ORION

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ORION

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FRONT AND BACK COVERS Formed in 1946 as Reserve Unit VPB-907 and called to active duty in 1951, Patrol Squadron Nineteen has most thoroughly "learned a trade and seen the world" as the recruitment slogans promised. VP-19 learned the Patrol business, consecutively, in P2V-2's, P4Y-2's, P2V-5's, P2V-7's, and P-3 Orions. Starting with their first deployment with P4Y-2's to Japan in 1951 — where they picked up the name "Big Red" by dropping big red flares to light big Red Korean targets for Marine attack squadrons — they have perennially shuttled from training-to-practice-to-a new deployment, scouring the far reaches of the Pacific.

If VP-19 veterans did not invent the phrase "stay loose and breathe through your nose," their busy schedule must surely have shown the wisdom of this nearly universal military axiom. The perpetual practice has taught VP-19 to adapt both quickly and well to new equipment in new surroundings. And with their Lockheed Neptunes they earned the 1959 Captain Arnold Jay Isbell Trophy for their overall excellence in the arts of Anti-Submarine Warfare.

Last December, just 5 months after first crew began familiarization training with a new-model aircraft for the fifth time in the squadron's brief history at yet another new base (NAS MOFFETT FIELD), Patrol Squadron 19 became fully operational with 9 new Orions.

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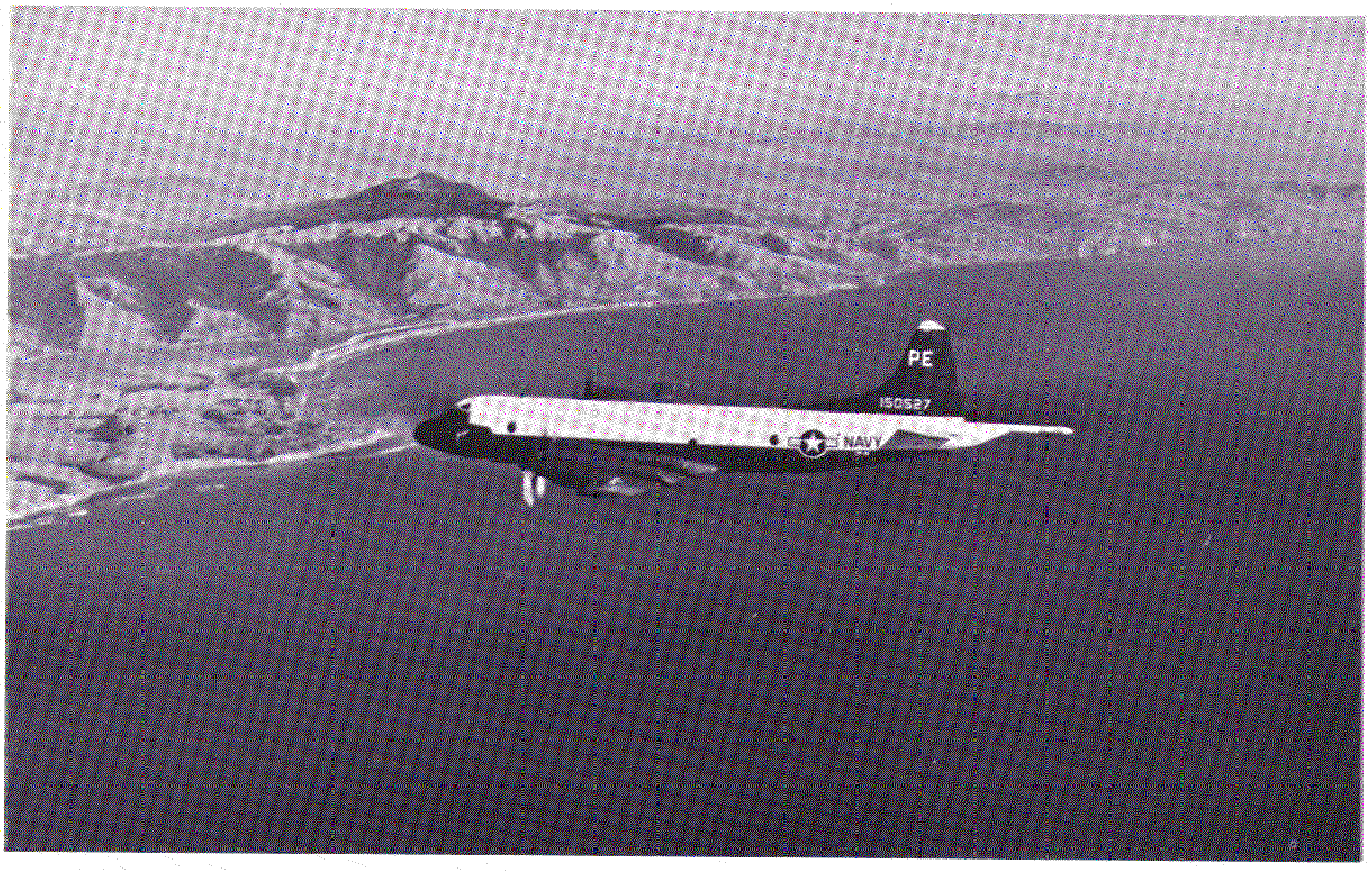
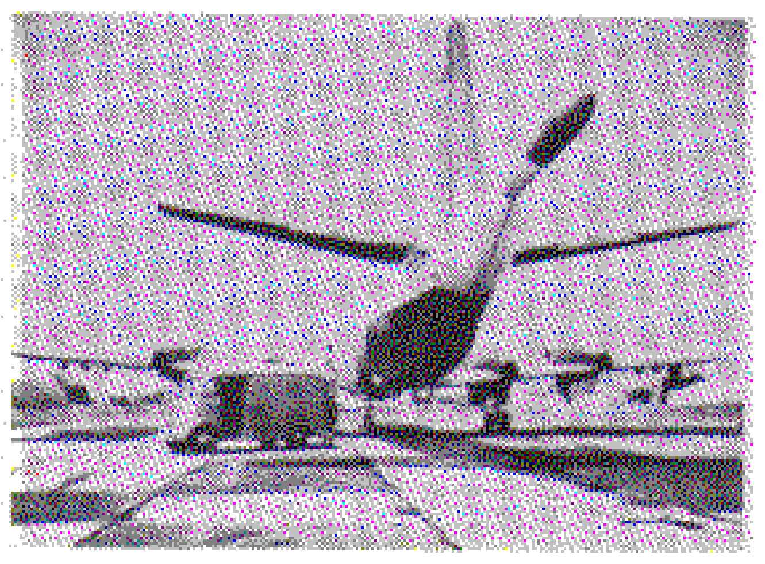


Foreword

It does not seem so very long ago that flight controls on all airplanes were so simple that anyone who was interested could readily understand the theory of their operation just by studying a particular aircraft installation. Ailerons, rudders, and elevators were usually coupled directly to the cockpit controls through cables and other mechanical linkages. Any further complications were limited to trimming devices utilizing trim tabs or an adjustable spring bias. Since World War II, there has been an astonishing increase in the size and performance of aircraft, and flight controls have become correspondingly more complex. The flight controls of a typical modern large airplane can contain a bewildering array of special devices which range through bob weights, static balance weights, spring tabs in various forms, hydraulic boosters, spoilers, spring cartridges, flying tabs, and so on. The Orion, in common with contemporary airplanes, has a fair share of the above devices. Some are necessary in order to obtain desirable flying characteristics, while others can be classified as refinements. One purpose of this article is to endeavor to explain the reasons for these complications, while still setting down a basic description of each of the flight control systems. The three principal flight control systems (aileron, rudder, and elevator — excluding the wing flaps) are described in a two-part article: Part One, contained in this issue of the Digest, describes all three control systems, but gives only brief details of hydraulic booster operation. Also certain unconventional features of the elevator control system will be described at length in Part Two of the article, to be published in a future Digest issue. The flight control boosters, as well as the wing flap control system, will be presented as separate articles in the future.

Editor



ORION FLIGHT CONTROLS

part one

GENERALLY SPEAKING, each of the Orion's hydraulically-boosted control systems is the same as a basic cable-actuated control system with the addition of hydraulic cylinders (boosters) helping the pilot to move the control surfaces in each control axis. In the boosted system, the pilot input controls are not only connected directly to the control surface operating linkage (as in the non-boosted control system in Figure 1), but are also connected to a hydraulic control valve which, according to pilot input, governs the direction and amount of travel of each booster. As indicated in Figure 1, booster shutoff controls can be operated by the pilot to shut off this hydraulic assistance and lock the control valve input linkage, in which case the boosted control system operates in the same manner as the non-boosted system. It should be pointed out that there are quite a few details omitted from this greatly simplified diagram (some of which are explained later in the discussion) but Figure 1 does illustrate clearly the basic operating principle.

Why Boosted Controls? Since the need for boosters is often questioned, we might point out briefly that as aircraft become larger and performances increase, the pilot force required to move the controls also increases—often beyond the pilot's capability—and he requires assistance.

Airplanes of the pre-war period could achieve a satisfactory flight control system—within the framework of the requirements that existed at that time—of relatively simple design. The size and performance of the airplanes were such that the control surface configuration and movements, and the force and leverage imparted by the pilot could all be chosen to achieve adequate flying characteristics and responsiveness within the range of the aircraft's performance. At the same time it was usually possible to achieve quite simply a natural "feel" in the cockpit controls.

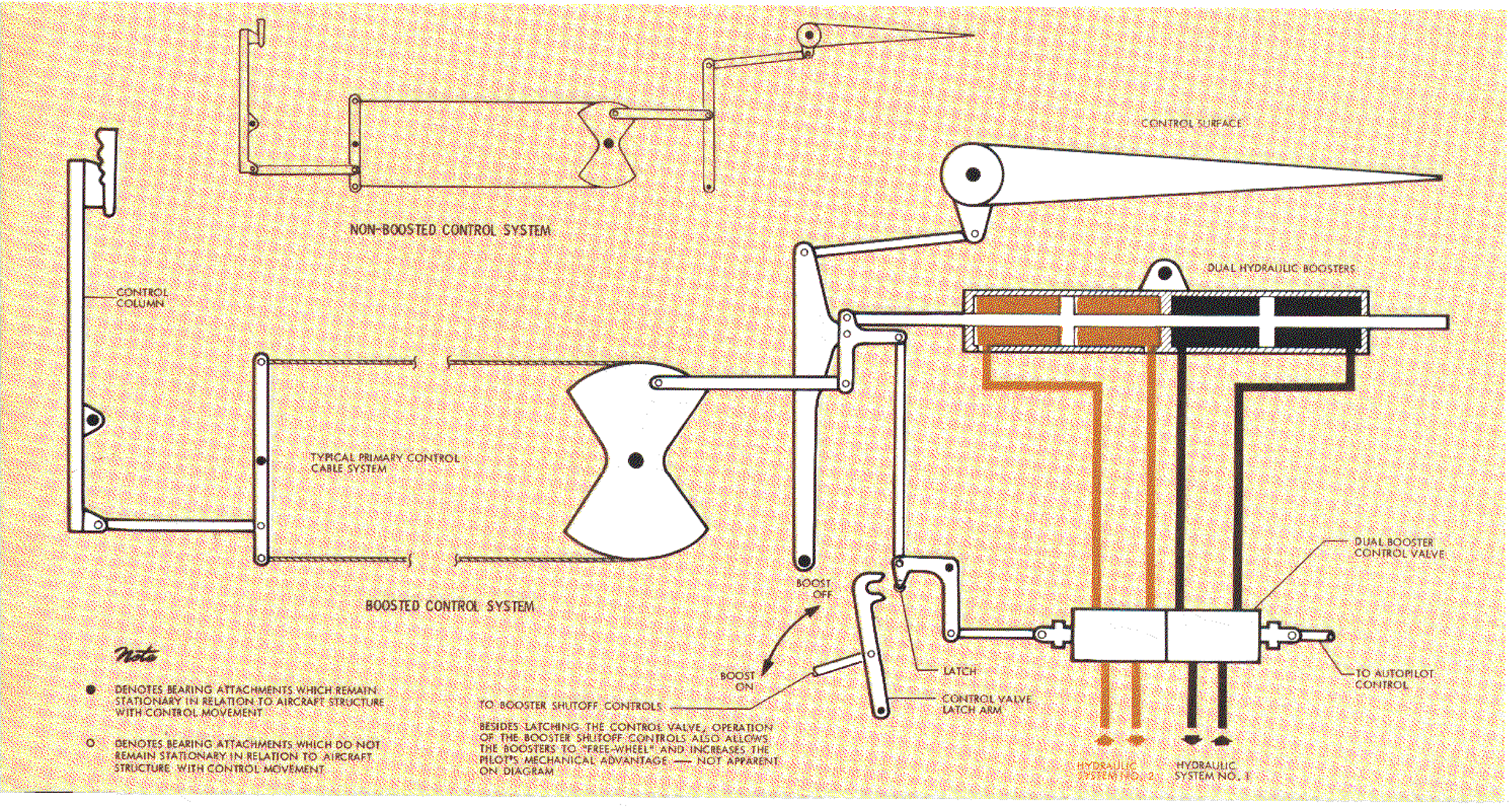
Today, the size and/or the performance of many aircraft have progressed to the point where the pilot needs additional power assistance and may also require artificial "feel" built into the system. The transition period occurred during the early 1940s, when it became apparent that some form of power assistance to the flight controls would be required for some of the more advanced future aircraft designs. Most aircraft manufacturers in this period chose to gain power assistance for the pilot by aerodynamic means alone, which at that time and for those particular airplane types was adequate and still less sophisticated than any alternative method.

Lockheed however had, in 1938, decided to take a long term view of this situation and develop hydraulic booster assisted controls which, although more complicated at that time, showed several major advantages over the aerodynamically assisted control system. Most important, hydraulic boosters showed promise of development for more advanced future aircraft, where it was envisaged that the control problems could not be solved by any other means.

This proved to be a sound policy. The Constellation was the first airplane to utilize hydraulic boosters on all flight control axes, and it is significant that no major modification was required to the basic flight control system throughout the entire range of Constellation and Super Constellation aircraft. It should be noted that this evolutionary line of transports, as it developed, represented a considerable increase in performance, a one hundred percent increase in engine power and aircraft gross weight, and a large increase in fuselage length. This approach was further substantiated on the "first generation" jet and jet-prop transports. Since the first flight tests, the Electra has not undergone any major rework of the flight controls while other transports, employing other types of control power assistance, in several cases had to finally resort to hydraulic boosters as a result of subsequent flight evaluation, or in-service handling experience.

Lockheed's background of development experience on hydraulically-powered controls thus began with the Constellation and an aileron application on the later variants of the P-38 Lightning during World War II. Boosters have subsequently been used on most of Lockheed's post-war aircraft. One notable exception, the P-2 Neptune, was originally designed at a time when mechanically-operated controls assisted by servo tabs were considered to be the best solution for an aircraft of this size and performance. The Orion's booster installations, refined but largely unchanged from those of the Electra, are the result of a steady program of improvement spanning many years of research, development, and successful operation on many different types of aircraft.

Figure 1 Control Booster Assembly — Basic Operating Principle



Note

● DENOTES BEARING ATTACHMENTS WHICH REMAIN STATIONARY IN RELATION TO AIRCRAFT STRUCTURE WITH CONTROL MOVEMENT

○ DENOTES BEARING ATTACHMENTS WHICH DO NOT REMAIN STATIONARY IN RELATION TO AIRCRAFT STRUCTURE WITH CONTROL MOVEMENT

BESIDES LATCHING THE CONTROL VALVE, OPERATION OF THE BOOSTER SHUTOFF CONTROLS ALSO ALLOWS THE BOOSTERS TO "FREE-WHEEL" AND INCREASES THE PILOT'S MECHANICAL ADVANTAGE — NOT APPARENT ON DIAGRAM

CONTROL SYSTEM DESCRIPTION — GENERAL

In many respects the aileron, rudder, and elevator control systems are similar and there are obvious advantages to describing these similarities before discussing specific and individual features of each system.

The dual flight station controls (see Figure 3) are connected via "closed" cable control systems to operating quadrants which are incorporated into each of the hydraulic booster assemblies. The quadrants and the boosters are then linked to the control surfaces by push-pull tubes—the latter being necessarily somewhat more elaborate to the ailerons than to the rudder and elevators.

We should perhaps point out at this stage in the discussion that we will only describe the operation of the boosters in this article to the extent necessary to obtain a *general* understanding of the Orion flight control system. In Figure 2 we have enlarged upon the information given in Figure 1. Although a simplified elevator control system (with supplementary control systems) is depicted, the diagram is still typical in principle of all three of the Orion flight control systems; detail design differences will be brought out in the following individual discussions of the three systems.

Each Booster Assembly, as shown in Figure 2, is actually a dual unit consisting of two boosters, and each of these is supplied by an independent hydraulic system. Except for a special application in the case of the rudder, both boosters in each assembly normally operate in tandem; however, the airplane can be flown satisfactorily with any one of the dual boosters in each control system inoperative.

Should a complete hydraulic or double booster failure occur, each control system can be quickly changed to a secondary manual type of control in which the pilot's effort is applied directly to the control surfaces. As shown in Figure 2, this is accomplished for each flight control system—aileron, rudder, and elevator—by pulling the pertinent "boost-off" control handle in the flight station (see Figure 3). This action results in the following:

1. The dual control valve is locked in the neutral position.
2. A dual shutoff and bypass valve is closed. As a result (a), the pressure inlet lines of both hydraulic systems are shut off ahead of the control valve and (b), the ports to either side of both booster

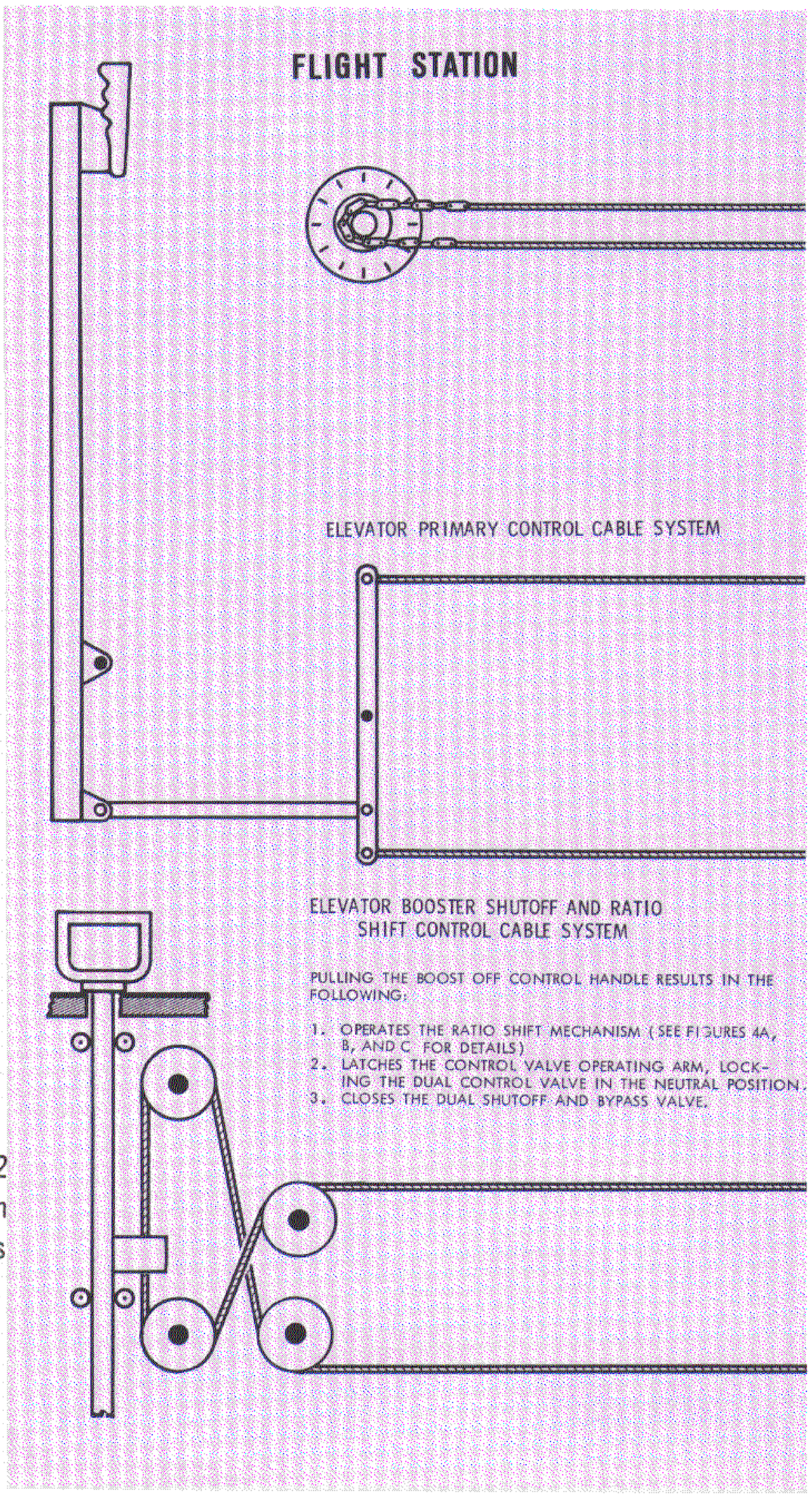


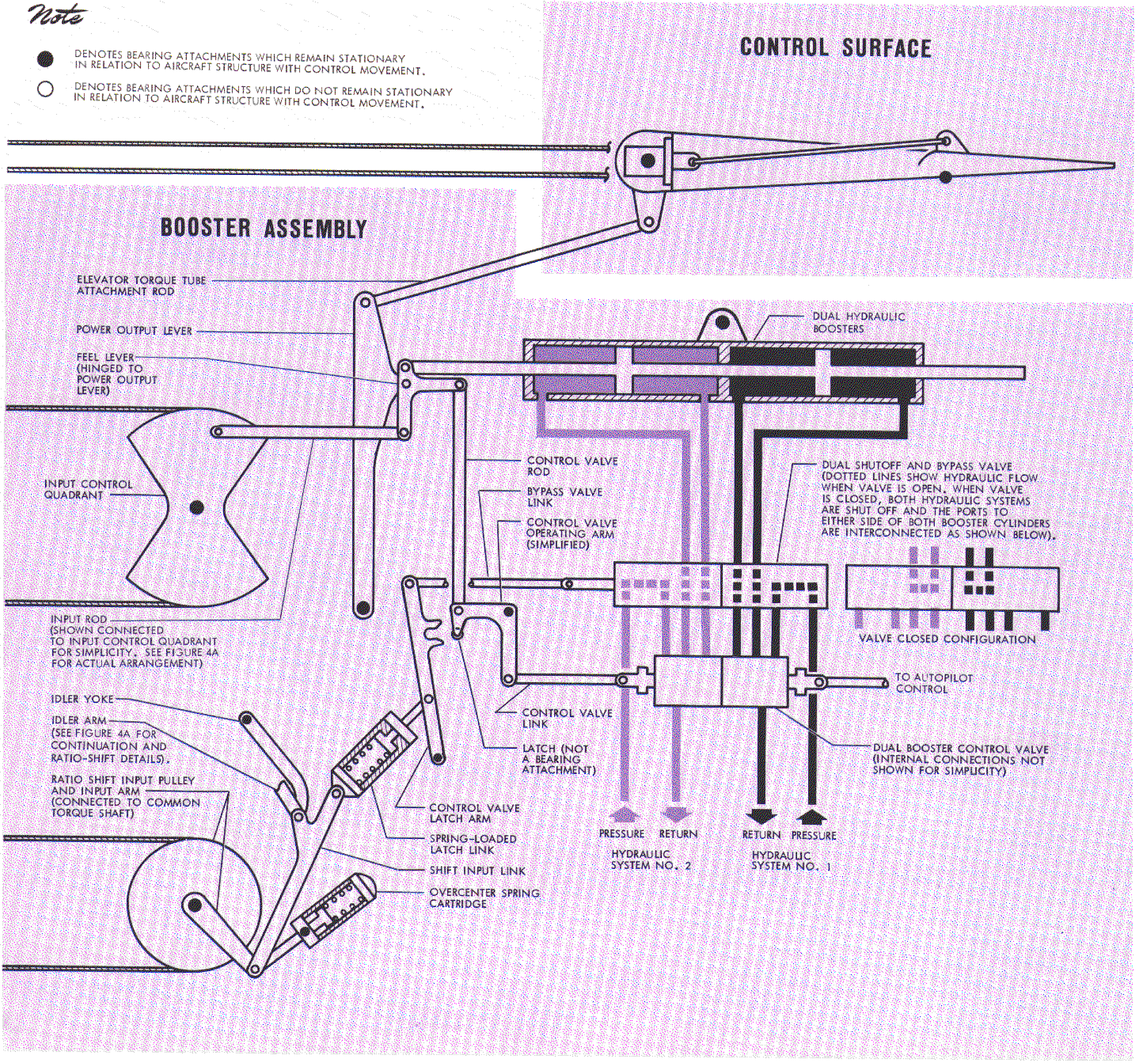
Figure 2
Simplified Elevator Control System
— Typical for all three axes

cylinders are interconnected so that hydraulic fluid can pass freely from one side of either booster piston to the other side as the controls are moved.

