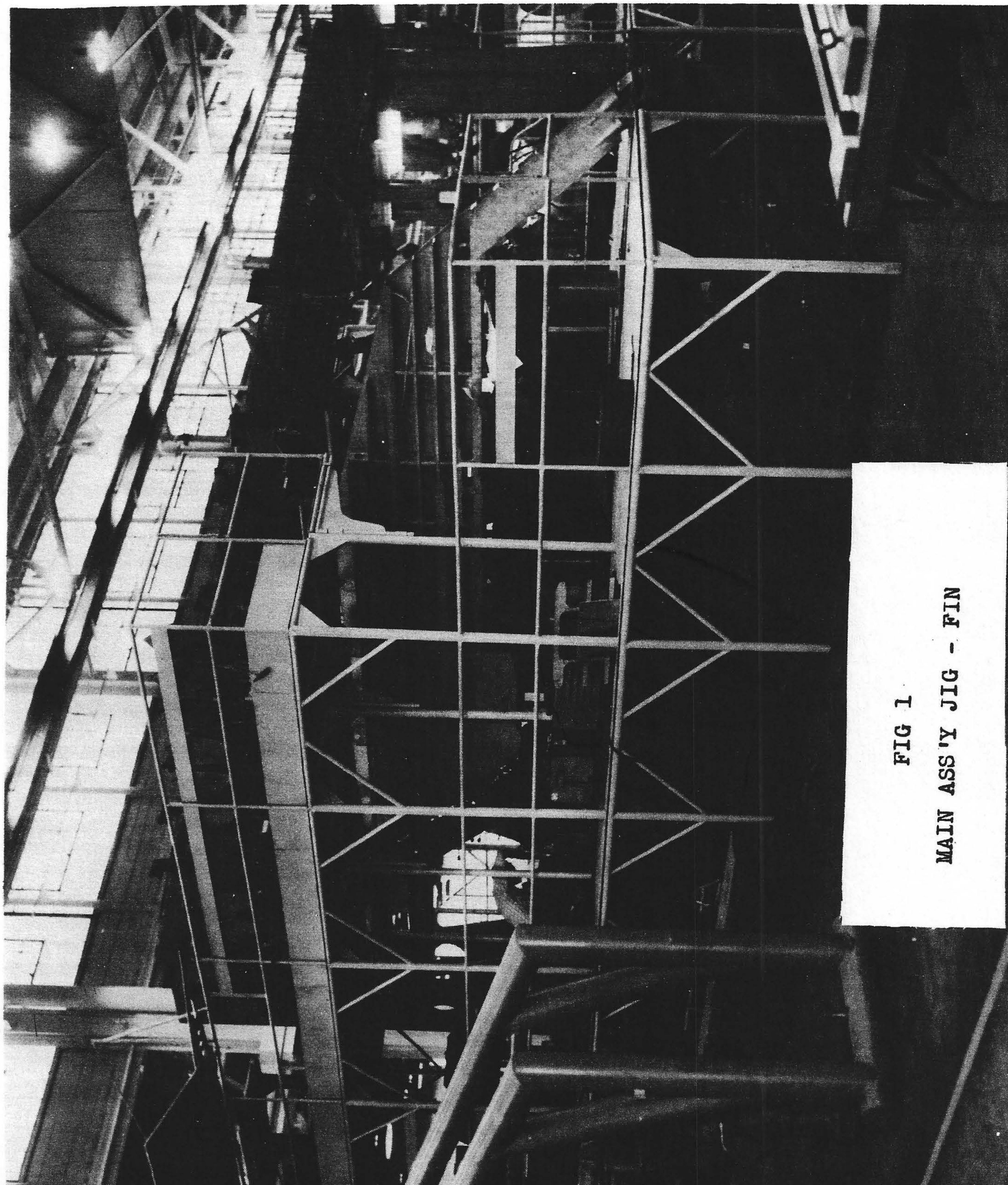


FIG 1

MAIN ASS'Y JIG - FIN

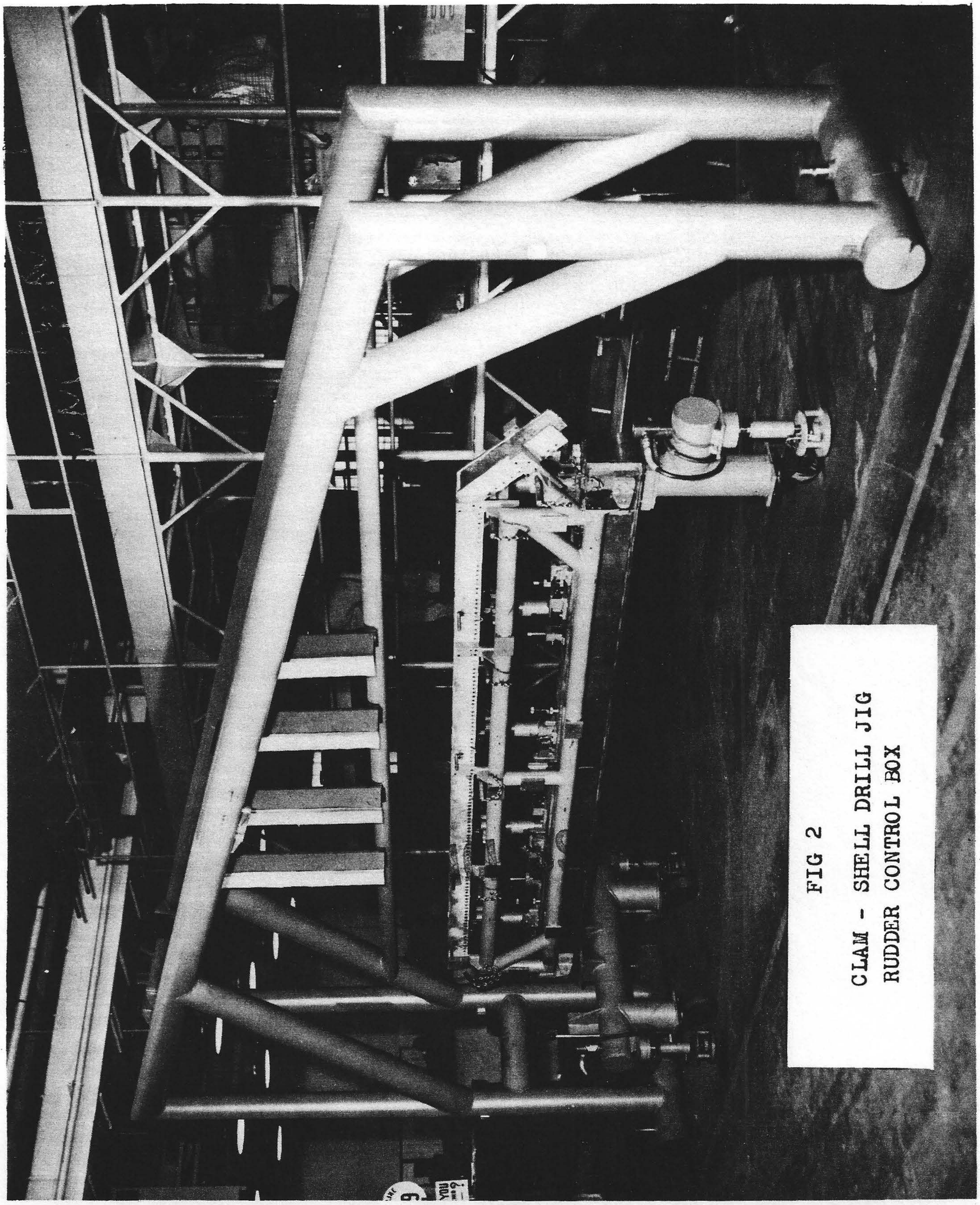
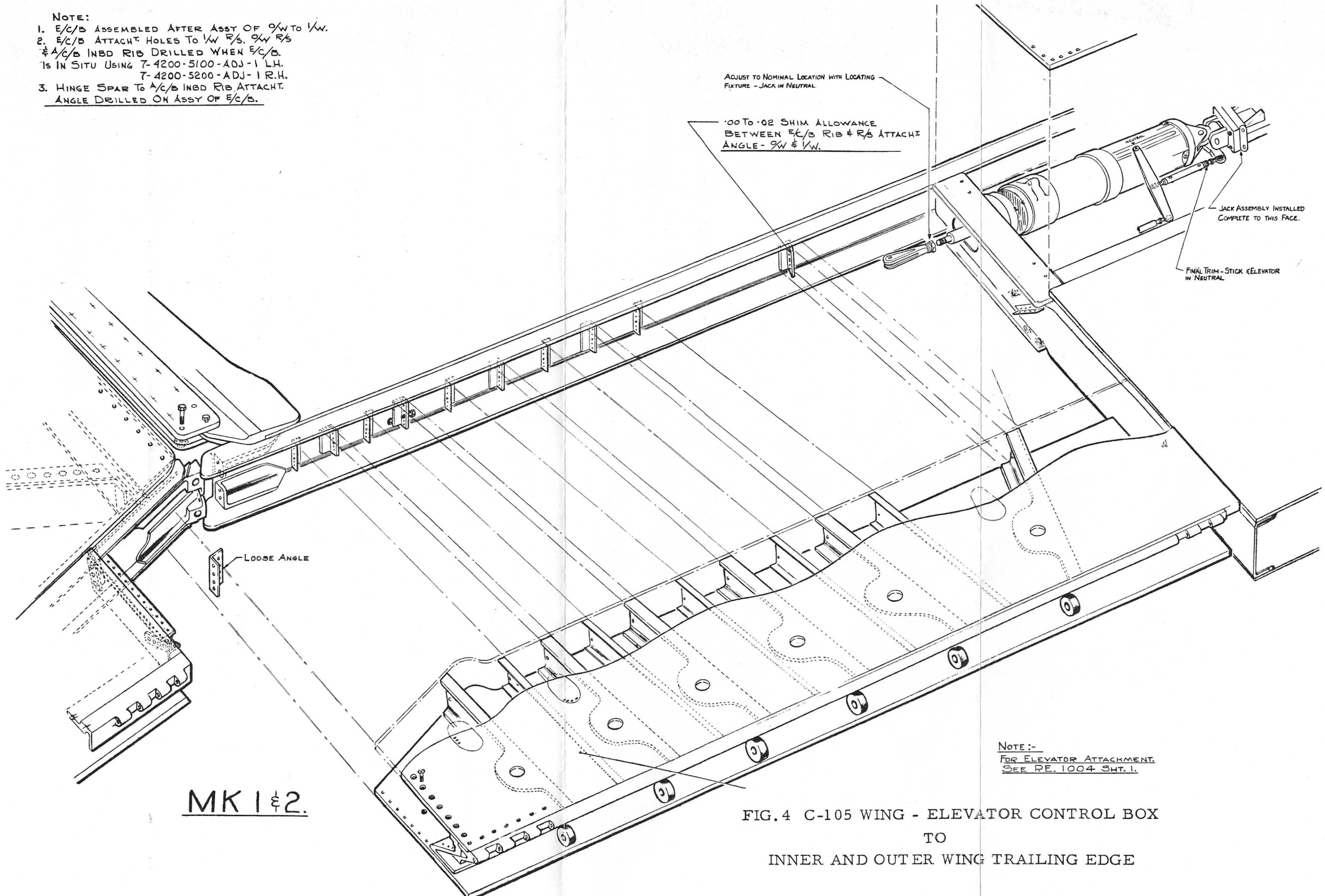


FIG 2

CLAM - SHELL DRILL JIG
RUDDER CONTROL BOX

FIG. 4 C-105 WING - ELEVATOR CONTROL BOX TO INNER AND OUTER WING ~~TRAILING~~ EDGE

NOTE:
1. E/C/B ASSEMBLED AFTER ASSY OF O/W TO I/W.
2. E/C/B ATTACH^T HOLES TO I/W R/S, O/W R/S & A/C/B INBD RIB DRILLED WHEN E/C/B. IS IN SITU USING 7-4200-5100-ADJ-1 L.H. 7-4200-5200-ADJ-1 R.H.
3. HINGE SPAR TO A/C/B INBD RIB ATTACH^T. ANGLE DRILLED ON ASSY OF E/C/B.




MK I & 2.

NOTE:- FOR ELEVATOR ATTACHMENT. SEE RE. 1004 SHT. 1.

FIG. 4 C-105 WING - ELEVATOR CONTROL BOX TO INNER AND OUTER WING TRAILING EDGE

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FIG. 5 C-105 WING - INTERCHANGEABILITY - ELEVATOR TRAILING EDGE TO ELEVATOR

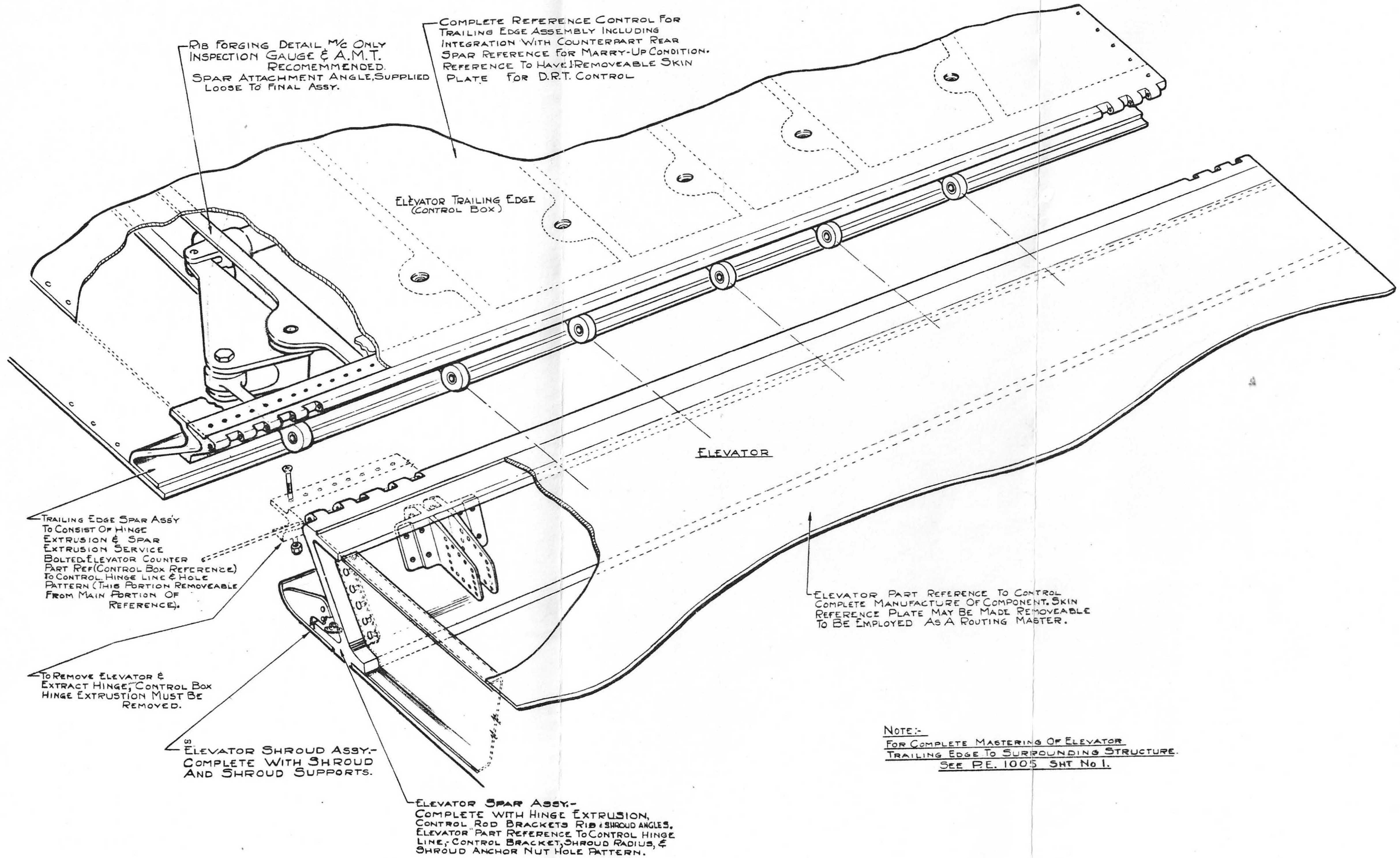


FIG. 5 C-105 WING - INTERCHANGEABILITY - ELEVATOR TRAILING EDGE TO ELEVATOR

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FIG. 6 EXPLODED VIEW OF ELEVATOR TO ELEVATOR CONTROL BOX JNT.

## Loose Items In Assembly Order

| Item | Description | L. Hand | R. Hand | Part No |
|---|---|---|---|---|
| 1 | Elevator Complete with Hinge Pin & Extrusion From Control Box. | 1-Off | | 7-1082-1 |
| | | | 1-Off | 7-1082-2 |
| 2A | Bolt. Control Box Hinge | 84-Off | 84-Off | MAS 334 P-23-5 |
| | | 18-Off | 18-Off | NAS 334 P-11 |
| 2B | Washer Control Box Hinge | 102-Off | 102-Off | AN 960 D-416 |
| 2C | Nut Control Box Hinge | 102-Off | 102-Off | AN 364-428 |
| 3A | Bolt Control Fitting | 6-Off | 6-Off | CSB 1000 C-17 |
| 3B | Stop Control Fitting | 6-Off | 6-Off | 7-1060-12 |
| 3C | Washer Control Fitting | 6-Off | 6-Off | AN-960-D1216 |
| 3D | Nut Control Fitting | 6-Off | 6-Off | AN 364-1216 |
| 4A | Diaphragm For Shrouds | 5-Off | | 7-1082-47 |
| | | 1-Off | | 7-1082-73 |
| | | | 5-Off | 7-1082-48 |
| | | | 1-Off | 7-1082-74 |
| 4B | Bolt Diaphragm | 12-Off | 12-Off | AN-3-4A |
| 4C | Washer Diaphragm | 12-Off | 12-Off | AN-960-10L |
| 4D | Nut Diaphragm | 12-Off | 12-Off | AN-364-1032C |
| 5A | Shroud | 1-Off | | 7-1082-51 |
| | | | 1-Off | 7-1082-52 |
| | | 1-Off | | 7-1082-53 |
| | | | 1-Off | 7-1082-54 |
| | | 1-Off | | 7-1082-55 |
| | | | 1-Off | 7-1082-56 |
| | | 1-Off | | 7-1082-57 |
| | | | 1-Off | 7-1082-58 |
| | | 1-Off | | 7-1082-61 |
| | | | 1-Off | 7-1082-62 |
| | | 1-Off | | 7-1082-63 |
| | | | 1-Off | 7-1082-64 |
| | | 1-Off | | 7-1082-65 |
| | | | 1-Off | 7-1082-66 |
| 5B | Screw Shroud | 17-Off | | AN 509-10R9 |
| | | 54-Off | | AN 509-10R10 |
| | | | 17-Off | AN 509-10R9 |
| | | | 54-Off | AN 509-10R10 |

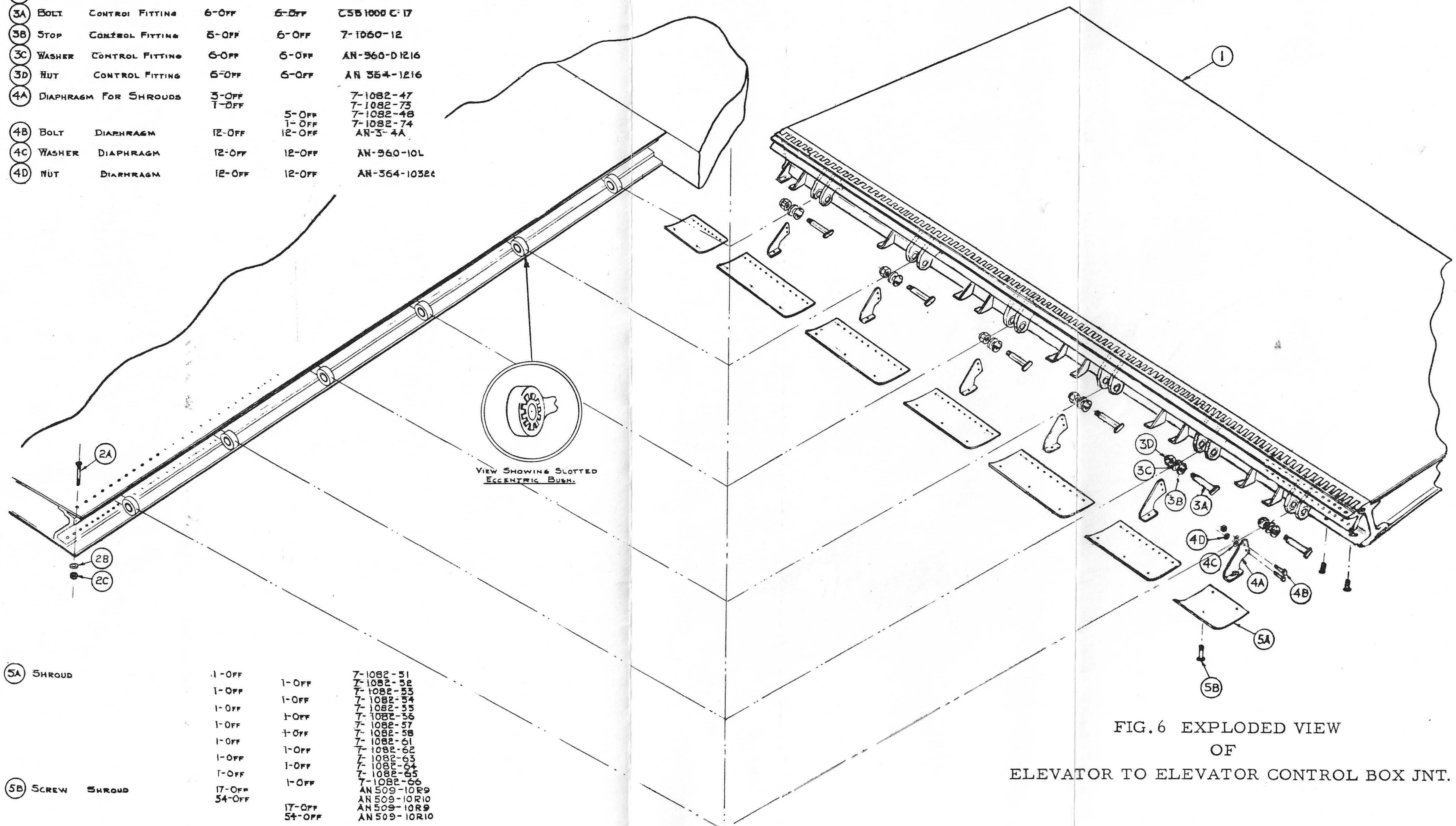



FIG. 6 EXPLODED VIEW OF ELEVATOR TO ELEVATOR CONTROL BOX JNT.

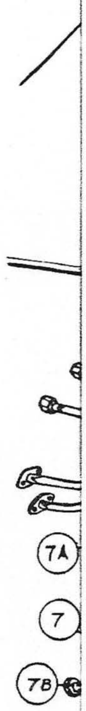
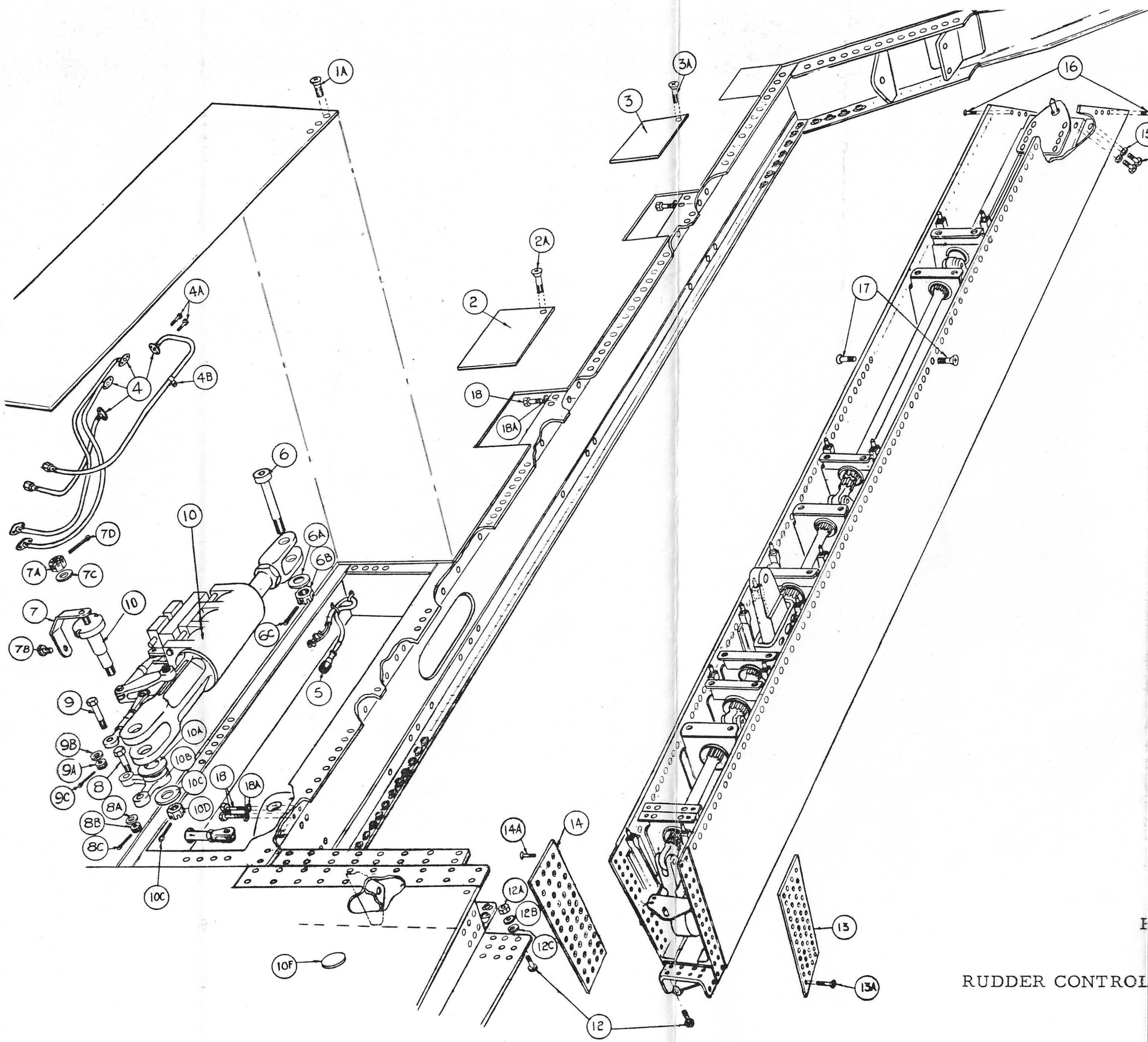





FIG. 7 EXPLODED VIEW OF RUDDER CONTROL BOX TO FIN TRAILING EDGE




| REF NO. | DESCRIPTON | QUANTITY | PART NUMBER |
|---|---|---|---|
| 1 | JACK ACCESS PANEL | 1 | |
| 1A | SCREW | | |
| 2 | ACCESS PANEL No1 | 1 | |
| 2A | SCREW | | |
| 3 | ACCESS PANEL No2 | 1 | |
| 3A | SCREW | | |
| 4 | HYDRAULIC PIPES | 1 | |
| | HYDRAULIC PIPES | 1 | |
| | HYDRAULIC PIPES | 1 | |
| | HYDRAULIC PIPES | 1 | |
| 4A | SCREW | | |
| 4B | SCREW | | |
| 5 | MULTIPIN SOCKET | 1 | |
| 6 | BOLTS - JACK TO LEVER No3 | 1 | |
| 6A | WASHER | 1 | |
| 6B | NUT | 1 | |
| 6C | SPLIT PIN | 1 | |
| 7 | JACK STEADY BRACKET | 1 | |
| 7A | NUT | 1 | |
| 7B | BOLT | 1 | |
| 7C | WASHER | | |
| 7D | SPLIT PIN | 1 | |
| 8 | BOLT-JACK BELLCRANK To CON. ROD | 1 | |
| 8A | NUT | 1 | |
| 8B | WASHER | 1 | |
| 8C | SPLIT PIN | 1 | |
| 9 | BOLT-JACK BELLCRANK To JACK. LINK. | 1 | |
| 9A | NUT | 1 | |
| 9B | WASHER | 1 | |
| 9C | SPLIT PIN. | 1 | |
| 10 | BOLT JACK To JACK ANCHORAGE | 1 | |
| 10A | WASHER | 1 | |
| 10B | BELL CRANK | 1 | |
| 10C | WASHER | 1 | |
| 10D | NUT | 1 | |
| 10E | SPLIT PIN | 1 | |
| 10F | COVER | 1 | |
| 11 | JACK | | |
| 12 | BOLTS LOWER SKIN To LOC HINGE & SPAR No 1 | | |
| 12A | NUTS | | |
| 12B | WASHERS | | |
| 12C | TAPER WASHERS | | |
| 13 | LH SPLICE PLATE | 1 | |
| 13A | SCREWS | | |
| 14 | RH SPLICE PLATE | 1 | |
| 14A | SCREWS | | |
| 15 | BOLTS SPAR No1 (TOP END) | | |
| 15A | WASHERS | | |
| 16 | SCREWS -(UPPER T/E FAIRING) | | |
| 17 | SCREWS - SPAR No3 | | |
| 18 | BOLTS - SPAR No3 | | |
| 18A | WASHERS | | |

FIG. 7
EXPLODED VIEW
OF
RUDDER CONTROL BOX TO FIN TRAILING EDGE

FIG. 8 INTERCHANGEABILITY CONTROL POINTS - FIN

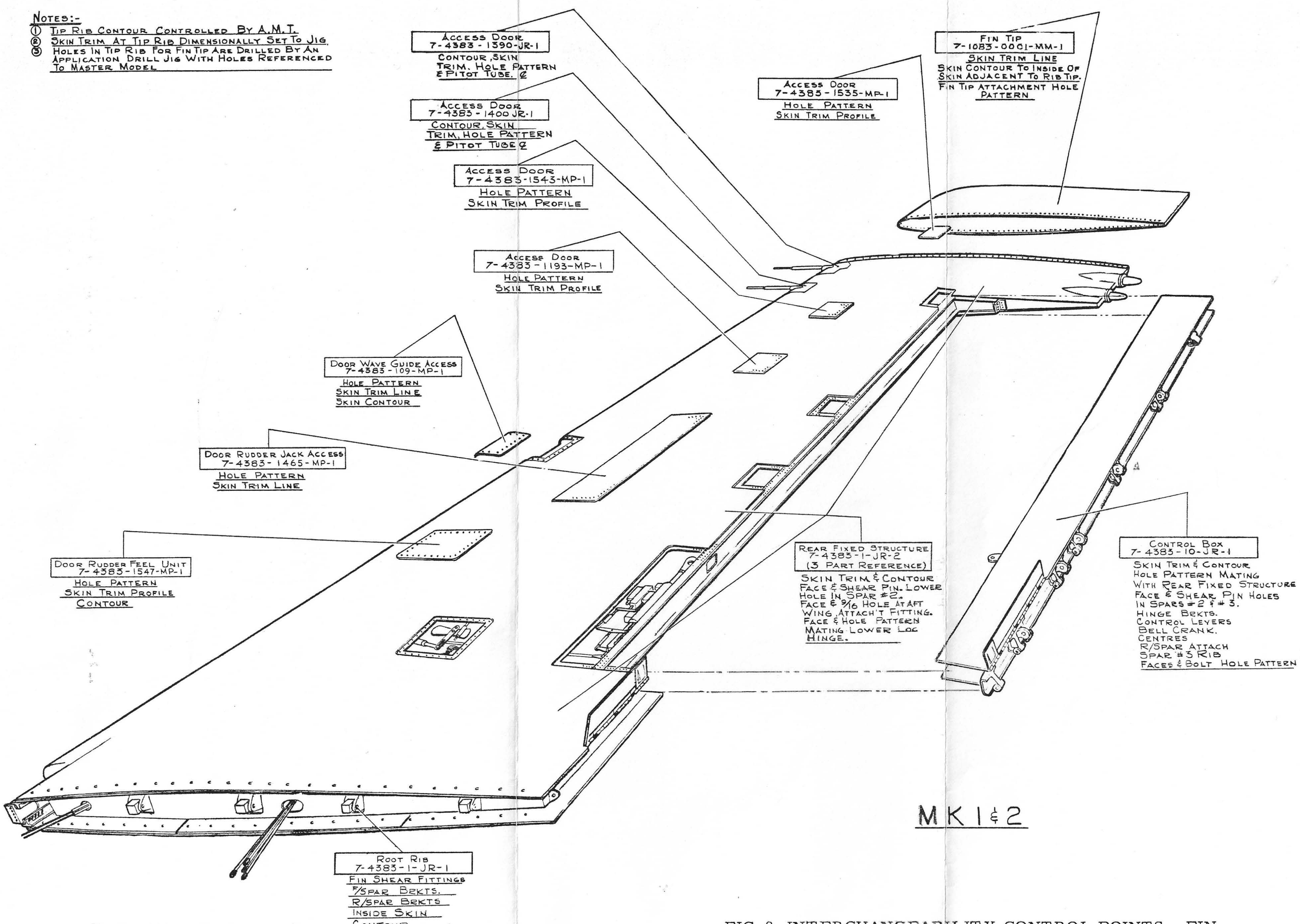



FIG. 8 INTERCHANGEABILITY CONTROL POINTS - FIN

FIG. 9 AILERON - INTERCHANGEABILITY CONTROL POINTS

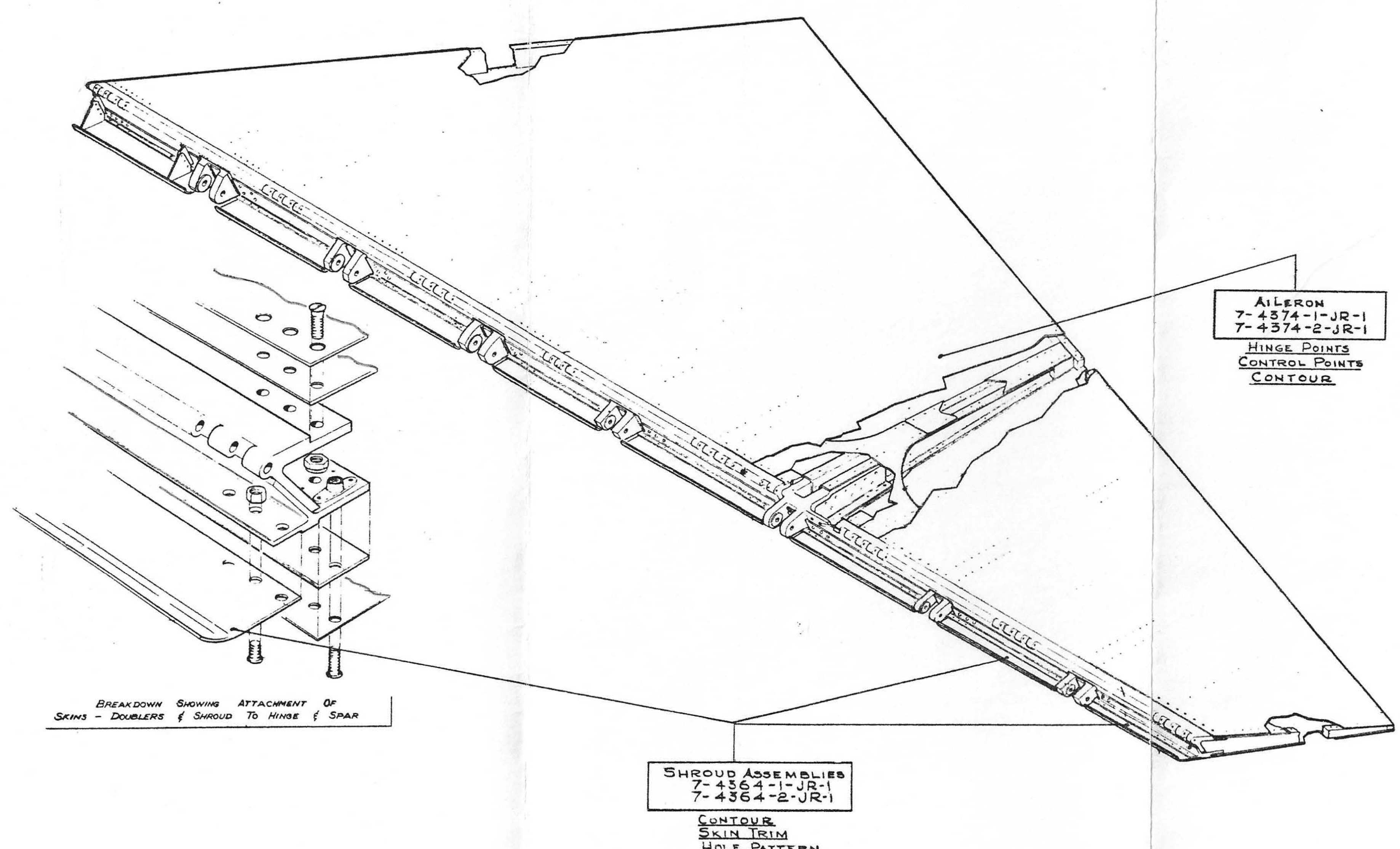



FIG. 9 AILERON - INTERCHANGEABILITY CONTROL POINTS

## 5.0 FUNCTIONAL TEST PROGRAM

As stated previously in this report, it is intended to prove the satisfactory reliability of the control system contained in the control boxes, to the extent that it will only be necessary to remove the control box structures at major overhaul periods for a completed inspection of the control system.

The control linkage can be regarded as a structure that moves. Since all movement takes place at bearings and since the velocities are low enough to preclude damage from inertia loads it should be possible to treat the mechanism as a static structure for purposes of fatigue investigation. A test program has been formulated to establish the fatigue life of the various components of the control mechanisms. Some progress has been made with this work and the results obtained on the elevator operating links have shown the need for some changes in these units. These changes have already been incorporated into the design of these units and all other similar parts. In addition to the fatigue testing of individual parts, the work being done on the flying control system test rig will also constitute a fatigue test on the complete mechanism for a duty cycle equal to the entire life of the aircraft.

The test program may be considered as falling into four separate phases as follows:

1. Bearing Tests
2. Installation and Removal Trials of the control surfaces and boxes in the Metal Mock-up.
3. Hinge Pin Removal Trial

4. Control Box Attachment Fatigue Tests

## 5.1 BEARING TESTS

Testing of bearings by various methods under conditions occuring in the flying controls, has been under way for over two years and is still continuing. This work has resulted in the accumulation of considerable knowledge regarding the factors affecting bearing life. The work has been divided into three separate phases.

### 5.1.1 LIFE TESTS ON THE AVRO BEARING TEST MACHINE

On this machine, bearings are checked at various load levels with an oscillating and "self aligning" motion. The effect of different methods of lubrication and various degrees of housing and spindle fit are checked. Three bearings are tested simultaneously at a fairly high speed so that representative samples of various types can be checked in a reasonable length of time. The main object of this rig is to check the comparative performance of various types and "make" of bearings and to study the effect of other factors on bearing life. It is not intended to give absolute values for bearing life under operating conditions.

As the requirements became more specific, many tests were carried out on various types of bearings that were considered suitable for the ARROW application. It became obvious that the Shafer bearing was the most suitable from a weight and space standpoint and the tests were continued on various sizes.

It was of course realized that the loading cases on the bearing test machine were only useful for comparative purposes and were not representative of actual flight conditions. Further development tests on Shafer bearings were therefore planned for the B-1 rig as described in paragraph 5.1.3.

During early work on the B-1 rig when initial testing was being done on hydraulic and control servo problems, indications of failure were observed in some bearings. This testing involved extended periods of quite severe vibration with an appreciable angular movement taking place at the bearings. A complete engineering re-examination of the flying control bearing problem was made with the help of Shafer engineers. The following important points were high-lighted by this re-examination.

1. The high frequency low amplitude loading which had caused the failures were unrealistic and only occurred as a by-product of the time spent in checking other control system problems. The failures were caused by lubricant being "hammered out" with no chance of being replaced by wiping action as the bearing moved through larger angles. This point was later checked by the realistic duty cycle on the rig.

2. The specification of pre-loaded bearings for this application was unnecessary and unwise. Because of the difficulty of controlling the amount of pre-load, some rollers were overloaded leading to early failures.

3. Shafer agreed to exercise much closer dimensional control over the component parts of the bearings and so supply us with non pre-loaded bearings having a minimum of back lash.

4. The initial work on the B-1 rig had shown that complete lack of "slop" in the bearings was not as important as had been previously assumed.

The bearing rig is now being used for further development tests on bearings. For example, on lubrication, a test was carried out to determine whether a forced oil feed was superior to normal greasing of bearings. The forced oil feed proved to be slightly better but not enough to justify the design complication of such an installation. Plain spherical bearings are being investigated and to date it is evident that they demonstrate a longer life, but the radial clearances are difficult to control and the problem of locking the ball to the pin has proved to be very difficult.

### 5.1.2 QUALIFICATION TESTS

The testing called for in Avrocan Specification E-350 is not intended to provide positive proof that the bearings are adequate for any specific life in the ARROW control system. The intention is to demonstrate a general standard of quality and to prove the load ratings under a specific set of conditions. These conditions cannot accurately duplicate those occurring on the aircraft flying control system.