3. The pilot's mechanical advantage is increased by a "gear shift" mechanism which reduces the total movement of each control surface to minimum but adequate proportions. In effect, pilots will find that "boost-off" movement of the flight controls requires more physical effort and the aircraft will be somewhat less responsive in brisk flight maneuvers.

The mechanism of each booster shutoff and ratio shift control system is an integral part of the booster assembly or package. The last item, the gear shift, is a particularly intriguing device and even though it seems awesomely complex at first acquaintance, it is well worth the effort to understand and follow through its operation.

Actually the whole arrangement works on a simple geometric principle and all the complexity lies in the mechanism needed to apply this principle. In both Figures 1 and 2 the input rod is shown connected directly to the input control quadrant. This is


Note

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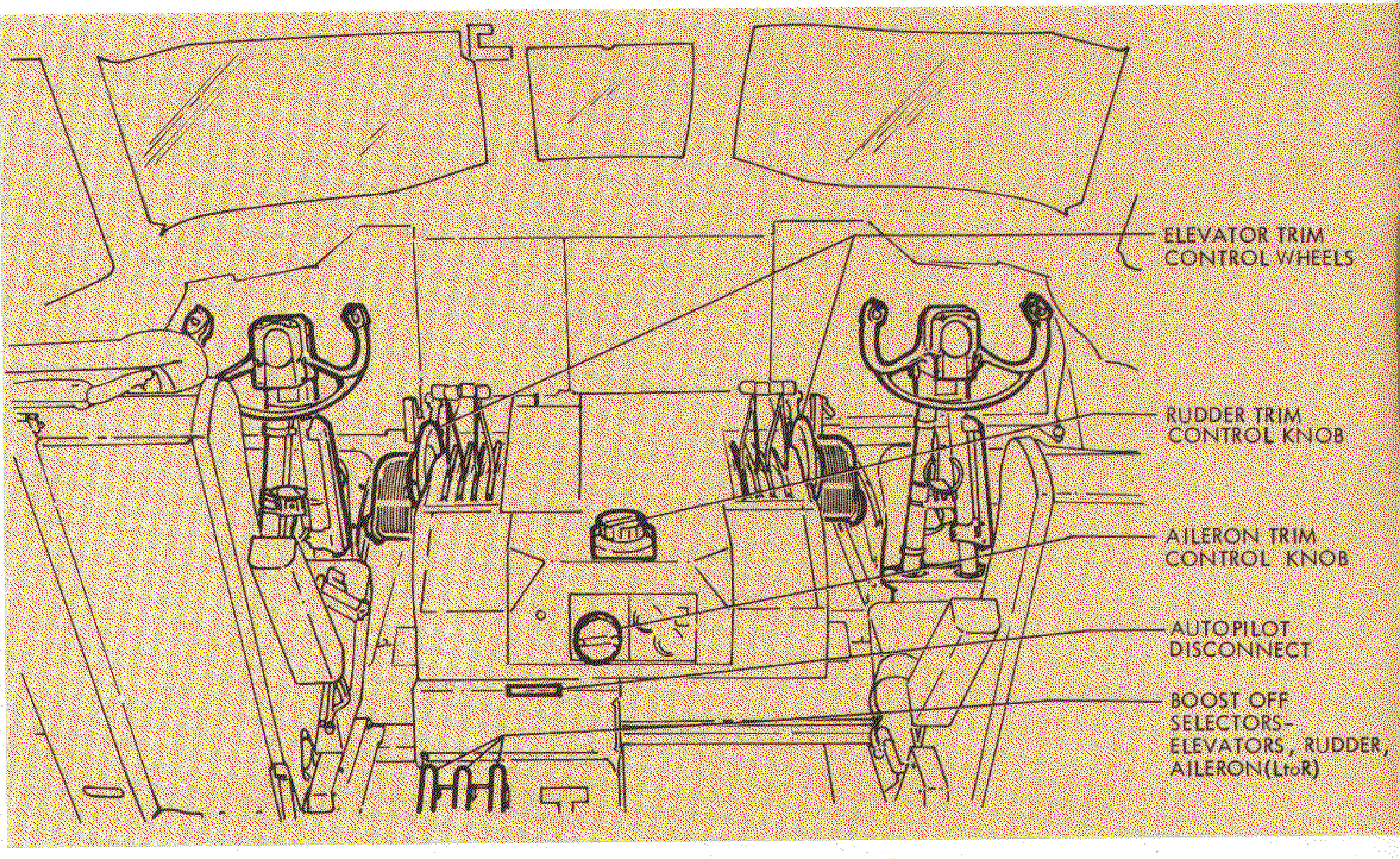
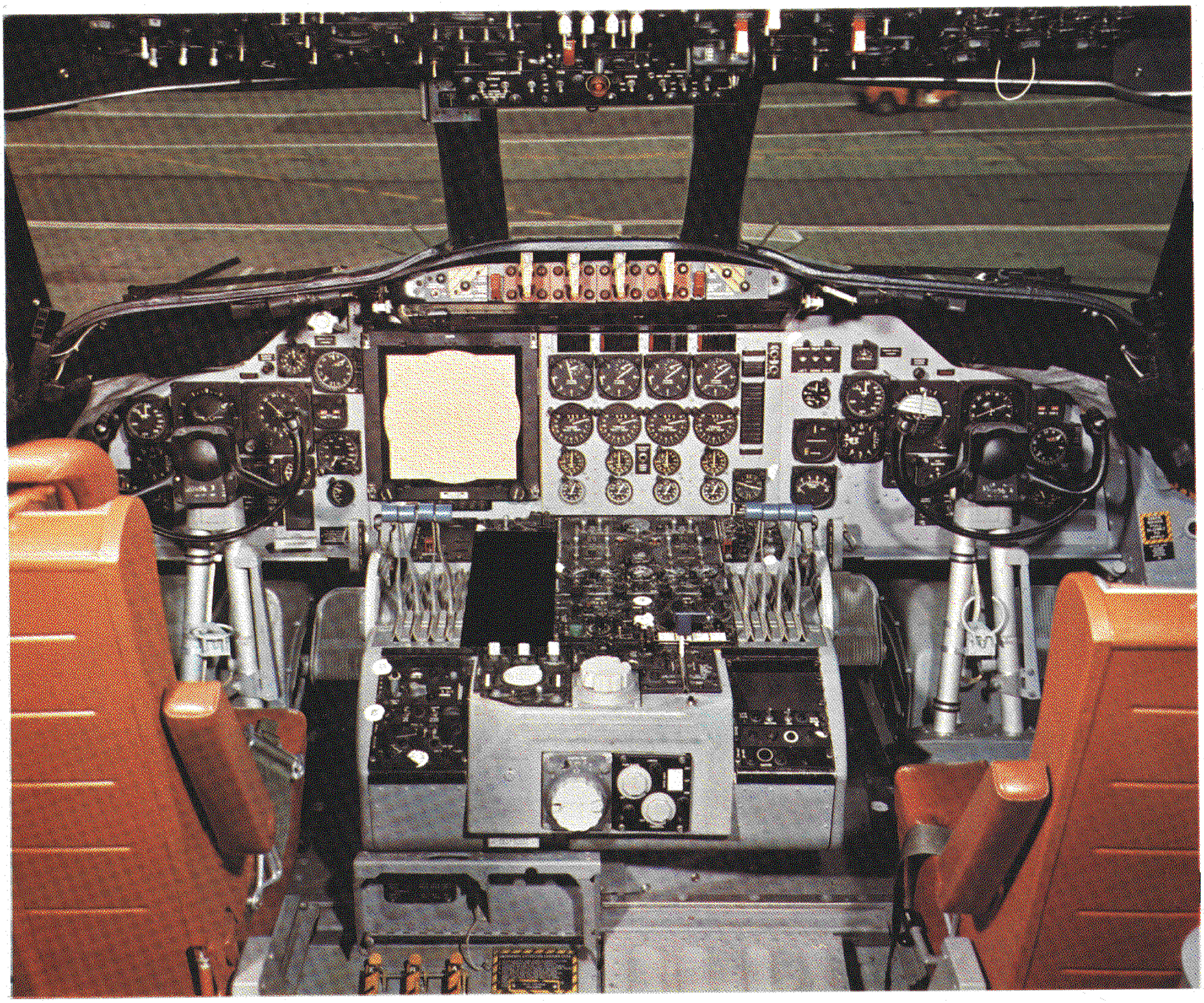
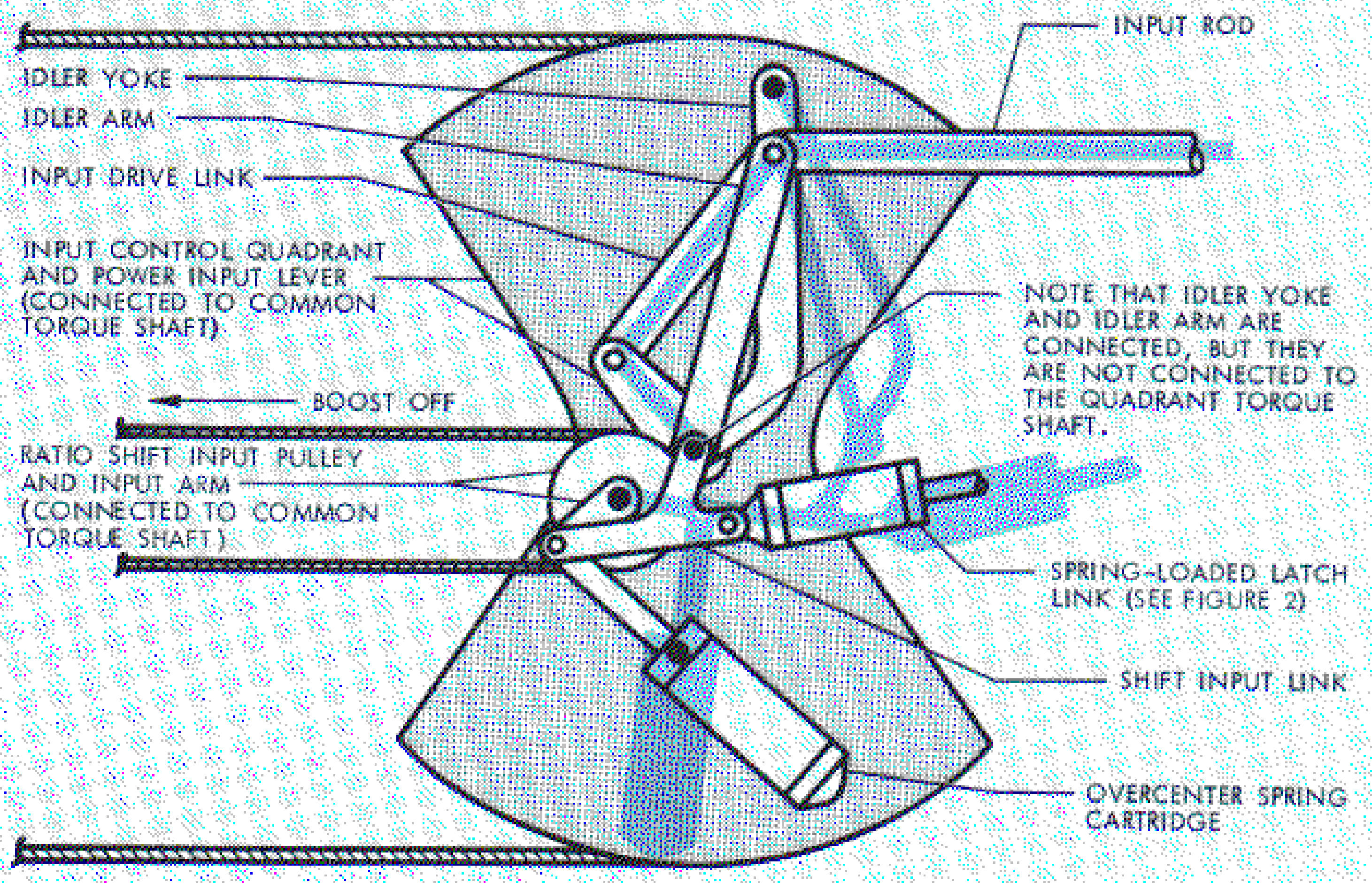


Figure 3
Orion Flight Station
Showing Flight Controls

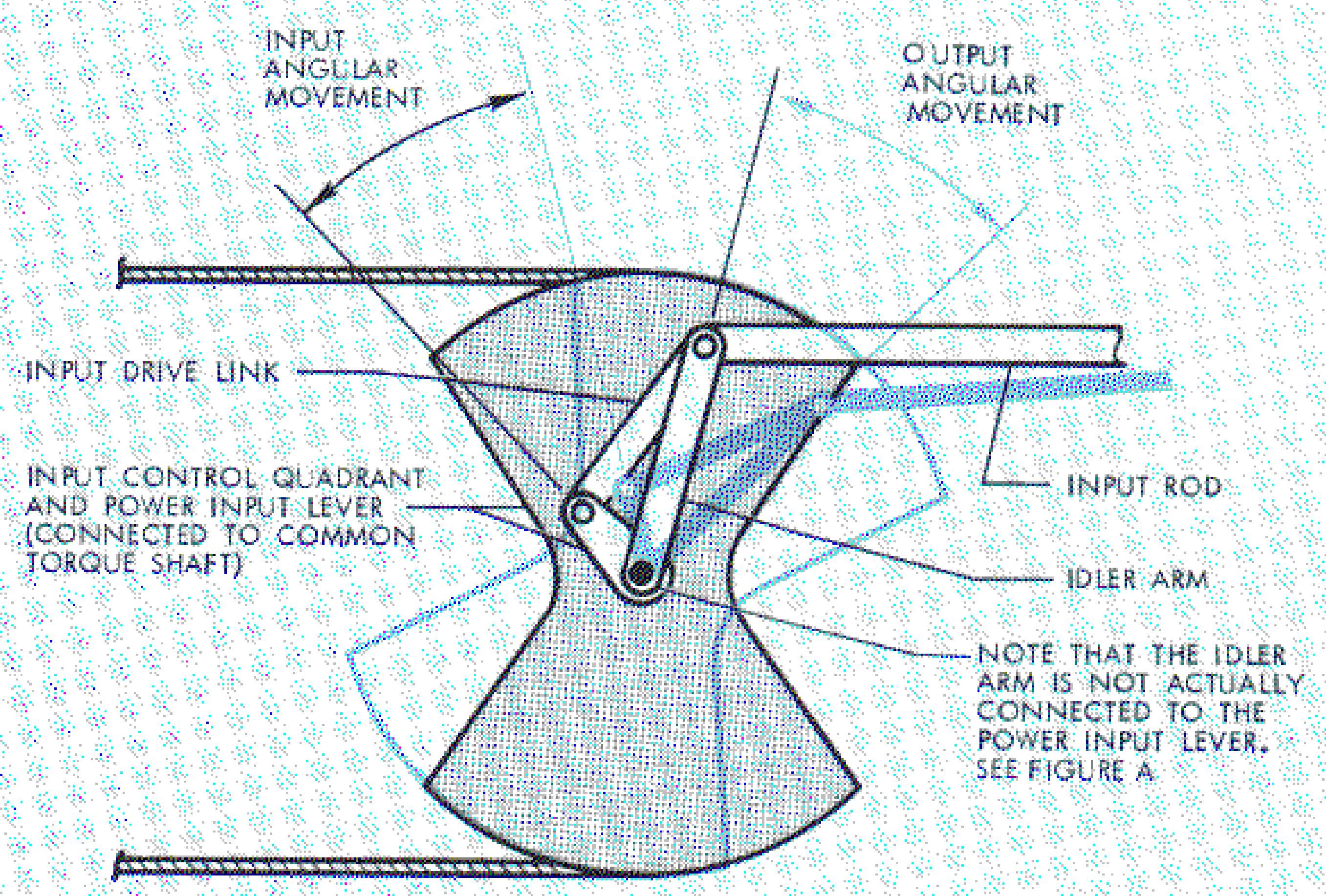


not strictly true, but the illustrations do truly represent "boost-on" operation where there is no relative movement between the input rod attachment and the quadrant. The actual arrangement is shown in Figure 4a, and in Figures 4b and 4c we show just the essential elements or components to illustrate the geometric principle of the linkage. Figure 4b shows the operation of the controls in the boost-on configuration and Figure 4c shows the operation in boost-off. It will be noted that, although the input angular movement is the same in both cases, the output angular movement is much less in the boost-off configuration. Some of the input movement in Figure 4c is "absorbed" in the relative movements of the input lever, the input drive link, and the idler. In boost-on these three components move as a fixed unit.

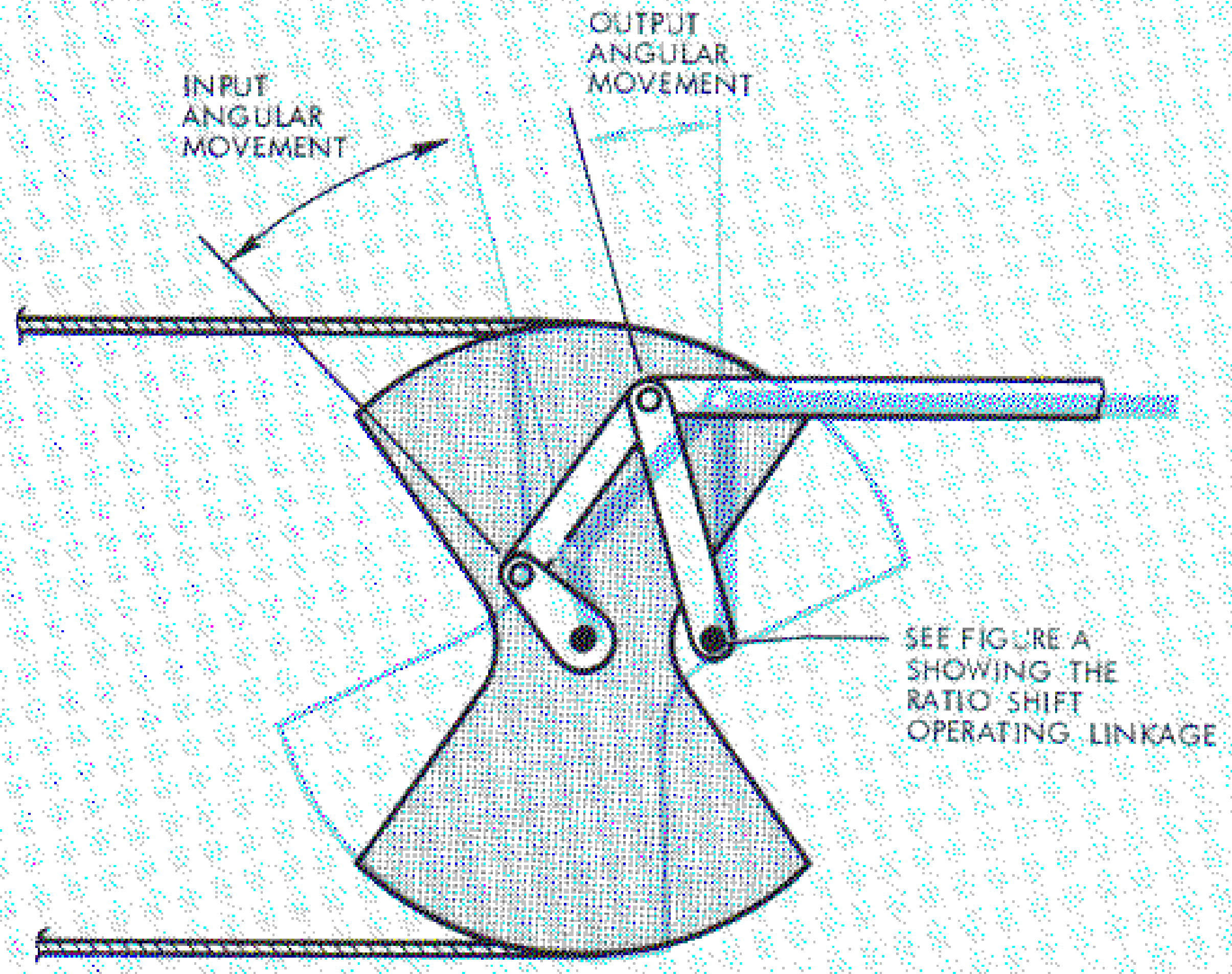
One advantage of the use of boosters is that the booster control valve can be utilized by the auto pilot (see Figure 2), enabling the autopilot signals to be converted into control surface movement with a high degree of efficiency. If the autopilot should malfunction, it will either be disconnected automatically, or it can be disconnected manually by both electrical and mechanical means. The autopilot can also be forcibly overridden by normal operation of the flight controls. This can be achieved with no undue effort on the part of either pilot, and without changing the flight controls to the "boost-off" configuration. The autopilot mechanical disconnect handle, which can be seen in Figure 3, operates on all 3 control axes simultaneously and is located adjacent to the three boost-off control handles.