For anti-friction bearings used under oscillating conditions, a standard method of load rating is used by most bearing manufacturers. This defines a "dynamic load" which a bearing must withstand for 10,000 oscillations through a $90^{\circ}$ angle and is in general agreement with bearing selection procedure laid down in ARDCM 80 Paragraph 8.3.3. The dynamic load, in this particular case, may be considered as a load that is applied to the bearing while the bearing is rotated through an angle of 90 degrees. The bearings produced by Shafer are designed to have an "average life" of 10,000 cycles at dynamic load which means that 90% of the bearings will achieve or exceed this life before failure. In the specification, this method of rating has been used as a basis for testing with some high and low temperature cycles included, to check the effect of these vehicles. In actual fact none of the bearings used in the ARROW Aircraft oscillate through as great an angle as 90 degrees, and the duty cycle used for design does not apply the dynamic load 10,000 times. A typical load spectrum applied approximately 3,000 applications of dynamic load together with a great many more applications of lower loads through smaller angles of oscillation.

In the qualifying of the Shafer bearings, only one bearing of each size has been tested. However, all bearings are geometrically similar, and the important elements of the bearing structures are stressed to approximately the same level. It is therefore reasonable to assume that, by testing one of each size of a fairly large number of bearings we are in fact demonstrating an accurate "average" life.

Some of the components of the special bearings, e.g. rollers, are standard items which are used in the standard range of Shafer bearings. In the last two years independent life tests of standard Shafer bearings have been conducted by Avro, and the results have confirmed the quoted life figures.

Since this testing, combined with the qualification testing, covers a large number of bearing components under similar conditions of stress, the results should indicate a good assessment of bearing quality.

A special Avrocan specification for flying control bearings of the ARROW will be prepared with qualification test requirements identical to the functional test requirements of the B-1 rig tests. The so-called "qualification" tests of the existing Avrocan Specification would be relegated to "inspection tests" in the new Avrocan specification. The inspection will be carried out by the bearing manufacturer and the qualification tests of the bearings will be carried out by Avro in the B-1 rig. Full qualification or limited flight approval would be granted before the first flight and would depend on the behaviour of the bearings in the B-1 rig and in the state of completion of these tests.

At the present time, the elevator flying control system has successfully completed an endurance test equivalent to 200 flying hours. From the load spectrum and servicing standpoint, this has been as fully representative as it is possible to make it.

The aileron and rudder system will be included in the B-1 rig with representative loadings and the testing will be extended for longer periods of time. This testing will be ahead of accumulated flying hours on the ARROW aircraft for a very considerable period of time.

The status of the bearing manufacturer's inspection tests at the time of writing is as follows:

Aileron

| BEARING | TEST STATUS | REMARKS |
|---|---|---|
| 7-1564-647 | Tested | Test satisfactory |
| -615 | Tested | Test satisfactory |
| -601 | Tested | Sample #1 failed due to cracked inner case during room temperature radial dynamic test. Sample #2 failed due to cracked inner race on completion of low temperature radial dynamic test. |
| -597 | Tested | Test satisfactory |
| -575 | Tested | Tested with preloading and passed. Preloading run eliminated. Bearing considered satisfactory. |
| -611 | Tested | Sample #1 failed radial dynamic high temperature test. Sample #2 passed. Bearing considered satisfactory since loads were reduced. |
| | Retested | Test satisfactory |
| 7-1564-587 | Tested | Passed test satisfactorily. Loads increased. |
| | Retested | Failed during room temperature radial dynamic test. |
| -593 | Tested | Failed to load of 23,000 lbs. which was higher than actual conditions in aircraft. Bearing considered satisfactory due to low design load of 4800 lbs. |
| | Retested | Tested at 4800 lbs. and passed test satisfactorily. |

Rudder

| BEARING | TEST STATUS | REMARKS |
|---|---|---|
| 7-1583-247 | Tested | Failed high temperature radial dynamic tests. Low temperature tests not conducted. Sample #2 passed high temp. test. |
| | Retested | Test satisfactory. |
| -361 | Tested | Satisfactory |
| | Redesign tested | Satisfactory |
| -364 | Tested | Test satisfactory |
| -363 | Tested | Sample #3 failed radial dynamic high temp. Cracked inner race. |
| -362 | Tested | Test satisfactory |
| -251 | Tested | Test satisfactory |
| -253 | Tested | Test satisfactory |
| -243 | Tested | Test satisfactory |
| -245 | Tested | Sample failed high temp. radial dynamic test. |
| 7-1562-621 | Tested | Test satisfactory |
| -611 | Tested | Incomplete test |
| -607 | Tested | Sample failed high temp. radial dynamic test. Test satisfactory. |
| 615 | Similar to 7-1562-613 | |

General

| | | |
|---|---|---|
| 7-1500-21 | Tested | Test satisfactory |
| -605 | | Considered satisfactory due to similarity to 7-1564-575. |

| BEARING | TEST STATUS | REMARKS |
|---|---|---|
| -613 | Tested | Test satisfactory |
| -603 | Not tested | Similar to 7-1564-587 |
| -595 | Tested | Test satisfactory |
| -531 | Tested | First sample failed room temperature radial dynamic test. Second sample failed high temperature radial dynamic test. |
| -567 | Tested | Similar to 7-1564-531 |
| -573 | Tested | Similar to 7-1564-531 |
| -561 | Tested | Similar to 7-1564-553 |
| -553 | Tested | Test satisfactory |
| -537 | Not tested | Similar to 7-1564-537 |
| -545 | Tested | Test satisfactory |
| -577 | Tested | Failed during high temperature radial dynamic tests after passing low and room temperature radial dynamic tests satisfactorily. |
| -585 | Tested | Failed due to cracked inner race during radial dynamic room temperature tests. |
| | Retested | Failed due to cracked inner race during high temperature radial dynamic test. |
| -607 | Tested | Sample #1 failed due to a cracked inner race during room temperature radial dynamic test. Sample #2 failed on completion of high temperature radial dynamic test. |

### 5.1.3 B-1 RIG TESTS

The B-1 test rig was built in the Avro Structural Test Department as a test facility for the complete ARROW I flying control system including aileron, elevator and rudder control surfaces and control boxes, jacks, servos linkages, control cables and the control column. At the date of writing, only the elevator control system has been installed and tested. This includes the complete system from the control surface back to the control column.

A considerable amount of test time has been spent on Frequency Response Tests on the complete elevator system and suitability tests on various items of the elevator control system, including control valves, pressure pipes, jacks etc.

In conjunction with the bearing test program, a test was scheduled on the B-1 rig in which the elevator control linkage, equipped with Shafer bearings was subjected to a duty cycle program. Each duty cycle was representative of one hour of flight in the high speed combat mission case from take off to landing. Specifically, a duty cycle is described as follows (extracted from the governing test requisition):

NOTE - In addition,one application of 100% of limit hinge moment is applied for each one hour duty cycle.

Duty Cycle

(a) Oscillate the elevator through 5 complete cycles in the unloaded condition.

(b) Shake elevators at resonant frequency for 30 seconds in the unloaded condition. Amplitude $\pm 1/2^{\circ}$.

(c) With a hinge moment rate of 4350 lbs.ft/degree approximately, $0^{\circ}$ indicating zero load conditions, make the following sequence:

| TIME | ELEVATOR ANGLE (-Elev. up) | AMPLITUDE | FREQUENCY (C.P.S.) |
|---|---|---|---|
| 8 1/2 min | $-5^{\circ}$ | $\pm 1^{\circ}$ | 1/2 |
| 50 1/2 min | $-3^{\circ}$ | $\pm 1^{\circ}$ | 1/2 |
| 12 sec | $-7^{\circ}$ | $\pm 1/2^{\circ}$ | 25 |
| 48 sec | $-5^{\circ}$ | $\pm 1/2^{\circ}$ | 25 |
| 12 sec | $0^{\circ}$ | $\pm 1/2^{\circ}$ | 25 |

The following information, relative to the bearing problem, is extracted from the A.T.R. (Advance Test Result) 2268/32 and /33.

"Springs representing a 4350 lb.ft/degree of elevator travel hinge moment rate were connected to the short chord elevators and the supporting beam tips have been deflected 2.82 in. up which correspond to a normal acceleration of 3 G".

During the early stages of bearing suitability tests, some difficulty was experienced in loss of preload. Due to poor control on the diameter of the bearing rollers, slop developed between the roller and the outer case. Since it was felt that this slop would have a serious effect on the amount of backlash in the control system, special steps were taken on the B-1 rig in an attempt to offset this effect.

Initially the elevator links on the L.H. and R.H. elevators contained pre-loaded bearings. After 25 cycles re-worked, close tolerance bearings having no pre-load were received from Shafer and installed in the rig in the L.H. side. To check the possible effect on back lash of built in pre-load, the bearings on this side were pre-loaded by being rigged against each other by the adjusting mechanisms. After 200 duty cycle hours it was concluded that this form of pre-loading made no appreciable difference to the development of backlash.

Lubrication

As described in Section 5.1, some difficulty was experienced in lubrication during the low amplitude high frequency cycling.

> "For the first 25 cycles, MIL-G-3278 lubricating grease was used in all bearings. Bearings were greased every 5 cycles during the first 25 cycles. Since the 25th cycle, low temperature grease type EP100 was used on three of the six links on the L.H. side. All other links were greased with MIL-G-3278 grease. After the 25th cycle the bearings were greased every 10 cycles".

At the end of 50 and 100 cycles of operation, backlash measurements were made and the link bearings were examined for signs of wear or roughness.

After both periods, the bearings were found to be suitable for further testing. The preloaded bearing in the main bellcranks at the jack fork end were also checked and exhibited a certain amount of roughness and loss of preload. Experience in other tests shows that this amount of roughness is still acceptable in a bearing of this sort. The backlash in the system had increased slightly but was still within acceptable tolerances.

The duty cycle testing program on the Shafer bearings was continued and 200 duty cycles have been completed to date. Additional backlash tests of the elevator output system from the jacks to the surfaces were conducted to the completion of 150 and 200 duty cycles.

The bearings were greased every 10 cycles. Except for 3 links on the L.H. side which were lubricated with EP 100 grease, all bearings were greased with MIL-G-3278 grease. It was apparent that both greases were equally effective.

Bearing Wear

Clearance between the inner and outer races of the bearings was measured at 150 and 200 duty cycles with the following results:

| 150 Duty Cycles | | | 200 Duty Cycles | |
|---|---|---|---|---|
| LINK | L.H. | R.H. | L.H. | R.H. |
| #1 Inboard | .0018 | .0062 | .0030 | .0083 |
| #2 | .0009 | .0013 | .0013 | .0018 |
| #3 | .0013 | .0043 | .0015 | .0049 |
| #4 | .0010 | .0056 | .0010 | .0067 |
| #5 | .0013 | .0013 | .0013 | .0028 |
| #6 | .0013 | .0006 | .0008 | .0011 |

NOTE - The L.H. links contained close tolerance rollers manufactured by Shafer.

It will be noted from the above table that the clearance in the bearings increased with the number of duty cycles but a continuous check on the control system backlash showed a value still within prescribed limits.

All the bearings were examined at the completion of 150 and 200 duty cycles of operation for roughness and deterioration. The link bearings were still satisfactory, but the roughness of the preloaded bearings in the main bell-crank had increased. The port bell crank bearing roughness at the end of 200 hours was quite noticeable, while starboard bearing roughness had also increased. These bearings had also suffered loss of preload.

Oilite Washer Wear

A creaking noise developed in the elevators during the first 100 cycles and continued during the last 100 cycle phase, gradually increasing in intensity. The noise was finally traced to No. 2 bellcrank on the R.H. side. At the completion of 150 cycles, this bellcrank was removed along with the inboard bellcrank and examined carefully for signs of deterioration.

The Oilite washers at the bellcrank pivot showed signs of scoring. It was suspected that the washers were losing their lubricant and it was determined that the lubricant that was being supplied through the bellcrank pivot pin was being directed to only one of the two washers. The pivot pins will be modified to incorporate 2 grease connections.

Canted Bolts

A number of the NAS 334 PA23-5 bolts that are used to attach the top skin of the control box to the hinge extrusion had canted heads and were replaced at the end of 150 cycles. A fracture was discovered in one of the shorter NAS 334 PA11 bolts located at the starboard outboard link.

No more trouble was experienced with the bolts to the end of the 200 cycles. It was thought that the countersinks had been drilled off centre causing the screw heads to cant when tightened up. The one fractured bolt would have been caused by the same reason.

Lubrication

During the lubrication operation of the YD 128 link bearings on the B-1 test rig, excessive pressures exerted on the grease gun resulted in the "springing" of one of the two dust caps used on each bearing. Restrictions to visibility at most bearing points make it impossible to determine if the dust caps are "Sprung". Even if this is ascertained the elevator control box lower skins have to be removed to permit link extraction for dust cap re-setting. Since this situation would not be acceptable in service, an investigation was carried out to determine a suitable method of preventing excessive greasing pressures and thus eliminate the "springing" of dust caps during lubrication. As a result of the above test program, the following recommendations were made:

(a) A 160 p.s.i. pressure relief valve should be used with the grease gun lubrication of the midget flush type grease fittings on all Shafer bearings.

(b) Sprung dust caps should be re-set by placing a hollow sleeve (approximately 2-3/16" diameter) concentrically over the cap and tapping gently. The bearing should be de-greased before re-setting is attempted.

(c) The grease nozzle should be applied to the midget flush type fitting as nearly in line as possible with the fitting centre line, to permit proper grease flow.

(d) Consideration should be given to the use of a low pressure, push-action type of grease gun in lieu of the lever-action type for lubrication of all flying control bearings.

(e) A "goose" neck extension should be used on the grease gun when lubrication is being carried out from the lower side of the elevator control box.

(f) A "Greasing Assembly" consisting of the following items should be used with a grease gun in the lubrication of the links.

  (i) Grease Nozzle - Alemite #314150 - to fit midget flush type fittings.

  (ii) 1/8" N.P.T. Nipple

  (iii) 1/8" N.P.T. Tee

  (iv) 1/8" N.P.T. Relief Valve - Tecalemit #7373-6-160 p.s.i.

Hinge Movement

Lateral movement of the hinge pin was a source of difficulty during the test program. It was necessary to re-position the hinge pin on the port elevator during the test program. No trouble was encountered during this operation. Stops were fabricated to prevent the re-occurrence of this movement.

Post Test Inspection

At the conclusion of the duty cycle program on the B-1 rig, a closer inspection of the control linkage was conducted. To accomplish this, all bellcranks, YD128 levers, and ancillary hardware were stripped from the control boxes. When first installed, it had been impossible to manually rotate the bearings in the levers and bellcranks.

After completion of the test program (duty cycles, frequency response etc.) the bearings could easily be turned by hand. The one exception was the main bellcrank bearing (at the jack fork end location). This bearing was rotated using a lever attached to the bearing inner race. Roughness was quite apparent. Wear on the oilite washers (7-1562-65) was very noticeable. Numerous indentations in the washers were observed. It should be noted that these washers were not made of heat-treated superoilite 16 material. Also Dow Corning 510-350 centistoke lubricant was used in place of Dow Corning 510-400 centistoke lubricant. Two of the washers have been forwarded to the Metallurgical laboratory to be checked for loss of the impregnated lubricant and for the presence of any M-1-L G-3278 lubricant that was normally injected through the bearing bolts.

At the conclusion of the duty cycle program, the frequency response test with mechanical inputs at the rear quadrant, and frequency response test with electrical input to the parallel servo, an inspection of the elevator hinges was conducted. The elevators and hinge extrusions were removed and measurements were made of the bores of the elevator hinge tangs and hinge extrusion tangs.

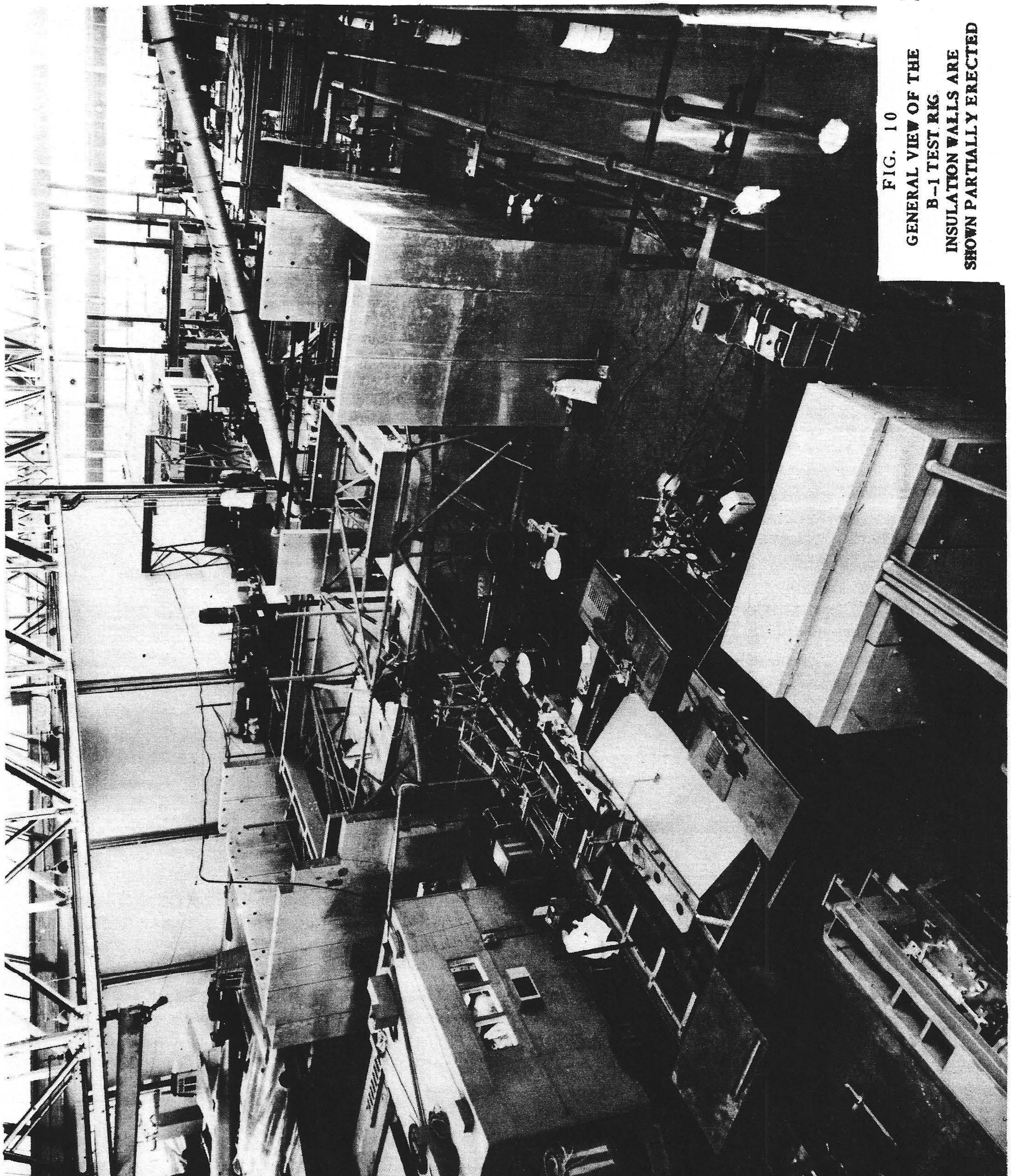


FIG. 10
GENERAL VIEW OF THE
B-1 TEST RIG
INSULATION WALLS ARE
SHOWN PARTIALLY ERECTED

The hinge showed no appreciable signs of wear.

The bores of the push pull rod (bellcrank connections) were measured for signs of wear. No elongation was found.

The complete control system with the exception of the oilite washers will be re-assembled on the B-1 rig for further testing.

## 5.2 REMOVAL AND RE-INSTALLATION OF FLYING CONTROL SURFACES, CONTROL BOXES AND CORRESPONDING LINKAGES

In response to an RCAF request, a series of demonstrations were carried out on the ARROW I metal mock-up to determine the times and man-power requirements with respect to the removal and re-installation of the flying control surfaces, control boxes and their corresponding control linkages.

### 5.2.1 DEMONSTRATION DETAILS

(a) A maximum of six Avro production mechanics, under the supervision of a shop foreman, performed the operations.

(b) All lifting and lowering of components was accomplished by the use of an overhead crane.

(c) The operations were timed by two members of the RCAF Maintenance Appraisal Team which is attached to the Maintenance Engineering Group of the Equipment Design Department.

(d) Observers of the demonstrations represented the RCAF T.S.D., Maintenance Engineering, Quality Control, Production Planning and Sales and Service.