DETAILS OF RATIO SHIFT LINKAGE. LINES IN COLOR SHOW OPERATION OF LINKAGE TO BOOST OFF. NOTE THAT THE POWER INPUT LEVER IS THE ONLY COMPONENT CONNECTED TO THE INPUT CONTROL QUADRANT. NOTE ALSO THAT THE IDLER-YOKE/IDLER-ARM INTERCONNECTION IS SHOWN AS A FIXED FULCRUM IN RELATION TO AIRCRAFT STRUCTURE ALTHOUGH THIS FULCRUM POINT CHANGES WHEN THE RATIO SHIFT CONTROLS ARE OPERATED.



PILOT'S MECHANICAL ADVANTAGE IN BOOST ON CONFIGURATION. COLOR SHOWS MOVEMENT OF CONTROLS FROM NEUTRAL. NOTE THAT THE ANGULAR OUTPUT IS IDENTICAL TO THE ANGULAR INPUT MOVEMENT.



PILOT'S MECHANICAL ADVANTAGE IN BOOST OFF CONFIGURATION. COLOR SHOWS SAME INPUT MOVEMENT OF CONTROLS AS IN FIGURE B NOTE THAT THE ANGULAR OUTPUT MOVEMENT IS NOW CONSIDERABLE LESS.

Figure 4
Details of Booster Ratio Shift and
Geometric Principle of Operation

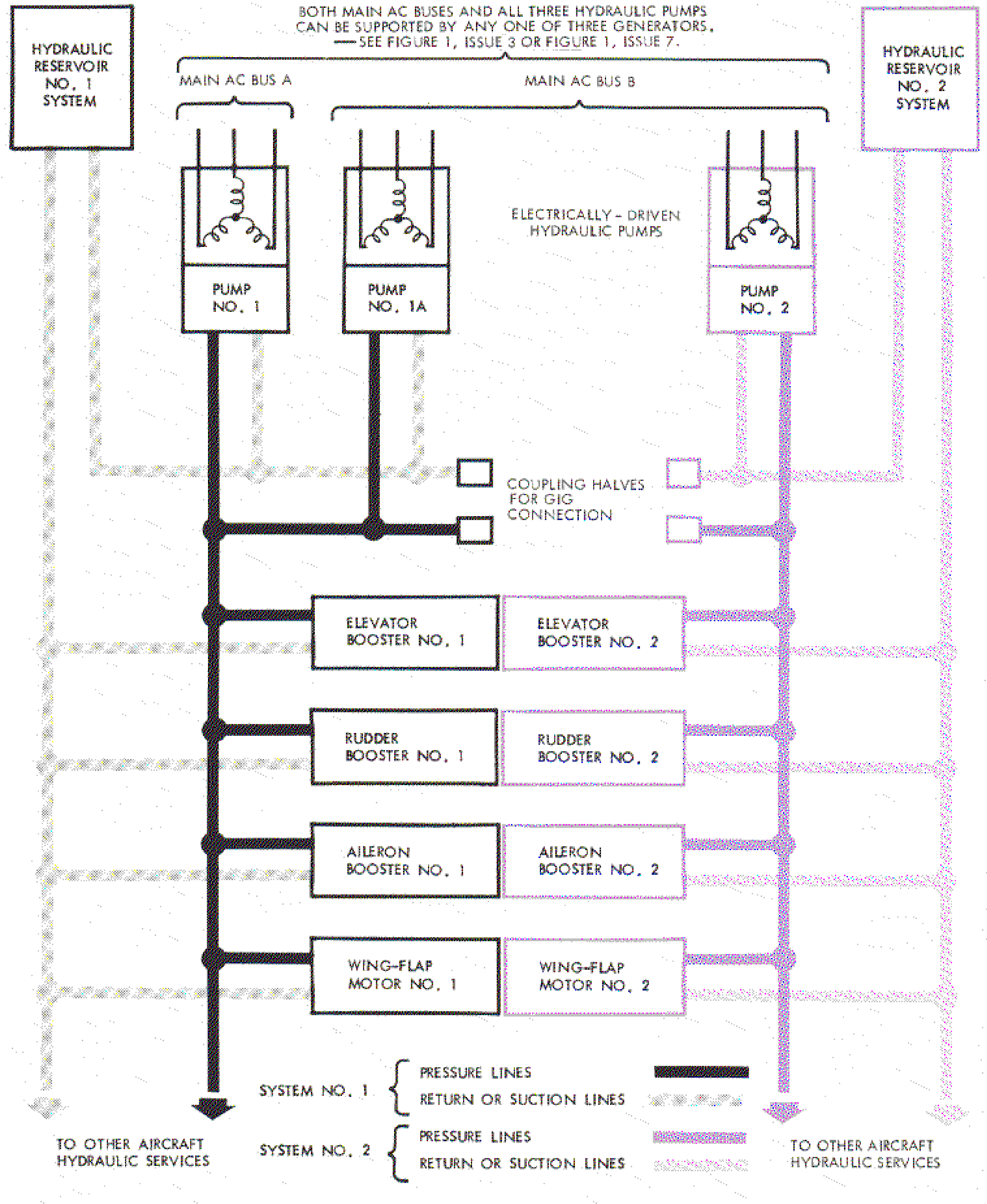


Figure 5 Flight Controls Hydraulic Systems — Block Diagram

Power Sources. In any hydraulically powered or boost-assisted control system, it is important to consider the dependability of the power sources. As shown in Figure 5, the three pumps that supply hydraulic system power are electrically driven by the two electric power buses. These buses are supported by separate generators normally, but the essential services (including the hydraulic pumps) are available on both buses if any one of the Orion's three generators (or external ac ground power) is available. Thus with a total of three hydraulic pumps, two separate hydraulic systems, and an automatic generator/bus transfer system, a complete hydraulic failure is an unlikely occurrence. Further, with electrically-driven pumps, neither hydraulic system is likely to be compromised by an engine failure as would be the case if the pumps were mounted on and driven directly by the engines.

To sum up, the boosted controls are unaffected by the loss of any two engines/generators during flight, and still unaffected by the loss of three engines so long as engine No. 1 is included, which of course does not have a generator. Incidentally, another advantage of this configuration is that boost-on operation of the flight controls can be ground tested by merely plugging in electric ground power.

Lockclad Cable. Minimizing friction in the cable systems to the boosters was a primary design objective. Long straight cable runs have been established and these allow extensive use of Lockclad cable, which consists of normal flexible cable, pre-stretched, with aluminum tubing swaged around it while the cable is still in tension. Normal control system operating loads are lower than the pre-stretched loads so that no elastic stretching of the cables is experienced during control operation. The manufacturing process also results in a control cable with a coefficient of expansion similar to that of the airframe structure, and the effect of ambient temperature changes on the flight controls is thereby lessened considerably. Throughout the cable systems Lockclad cable is used in preference to flexible cable which, for the most part, is used only around pulleys.

Cable Slack Take-up Units. The ailerons and rudder use single closed-cable systems, and cable slack take-up units are located close to the operating quadrants of the booster units. The elevator control system incorporates similar slack take-up units within cable tension regulator assemblies. A typical cable slack take-up unit installation is depicted in Figure 7, and Fig. 6 shows details of their construction. These units should not be confused with cable tension regulators. When each control system is rigged with the correct cable tension, the terminals in the units will be butted against the ends of the slots (the terminals are shown at the other ends of the slots in Figure 6), so that each cable tension load will be taken by the side plates of its respective unit. As the name implies, the function of these units is to take up any possible slack which might result in the unloaded cable when the other cable in a closed-cable system is being subjected to unusually high tension loads during control operation. For normal operation, the rigged system cable-tension load is such that no slack will develop in any cable, even allowing for extremes of temperature.

The elevator employs a double closed-cable system, and cable tension variation is somewhat more critical than with the aileron and rudder control axes. Consequently, tension regulators are employed at the elevator booster input quadrant. These maintain the prescribed cable tension in each elevator cable system under the most extreme conditions of temperature variation and operating load. Further details of the tension regulators are given in the "Elevator Control System" section.

Conventional Hinged Control Surfaces are used in all three control systems. Metal skin and ribs are assembled upon one or two spar beams with hinge brackets attached to the forward beam. The elevators and ailerons are balanced to varying degrees by balance weights which are also attached to the control surface front spar (see Figure 8).

Mechanically-operated trim tabs, which have no servo action, are provided on all control surfaces. (These should not be confused with the force link tabs which are also installed on the elevators.)

Trim Tab Actuators. The cable-operated system to the trim tab shown in Figure 2 is typical for all three control axes. Single closed-cable systems operate one or two trim tab actuators (one for each control surface) so that there is a total of five per airplane. These are identical and all of them use demagnetized components although this construction requirement is only necessary for the three units in the empennage, which are in close proximity to the MAD gear. For the same reason, the actuators also use non-magnetic cable (actually corrosion resistant cable to spec. MIL-C-18375). In each control system the cable lengths attached to the drums differ according to requirements.

A typical trim tab actuator installation is shown in Figure 9, while Figure 10 shows a detailed cross-sectional view of one of these units. The actuator assembly consists of a cast aluminum alloy main housing, which supports a fixed Acme screw shaft. The cable wound drum incorporates two integral nuts and needle bearings. When driven, it rotates on the Acme shaft and transmits a linear movement through thrust bearings to the drum housing, which has two rod end attachments. The main housing serves as a mounting bracket, and guides and prevents rotation of the drum housing during linear movement.

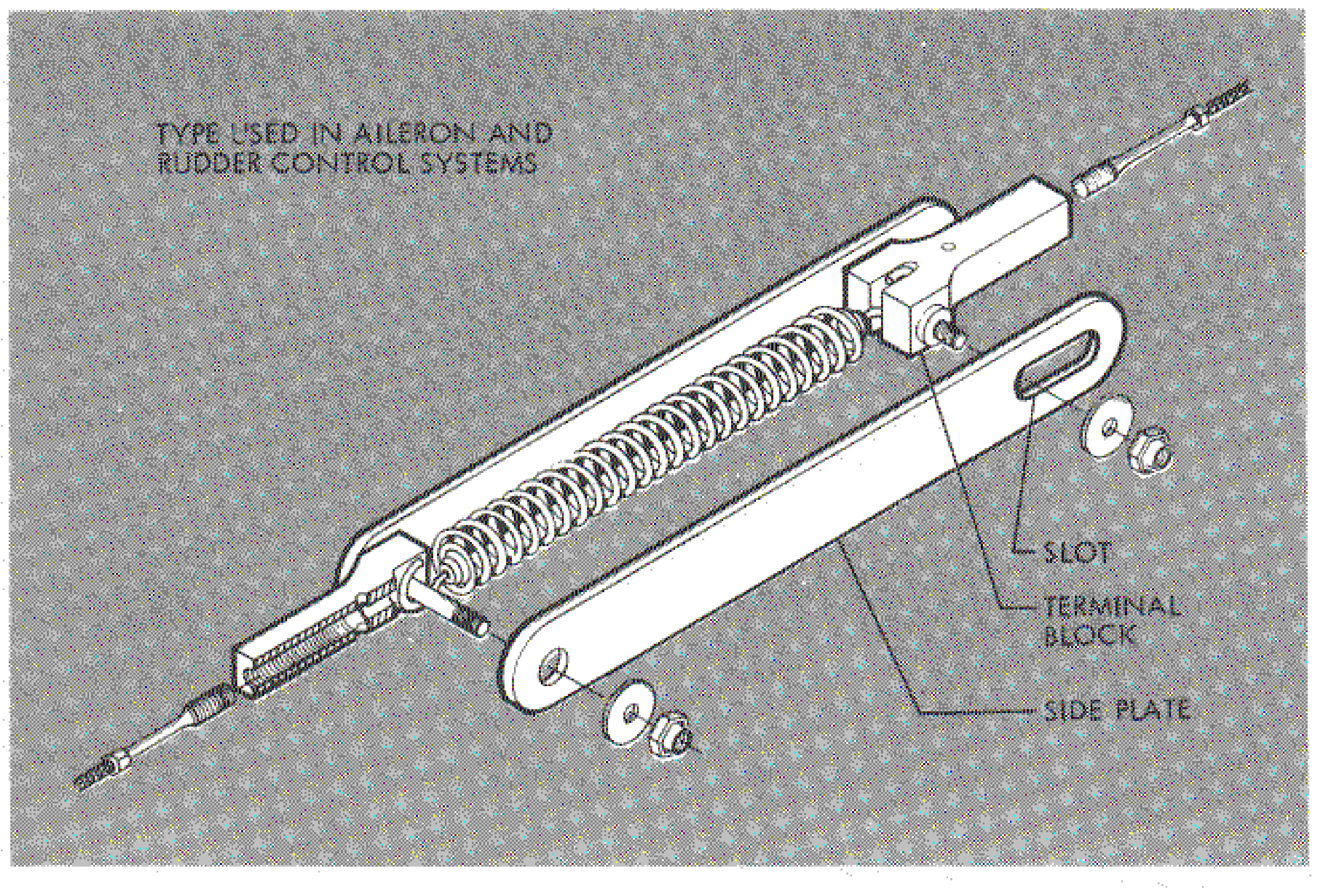


Figure 6 Cable Slack Take-up Unit

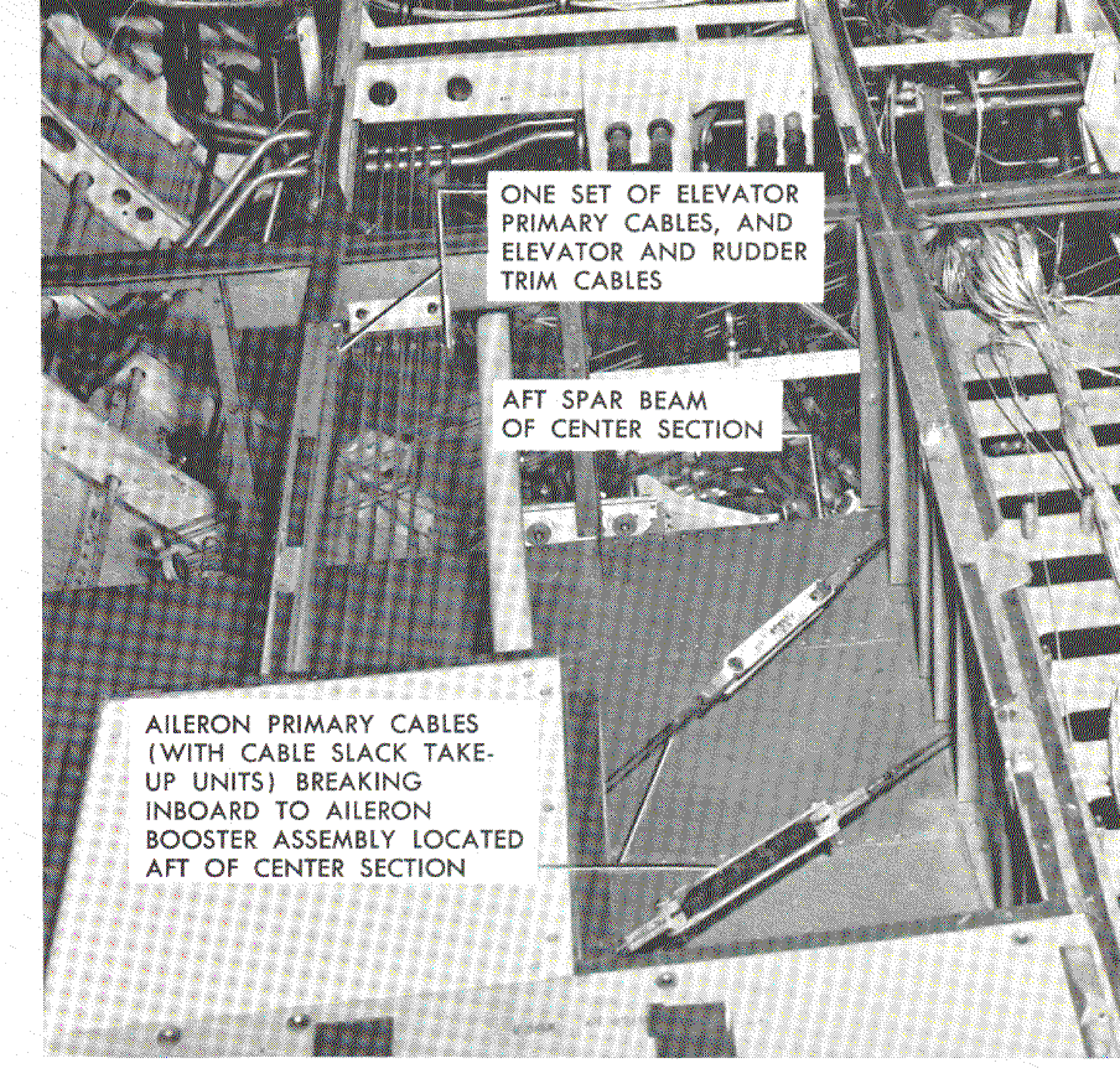


Figure 7 View Looking Aft Below Cabin Floor Showing Typical Installation of Cable Slack Take-up Units — Electra installation shown; Orion is similar

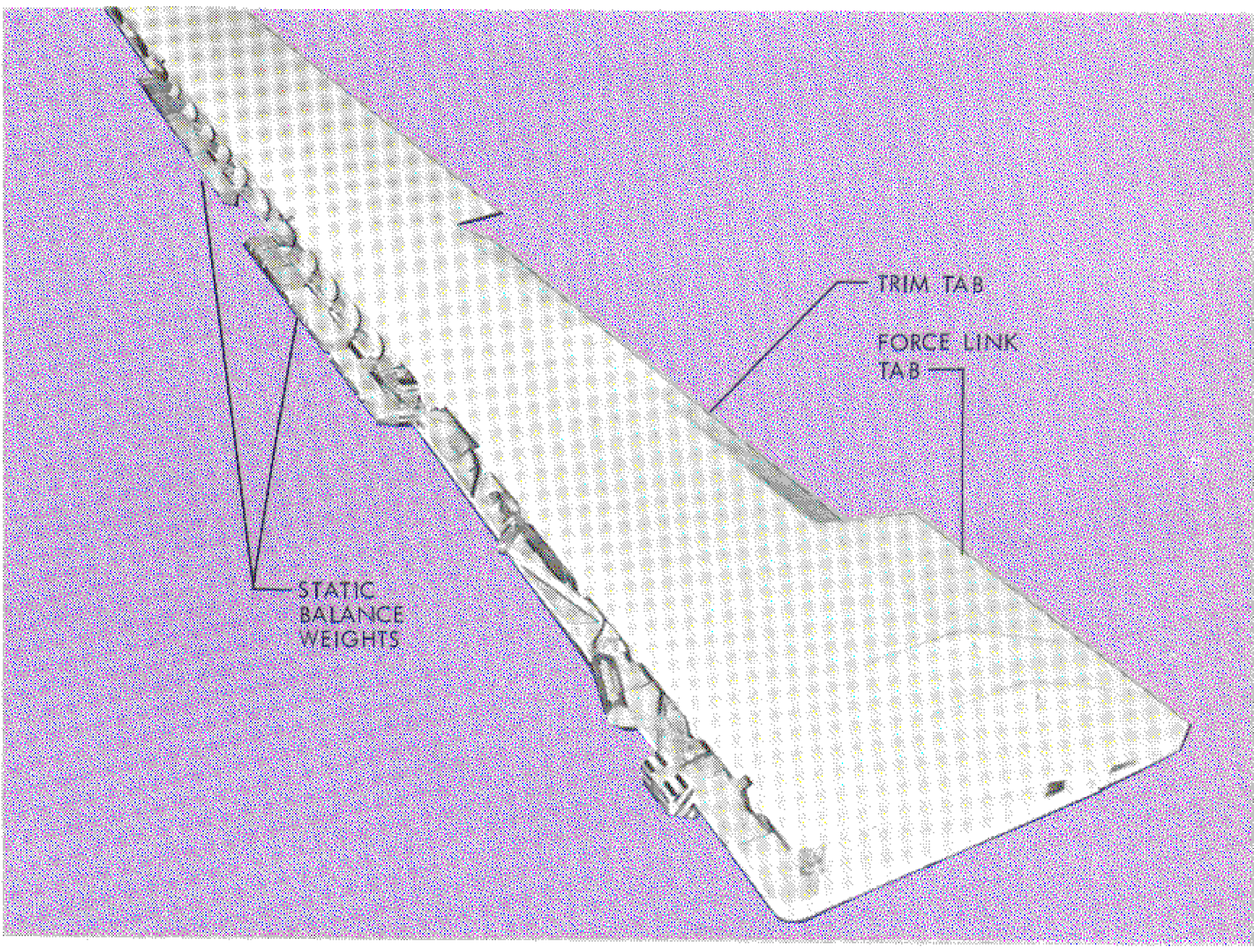
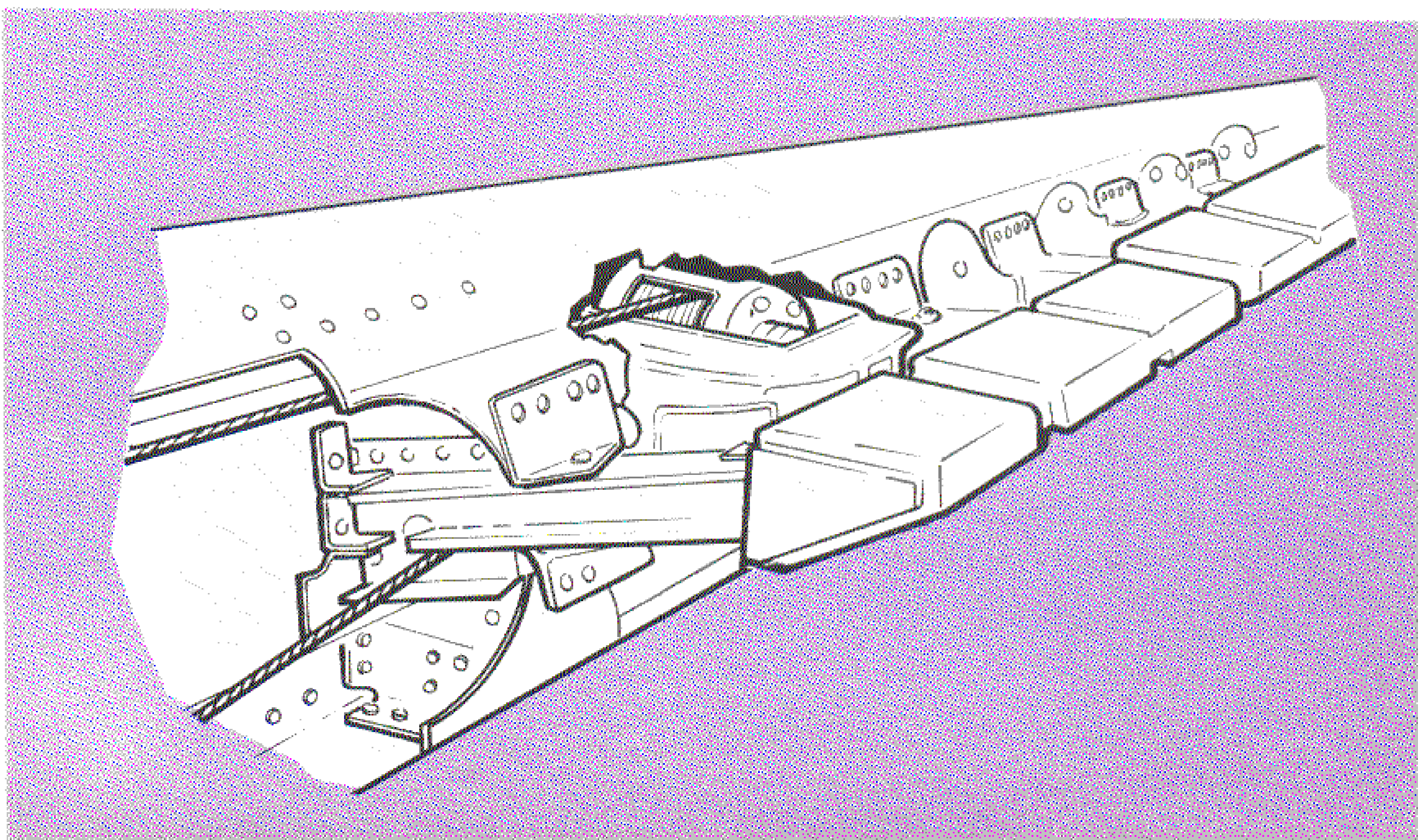


Figure 8 View of Elevator Showing Tabs and Balance Weights

Figure 9 Elevator Trim Tab Actuator Installation in Left Elevator



The operating cable is wound around grooves on the drum and two swaged ball fittings and nylon washers on the cable index the location of the cable on the drum. The Acme screw thread pitch is the same as that of the drum cable grooves so that the cables do not shift with the drum motion. With drum pitch diameter of 2.875 inches, each nine inches of cable travel causes about one turn of the drums and about .25 in. of linear travel. At cable load of 45 pounds, minimum linear load output is specified as 570 pounds.

The tab actuators are mounted by four bolts to the structure of each control surface front spar. The trim tab cables approach the actuator parallel and close to the surface hinge line with the result that tab position relative to the primary control surface is not affected by motion of the control surface. Each actuator drives its tab through two parallel push rods, either of which is capable of transmitting full hinge moment requirements.

Viscous Dampers are installed on the elevator and rudder control surfaces, and also on the copilot's control column. A typical installation is shown in Figure 11. There are five such dampers installed on the Orion and they are all of similar basic design. The four units mounted in the empennage are constructed of non-magnetic material to prevent interference with the MAD equipment; the units also differ in the attachment parts required for a particular installation.

As shown in Figure 12, movement of the damper attachment arm rotates a disc in a viscous fluid. The dampers offer little or no resistance to normal control movement but friction is generated between the disc and the fluid by rapid movement so that the disc offers considerable resistance to oscillatory or vibrational movement of the item to which it is attached. As a safeguard against a seizure occurring in any of the dampers, the lever at the top of each unit is attached to the damper shaft with a rivet, which acts as a sheer pin. Needless to say it is important to ensure that any replacement rivet conforms to the design specification.

We have now exhausted the similarities between the three control axes. We shall now briefly describe each of the flight control systems individually, including the associated trim tab controls. It will be noted that all the primary flight controls have been superimposed on an isometric drawing of the aircraft in the center pages. The reader should find this drawing useful for general orientation of a system, but reference should be made elsewhere in these pages for more detailed drawings of individual components.

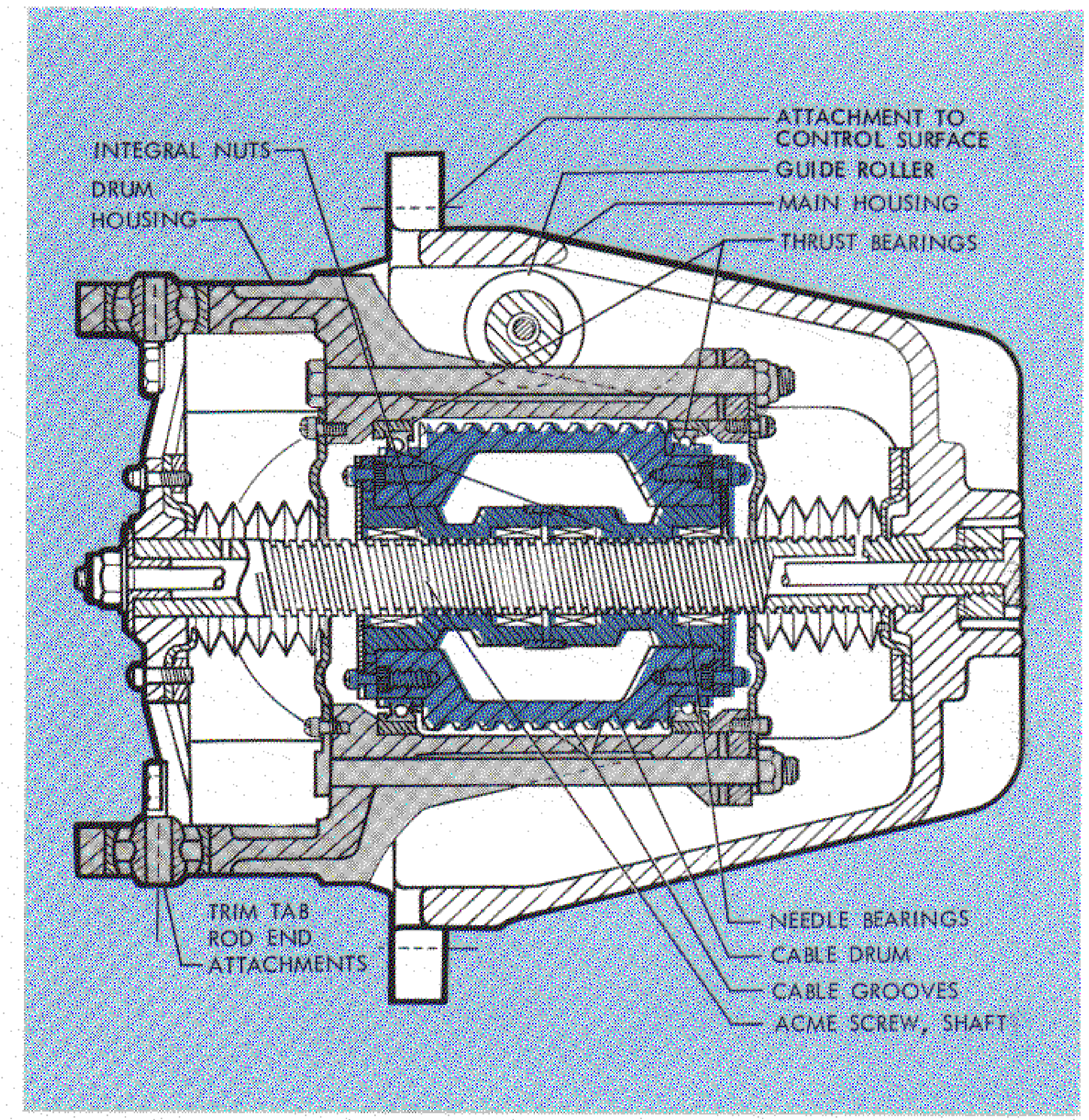


Figure 10 Trim Tab Actuator — Cross Section

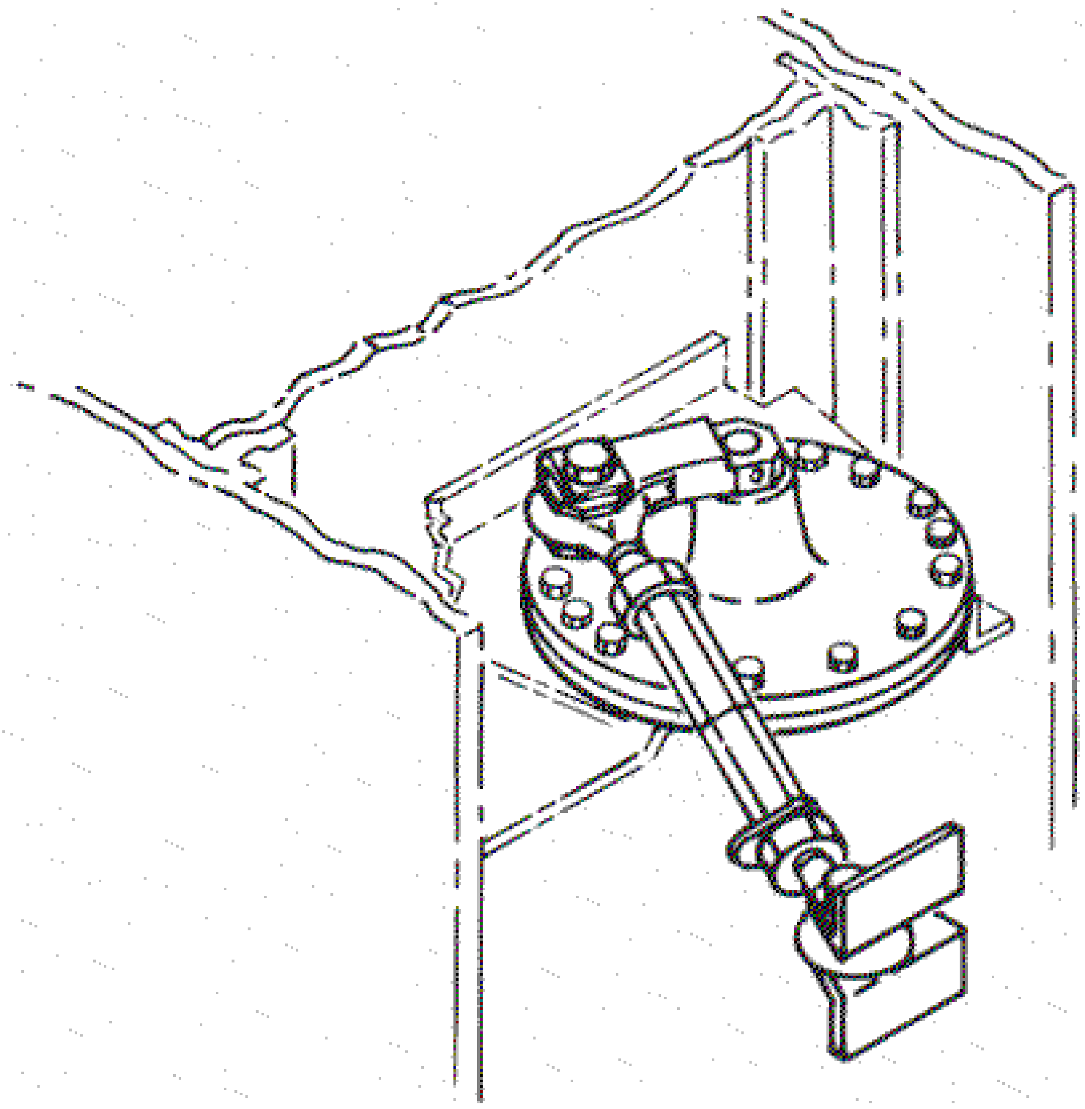


Figure 11 One of Two Viscous Damper Installations to Rudder

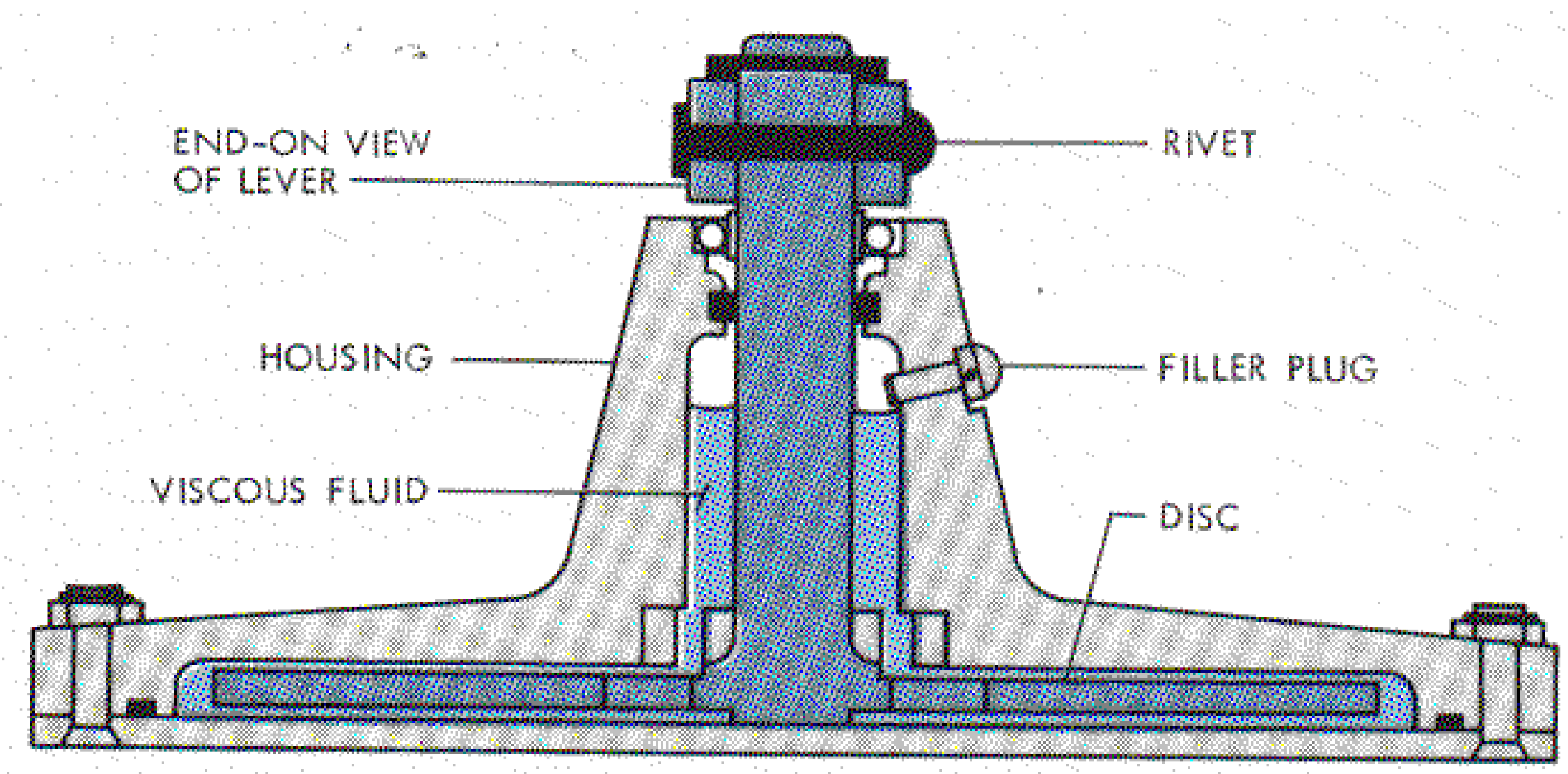


Figure 12 Viscous Damper — Cross Section

AILERON CONTROL SYSTEM

Briefly the aileron control system differs from the typical control system shown in Figure 2 primarily in the flight station controls and a more extensive push-pull rod system extending from the booster assembly to the aileron control surface in each wing. The aileron booster assembly also differs slightly from that shown in Figure 2. As can be seen in Figure 13, the aileron input control quadrant is actually connected to the power input lever through an idler linkage, which was necessitated by this particular booster assembly installation.

Within each pilot's control column, pilot forces from each of the aileron control wheels are carried by an upper shaft supported in ball bearings to a sprocket of about 2 inches pitch diameter. Motion of this sprocket is transmitted to a lower quadrant of about six inches pitch diameter through roller chains and Lockclad cable lengths, which are enclosed by the column legs of aluminum alloy tubing (see Figures 14 and 15). Thus 120 degrees control wheel rotation (left or right) generates 33½ degrees rotation of the lower quadrant and integral output arm, and also produces approximately 4 inches of cable travel. The ends of the primary cables are attached to the output arms of the separate columns, and a rigid tubular strut between the arms interconnects the pilot's and copilot's aileron controls.

Attached to the lower quadrant and base of each control column is a small friction device, which is designed to dampen any small movements of the aileron control linkage in the column. The purpose of the dampers is to prevent inadvertent operation of the autopilot disconnect switches located in the control wheel hubs. The phenolic plate in each of