(e) In the case of the elevator control box, the lower skin was removed and the bell crank levers and link rods extracted. This is the recommended standard practice for this component. The master control rod cannot be removed, however, without removing the complete control box, but it is expected that the rod will have a life equivalent to that of the aircraft. In the case of the aileron and rudder control boxes, the complete box was removed in order to remove the control linkages.

(f) Power (air driven) screw drivers were used wherever possible to remove and replace bolts.

(g) No split-pins or other forms of locking were used in the demonstrations.

(h) No bolts were torque loaded, nor were the correct bolts used in all cases.

(i) Following the completion of the demonstrations, all discrepancies were considered and an estimated time was calculated for each demonstration to give a more realistic time factor.

(j) The times listed in the "ACTUAL" column are actual times to perform the described operations. The total elapsed time represents the total time taken to carry out the complete operation. In some cases this is less than the sum of the individual times due to the fact that some of the individual operations overlap.

NOTE - Items marked (*) are variations from the recommended procedures and are further explained in the "Demonstration Conclusions" section.

5.2.2 REMOVAL DESCRIPTION

The following pages record the actual removal operations, the type of attachment, number of man-hours actually consumed and an estimated number of man-hours that include discrepancies in the installation.

5.2.3 DEMONSTRATION OBSERVATIONS

(a) To obtain maximum utilization of man-power, the removal of the rudder and its control box was combined. That is, the access panels on the fin were being removed at the same time as the shrouds and link bolts were being removed.

(b) Plugs were not fitted to the access holes in the control box skin.

(c) 57 bolts were not fitted at the fin-to-rudder control box joint line since anchor nuts had not been provided. Of the remaining bolts, a considerable number were screwed into tapped holes in the skin in place of using anchor nuts.

(d) The rudder sling positioned the rudder very well for removal and re-installation. However, since no sling was available for the control box, it was slung by means of wire cables.

(e) During the re-assembly of the rudder linkage in the control box, an attempt was made to adjust the link rod positions by measurement. This proved to be unsuccessful since the control rod had to be adjusted when the link rods were connected to the rudder. (See demonstration detail for the adjustment of linkage in the control box).

(f) Plain bushings in place of bearings in the control linkage prevented the various bolts from being tightened more than finger tight, since the linkage would have locked otherwise.

(g) It was found that the rudder jack had to be removed to obtain access to four of the bolts attaching the control box to the fin. While this was accomplished in ten minutes during the demonstration, the same operation on a production aircraft would entail three to four hours labour since the hydraulic system and the electrical system must be disrupted in addition to the control linkage.

(h) The upper three removable shrouds were fitted prior to the link bolts because the rudder had to be held hard over to the right to permit access to the shroud bolts.

The lower three shrouds were fitted after the link bolts. Some of the shroud attaching bolts fouled the shroud diaphragm.

(i) The removable rudder shrouds appear to be the critical factor in this operation, since almost twice as much time was spent on their removal and replacement as was spent on all other sections of the rudder.

Aileron

(a) Similar discrepancies existed in this case as in the case of the rudder. (e.g. no split-pins or locking of bolts, bushings in place of bearings etc.). In addition, no link fairings were fitted and the removable anchor nut plates on the control box ribs were not fitted.

(b) Only 12 of a total of 106 bolts were used to attach the aileron jack access panel becuase of lack of anchor nuts.

(c) No cover plates were fitted on the control box upper surface and only some sections of the hinge were used, amounting to about 30% of the total length.

(d) During the removal of the bolts from the under side of the control box the mechanics were standing on two B4 maintenance platforms, necessitating the accomplishment of the work with their arms stretched above their heads in a very tiring position.

(e) Considerable difficulty was encountered during the hinge pin removal. An air driven 3/8" drill gun failed in an attempt to pull the pin and a 1/2" electric drill gun had to be used to accomplish the task. Upon investigation, it was found that a discrepancy existed in the alignment of the aileron box and the wing torsion box causing a deformation in the aileron hinge. In addition, the aileron hinge had not been lubricated on installation. Subsequently it was proven on the B1 rig tests, as described in Chapter 6 Paragraph 6.1.4, that it was possible to remove the elevator hinge with a 3/8 diameter shop air gun with no difficulty. The elevator had been subjected to 200 hours of endurance testing and the control surface hinge was properly lubricated and structurally representative.

(f) During the removal of the aileron, the forward (hinge) end of the aileron had to be lifted up to enable the aileron to clear the elevator without fouling.

(g) Both the aileron and its control box were slung by wire cables since the proper slings were not available yet.

(h) During the demonstration, it was observed that the aileron fouled the elevator towards the rear of the surfaces as the aileron was moved through its arc of travel.

Elevator

(a) Similar discrepancies existed in this case as in the cases of the rudder and aileron (e.g. no split-pins locking of bolts, bushings in place of bearing etc.). In addition, the hinge pin was in two pieces.

(b) It was observed during this operation that the shroud brackets, which are not numbered and were not kept in their correct order when removed, caused considerable lost time through being re-fitted in incorrect locations.

(c) Many of the bolts in the lower skin and in the butt straps were of incorrect length.

(d) 21 bolts in the butt straps and one in the lower skin were not fitted.

(e) The elevator was lifted by rope through the link fittings since the sling was not available.

(f) The four extra men used during the replacement of the elevator were required to assist in the support of the control surface, since the errors in attitude of the mock-up made the full use of the cradle impossible.

## RUDDER AND RUDDER CONTROL BOX DEMONSTRATION

### RUDDER REMOVAL

| ITEM | OPERATION | ATTACHMENT | MEN X MIN ACTUAL | MEN X MIN ESTIMATED |
|---|---|---|---|---|
| 1. | Remove L.H. rudder jack access panel | 114 x 1/4" bolts | 1 x 5 | |
| 2. | Disconnect master bell crank lever from rudder jack. | 1 x 5/8" bolt | 1 x 5 | |
| 3. | Swing rudder 30 to the right and remove link rod bolts from hinge fittings. | 1 x 3/8" bolt<br>4 x 1/2" bolt | | |
| | Swing rudder hard over to the right and remove shrouds in the rudder-fin gap for access to the rudder hinge bolts and link bolts. | 100 x 3/16" bolts | 6 x 20 | |
| 4. | Attach sling for removal of rudder<br>Remove hinge bolts<br>Withdraw rudder | 7 x 5/8" bolts | 6 x 15 | |
| | TOTAL ELAPSED TIME | | | 2 HRS |

### RUDDER CONTROL BOX REMOVAL

| ITEM | OPERATION | ATTACHMENT | MEN X MIN ACTUAL | MEN X MIN ESTIMATED |
|---|---|---|---|---|
| * 5. | Remove 6 rib attachment access panels. | 128 x 3/16" bolts | 2 x 5 | |
| 6. | Attach sling for removal of rudder control box. | | 2 x 5 | |

| ITEM | OPERATION | ATTACHMENT | MEN X MIN ACTUAL | MEN X MIN ESTIMATED |
|---|---|---|---|---|
| * 7. | Remove the rudder jack for access to 4 attaching bolts and remove these four bolts. | 2 x 3/16'' bolts<br>2 x 1/4'' bolts | 1 x 10 | |
| 8. | Remove bolts attaching rudder control box to fin.<br>Lower rudder control box to bench | 368 x 3/16'' bolts | 6 x 52 | |
| | TOTAL ELAPSED TIME | | | 2 Hrs |
| | TOTAL FOR RUDDER AND BOX | | 1hr 35 min | 4 Hrs |

## REMOVAL OF CONTROLS FROM CONTROL BOX

| ITEM | OPERATION | ATTACHMENT | ACTUAL | ESTIMATED |
|---|---|---|---|---|
| 9. | Remove link rods.<br>Remove bolts connecting control rod to bell crank levers.<br>Remove the control rod in sections (NOTE: The rod sections have opposite handed threads at each end).<br>Remove the pivot bolts from the bell crank levers.<br>Remove the bell crank levers from the box. | 5 x 5/8'' bolts<br>1 x 7/8'' +<br>4 x 5/8'' bolts<br><br>5 x 1'' bolts | 3 x 25 | |
| | TOTAL ELAPSED TIME | | 25 min | 1 hr. 25 mins. |

## INSTALLATION OF CONTROLS IN CONTROL BOX

| ITEM | OPERATION | ATTACHMENT | ACTUAL | ESTIMATED |
|---|---|---|---|---|
| 10. | Install the bell crank levers in the box.<br>Install the control rod on the levers, leaving the lock nuts loose.<br>Connect the link rods to the bell crank levers | | | |

## ADJUSTMENT OF THE LINKAGE IN THE CONTROL BOX

| ITEM | OPERATION | ATTACHMENT | MEN X MIN ACTUAL | MEN X MIN ESTIMATED |
|---|---|---|---|---|
| | Position the rudder to the rear of the control box.<br>Connect the rudder to the control box by hinge bolts<br>Connect the master bell crank link rod to the rudder.<br>Adjust the length of the control rod sections successively outward from the master bell crank, to line up the link rods with the connecting holes in the rudder.<br>Fit the bolts and tighten the lock nuts on the control rod.<br>Disconnect the rudder from the control box. | | 3 x 145 | |
| | | TOTAL ELAPSED TIME | 2 hr 25 | 4 hrs. |

## REPLACEMENT OF CONTROL BOX

| ITEM | OPERATION | ATTACHMENT | ACTUAL | ESTIMATED |
|---|---|---|---|---|
| 11. | Sling the control box with the crane and offer up the box to the fin in its correct relative position. | | 6 x 10 | |
| 12. | Connect the box to the fin | | 6 x 62 | |
| *13. | Install the rudder jack | | 2 x 20 | |
| *14. | Replace six fin access panels | | 2 x 20 | |
| | | TOTAL ELAPSED TIME | 1 hr 30 mins | 2 hrs.30 min |

## REPLACEMENT OF RUDDER

| ITEM | OPERATION | ATTACHMENT | ACTUAL | ESTIMATED |
|---|---|---|---|---|
| 15. | Sling the rudder with the crane and offer up the rudder to the rear of the control box | | 6 x 10 | |

| ITEM | OPERATION | ATTACHMENT | MEN X MIN | |
|---|---|---|---|---|
| | | | ACTUAL | ESTIMATED |
| 16. | Connect the rudder hinge bolts and disconnect the sling.<br>Swing the rudder hard over to the right and fit the shrouds.<br>Connect the link rods.<br>Connect the master bell crank lever to the rudder jack and replace the rudder jack access panel | | 6 x 120 | |
| | | TOTAL ELAPSED TIME | 2 hrs. | 2 hrs. |

## AILERON AND AILERON CONTROL BOX DEMONSTRATION

### REMOVAL OF AILERON

| ITEM | OPERATION | ATTACHMENT | MEN X MIN ACTUAL | MEN X MIN ESTIMATED |
|---|---|---|---|---|
| 1. | Remove the aileron shroud brackets as required | 62 x 3/16" bolts | 3 x 9 | |
| 2. | Support the aileron in the fully "up" position | | | |
| 3. | Disconnect the link rods from the aileron | 2 x 11/16" bolts<br>2 x 13/16" bolts<br>3 x 1/2" bolts | 3 x 32 | |
| 4. | Reset the aileron to neutral and place a cradle under it to support the weight. | | | |
| 5. | Withdraw the hinge pin. | | 4 x 23 | |
| 6. | Remove the aileron from the cradle with the crane and place on a bench | | 3 x 12 | |
| | | TOTAL ELAPSED TIME | 1 hr 3 min | 1 hr 30 min |

### REMOVAL OF CONTROL BOX

| ITEM | OPERATION | ATTACHMENT | MEN X MIN ACTUAL | MEN X MIN ESTIMATED |
|---|---|---|---|---|
| 7. | Remove the aileron jack access panel from the underside of the outer wing. | 106 x 1/4" bolts | | |
| 8. | Remove bolt attaching master bell crank to jack | 1 x 7/8" bolt | | |
| 9. | Support aileron control box on cradle | | | |

| ITEM | OPERATION | ATTACHMENT | MEN X MIN | |
|---|---|---|---|---|
| | | | ACTUAL | ESTIMATED |
| 10. | Remove bolts securing the control box to the wing | 400 x 1/4" bolts | 3 x 33 | |
| 11. | Remove the control box from the cradle with the sling and place on trestles. | | 3 x 4 | |
| | | TOTAL ELAPSED TIME | 33 min. | 1 hr 30 min |

REMOVAL OF CONTROLS FROM CONTROL BOX

| | | | | |
|---|---|---|---|---|
| 12. | Disconnect the bolts attaching the link rods to the bell cranks and remove the link rods.<br><br>Remove the pivot bolts from the bell crank levers.<br><br>Disconnect the bell cranks from the control rod (except the master bell crank) and remove the control rod from the control box complete with the master bell crank.<br>Remove the master bell crank lever from the control rod and remove the remaining bell cranks from the box. | 3 x 5/8" bolts<br>3 x 7/8" bolts<br>1 x 3/4" bolts<br>6 x 5/8" bolts<br>1 x 1/2" bolts<br>2 x 5/8" bolts<br>1 x 3/8" bolt<br>2 x 5/16" bolts<br>1 x 7/16" bolts<br>1 x 5/8" bolt | 3 x 20 | |
| | | TOTAL ELAPSED TIME | 20 min | 1 hr 15 min |

INSTALLATION OF CONTROLS IN CONTROL BOX

| | | | | |
|---|---|---|---|---|
| 13. | Fit the bell crank levers to the control box and connect the master bell crank lever to the control rod.<br>Fit the control rod to the bell cranks.<br>Connect the link rods to the bell crank levers | | 3 x 31 | |
| | | TOTAL ELAPSED TIME | 31 min | 1 hr 30 min |

## INSTALLATION OF THE CONTROL BOX

| ITEM | OPERATION | ATTACHMENT | MEN X MIN ACTUAL | MEN X MIN ESTIMATED |
|---|---|---|---|---|
| 14. | Remove the outboard elevator shroud to permit mating of the box to the wing without interference. | | | |
| 15. | Place the control box on the cradle and move the cradle so that the box is in the correct position relative to the wing. | | 3 x 12 | |
| 16. | Fit the control box attachment bolts.<br>Connect the master bell crank lever to the aileron jack | | 3 x 34 | |
| | TOTAL ELAPSED TIME | | 34 min | 2 hrs |

## REPLACEMENT OF THE AILERON

| ITEM | OPERATION | ATTACHMENT | MEN X MIN ACTUAL | MEN X MIN ESTIMATED |
|---|---|---|---|---|
| 17. | Position the aileron on the cradle and move the cradle to align the aileron half-hinge holes. | | 3 x 10 | |
| 18. | Insert the hinge pin<br>Support the aileron in the fully "up" position<br>Connect the link rods to the aileron.<br>Fit the shroud brackets<br>Fit the shrouds. | | 3 x 93 | |
| | TOTAL ELAPSED TIME | | 1 hr 33 min. | 1 hr 30 min |

## ELEVATOR AND ELEVATOR CONTROL MECHANISM DEMONSTRATION

### REMOVAL OF ELEVATOR

| ITEM | OPERATION | ATTACHMENT | MEN X MIN ACTUAL | MEN X MIN ESTIMATED |
|---|---|---|---|---|
| 1. | Support the elevator in the fully "up" position | | | |
| 2. | Remove the bolts from the shrouds and remove the shroud brackets as necessary | 68 x 3/16" bolts | 3 x 9 | |
| 3. | Disconnect the link rods from the elevator | 6 x 13/16" bolts | 3 x 25 | |
| 4. | Re-set the elevator to neutral | | | |
| 5. | Support the elevator on a cradle and remove the bolts securing the hinge to the elevator control box. | 102 x 1/4" bolts | 3 x 32 | |
| 6. | Remove the elevator complete with the hinge, with the aid of the crane and place on trestles. | | 3 x 8 | |
| 7. | Remove the hinge pin | | 2 x 2 | |
| | | TOTAL ELAPSED TIME | 2 hrs | 1 hr 30 min |

### REMOVAL OF THE CONTROL MECHANISM

| | | | | |
|---|---|---|---|---|
| 8. | Remove the elevator control box lower skin and the upper surface access panels | 500 x 1/4" bolts | 3 x 29 | |

| ITEM | OPERATION | ATTACHMENT | MEN X MIN | |
|---|---|---|---|---|
| | | | ACTUAL | ESTIMATED |
| 9. | Disconnect the master bell crank lever from the elevator jack.<br>Disconnect the bell crank levers from the control rod<br><br>Remove the pivot bolts from the bell crank levers.<br>Remove the bell crank levers, starting at the inboard end.<br>Remove the link rods from the bell crank levers | 1 x 7/8" bolt<br><br>5 x 1/2" bolts<br>1 x 1" bolts<br><br>6 x 1" bolts<br><br><br>6 x 7/8" bolts | 3 x 43 | |
| | | TOTAL ELAPSED TIME | 43 min | 2 hrs |

## INSTALLATION OF THE CONTROL MECHANISM

| | | | | |
|---|---|---|---|---|
| 10. | Connect the link rods to the bell cranks.<br>Fit the bell cranks to the box, starting at the outboard end.<br>Connect the bell cranks to the control rod and the master bell crank to the elevator jack. | | 3 x 120 | |
| 11. | Replace the control box lower skin and upper surface access panels. | | 3 x 55 | |
| | | TOTAL ELAPSED TIME | 2 hr 55 min | 4 hrs |

## REPLACEMENT OF THE ELEVATOR

| | | | | |
|---|---|---|---|---|
| 12. | Place the elevator on the mobile cradle using the crane and position it correctly relative to the control box for the attachment of the bolts. | | 3 x 5 | |

| ITEM | OPERATION | ATTACHMENT | MEN X MIN | |
|---|---|---|---|---|
| | | | ACTUAL | ESTIMATED |
| 13. | Fit the attachment bolts at the hinge line. | See item "f" of elevator demonstration observations | 10 x 25 | |
| 14. | Raise the elevator to the fully "up" position for link rod attachment and fitting of the nuts to the hinge bolts | | 3 x 15 | |
| 15. | Connect the link rods. | | 4 x 75 | |
| 16. | Fit the nuts to the hinge bolts. | | 4 x 52 | |
| 17. | Fit the shroud brackets and shrouds. | | 4 x 75 | |
| | | TOTAL ELAPSED TIME | 2 hrs 47 min | 2 hrs 30 min |

| | TESTS | ESTIMATED |
|---|---|---|
| Total elapsed time for rudder, 1 aileron, 1 elevator & control boxes | 20 hrs 54 min | 33 hrs 10 min |
| Total elapsed time for rudder, 2 aileron, 2 elevator & control boxes | 33 hrs 53 min | 52 hrs 25min |

5.2.4 DEMONSTRATION CONCLUSIONS

(a) When the rudder and rudder control box are to be installed, the rudder should be fitted to the control box as soon as the box is secured with sufficient screws to locate it on the fin. This enables the fitting of the shrouds to begin as soon as possible.

(b) When removing the rudder control box, the bottom hinge bracket should be left bolted to the box.

(c)* A design change in the rudder jack mounting area has been made, making it unnecessary to remove the rudder jack for access to the four box-to-spar bolts noted in Item 10 of the rudder demonstration detail.

(d)* Since control box attachment bolts are located only in the lower fin trailing edge area, it is necessary to remove only the four lower access panels on the fin trailing edge.

(e) For ease of removal of the large number of bolts in the lower skins of the control boxes, mechanics should work with power screw drivers while lying flat on their backs on the work stands. In this manner the job is much less fatiguing.

(f) Oildag (O.D. 200) the prescribed lubricant, should be used on the hinge pin as recommended. In the case of these demonstrations, the hinge pins had not been lubricated and this accounted for some of the difficulty of removing the aileron hinge pin. In addition, hexagonal ends on the pins, which will be provided on production aircraft, will further assist the removal of the pin. It is interesting to note here that a proper length hinge pin was inserted and removed from the elevator hinge after the two piece pin had been removed. No trouble was experienced and the total operation was completed in approximately four minutes.

(g) The interference noted between the aileron and elevator was traced to a structural measurement error in the metal mock-up and a further check of the production aircraft geometry proved that no error exists in the design of this area.

(h) To avoid structural damage to the hinge during the mating of the elevator to the control box, the elevator must be positioned accurately and carefully at the correct height.

(i) A design change has been made to rectify the accessibility to the rudder shroud attachment bolts.

(j) The times noted in the "Actual" columns of the demonstration detail sheets are those recorded by the time observers during the demonstrations. The "Estimated" columns contain the times considered to be more representative of a production aircraft based on the shortcomings of the demonstrations as noted in the demonstration observations paragraphs.

(k) The demonstration appeared to prove that all the components dealt with can be removed and replaced without any real difficulty. Whilst it cannot be claimed that all of the parts used were fully representative, it is felt that any major obstacles would have shown up during operations. Since nothing of this nature occurred, it is considered that the RCAF, even with limited equipment, will have little difficulty in carrying out all of operations demonstrated.