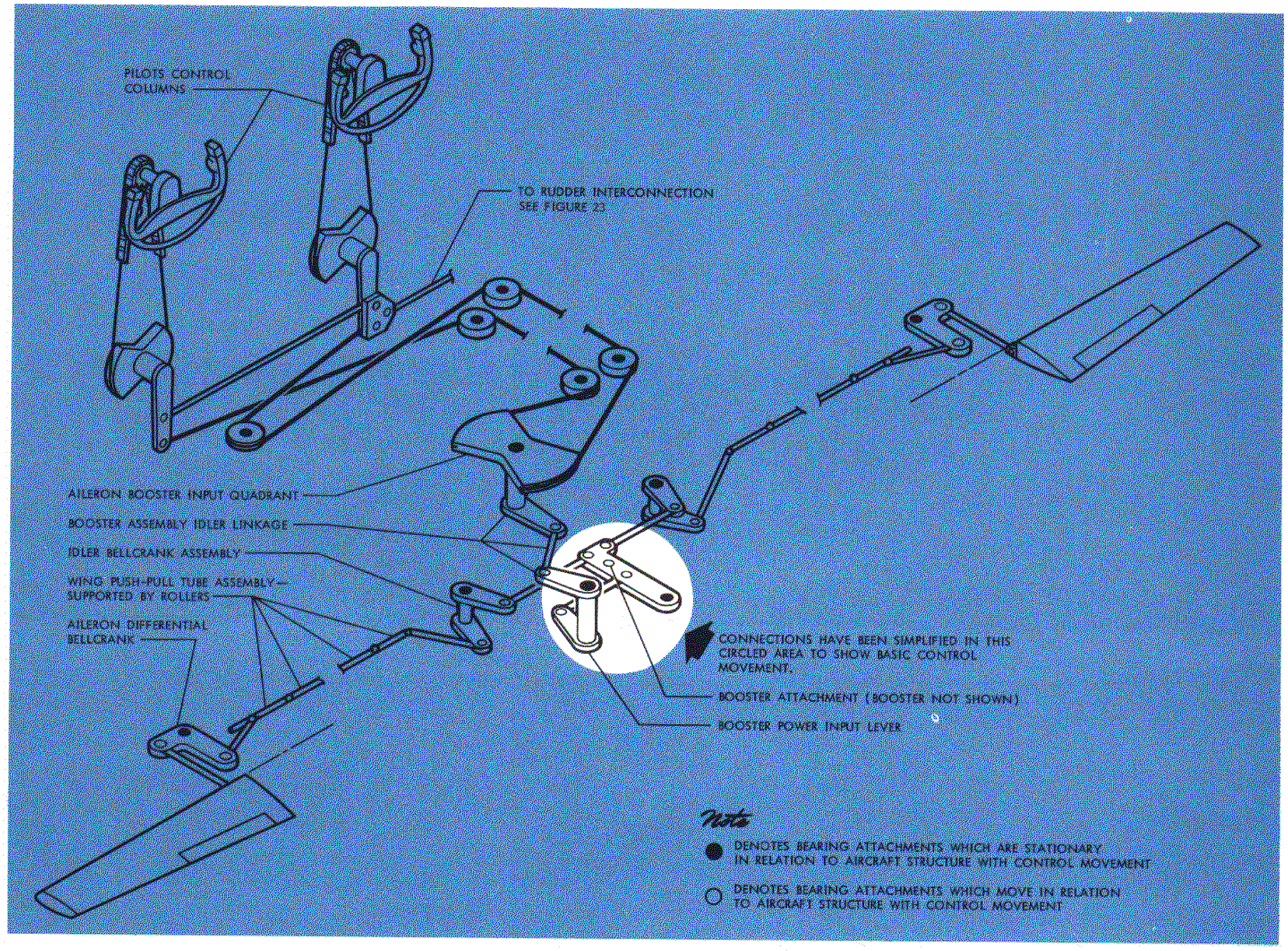


Figure 13 Sketch of Aileron Control System — Booster not shown

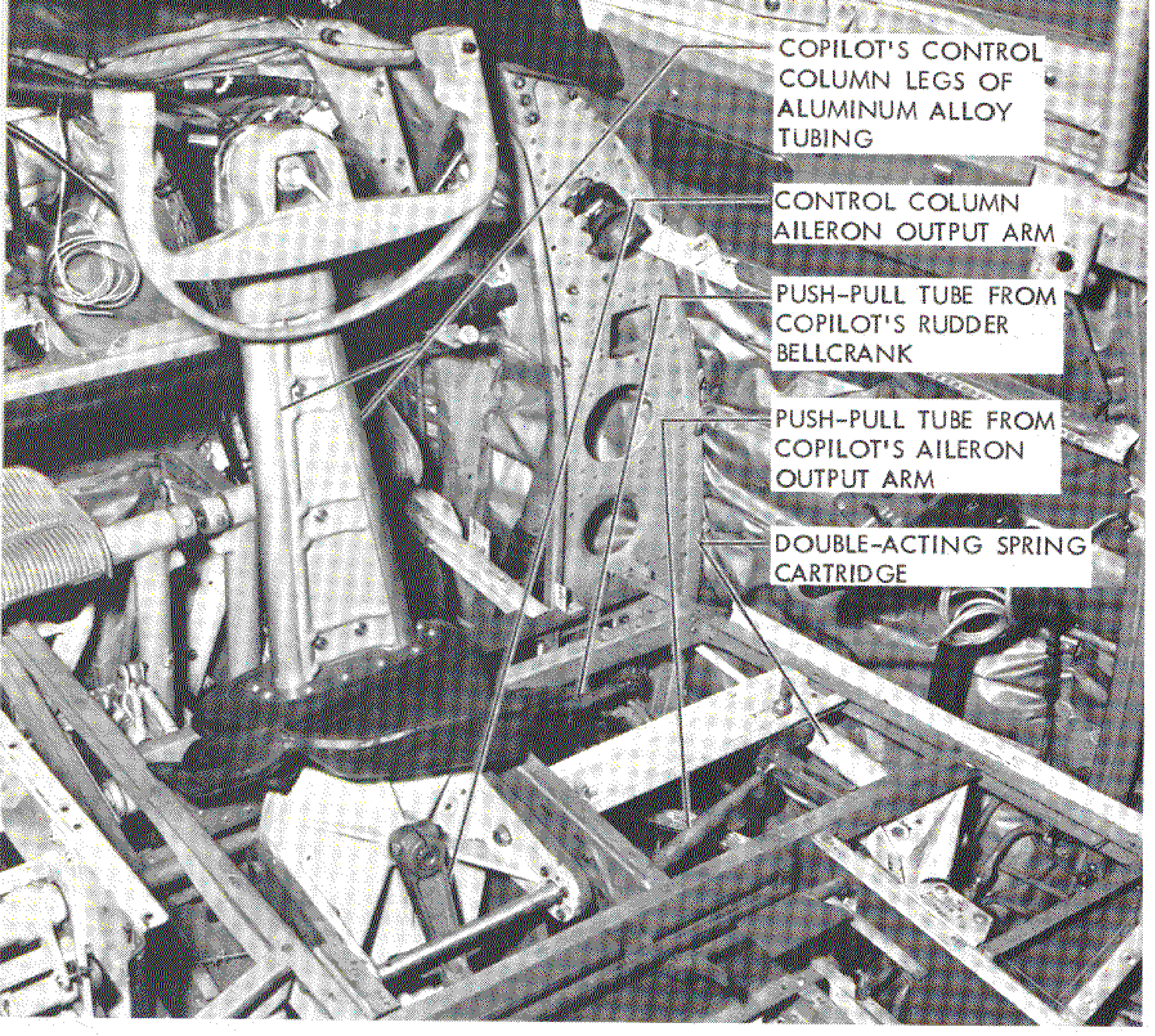


Figure 14 Copilot's Control Column Showing Aileron Controls — Electra installation shown; Orion is similar

the friction devices is impregnated with graphite so that any static electricity, produced by friction, is readily conducted away and does not interfere with electronic equipment (see Figure 15).

Flexible steel cables of 1/8-inch diameter are routed from the output arm of each control column to the right side of the aircraft below the floor. The same type of cable constitutes the core of the Lockclad sections used in the predominantly straight runs aft. Fairlead rollers support the rigid Lockclad cable. After passing aft within the control cable tunnel above the center section, the cables break inboard (see Figure 7) to attach to the input quadrant of the aileron control booster assembly mounted at the aircraft centerline just aft of the wing rear spar beam. Cable slack absorbers, described earlier, are installed on each primary cable close to its attachment to the booster input quadrant.

The aileron booster is actually installed in the hydraulic service center in the fuselage, and access can be gained to it through a hatch in the cabin floor and also through the externally-located service center access door (see Figure 16). This location of the aileron booster lends itself to the design of relatively straight push-pull rod systems which are routed along the aft face of each wing rear beam to the ailerons. These rods are exposed to view whenever the wing flaps are extended.

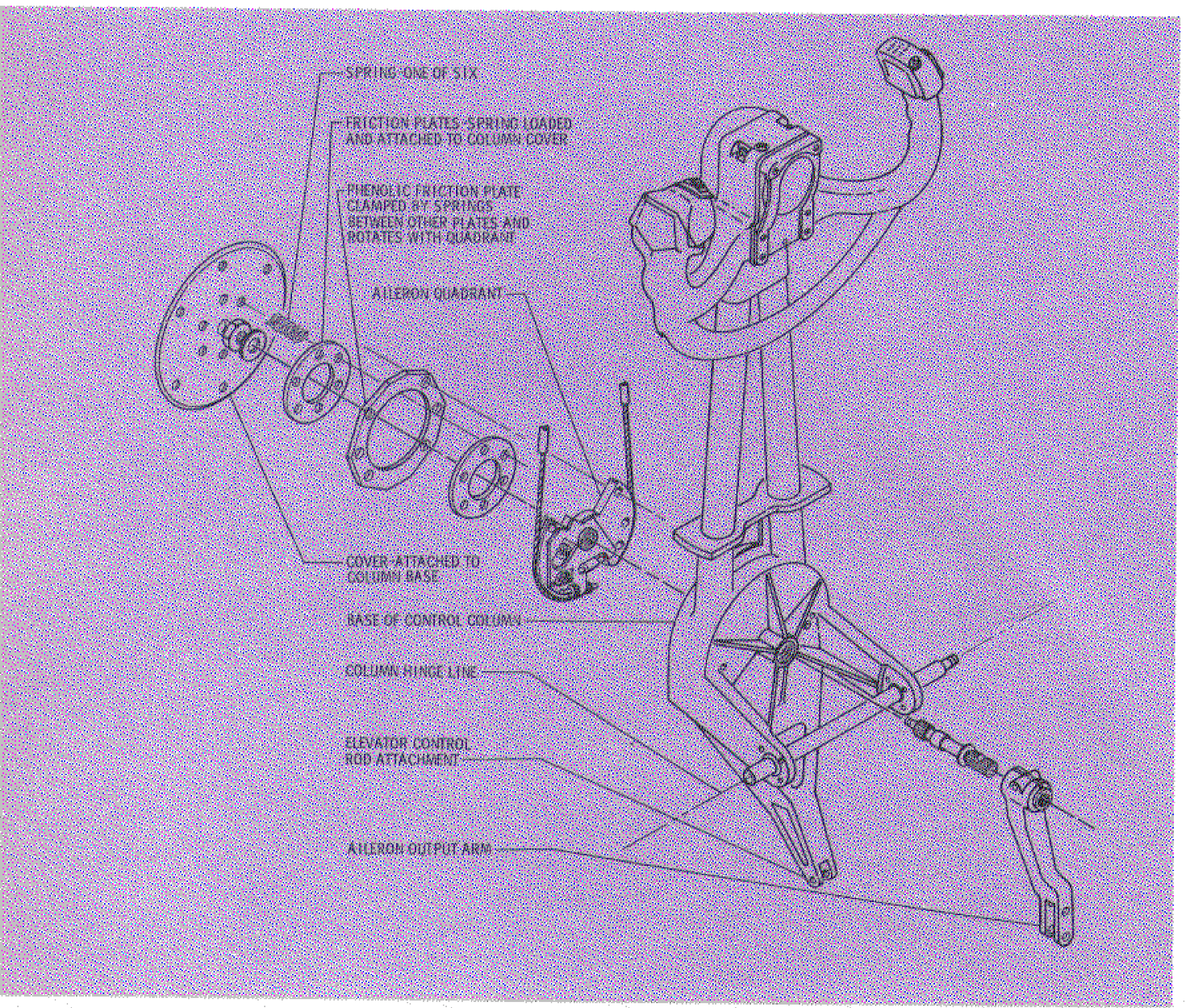


Figure 15
Principal Components
of Friction Device
at Base of Each
Control Column

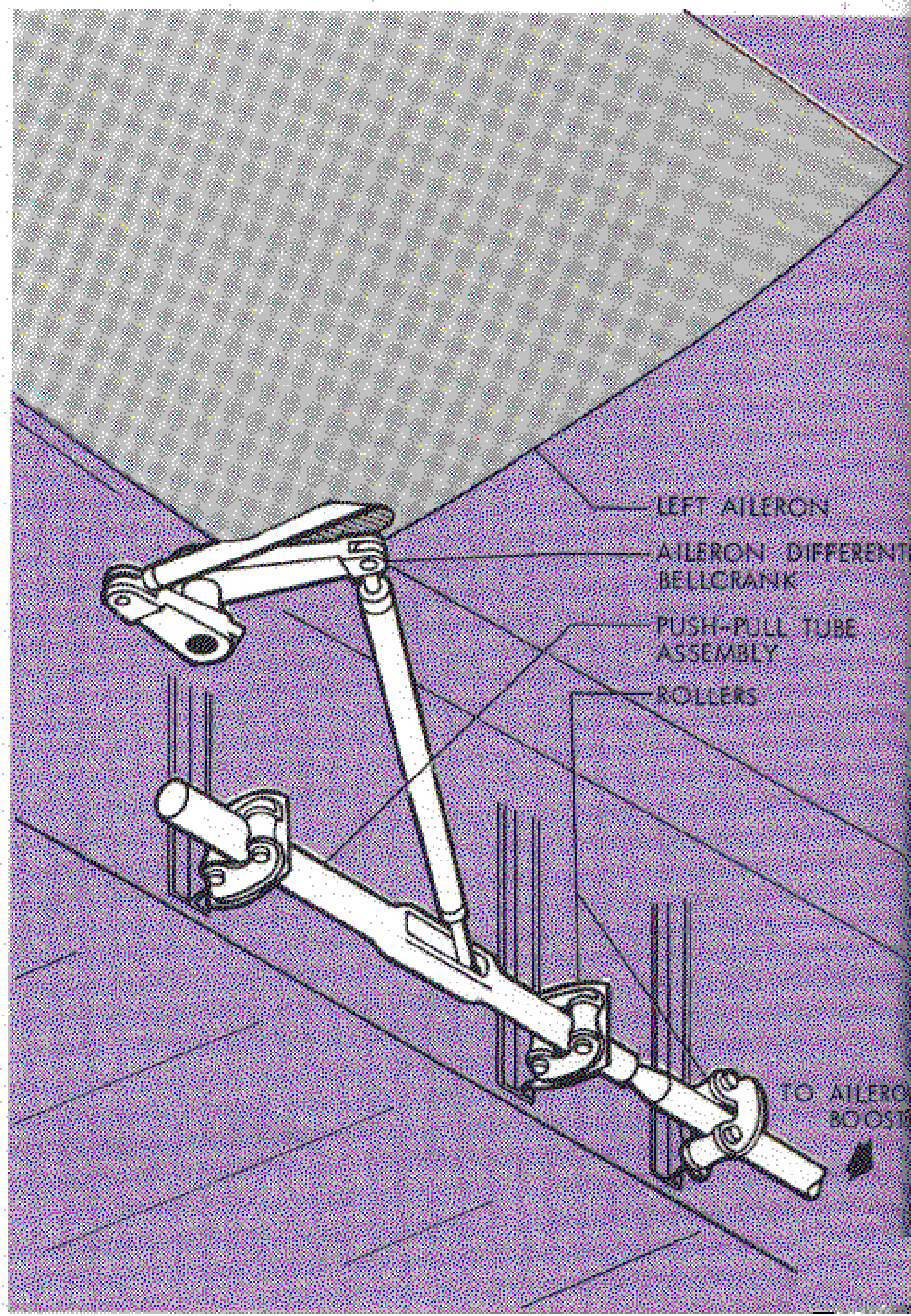


Figure 17
Detail of Aileron
Push-Pull Tube
Installation in Wing

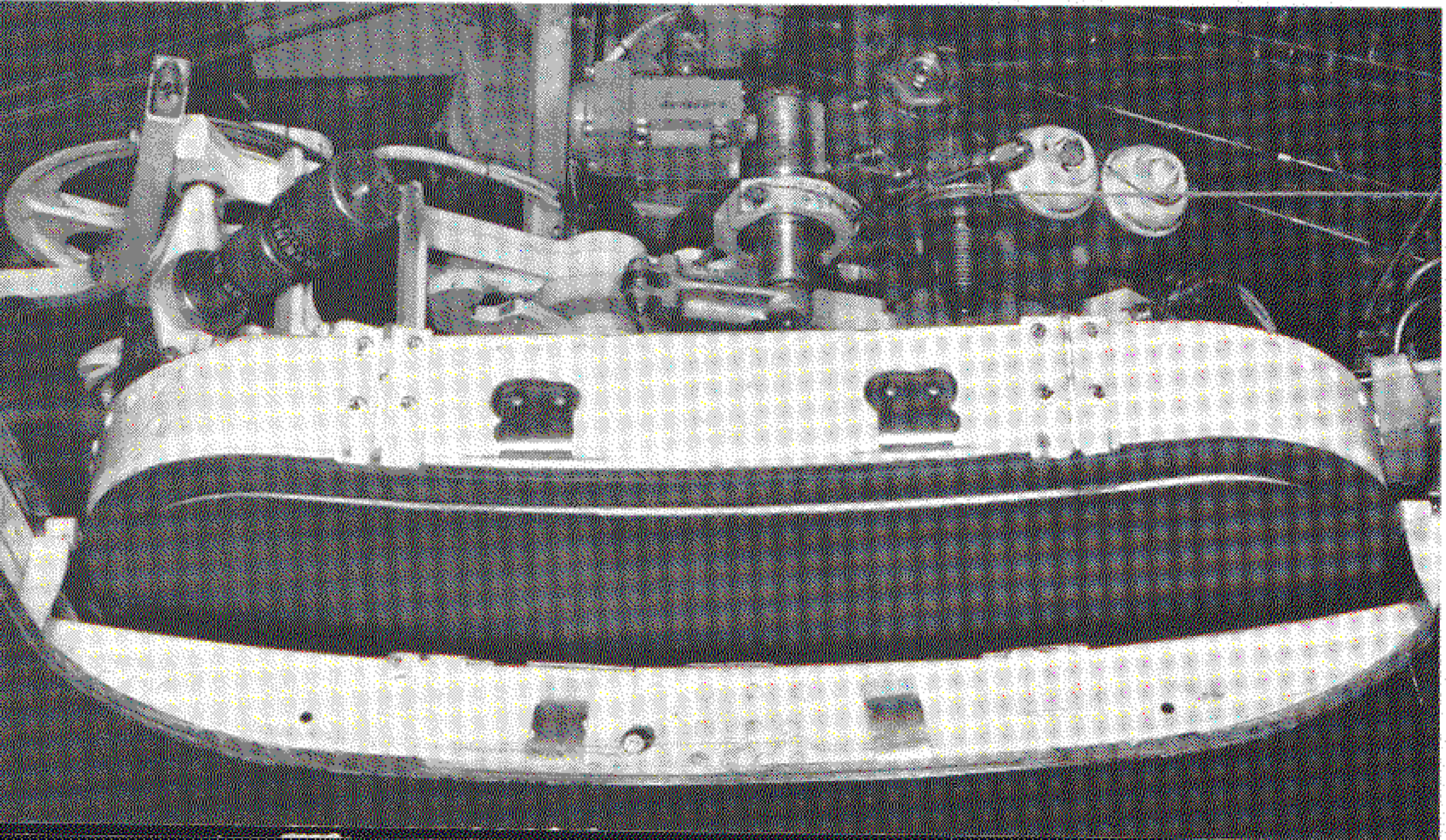


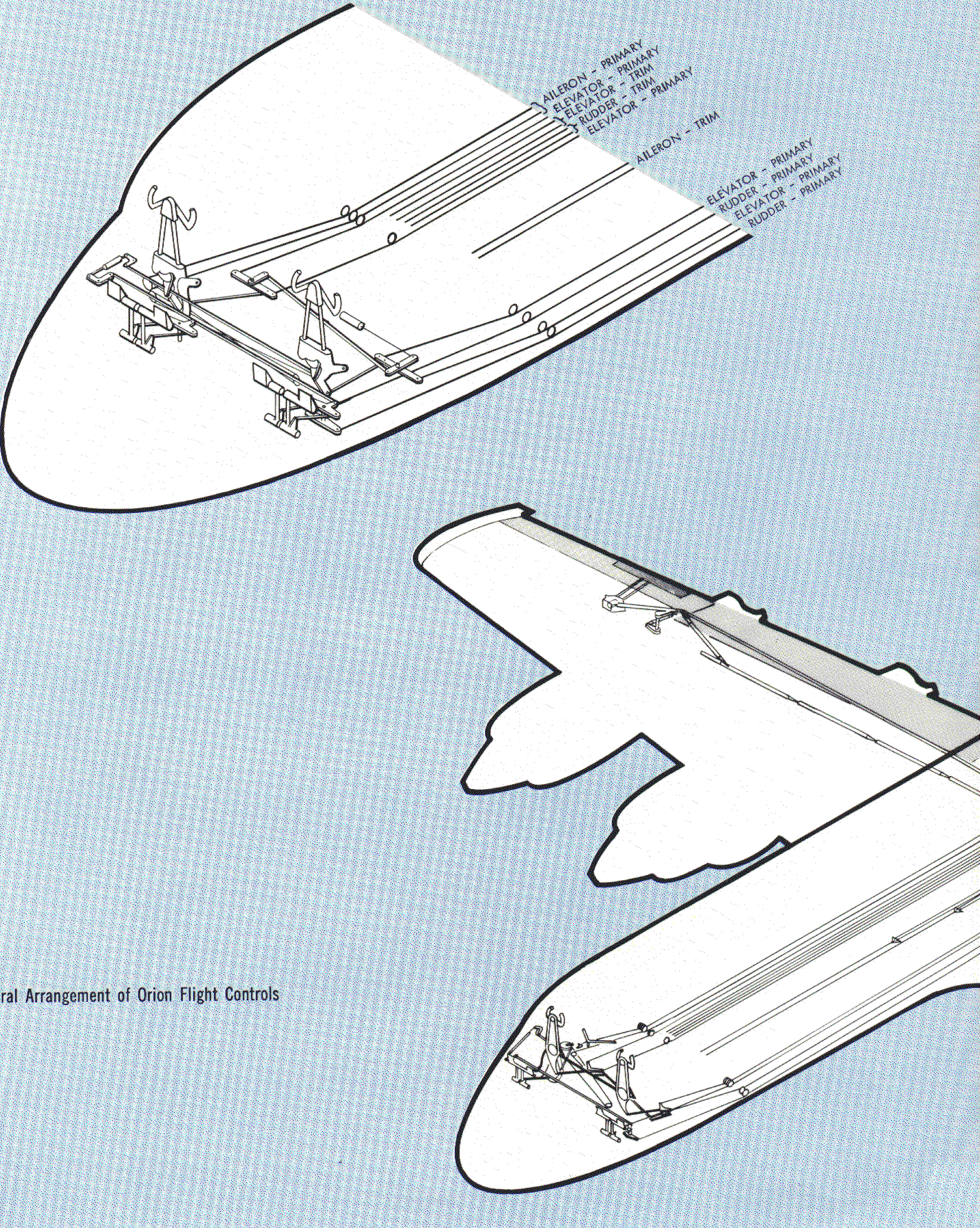
Figure 16
Aileron Booster
Installation —
View looking forward
through hydraulic service
center access door

Motion of the booster output lever is transmitted by push-pull tubes to two idler bellcrank assemblies located at the left and right fuselage sides. A torque tube on each bellcrank assembly passes through fuselage pressure seals and drives an arm and rod above the flap leading edges. The idler arm rod in each wing drives the inboard end of a long push-pull tube assembly having a total spanwise motion of about 10½ inches. This push rod assembly in each wing is supported at ten points by steel or teflon rollers. The two inboard and two outboard roller sets are of steel and are installed fore and aft of the push rods to react to bellcrank loads, while the six roller sets in the center of each push rod assembly are made of graphite-impregnated teflon and are aligned above and below the push rods to react against wing bending. At the outboard end of each assembly, the rod terminates in a cross-head tube, from the center of which another push rod drives the aileron differential bellcrank. The outboard arm of the differential bellcrank is connected to the aileron inboard end by a push rod. Figure 17 gives some idea of the basic design of the push-pull tube assembly in each wing.

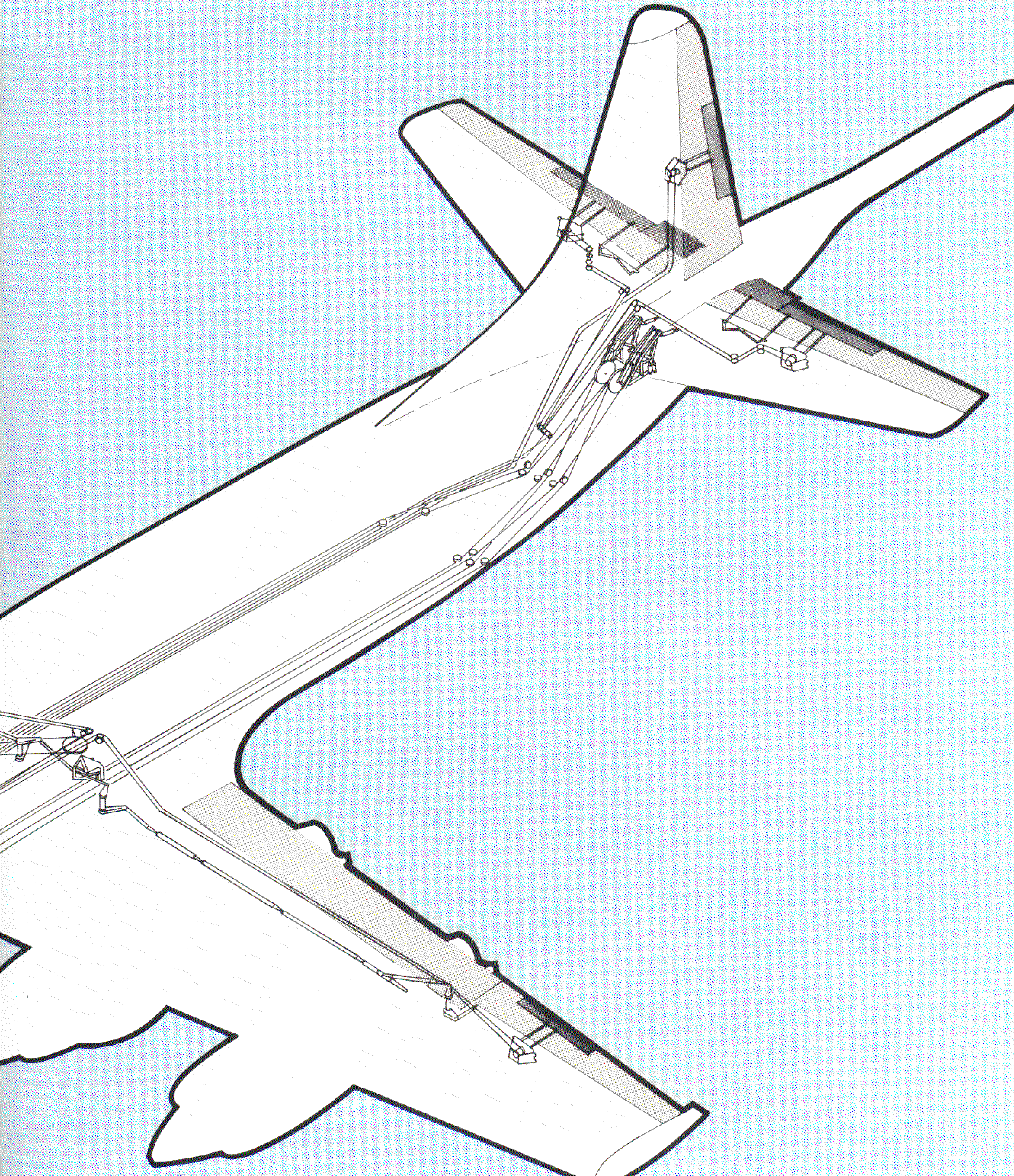
The use of push rods to transmit the drive to the aileron control surfaces through the wing differs from the more usual cable systems used on other aircraft designs. One advantage gained by this method is lack of slack in the systems due to the thermal expansion differential between steel cables and aluminum structure. However, quite apart from temperature considerations, it is interesting to note that the relative deflection of the aileron push-pull rod system under design hinge moments was found during static tests of the Electra control system (which is essentially the same design as that of the Orion) to permit only one degree of aileron deflection for each 10,000 inch-pounds of aileron hinge moment with the rod control system blocked at the booster attachment.

The ailerons are of sheet alclad skin and rib construction, built upon front and rear spars. Supported at 4 hinge points, each aileron extends all the way from the outboard end of the flaps to the wing tip, with the hinge line located within the wing at the 72½ percent chord position. Six balance weights are attached by brackets to the front spar beam so that each aileron has an initial nose heavy unbalance of 8 to 16 inch-pounds. In service this unbalance may vary from 0 to 18 inch-pounds before rebalancing becomes necessary. The ailerons are rigged on the ground so that they have a certain amount of droop, but in-flight deflection forces are such that the ailerons assume an approximately faired position.

It will be noted on Figures 13 and 14 that an interconnection with the rudder controls is indicated. This feature is discussed following the description of the rudder control system.



General Arrangement of Orion Flight Controls



RUDDER CONTROL SYSTEM

The rudder pedals extend from opposite sides of housings located forward of each control column (see Figure 19). The design is conventional in that each pedal travels in an arc about independent torque tube brackets, mounted below the flight station floor, for rudder control, and they may also be rotated independently about their "heel line" by toe pressure to permit differential brake control while taxiing.

The pedal housing is a non-structural fairing installed to prevent foreign objects from falling into the sub-floor control area. The curved side-slots, through which the pedal supports travel during rudder operation, are provided with soft bristle brushes to close the aperture while permitting control motion with minimum friction.

Each pair of pedals may be adjusted individually so that each pilot may adjust them for comfortable leg range independently of the seat adjustment. A worm and sector drive is incorporated in the torque tube output crank arm on each rudder pedal and the worm gears for each pair of pedals are rotated by flexible shafts from the adjustment-crank gear box on the aft face of each pedal island (see Figure 20).

Reciprocal action of the pedals at each pilot's station is maintained by parallel push rods, one from each pedal lever, which are attached to opposite arms of a three-arm bellcrank mounted aft of the pedals as shown in Figure 18. The two bellcranks, one for each pilot's station, are coupled by a push-rod to coordinate the pilot's and copilot's pedal action. The arm on the copilot's bellcrank, to which the coordinating push-rod is attached, is also used for attachment of the aileron-rudder centering interconnection, which is explained later. The cable system is connected to arms on a lower extension of the pilot's bellcrank assembly.

From the pilot's bellcrank, the rudder cables are routed in a straight cable tunnel below the cabin floor structure to Fuselage Station 1030 where a cluster pulley bracket permits a bend toward the lower center of the aft pressure bulkhead. After passing through this bulkhead, the cables are routed upward to the rudder booster input quadrant. A cable slack absorber is installed on each cable near to the input quadrant to maintain a minimum load on the slack cable during system operation. As in the other control systems, ⅛-inch Lockclad cable

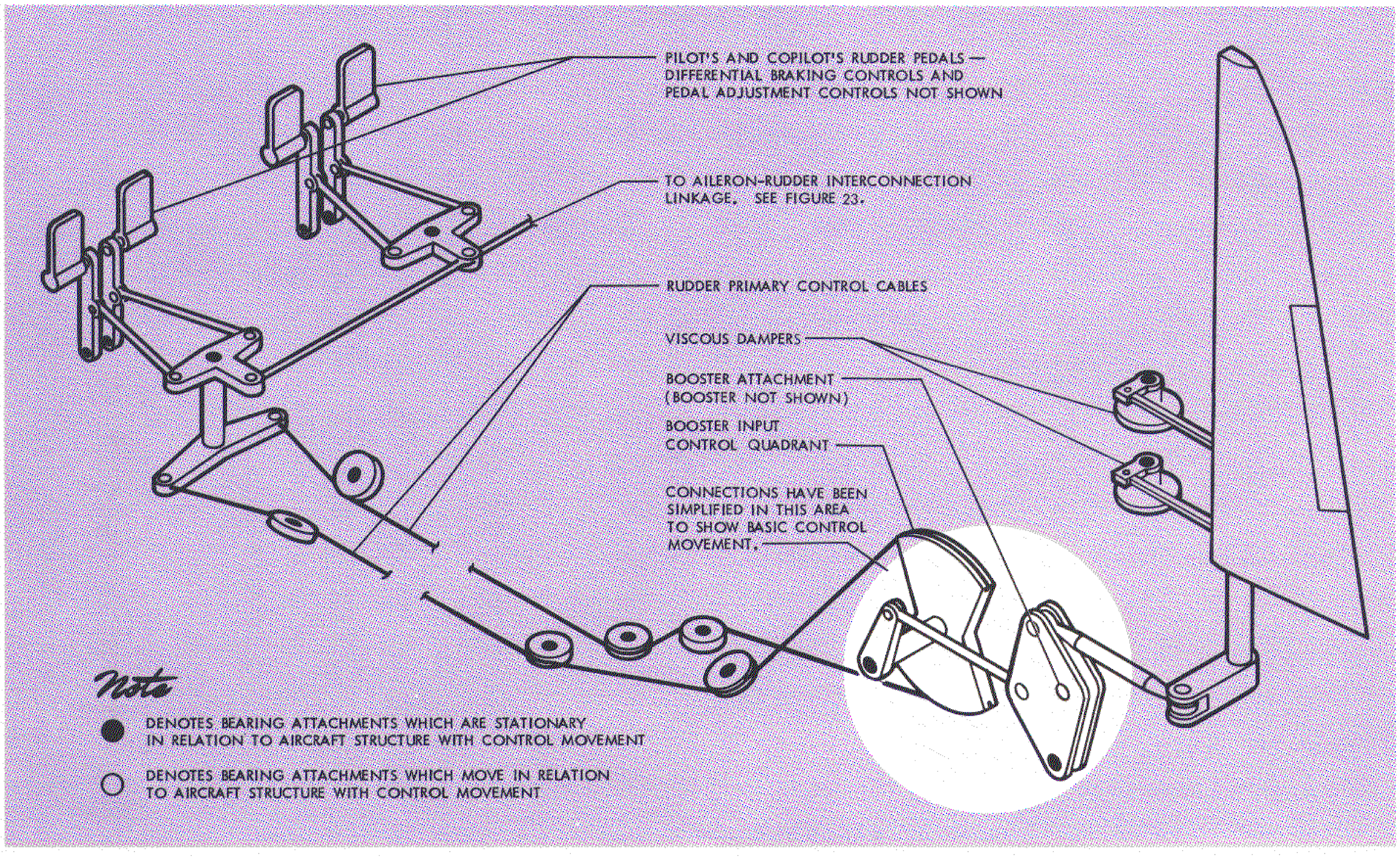


Figure 18 Sketch of Rudder Control System — Booster not shown

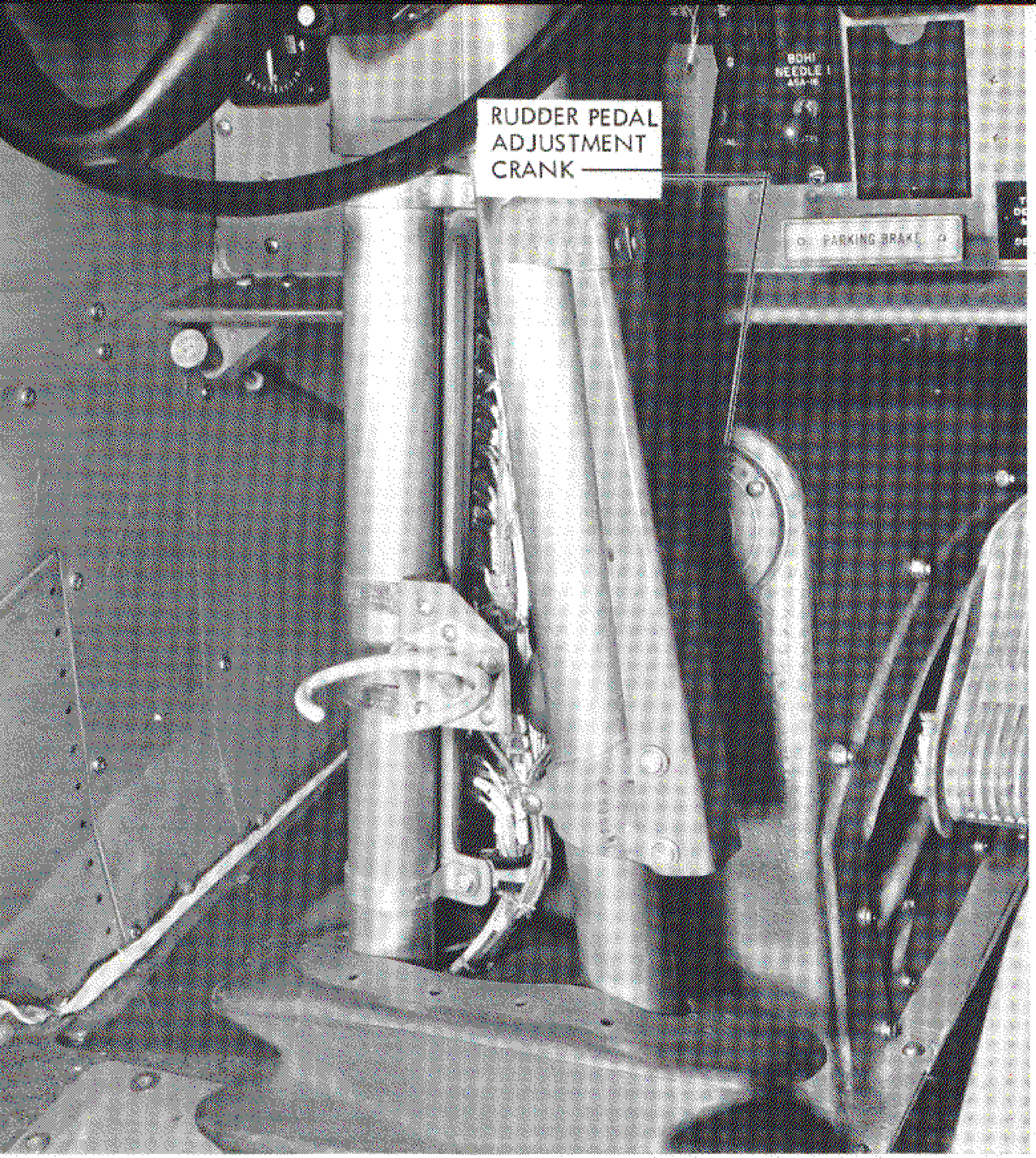


Figure 19 Detail of Pilot's Rudder Controls

is used for the long straight runs and flexible cable is used elsewhere.

The rudder booster assembly is almost identical to the elevator unit, and is mounted in the fuselage aft section below the horizontal stabilizer center section, to the left of, and alongside, the elevator booster (see Figure 21).

The rudder consists of sheet alclad skin, spar and rib construction. Four hinge fittings on the forward spar attach the rudder to the vertical fin, and a torque tube attached to the lower rib of the rudder transmits the output load from the booster to the control surface. The operating arm on the rudder torque tube is connected to the booster assembly by a push-pull rod. Static balance weights are not utilized on the rudder. Static unbalance of the rudder is controlled during manufacture to a maximum of 2,340 inch-pounds, leaving an allowance of another 100 inch-pounds increase in unbalance for service repairs.

Two rotating disc viscous dampers (see description on page 12) are mounted on the vertical fin rear spar and connected to the rudder front spar by push rods. They impose negligible resistance to normal control motion, and the purpose of the damper installations is a fail-safe provision to inhibit surface oscillation in the event of failure in the booster drive rod, torque arm, or input bellcrank. It should perhaps be noted that, in the event of such a failure, control of the aircraft can be maintained utilizing the rudder trim tab controls.

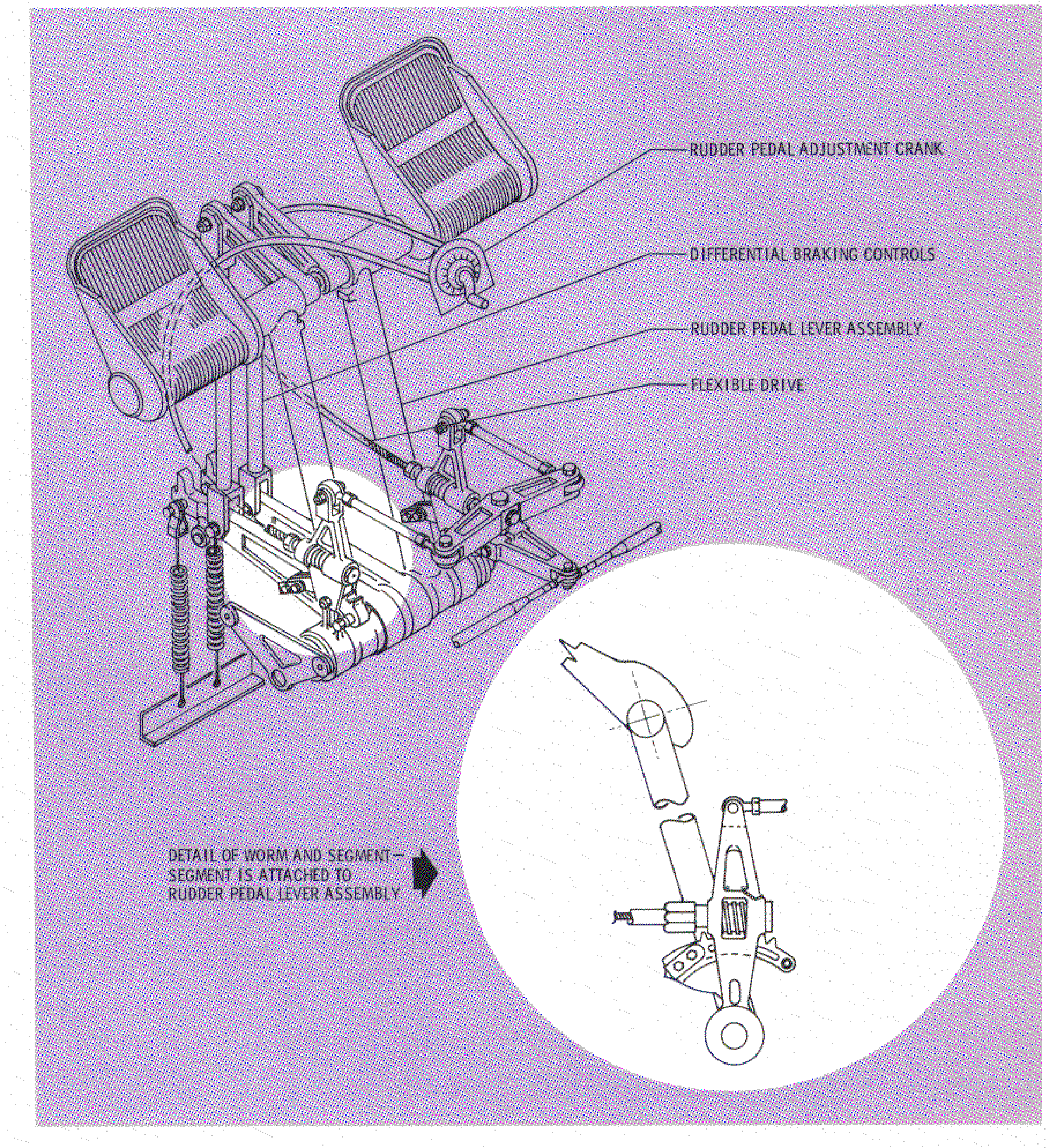


Figure 20 Details of Rudder Pedal Adjustment Controls

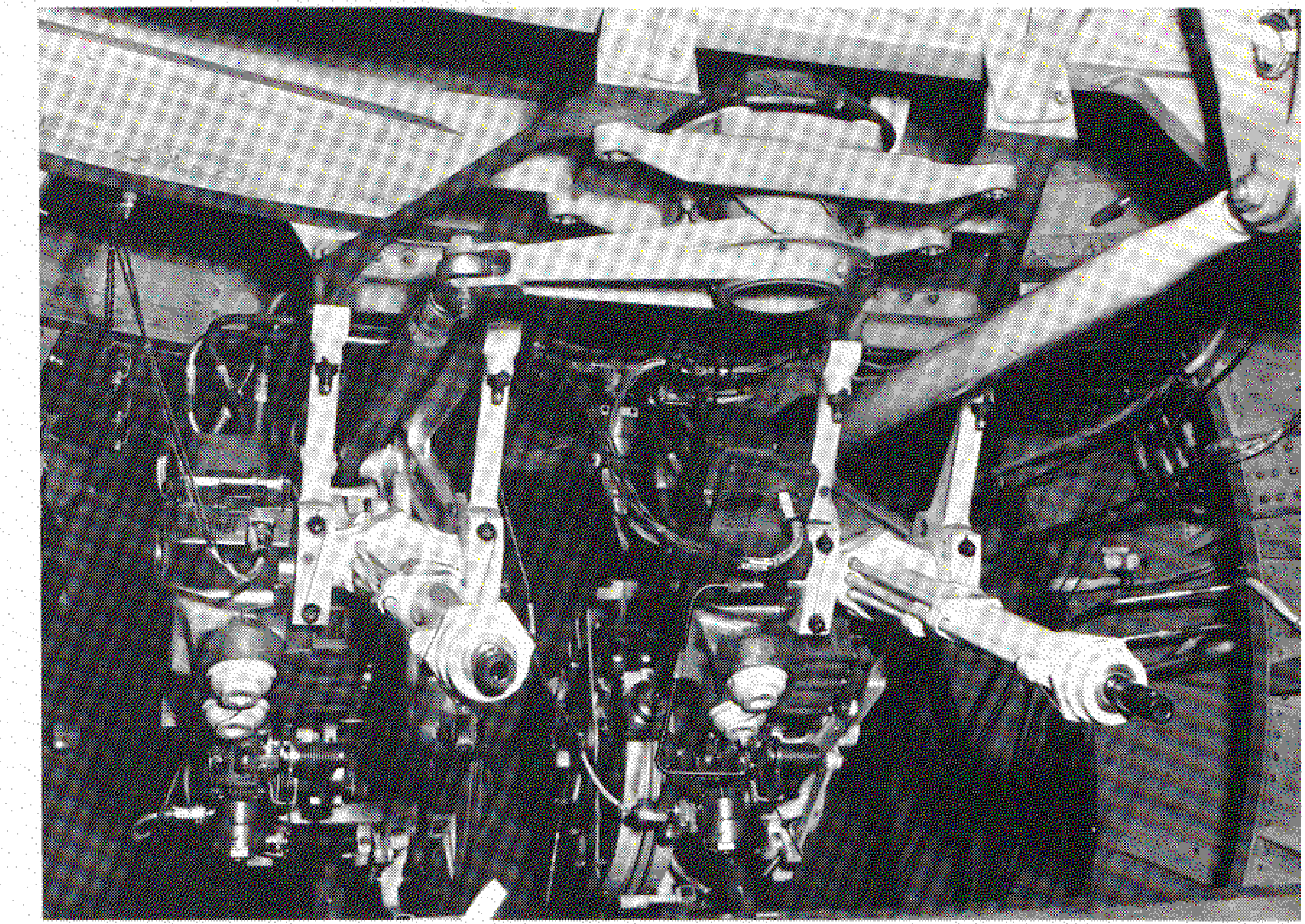


Figure 21 Rudder (left) and Elevator (right) Booster Installations — View looking forward