FIG. 11
RUDDER & RUDDER CONTROL BOX
IN SITU.

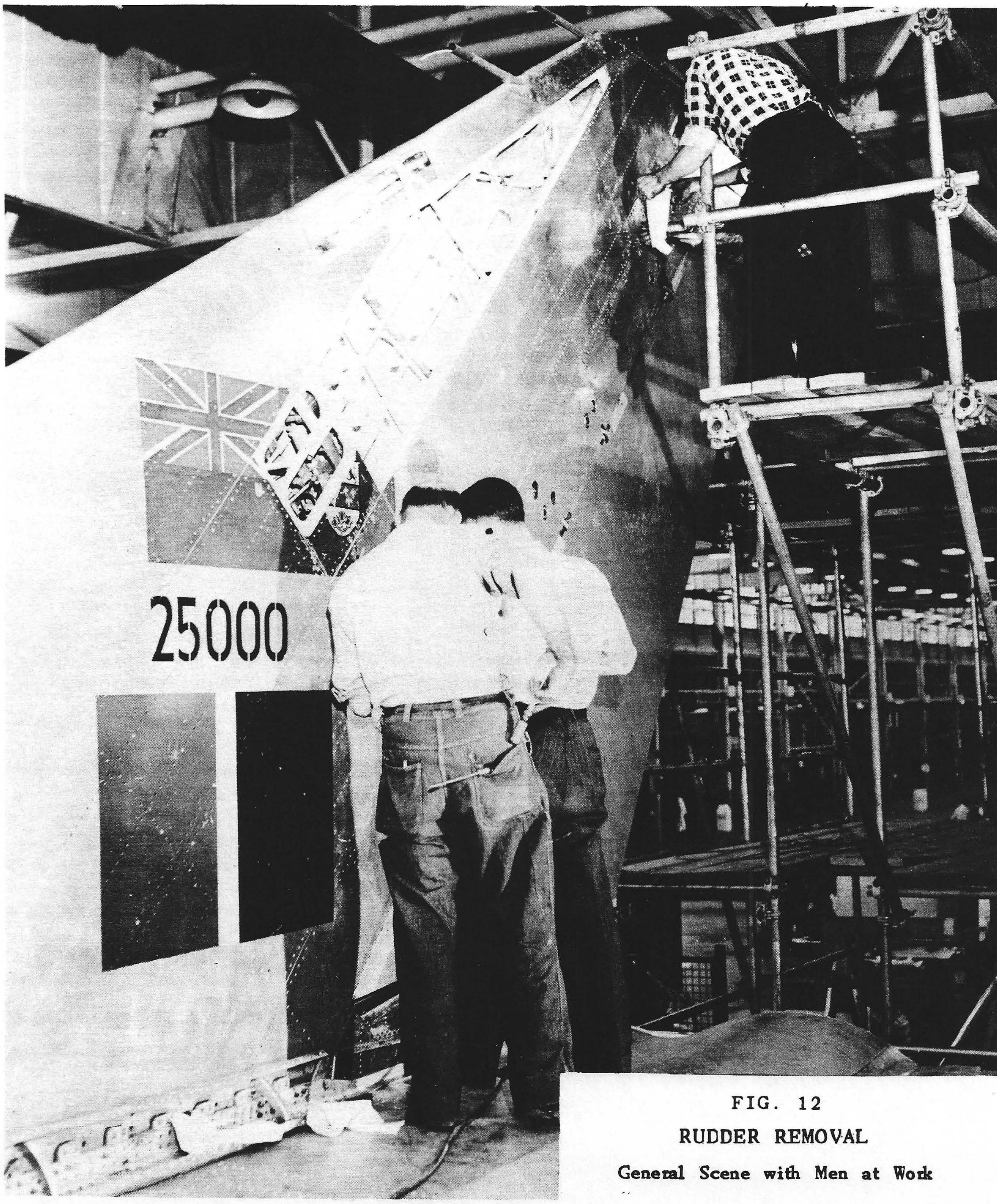



FIG. 12
RUDDER REMOVAL
General Scene with Men at Work


FIG. 13
DISCONNECTION OF RUDDER
FROM CONTROL BOX

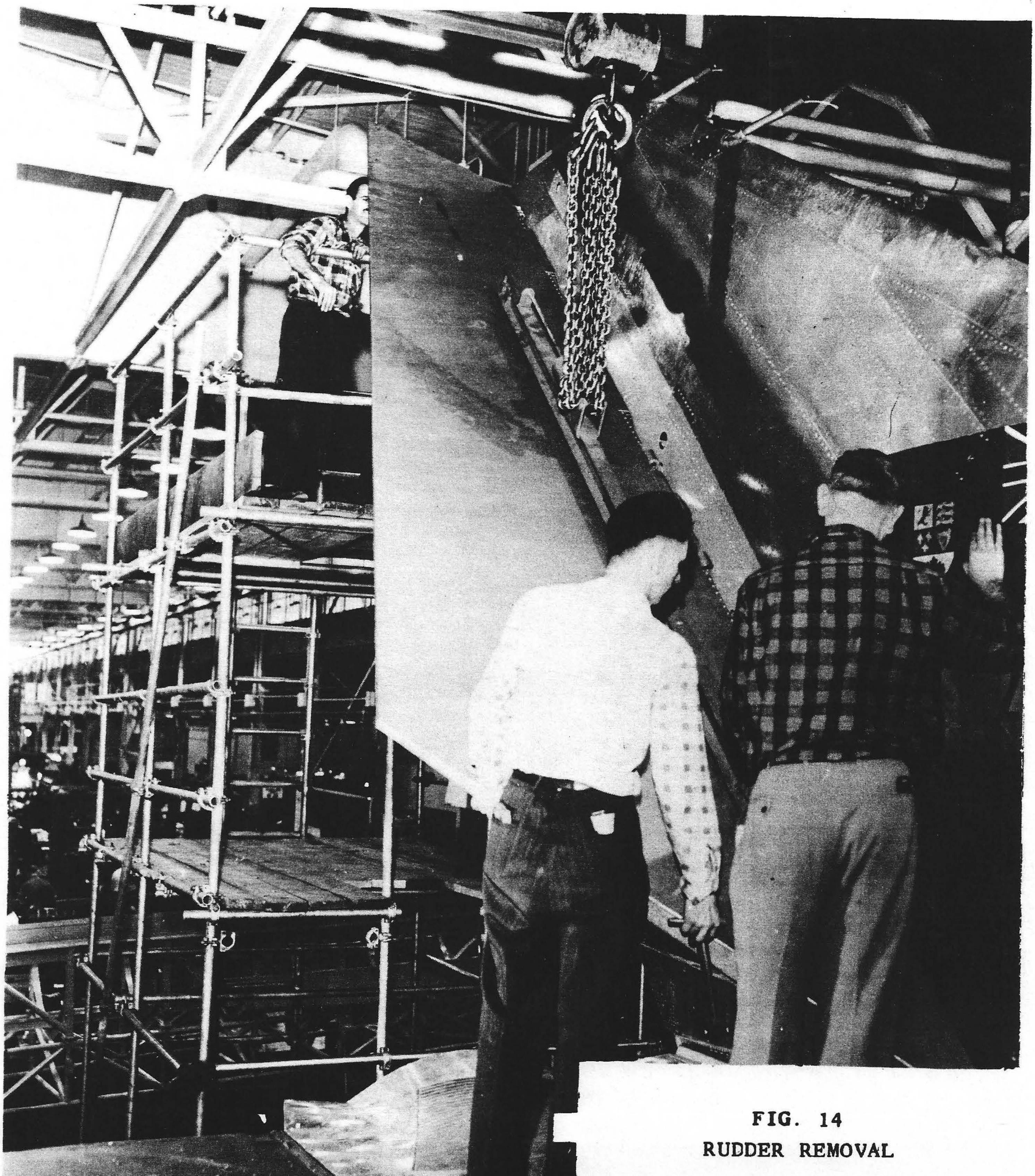


FIG. 14
RUDDER REMOVAL

FIG. 15
RUDDER CONTROL BOX REMOVAL

General Scene with Men at Work

FIG. 16
REMOVAL OF
RUDDER CONTROL BOX

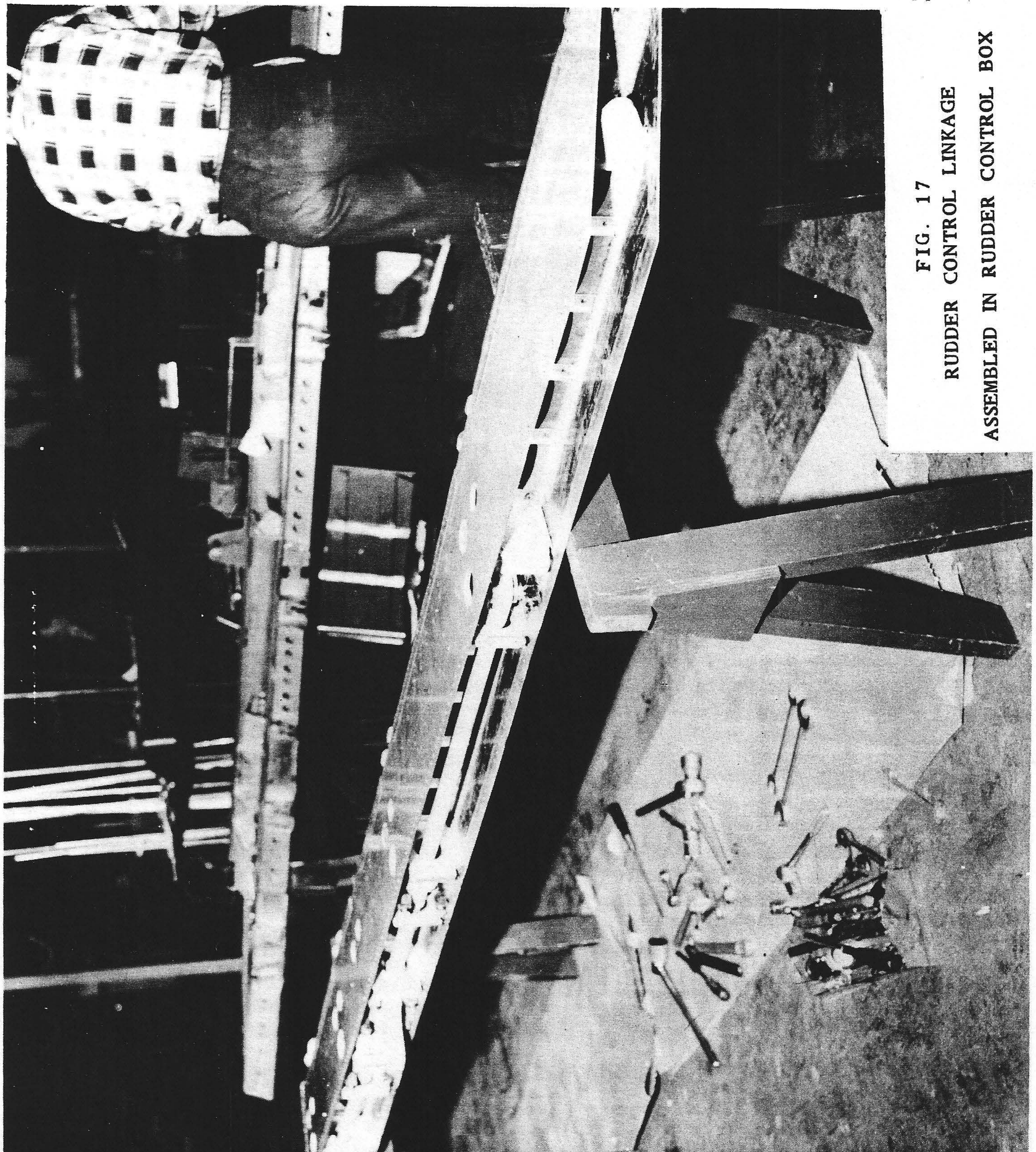


FIG. 17
RUDDER CONTROL LINKAGE
ASSEMBLED IN RUDDER CONTROL BOX

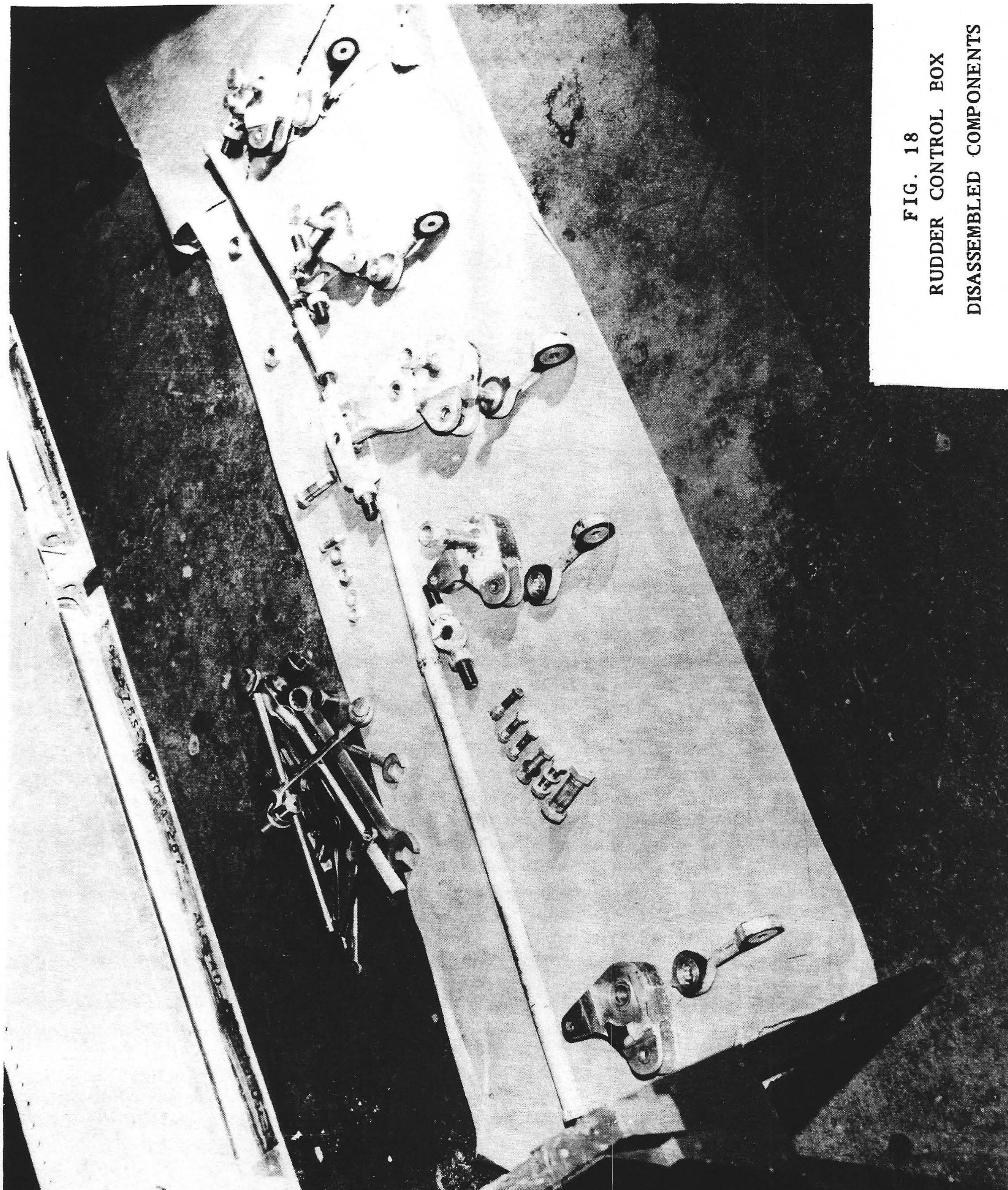


FIG. 18
RUDDER CONTROL BOX
DISASSEMBLED COMPONENTS

FIG. 19
RUDDER CONTROL ROD ADJUSTMENTS

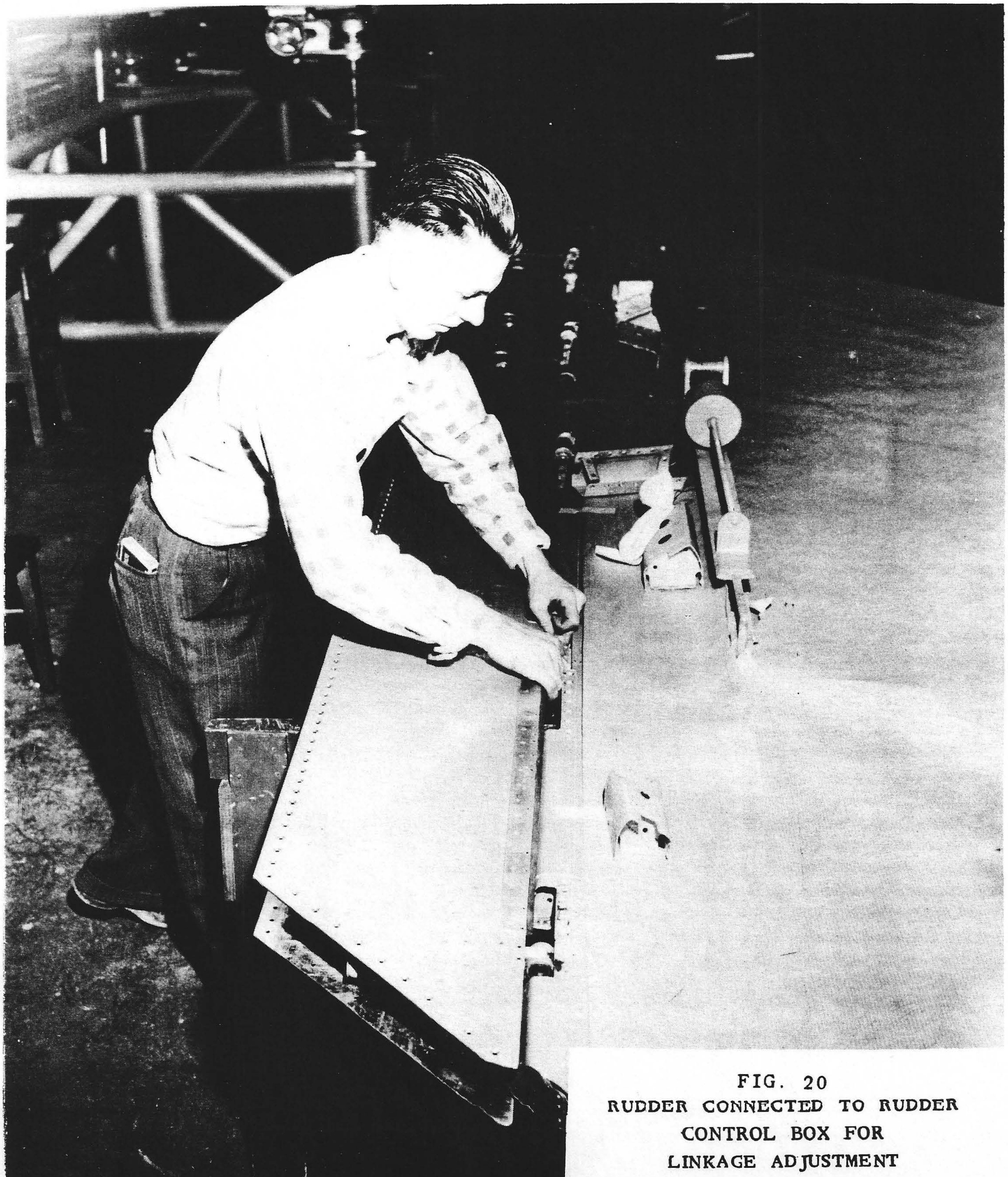


FIG. 20
RUDDER CONNECTED TO RUDDER
CONTROL BOX FOR
LINKAGE ADJUSTMENT

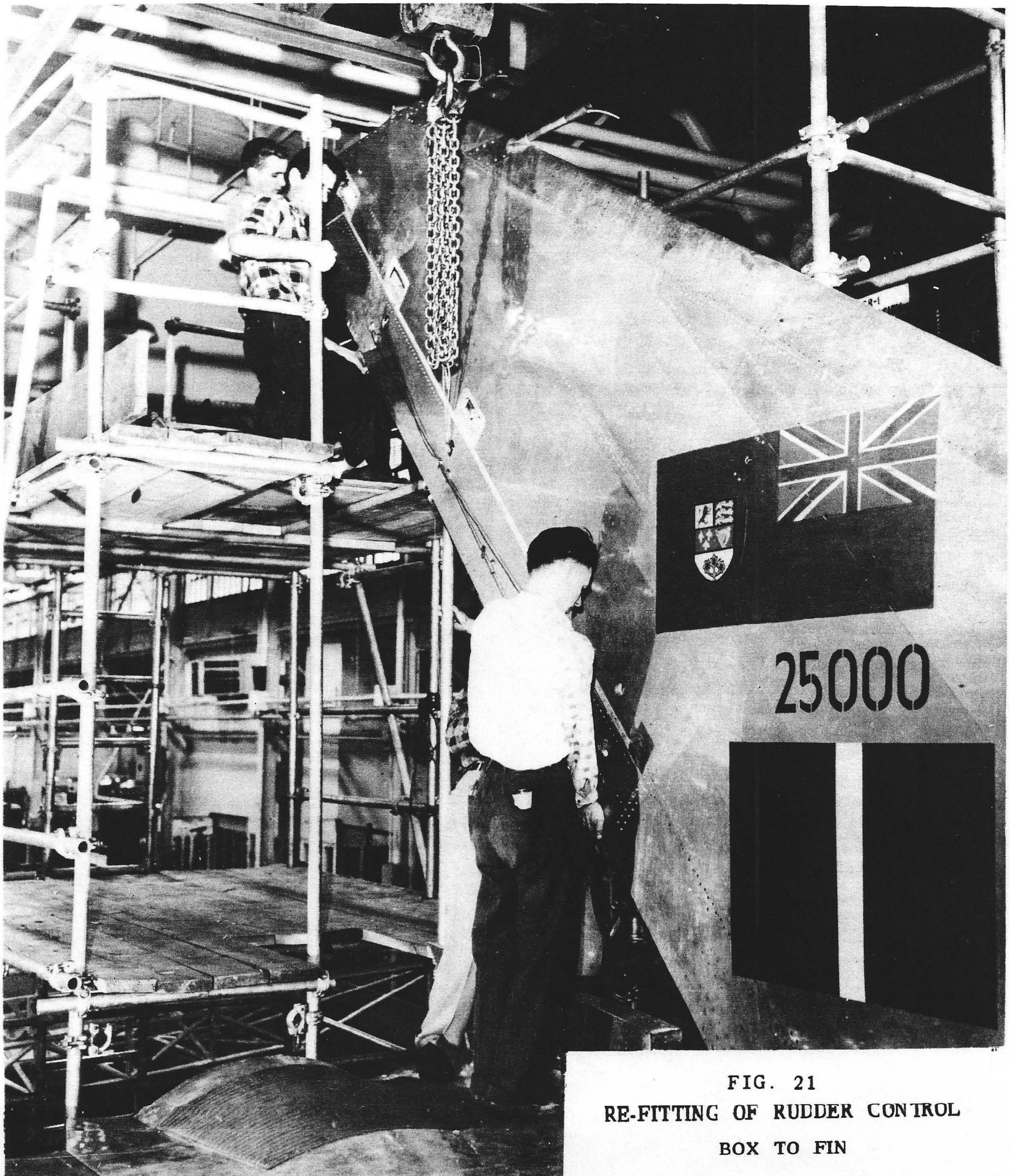



FIG. 21
RE-FITTING OF RUDDER CONTROL BOX TO FIN

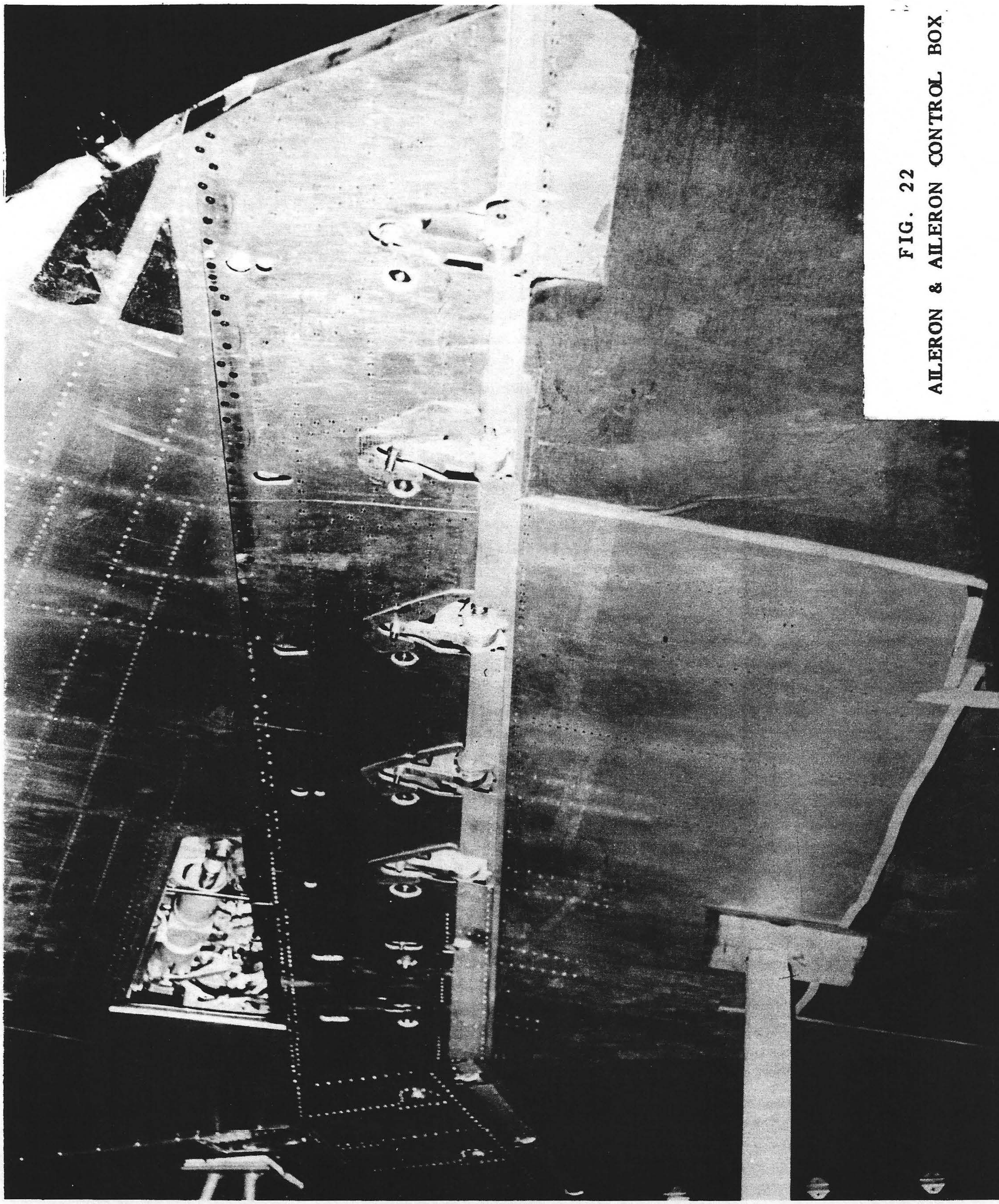


FIG. 22
AILERON & AILERON CONTROL BOX

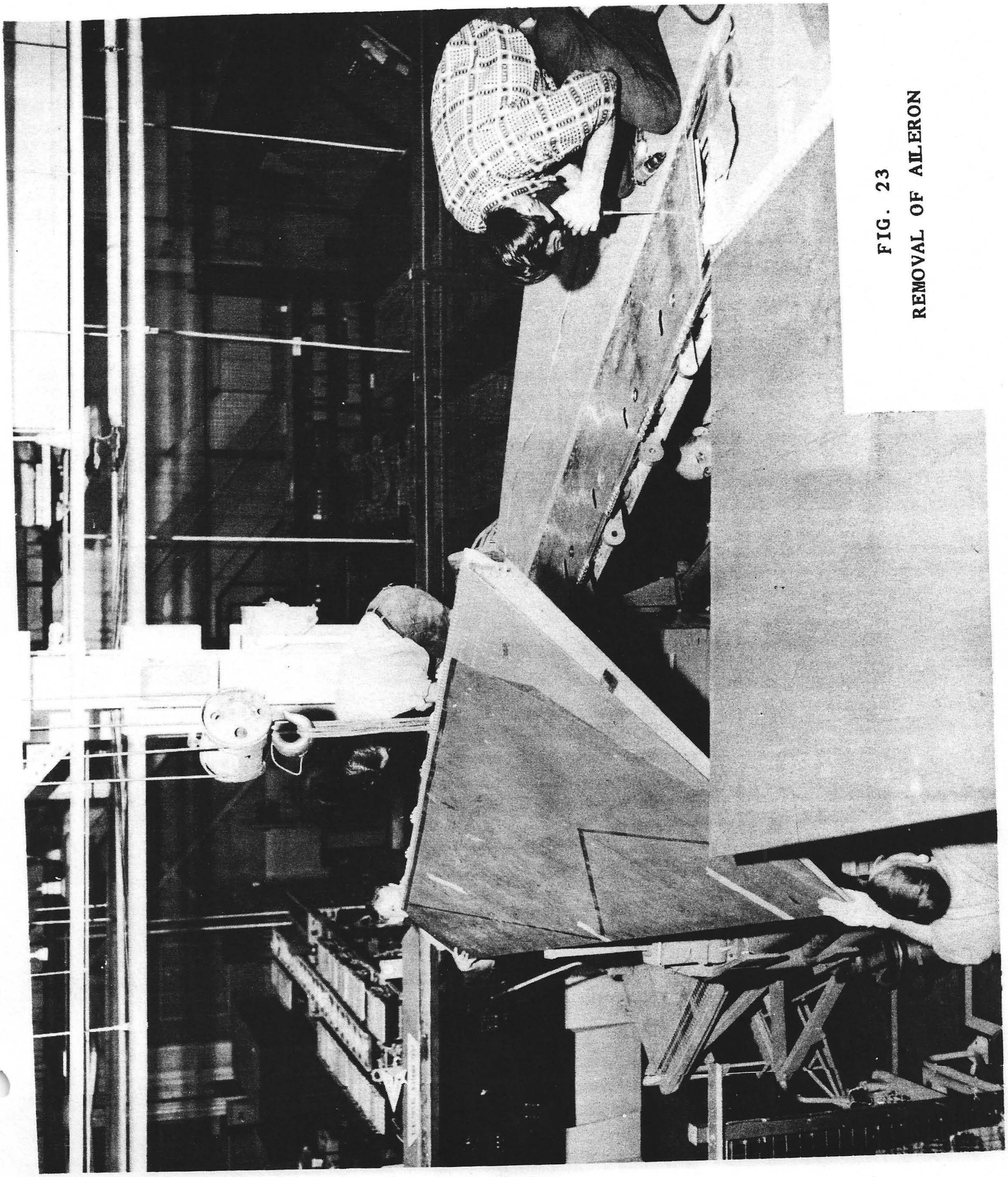


FIG. 23
REMOVAL OF AILERON

FIG. 24

AILERON CONTROL BOX REMOVAL

General Scene with Men at work

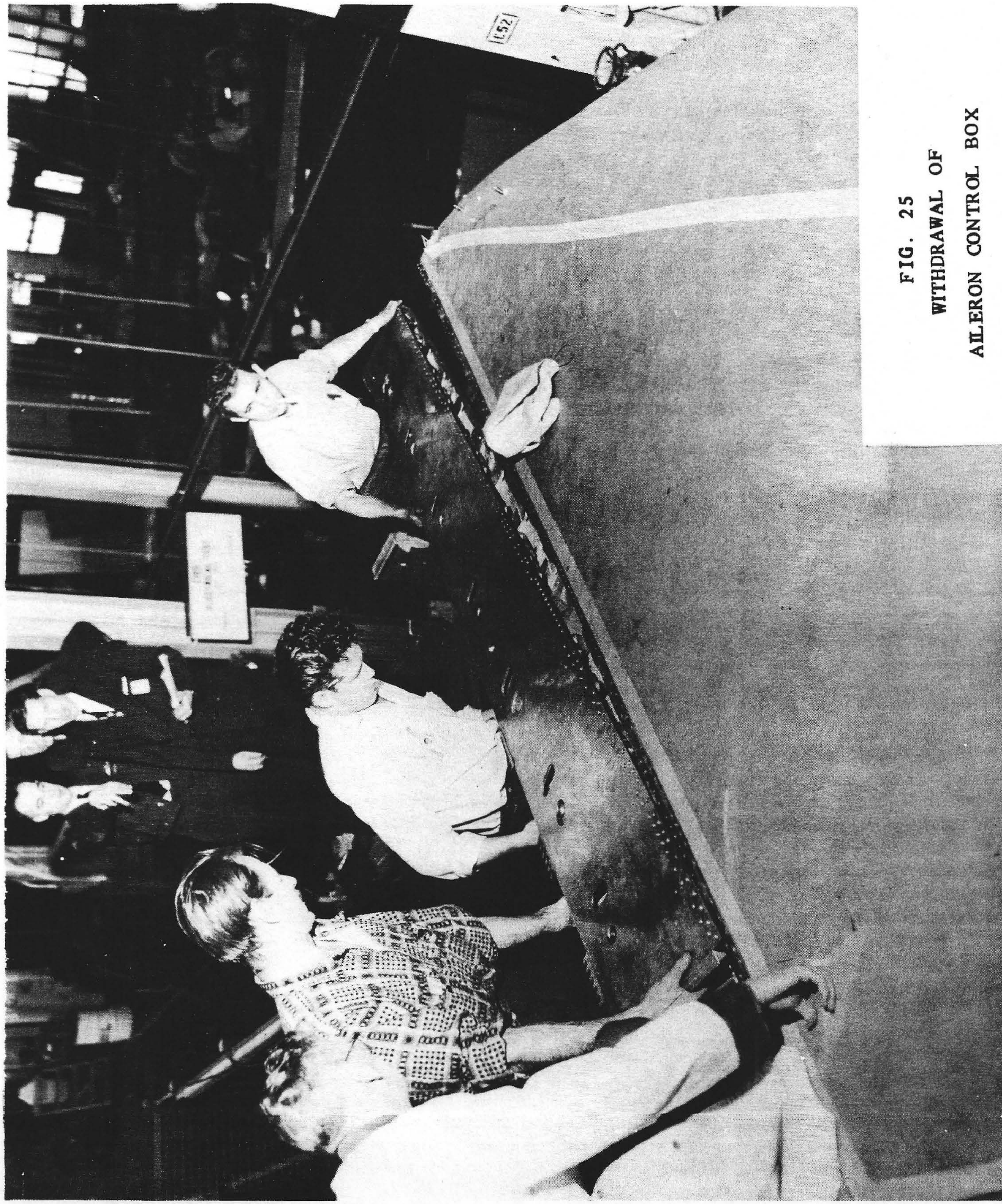



FIG. 25
WITHDRAWAL OF
AILERON CONTROL BOX

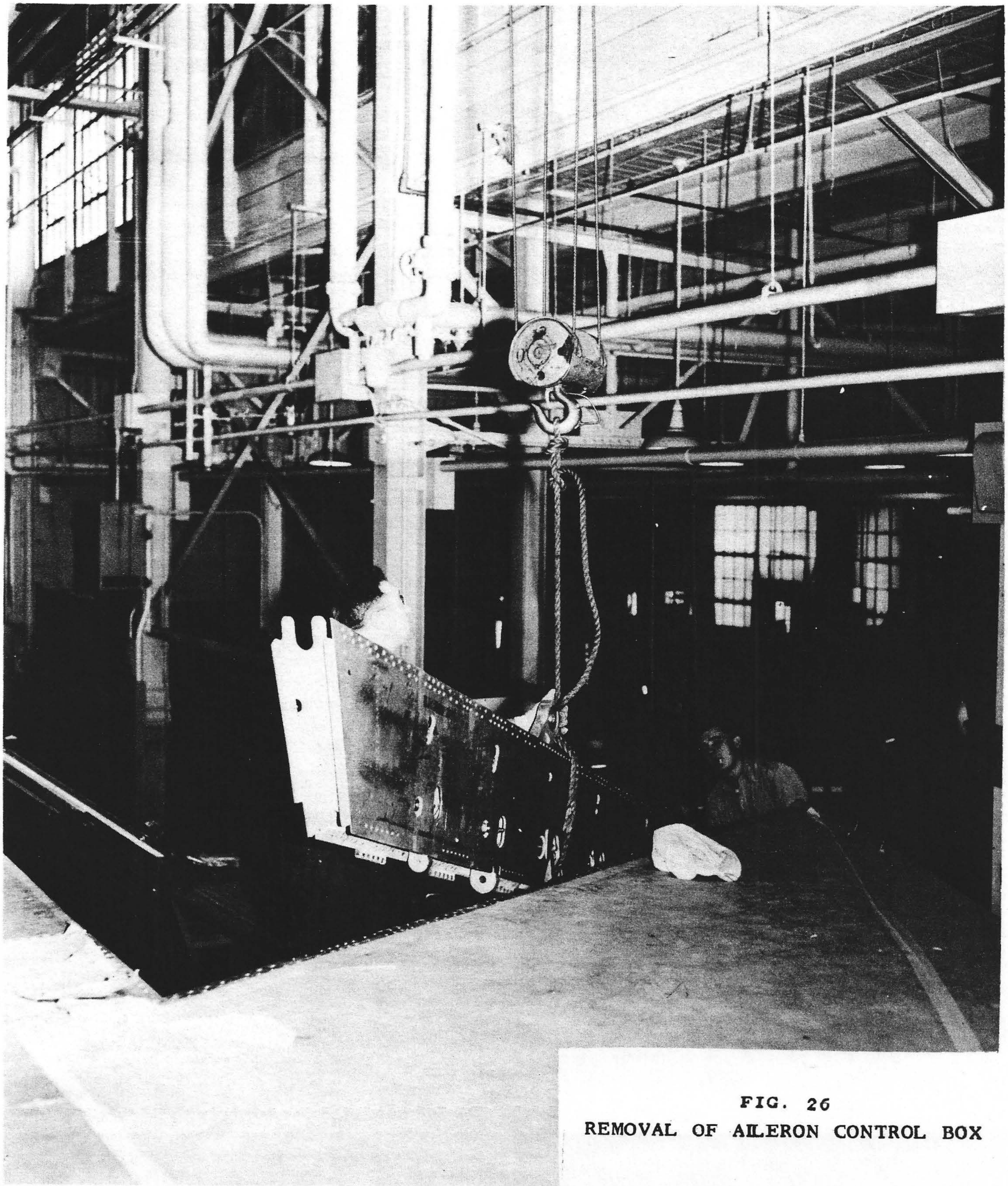


FIG. 26
REMOVAL OF AILERON CONTROL BOX

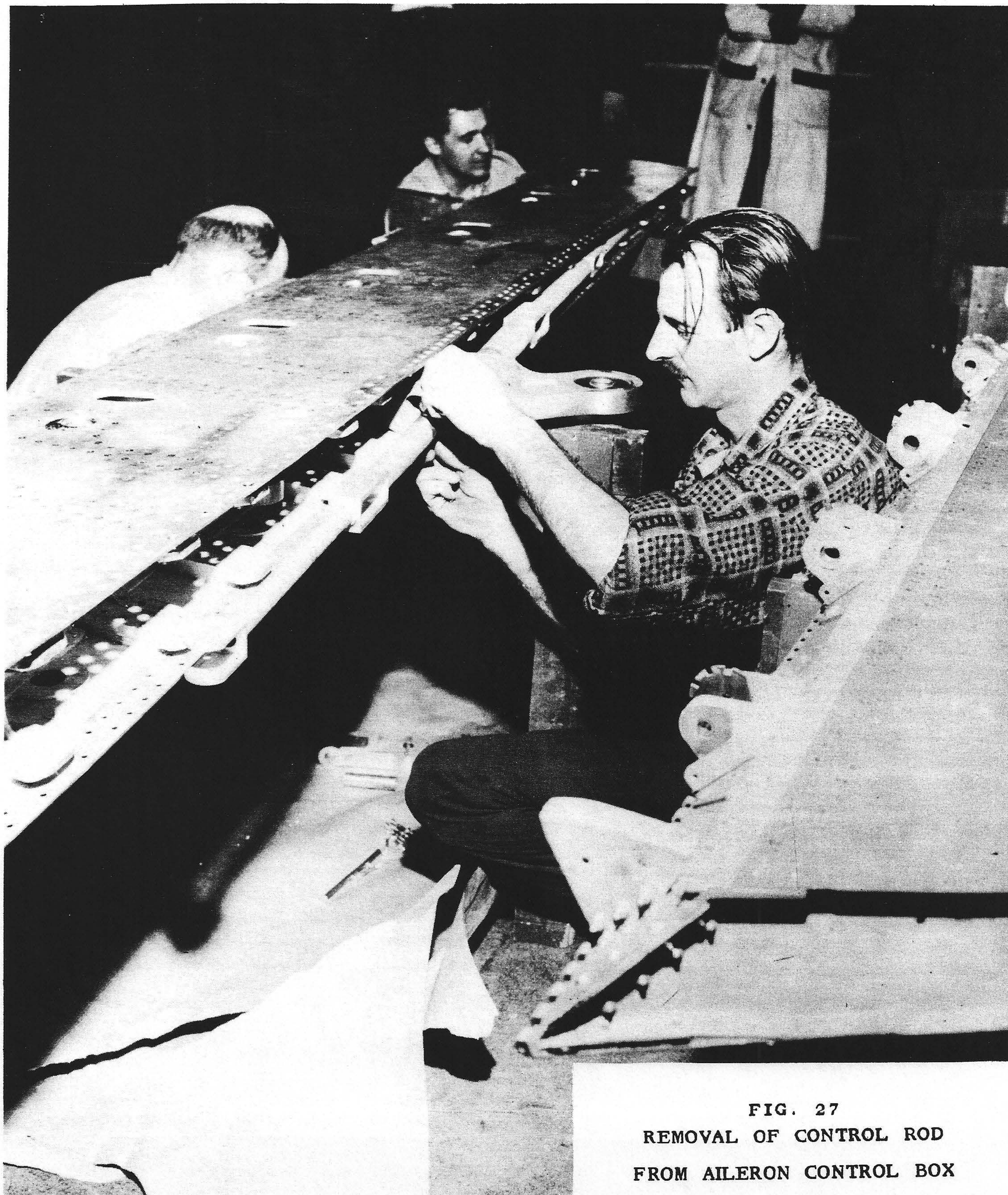


FIG. 27
REMOVAL OF CONTROL ROD
FROM AILERON CONTROL BOX

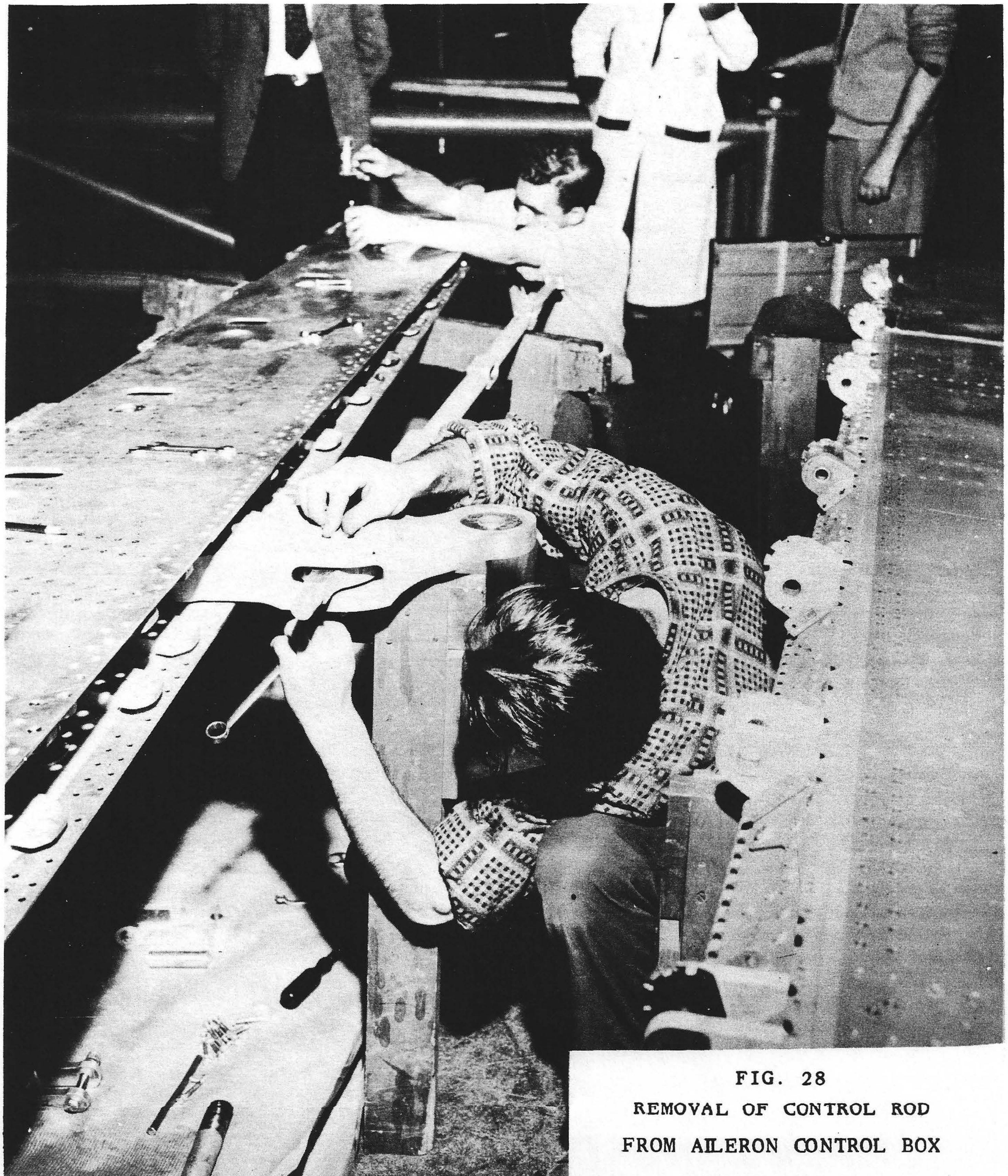


FIG. 28
REMOVAL OF CONTROL ROD
FROM AILERON CONTROL BOX

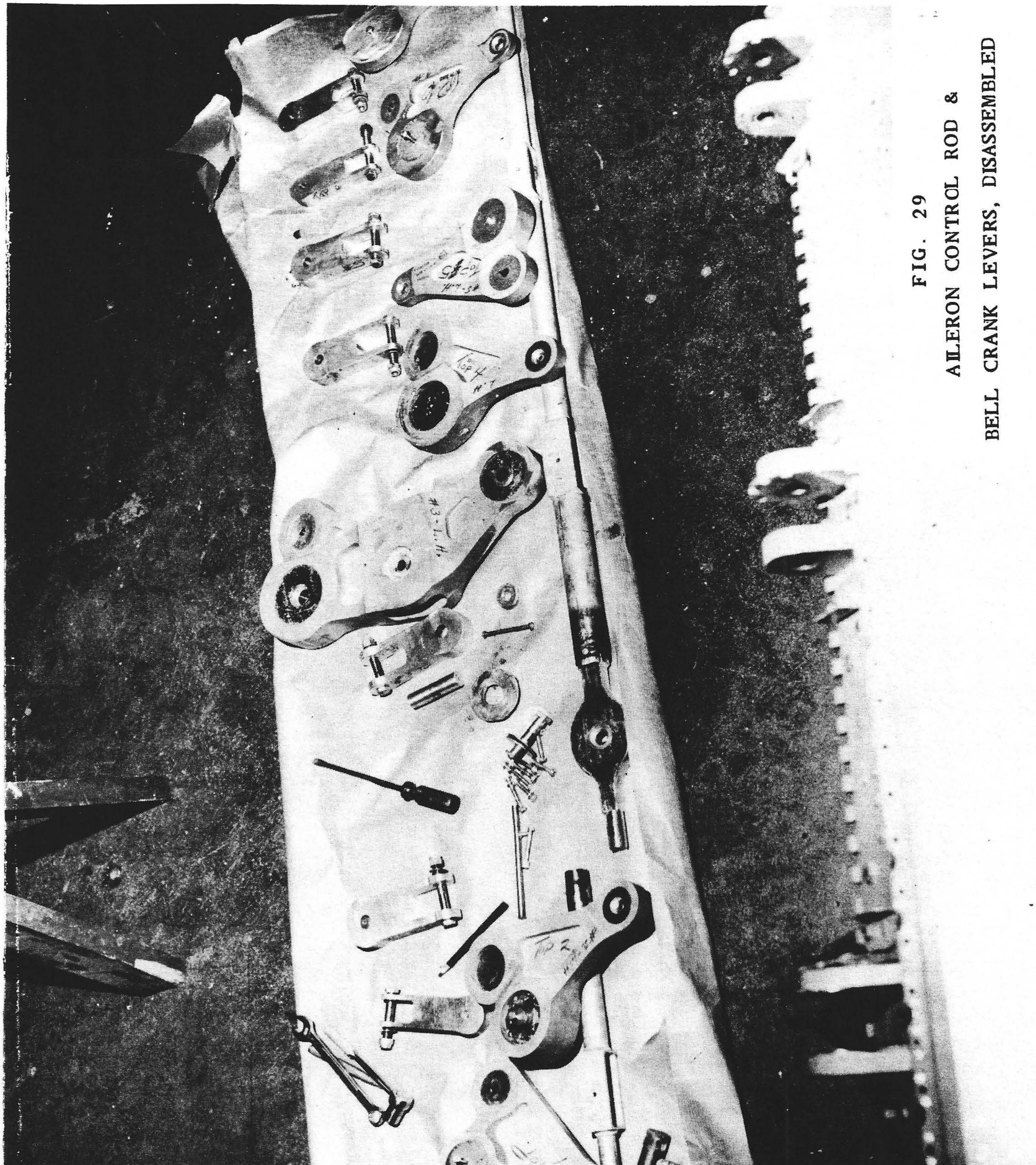


FIG. 29
AILERON CONTROL ROD &
BELL CRANK LEVERS, DISASSEMBLED

FIG. 30

AILERON HINGE PIN INSERTION

FIG. 31
ELEVATOR REMOVAL
General Scene with Men at Work with Power Screw Drivers

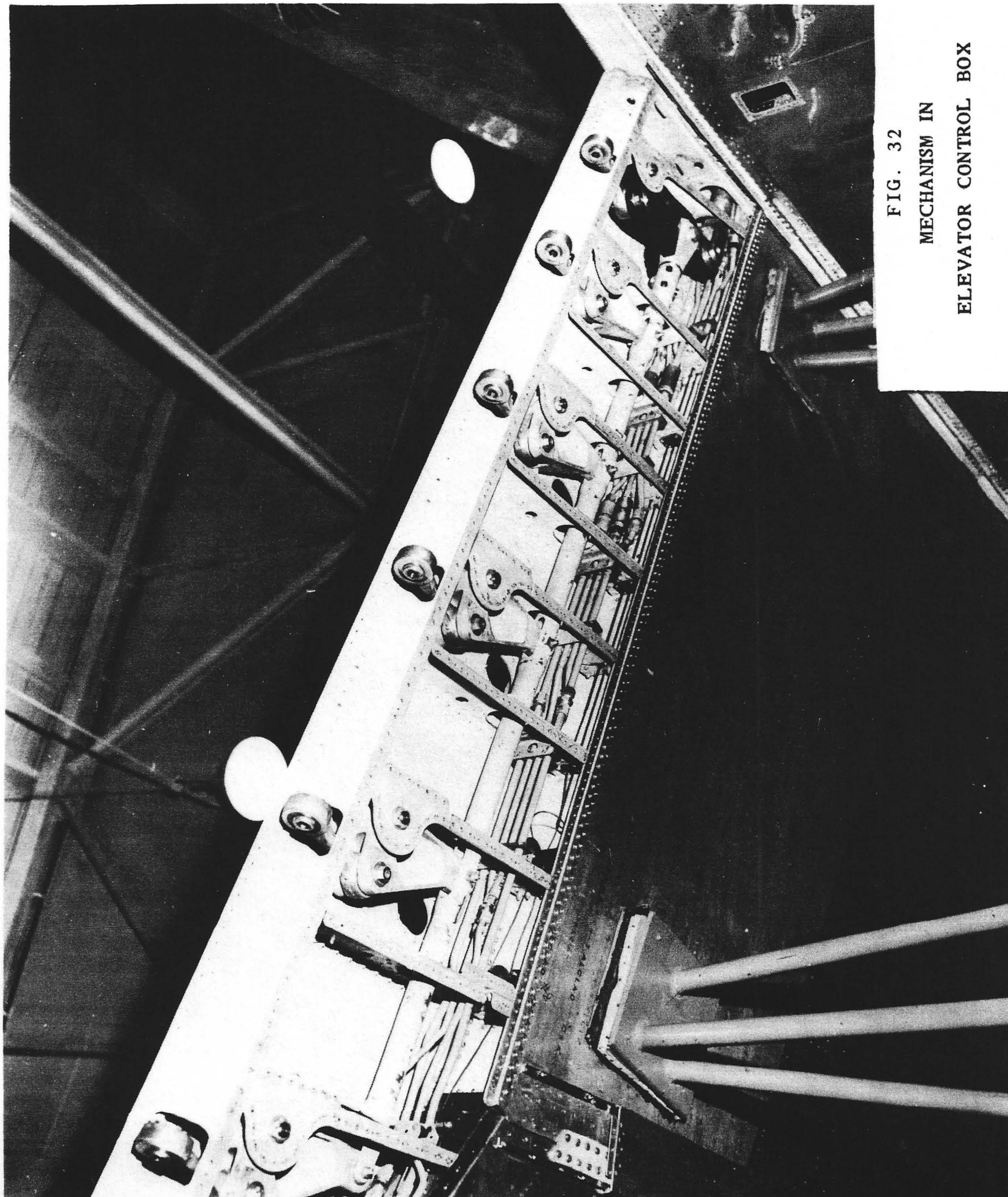


FIG. 32
MECHANISM IN
ELEVATOR CONTROL BOX

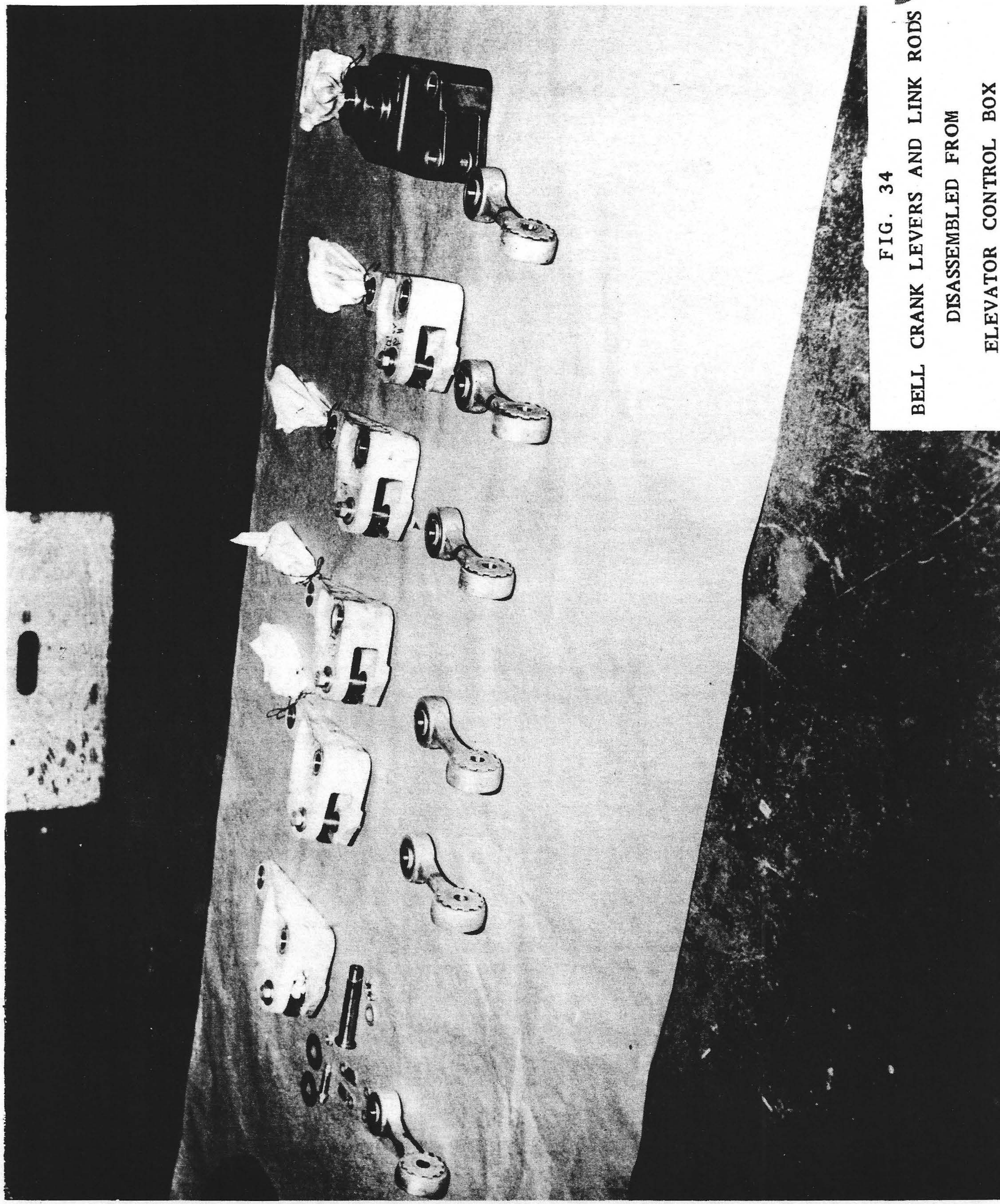


FIG. 34
BELL CRANK LEVERS AND LINK RODS
DISASSEMBLED FROM
ELEVATOR CONTROL BOX