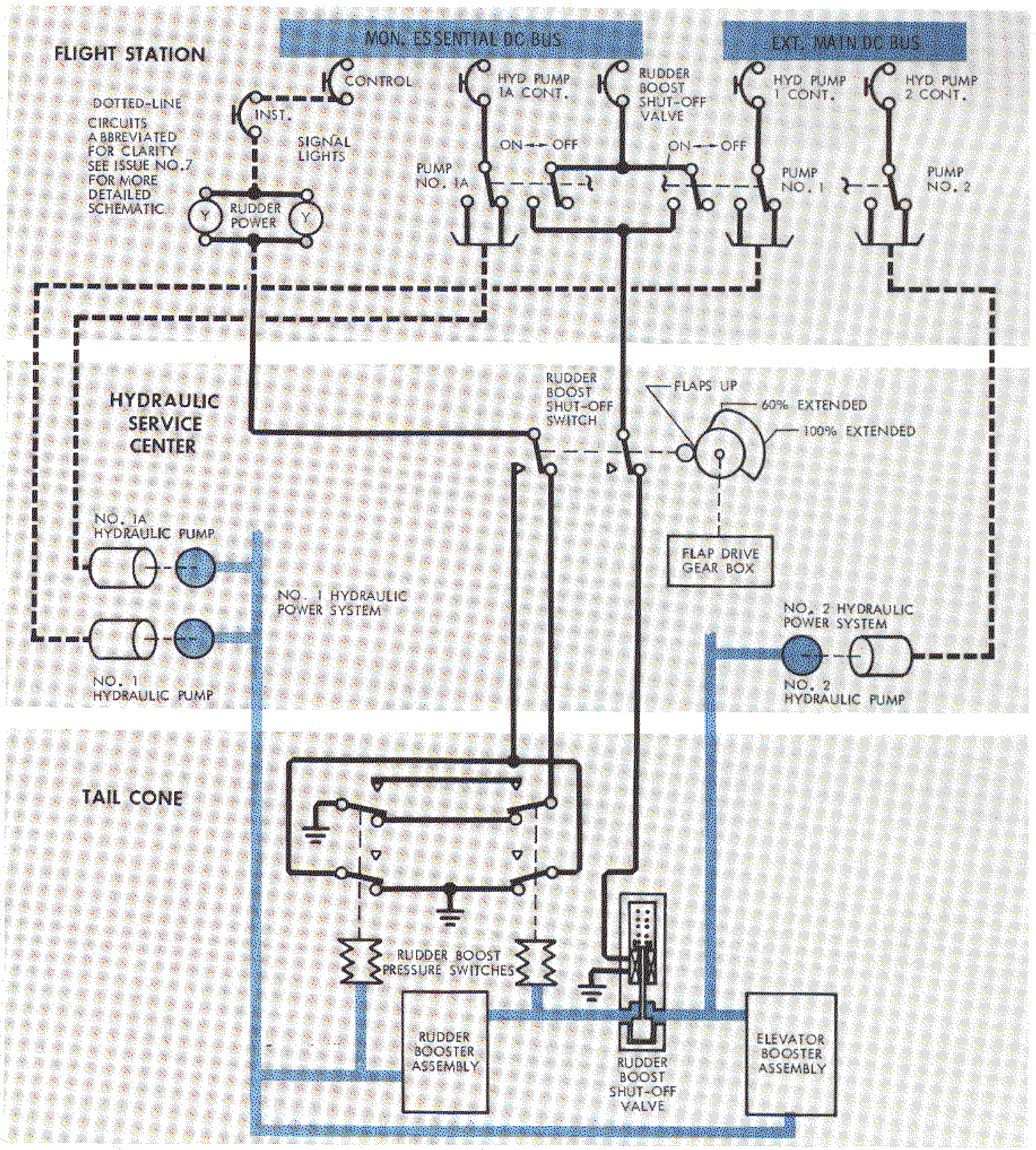


Figure 22
Schematic Showing
Rudder Interconnection
with Wing Flap
Control System

The booster application in the case of the rudder differs from the other two flight control systems in that it is interconnected with the wing flap control system. An electrically operated shutoff valve is located in the No. 2 hydraulic system pressure line just upstream of the booster. As can be seen in Figure 22, this solenoid valve automatically shuts off No. 2 system hydraulic power to the booster when either of the No. 1 system pump control switches are "ON" if a limit switch, mounted on the flap drive gear box, senses that the flaps are less than 14° (60 percent) extended. Thus, when the flaps are retracted, or are extended less than 60 percent, only one of the system rudder boosters is operative. This arrangement increases the effort required of the pilot to move the rudder, and effectively eliminates the possibility of excessive rudder hinge moments being applied at high air speeds. During take-off, approach, and landing — when the flaps are extended beyond the 60 percent position — the No. 2 shutoff is open, and both rudder boosters are operative.

An indicator light (identified "RUDDER POWER") on the center instrument panel is connected through a separate pole of the flap position sensing limit switch and (through a network circuit) to two 2-pole pressure switches—one at the rudder booster No. 1 system pressure inlet and one at the No. 2 system inlet. This advisory light circuit will illuminate the "RUDDER POWER" warning in 3 circumstances:

1. If No. 2 system pressure *does* reach the rudder booster when the flaps are *less* than 60 percent extended with No. 1 system also operative.
2. If pressure from either of the two power systems does *not* reach the rudder booster when the flaps are *more* than 60 percent extended.
3. If neither No. 1 nor No. 2 system pressure reaches the rudder booster, regardless of flap position.

Note that the interlock with the No. 1 system pump control switches makes it advisable for flight crews to turn both No. 1 system pumps "OFF" promptly if pressure is lost in the No. 1 system. If the No. 1 and/or the No. 1A pump control switch is left "ON" after pressure is lost in the No. 1 system, the rudder booster will be rendered completely inoperative when the flaps are either less than 60 percent extended or are retracted to less than 60 percent.

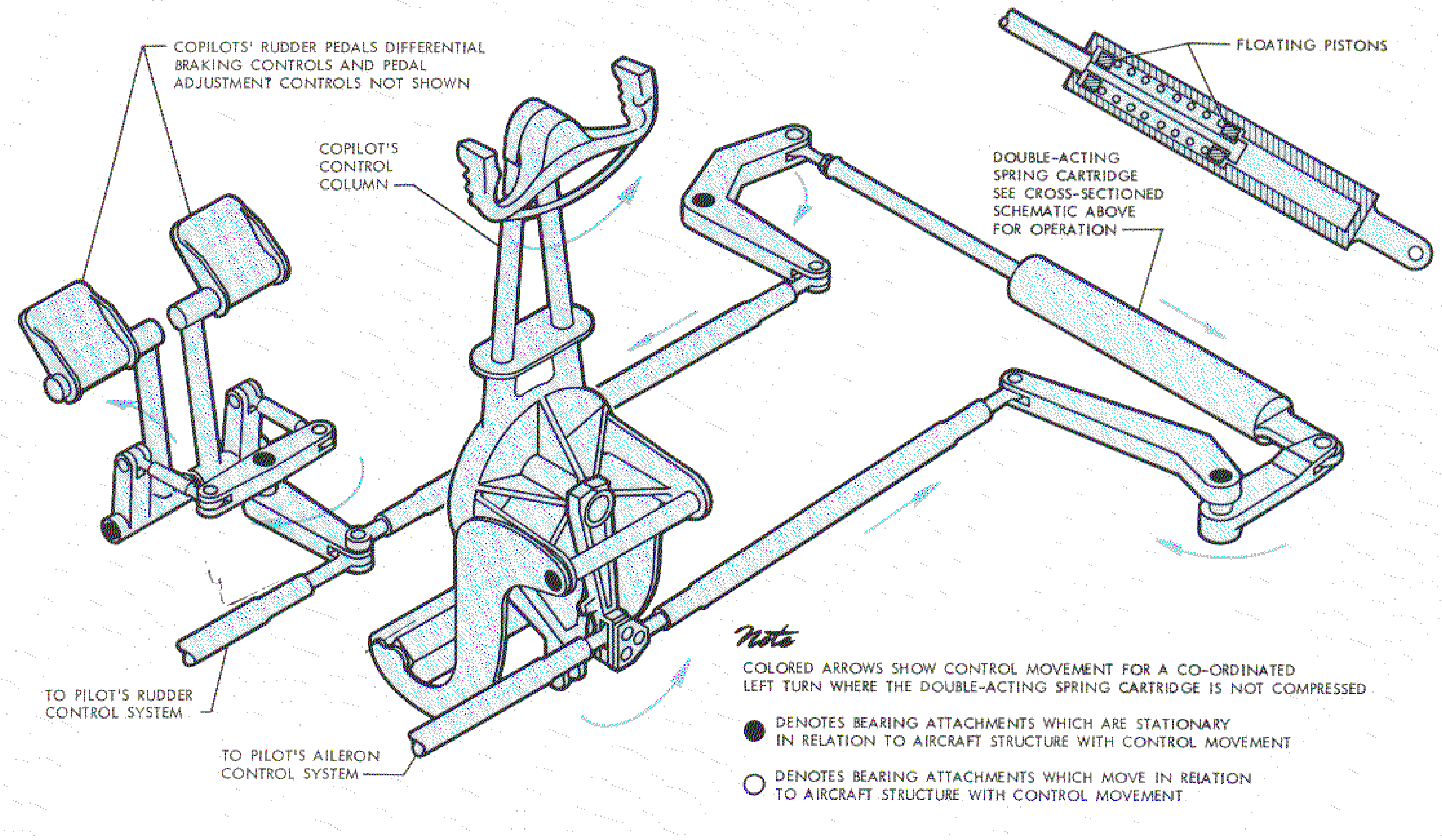


Figure 23a
Sketch of Aileron-Rudder
Interconnecting Control Linkage

AILERON-RUDDER INTERCONNECTION

This installation, shown in Figures 23a and 23b is designed to provide good aileron centering without high break-out forces and with no noticeable effect on coordinated maneuvers using both aileron and rudder.

A double acting spring is connected by a bellcrank and push rod to the aileron output arm at the base of the copilot's control column and by another bellcrank and push rod to the copilot's rudder pedal bellcrank. By following the arrows on Figure 23a it will be seen that movement of the rudder to the left will produce a force to cause the aileron wheel to rotate counter-clockwise. Conversely, clockwise rotation of the aileron wheel will produce a force moving the rudder to the right. In both of these examples the geometry of the inter-connecting linkage is such that the relative movements of the ailerons and rudder result in a coordinated maneuver (a normal turn, for example) and there is little or no force produced between the systems.

However, when aileron and rudder are moved in opposite directions (as in the case of sideslips), the spring in the inter-connected cartridge is compressed to produce a force which tends to return the controls to neutral. The characteristics of this arrangement are such that, with the rudder held in neutral and the aileron wheel rotated clockwise the spring is compressed and produces a wheel-force of 3.5 pounds tending to center the wheel. If the rudder is now deflected full left (opposite direction to a coordinated maneuver), the wheel force tending to rotate it in a counter-clockwise direction is increased to 6.7 pounds.

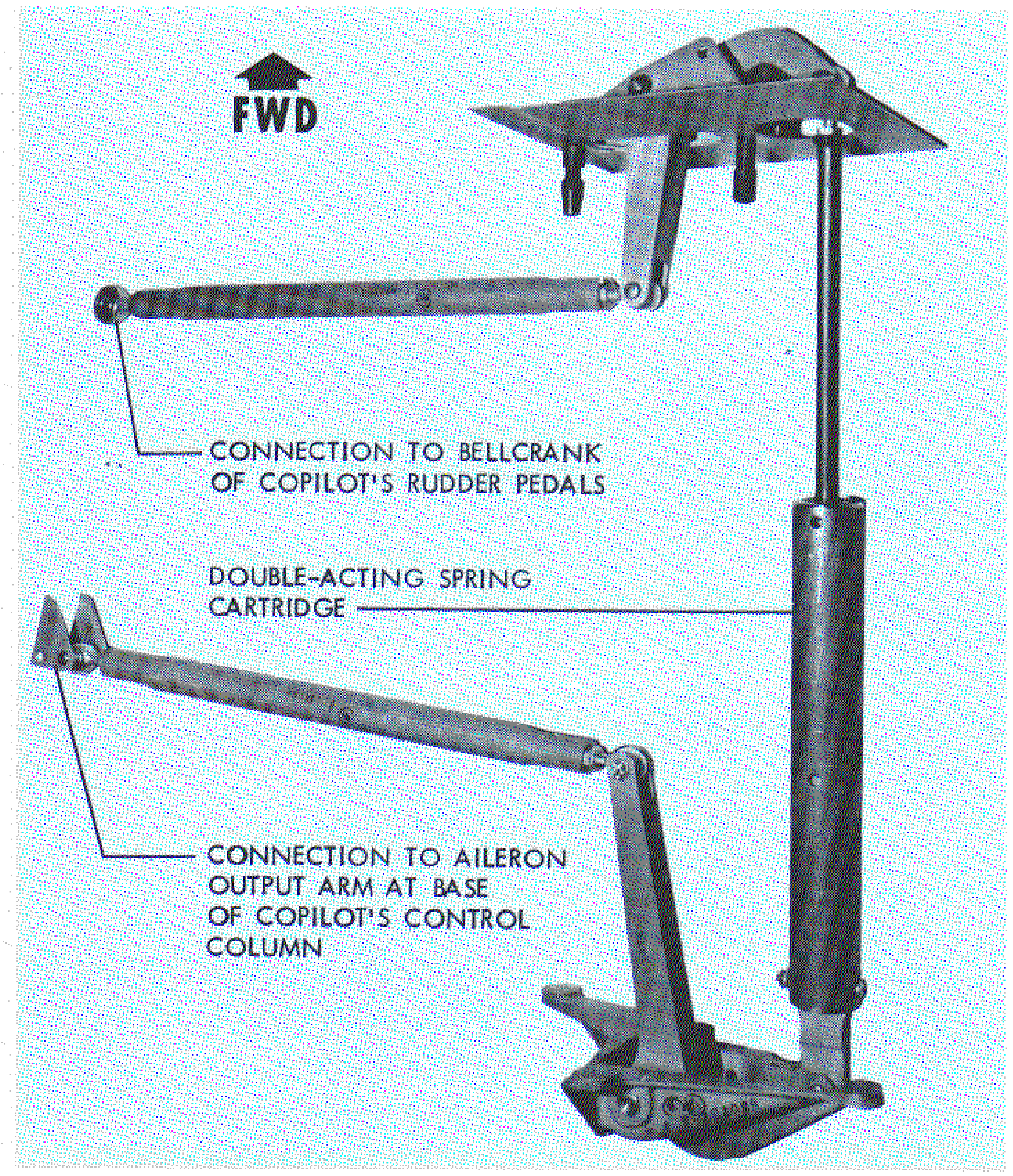


Figure 23b Aileron-Rudder Interconnection Components

AILERON TRIM TAB CONTROL SYSTEM

The aileron trim tab control unit has a 3-inch diameter fluted knob with a retractable crank, and it is mounted on the aft vertical face of the flight station control pedestal (see Figure 24). The edge-lighted tab position indicator occupies the upper 90 degrees of the knob bezel, and has a pointer to show the angular setting of the tabs with respect to the ailerons. The pointer is driven by a planetary gear train. About 16 turns of the crank are required to move the aileron tabs through their full 40-degree travel (full up to full down). As shown in Figure 25, movement of the crank is transmitted by three torque shafts and two right-angle gear box units to a sprocket on the lower horizontal torque shaft, which drives a chain with cable terminal ends.

Two 3/32-in. diameter cables are attached to the sprocket chain ends below the flight station floor. Ball fittings are swaged onto the cables to prevent cable overtravel by contact with stops on the structure at Fuselage Station 288. The cable lengths run aft to a point over the wing center section, where a divider plate on each cable permits attachment of separate pairs of cables. The paired cables are then routed left and right to the aileron tab actuator in each wing. The tab actuators are described on page 11.

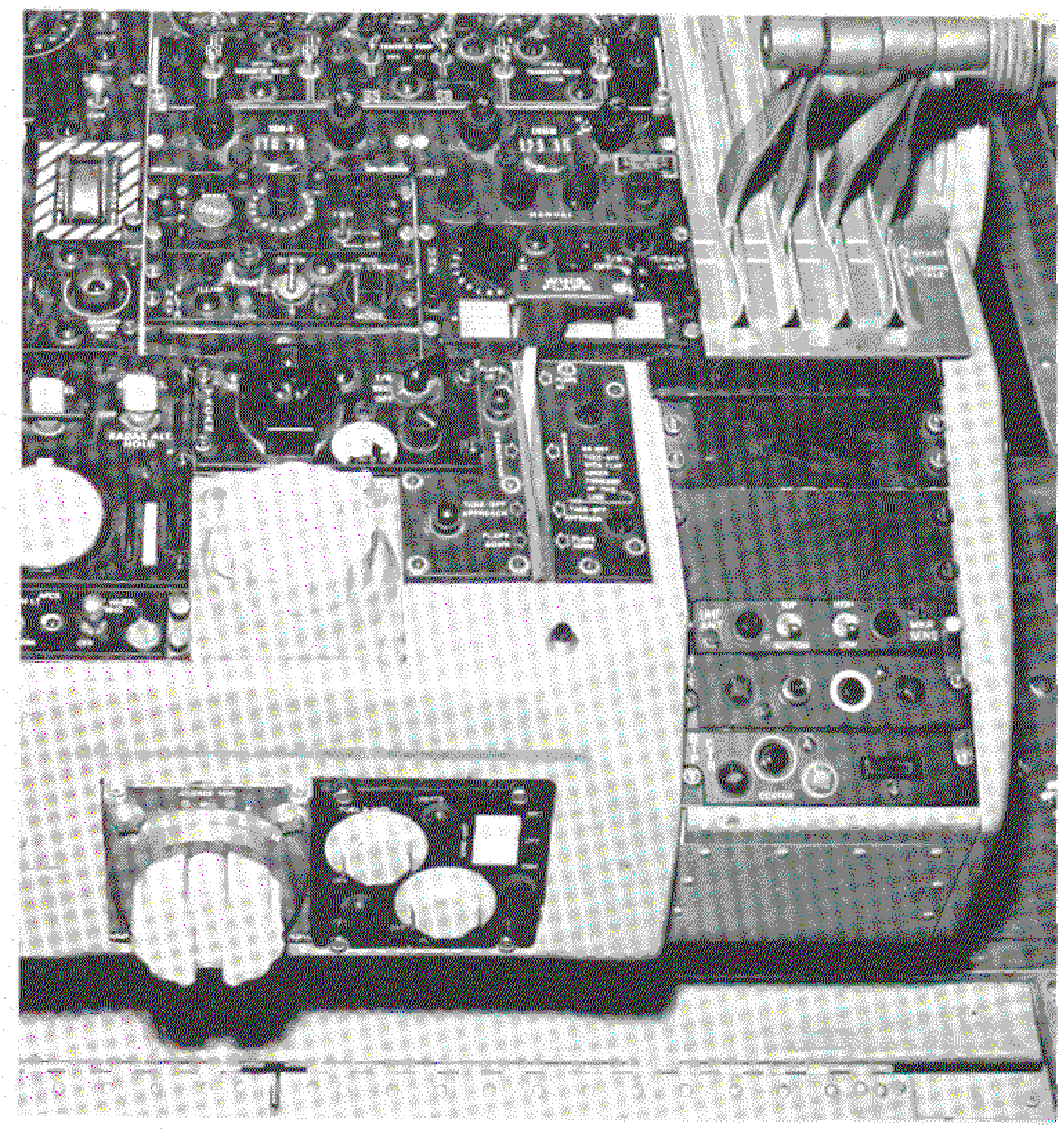
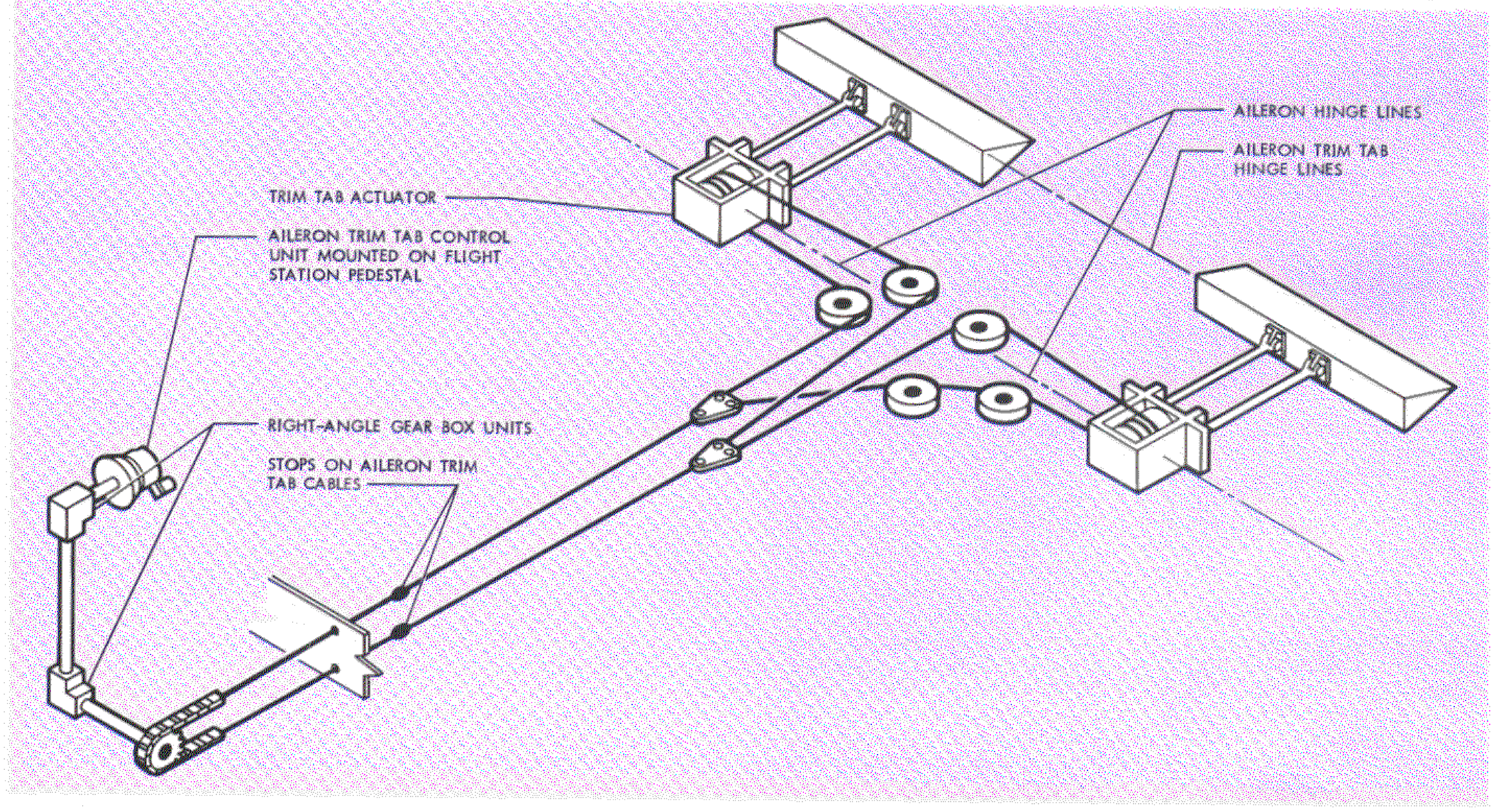


Figure 24 View of Control Pedestal Showing Aileron and Rudder Trim Controls

Figure 25 Sketch of Aileron Trim Control System



RUDDER TRIM TAB CONTROL SYSTEM

The rudder trim tab control unit is similar to the aileron unit and is mounted just above it (see Figure 24). The control knob surmounts the edge-lighted tab position indicator which is driven by an independent planetary gear train. About 18 turns of the flush-folding crank of the trim control unit produce 50 degrees of tab travel, which is shown on the indicator scale as 25 degrees left and right.