## 5.3 ELEVATOR HINGE PIN REMOVAL

The elevator control surface is attached to the elevator control box by means of a piano hinge. One half of the hinge is bolted to the control box and the other half is bolted to the elevator. In order to remove the control surface it is necessary, due to the inaccessibility of the hinge pin to unbolt the hinge from the control box and remove complete with the control surface. If the control box has to be changed, the replacement box will be provided complete with half hinge installed since the half hinge is not interchangeable with respect to the control box. In this case the hinge pin must be withdrawn to separate the 2 half hinges in the elevator surface.

In the case of the aileron, the hinge pin end is exposed and the pin may be withdrawn to remove the aileron from the aileron box. Again the hinge halves are not interchangeable with respect to the control box or control surface. If an aileron or an aileron box had to be replaced, it would be supplied complete with half hinge. If a control box half hinge were damaged, a new half hinge could be fitted by installing as may screws as possible and drilling the remaining holes oversize. Design have provided for only one such change, allowing an increase in hole size to 5/16" diameter from the nominal 1/4" diameter.

It was felt by the RCAF that the hinge removal might present a problem. Their experience in the past had shown that a fair amount of wear takes place after an accumulation of flying hours, and frequently results in jammed pins.

Particular attention was paid to the performance of the elevator hinge pin on the Bl test rig. At 200 hours of endurance testing, the hinge pin was removed in about 10 seconds by connecting a Power Vane 3/8 inch drill gun model 310,1500 equipped with a Jacobs chuck 34B to the end of the pin. Absolutely no difficulty was experienced in removing the pin and there were no signs of appreciable wear on the pin.

The 200 hours of endurance testing is representative of 200 hours of flying, each hour being representative of a complete flight cycle. In addition another 100 hours of miscellaneous testing has been carried out on the hinge pin.

No trouble is expected with the hinge pin removal.

## 5.4 CONTROL BOX ATTACHMENT FATIGUE TESTS

As mentioned elsewhere in the report, the subject of interchangeability became important when it was thought that it might be necessary to remove the control boxes at fairly frequent intervals in order to service or inspect the control linkages.

As described in paragraph 4.4 the minimum tolerance required on the attachment holes to ensure interchangeability was ± .0075" while the design hole tolerance is ± .002".

A test program was instigated to determine the affect of opening up the tolerance on the control box attachment holes on the fatigue characteristics of the joint. The test was conducted at the Krouse Test Lab in Columbus

Ohio and the samples were supplied by Avro Aircraft. (See Figures 3 and 4). This test occurred in two stages:

(a) Nine sample skin splices, consisting of a .25"-75S76 skin spliced to a .072"-4130 steel sheet (H.T. 150,000) and .091"-75S76 sheet, were fatigue tested to a fully reversed load of 3,000 lbs. (See Photographs).

Three samples employed the use of .250/.252 holes.

Three samples employed the use of .257/.260 holes.

Three samples employed the use of .266/.269 holes.

All samples used NAS334 screws

The results of the first stage of testing were as follows:

Sample 1 (.250/.252) - Ran $2.5 \times 10^6$ cycles with no failure

Sample 2 (.250/.252) - Failed after $1.98 \times 10^6$ cycles through the bolt holes in the skin.

Sample 3 (.250/.252) - Failed at $2.5 \times 10^6$ cycles. Cracked through the butt strip but still supported the load.

Sample 4 (.257/.260) - Failed at 235,000 cycles through bolt holes in skin. The failure was accompanied by considerable heating.

Sample 5 (.257/.260) - Completed $2.5 \times 10^6$ cycles, no failure.

Sample 6 (.257/.260) - Completed $2.5 \times 10^6$ cycles, no failure.

Sample 7 (.266/.269) - Completed $2.5 \times 10^6$ cycles, no failure.

Sample 8 (.266/.269) - Completed $2.5 \times 10^6$ cycles, no failure.

Sample 9 (.266/.269) - Completed $2.5 \times 10^6$ cycles, no failure.

Of these 9 samples, all but number 2 proved to be satisfactory. Number 2

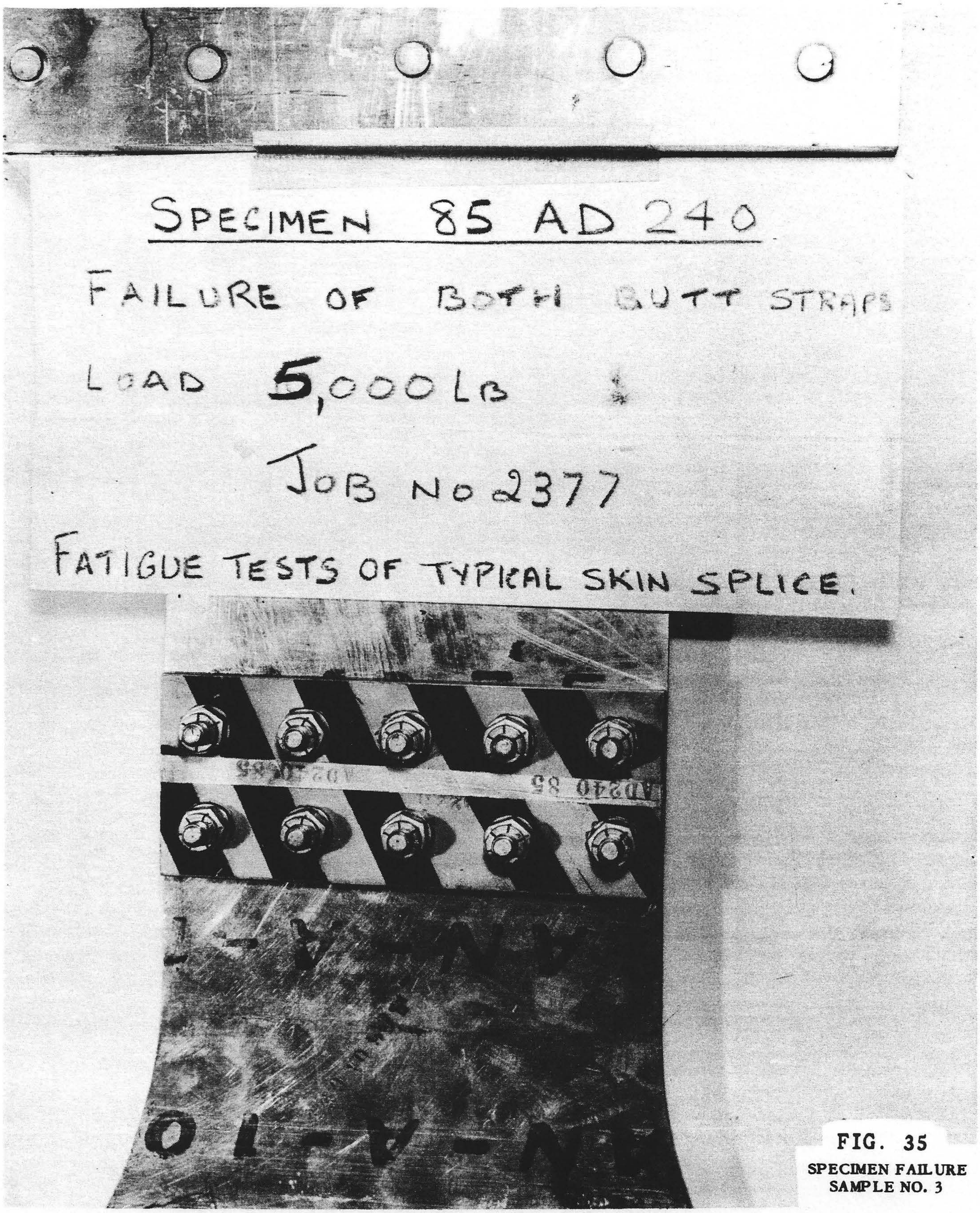



FIG. 35
SPECIMEN FAILURE
SAMPLE NO. 3

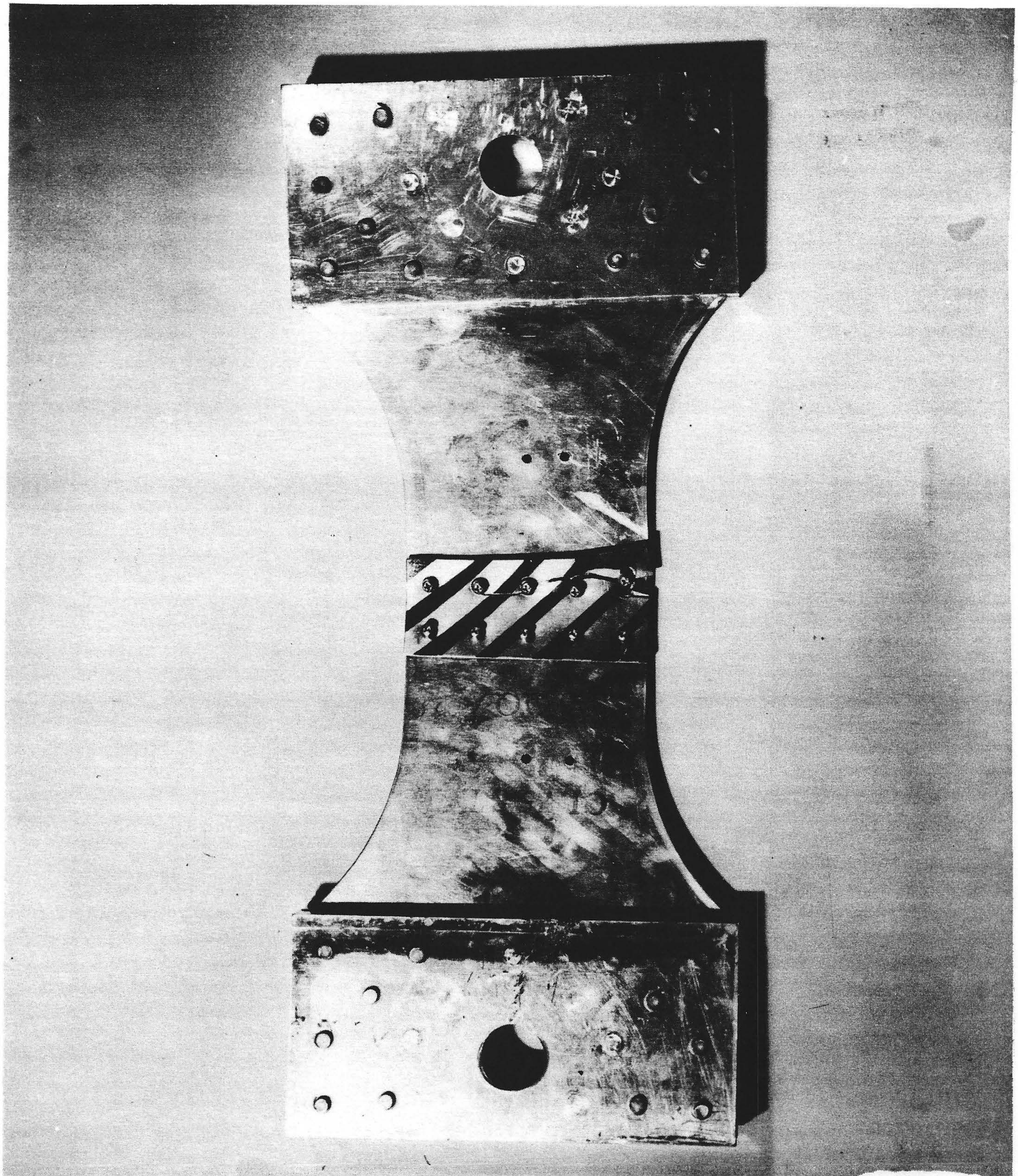


FIG. 36

SPECIMEN FAILURE
SAMPLE NO. 4

failed prematurely and exhibited definite symptoms of fretting corrosion. This indicated that the clamping provided by the bolts was sufficient to stop relative slipping between the plates only at a low load level. Therefore the joint would only have a satisfactory fatigue life at low load level. It was decided that further specimens were required to demonstrate the fatigue life at the higher load levels.

(b) Three sample skin splices, consisting of a .25"-75S76 skin spliced to a .072"-4130 steel sheet (H.T. 150,000) and .091"-75S76 sheet were fatigue tested to a fully reversed load of 4000 lbs.

All three samples employed the use of .266/.269 holes with 1/4" diameter NAS bolts.

The results of the second stage of testing were as follows:

Sample 1 (.266/.269) - 172,000 cycles

Sample 2 (.266/.269) - $1.3 \times 10^6$ cycles

Sample 3 (.266/.269) - 553,000 cycles

Final results of the tests and the test samples have not been received at the time of writing but all samples failed in the skin through the bolt holes and in one case also through the butt strap.

It appears from these preliminary results that it will be impossible to open up the attachment holes and therefore, it will not be possible to ease the problem of achieving interchangeability by this method.

## 6.0 MAINTENANCE CONSIDERATIONS

With respect to the maintenance aspects of the control surfaces and control boxes, two basic philosophies may be considered:

(a) The control boxes, containing inaccessible primary control mechanisms, could be considered to be in the same category as an engine. Based on exhaustive reliability tests completely representative of actual flight conditions, a safe overhaul life could be established. At a certain number of specified operating hours the boxes would then be removed for inspection and overhaul. If test results, backed up by a reasonable amount of development flying hours, so indicate, it is reasonable to expect that the control boxes complete with control mechanisms could achieve a safe life equal to the life of the complete aircraft.

OR

(b) Since a mechanical failure in the primary control system of the aircraft will almost certainly be disastrous, and since test results cannot always accurately anticipate the reliability of a system in actual service, it would be necessary to carry out a detailed inspection of all the units of the control system in the control box at fairly frequent intervals. This might occur at 25, 50, 100 or 150 hours intervals. Depending upon experience, this inspection period could be extended.

### 6.1 FACTORS LEADING TO DECISION REGARDING THE MAINTENANCE POLICY

6.1.1

The results of the test program are discussed in detail in Chapter 5 of this report.

To date, the test program has not reached the point where it can guarantee that the various bellcrank bearings have sufficient reliability to preclude the removal of the control boxes for frequent periodic inspection. It is obvious, of course, that satisfactory reliability must be obtained, or a design change will have to be carried out. However, whether the overhaul life would have to be 25, 50, 100 or 150 hours, is still to be determined.

6.1.2

The aileron and rudder control boxes must be removed in order to carry out an adequate inspection of the control linkages and bearings.

6.1.3

The removal of the hinge pin is not expected to present a problem. Tests showed that it could be removed quite easily with a 3/8" diameter shop air gun after 200 hours of endurance testing.

6.1.4

The test program indicated that is is unlikely that the interchangeability problem may be alleviated, by opening up the control box skin attachment holes. Therefore, the degree of interchangeability that will eventually be achieved, is dependent upon the success of the tooling methods and can only be fully proven on the first few ARROW I aircraft.

## 6.2 MAINTENANCE POLICY DURING FLIGHT DEVELOPMENT PROGRAM AT AVRO

From the above mentioned facts, choice (b) is selected as the basic maintenance philosophy for the rudder, aileron and elevator control boxes for the first stage of the ARROW I flight development program.

During this period, it is not at present intended to remove the control boxes for the specific purpose of inspecting the control linkages and bearings at intervals less than 50 hours. This is mainly because the control system has been tested in the B-1 rig under test conditions which are representative of actual flight conditions, with the exception of high temperature. The control linkages have already demonstrated satisfactory reliability for 200 hours of endurance testing and it is planned to carry on the endurance testing when the aileron and rudder systems are added to the B-1 rig.

However, it is expected that during the development program, it will be necessary to remove the control boxes for various reasons and at that time, the linkages and bearings may be inspected.

The duty cycle to which the elevator control system was subjected on the B-1 rig was based on the best available data at the time.

During the initial flights of the first ARROW I aircraft, it is intended to verify the duty cycle by measuring the control surface loading and rates of movement. Frequency response tests and backlash test will also be carried out during this phase, which will indicate to a certain extent the condition of the control linkages. Details of these tests are as follows:

Frequency Response Test

(a) In the case of elevators and ailerons, a sinusoidal input will be applied to the stick up to 10 c.p.s. The phase and amplitude of the surface motion will be recorded, also the differential servo motion (which should be constant) and the valve motion will be recorded as a continuous trace.

(b) With a constant input to the parallel servo (to hold the input in a fixed location) a sinusoidal input will be applied to the differential servos up to 10 c.p.s. The phase and amplitude of the surface motion will be recorded. The valve motion and parallel motion will be recorded.

(c) When testing the aileron system as described in (a) and (b), the rudder motion, force and amplitude will be recorded along with valve and differential servo motion.

Backlash Tests

The backlash in each surface will be measured at the trailing edge. The surface will be moved up and down against an energized jack.

## 6.3 OPERATIONAL MAINTENANCE

When the aircraft goes in operational service, the removal frequency of control boxes will depend upon experience gained during the development stage.

Three courses of action are available for maintaining the control system linkages in the control boxes.

(a) After a recommended number of flying hours, remove the rudder and aileron boxes, and the bottom skin of the elevator box, remove the control mechanism, inspect, and replace if serviceable. This would ground the aircraft while the individual control units were being carefully inspected on the bench for signs of wear and deterioration.

OR

(b) After a recommended number of flying hours, remove the rudder and aileron boxes, the bottom skin of the elevator and remove the control mechanism. Replace the used control units with new spare ones and replace the control boxes and bottom skin of the elevator box.

This would eliminate the inspection time on the control units and the possibility of re-installing parts that might be approaching the wear-out point.

OR

(c) At a recommended number of flying hours, remove the complete rudder, aileron and elevator control boxes and replace with new or overhauled spare boxes complete with control units. This method requires complete interchangeability of control boxes but eliminates time required to remove and replace control units and the inspection time.

If complete interchangeability of control boxes is achieved, item (c) is obviously the best maintenance procedure. This method essentially considers the control box as a lifed item similar to an engine. ?

If complete interchangeability is not achieved, item (b) will be recommended for the most efficient squadron maintenance procedure. Not Eng

6.3 MAINTENANCE SCHEDULE

The following tables include information extracted from the ARROW I

Preliminary Maintenance Schedule pertaining to the maintenance procedures for the rudder, ailerons and elevator control linkages installed in the control boxes. These procedures will apply for the ARROW 1 and ARROW 2 aircraft allocated to the flight development program at Avro.

## 6.4 MAINTENANCE PROCEDURES

The method of removing and replacing the control surfaces and control boxes for inspection and overhaul purposes is described in detail in Chapter 5.0 paragraph 5.2. The frequency of removal is described in the Maintenance Schedule.

## FLYING CONTROLS-MECHANICAL INSPECTION - 50 HOUR

| AREA | ITEM | LOCATION | OPERATION | EQUIPMENT REQUIRED | TIME (Men x Min.) |
|---|---|---|---|---|---|
| INNER WING | Elevator Control Box | Bolted to main spar of inner wing (REAR?) | 1. Remove elevator control surface.<br>Remove bottom skin of elevator box.<br>Remove complete elevator control system with exception of long push-pull rod.<br><br>2. Inspect links and bellcranks for signs of fatigue, wear, or overheating.<br>Inspect bearings for wear, deterioration, and record clearances.<br>Check dust caps for signs of springing.<br>Remove excess grease from inside control box.<br>Check pivot bolt bearing housing in box for security.<br>Check bellcrank pickup points on push-pull rod for signs of wear.<br>Check clearance of all flying control parts on adjacent structure. | 1. Hydraulic Test Machine Trailer<br><br>2. B4 Stand<br><br>3. Elevator Sling<br><br>4. Elevator box sling<br><br>5. Universal stand for removing elevators and control boxes. | 6 men x 18 hrs (includes replace't Time)<br><br>2 men x 8 hrs |
| | | | | TOTAL | 8 men x 26 hrs. |

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| AREA | ITEM | LOCATION | OPERATION | EQUIPMENT REQUIRED | TIME (Men x Min.) |
|---|---|---|---|---|---|
| OUTER WING | Aileron Control Box | Bolted to main spar of outer wing [REAR] | 1. Remove aileron control surface, Remove aileron control box.<br>Remove complete aileron control system from box.<br><br>2. Inspect links and bellcranks for signs of fatigue, wear or overheating.<br>Inspect bearings for wear, deterioration and record clearances.<br>Check dust caps for signs of springing.<br>Remove excess grease from inside control box.<br>Check pivot bolt bearing housing in box for security.<br>Check bellcrank pickup points on push-pull rod for signs of wear.<br>Check clearance of all flying control parts on adjacent structure. | 1. Hydraulic Test machine Trailer<br>2. B4 Stand (2)<br>3. Aileron Sling<br>4. Aileron Box Sling<br>5. Universal stand for removing aileron and aileron box (4)<br><br>TOTAL | 3 men x 18 1/2 hrs.<br>(Includes replace t Time)<br><br>5 men x 261/2 hrs |

| AREA | ITEM | LOCATION | OPERATION | EQUIPMENT REQUIRED | TIME (Men x Min.) |
|---|---|---|---|---|---|
| FIN AND RUDDER | Rudder Control Box | Bolts to Rear Fin Spar | 1. Remove rudder control surface.<br>Remove rudder control box.<br>Remove complete rudder control system from box<br><br>2. Inspect links and bell-cranks for signs of fatigue, wear or over-heating.<br>Inspect bearings for wear, deterioration and record clearances.<br>Check dust caps for signs of springing.<br>Remove excess grease from inside control box. | 1. Hydraulic Test Machine Trailer<br><br>2. Fin Servicing Stand<br><br>3. Rudder Sling<br><br>4. Rudder Box Sling | 6 x 27 hrs 50 min (includes Replace't Time)<br><br>2 men x 4 hrs |
| | | | | TOTAL | 8 men x 31 hrs 50 min |

## FLYING CONTROLS-MECHANICAL INSPECTION - 12 1/2 HOUR

| AREA | ITEM | LOCATION | OPERATION | EQUIPMENT REQUIRED | TIME (Men x Min.) |
|---|---|---|---|---|---|
| INNER WING | Elevator System | | | | |
| | Bellcrank Pivot Bolts | Elevator control box<br>Grease nipples unobstructed on upper and lower skin | Lubricate | Greasing Assembly<br>Grease gun,<br>Alemite #314150<br>nozzle 1/8 N.P.T.<br>nipple & tee<br>#7573-6 Tecalemite<br>1/8 N.P.T.<br>Relief Valve -<br>160 p.s.i. | |
| | Control Rod Bell-crank Bearings | Elevator control box<br>Accessible through access panels in upper skin | Lubricate | | |
| | Master Bellcrank Jack Rod Bear-ing | Elevator control box<br>Accessible through access panels in upper skin | Lubricate | | |
| | Link Rod Bear-ings | Elevator Control box<br>Both ends of rod accessible with elevator in Max. "up" position | Lubricate | | 3 x 60 |

| AREA | ITEM | LOCATION | OPERATION | EQUIPMENT REQUIRED | TIME (Men x Min.) |
|---|---|---|---|---|---|
| OUTER WING | <u>Aileron System</u> | | | | |
| | Bellcrank Pivot Bolts | Aileron control box<br>Grease nipples unobstructed on upper and lower skin | Lubricate | | |
| | Control Rod Bellcrank Bearings | Aileron control box<br>Accessible through access panels in lower skin | Lubricate | | |
| | Master Bell-crank Jack Rod Bearings | Aileron box<br>Accessible through aileron jack access panel | Lubricate | | |
| | Link Rod Bearings | Aileron control box<br>Accessible with link rod fairings removed. | Lubricate | | 5 x 60 min |
| FIN AND RUDDER | <u>Rudder System</u> | | | | |
| | Bellcrank Pivot Bolts | Rudder control box<br>Grease nipples unobstructed on skin | Lubricate | | |
| | Control Rod - Bellcrank Bearings | Rudder control box<br>Accessible through access plugs on left and right hand side of skin | Lubricate | | |

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| AREA | ITEM | LOCATION | OPERATION | EQUIPMENT REQUIRED | TIME (Men x Min.) |
|---|---|---|---|---|---|
| | Master Bellcrank - Jack Rod Bearings | Rudder control box Accessible through rudder jack access panel. | Lubricate | | |
| | Link Rod Bearings | Rudder control box Rudder rod bearing accessible with rudder turned to right side. The bellcrank end bearing accessible through access plugs on L.H. skin. | Lubricate | | |
| | | | | | 3 x 50 min |
| | | | Estimated for | Total Lubrication | 11 x 60 min (1 hr) |

NOTE - Lubrication man hours are based on establishing one hour for carrying out this operation. If the lubrication time can be extended, for example, to 2 hours the number of men involved would be halved.

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