Knob rotation torque is transmitted from the pedestal-mounted unit downward to a right-angle gear box and then to a transverse torque shaft (see Figure 26). A sprocket on the righthand end of this shaft drives a chain connected to a closed cable system which continues aft to the rudder actuator. Lock-clad cable is used for the straight run to the aft end of the fuselage, and 3/32-inch diameter flexible cable for the remainder. The trim tab actuator is described on page 11.

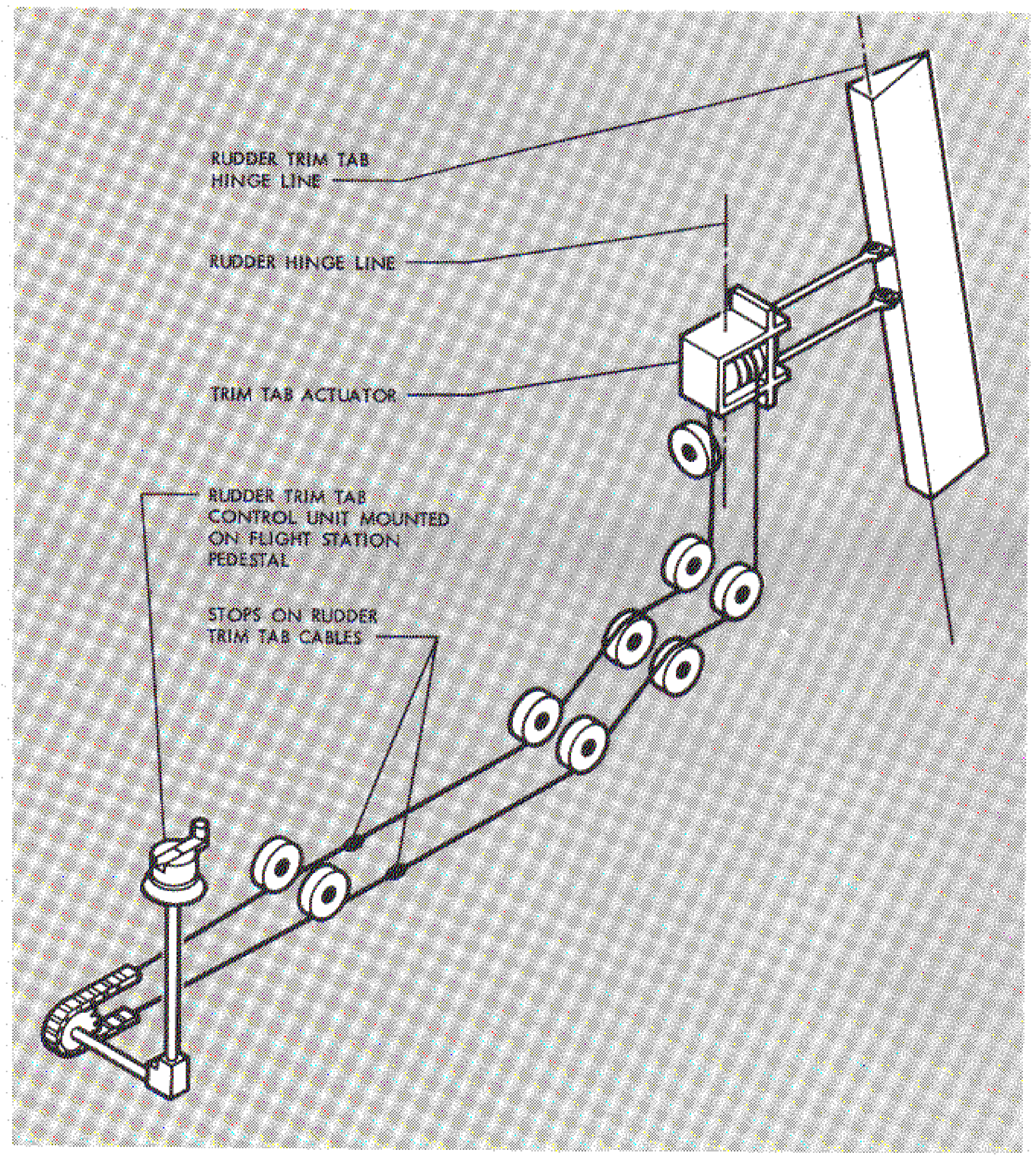


Figure 26 Sketch of Rudder Trim Control System

ELEVATOR CONTROL SYSTEM

The pilot's and copilot's control columns are pivoted in floor structure about two feet either side of the aircraft centerline. They are hinged so as to produce a forward (nose down) moment, and a bobweight (also called a stability augmenter weight), installed on the copilot's column, increases the total moment of the columns to a nominal value of approx. 19 pounds stick force in terms of pilot effort. The purpose of this stick force is explained later but, under static (1g) conditions, the force remains essentially constant with elevator position and is statically balanced by a spring cartridge so that its effect is not perceivable to the pilot (see Figures 27 and 28).

A viscous damper (see description on page 12) is attached to the bottom of the copilot's control column by a pushrod and crank assembly (see Figures 27 and 29). Its purpose is to damp oscillations in the elevator control system which might possibly result from a rapid movement of the control columns at high air speeds. For extremely rapid column movements (maximum rate allowed by booster unit), the stick force is increased approximately 1.25 pounds by the viscous damper, but it has practically no effect in normal flight maneuvering.

Unlike the rudder and aileron controls, the elevators have two independent cable systems, each of which is connected through control rods and bellcranks to each of the control columns. The two cable systems are routed aft, on opposite sides of the fuselage, to dual input quadrants on the elevator booster assembly. Since the dual controls in the flight station are interconnected by a control rod, it follows that a failure in *any* part of the elevator control system between the columns and the booster assembly would still leave the elevators operable from both pilot positions (see Figure 31).

Cable Tension Regulators. As mentioned earlier, the input quadrant on the elevator booster is a dual assembly and, unlike the other two primary control cable systems, incorporates cable-tension regulators

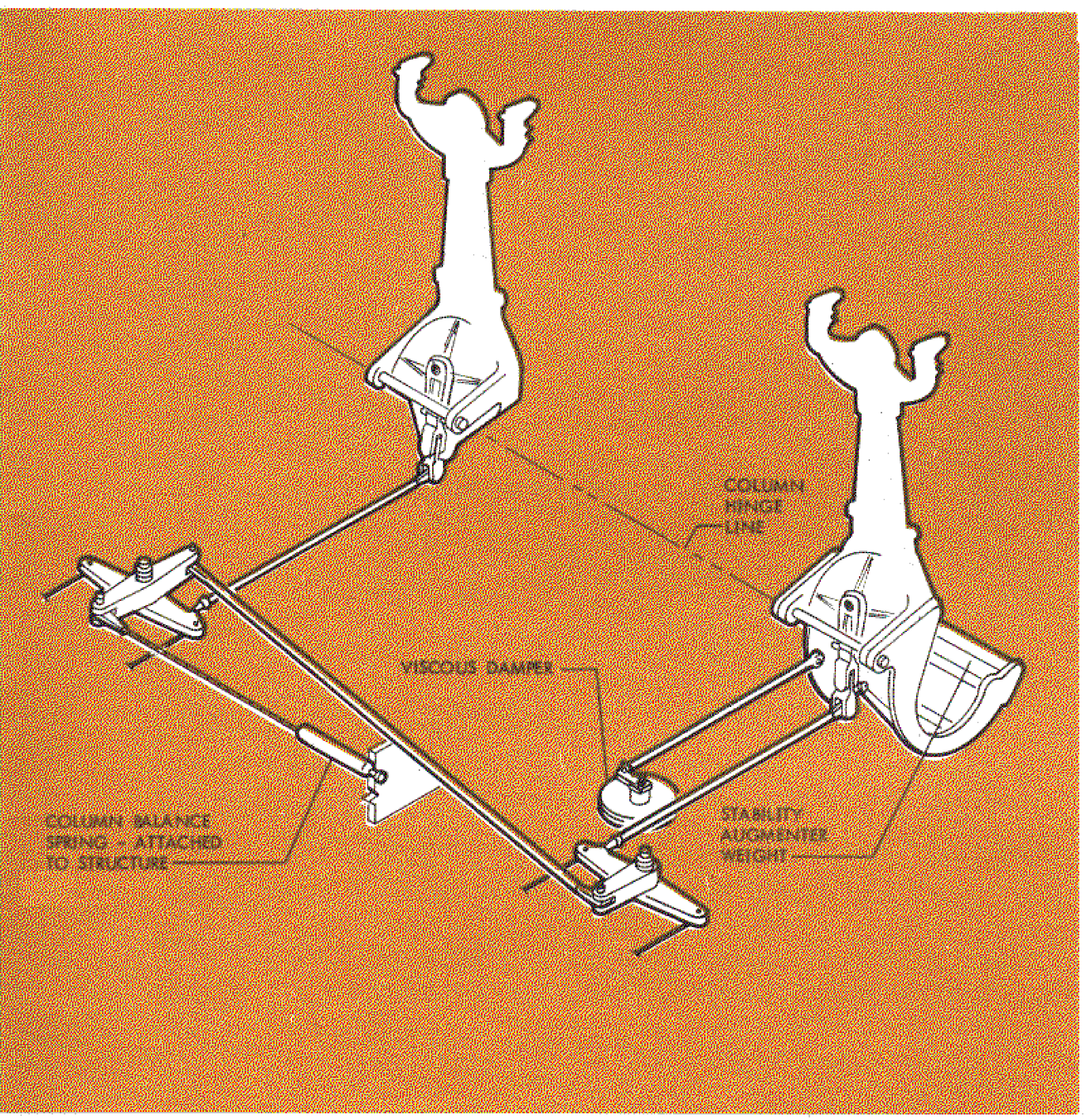


Figure 27 Sketch Showing Control Columns, Stability Augmenter Weight, and Balance Spring

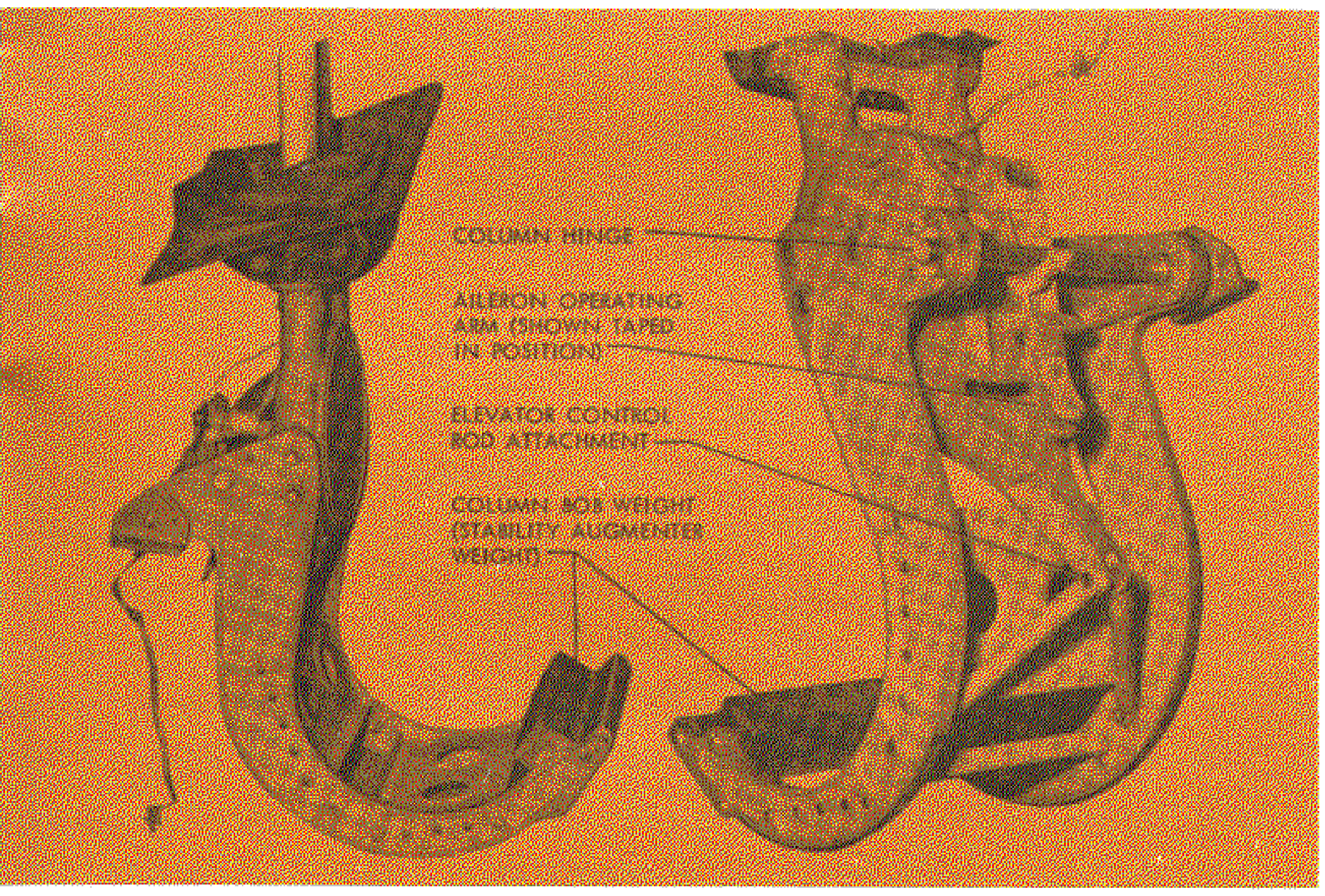


Figure 28 Stability Augmenter Weight on Copilot's Control Column

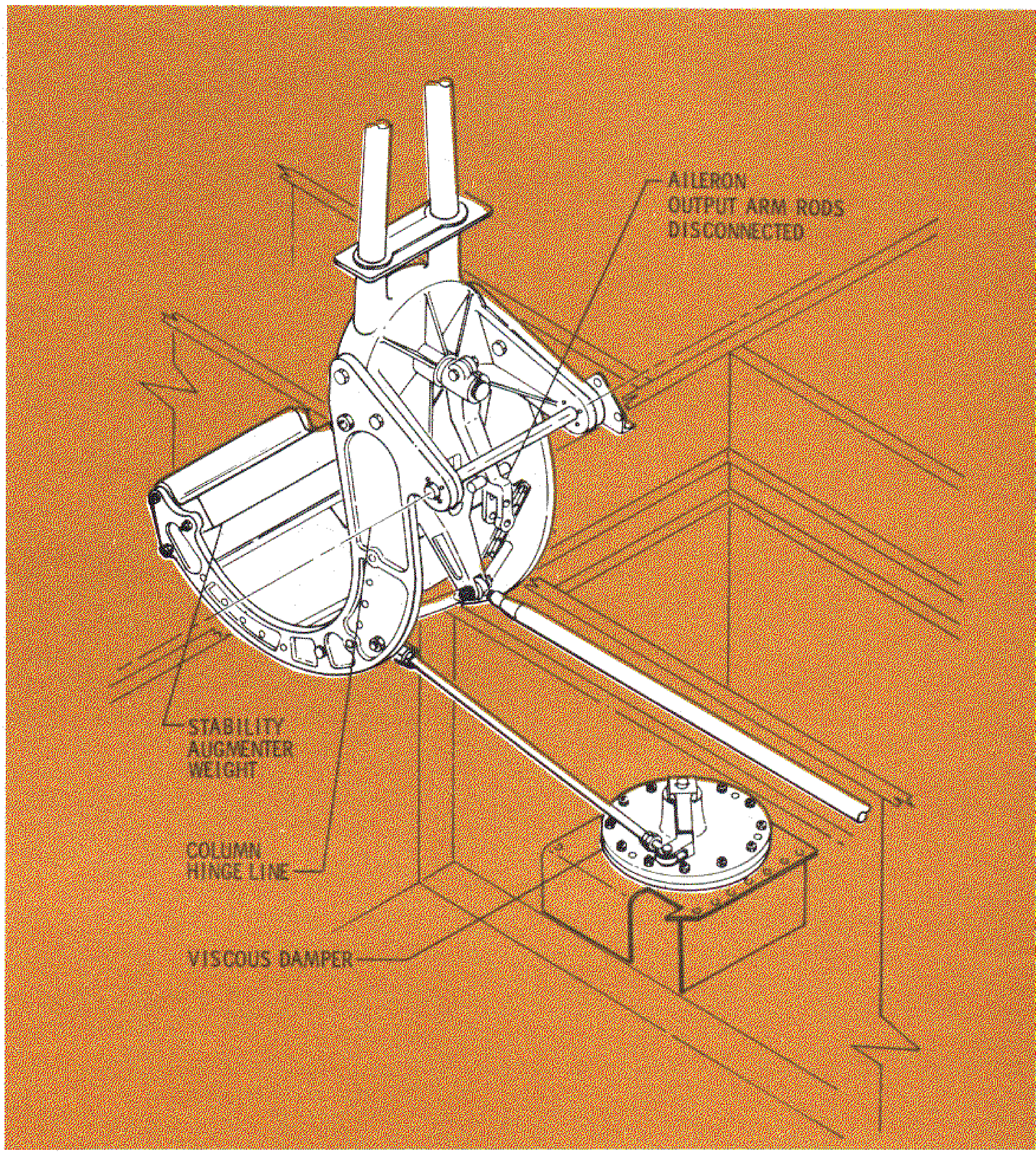


Figure 29 Detail of Viscous Damper Installation to Copilot's Control Column

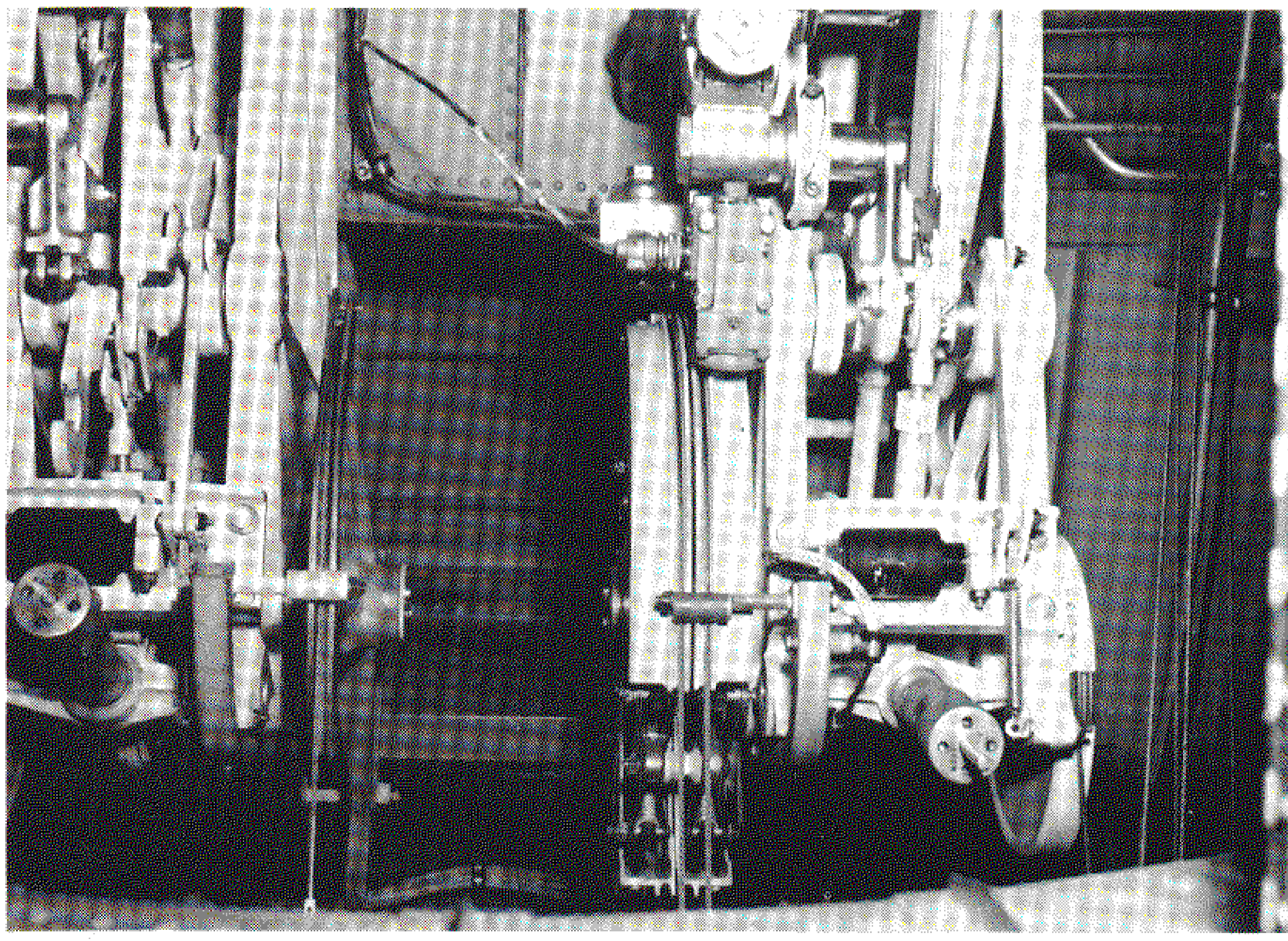


Figure 30 View Looking Up at Rudder and Elevator Booster Installations in Aft Fuselage

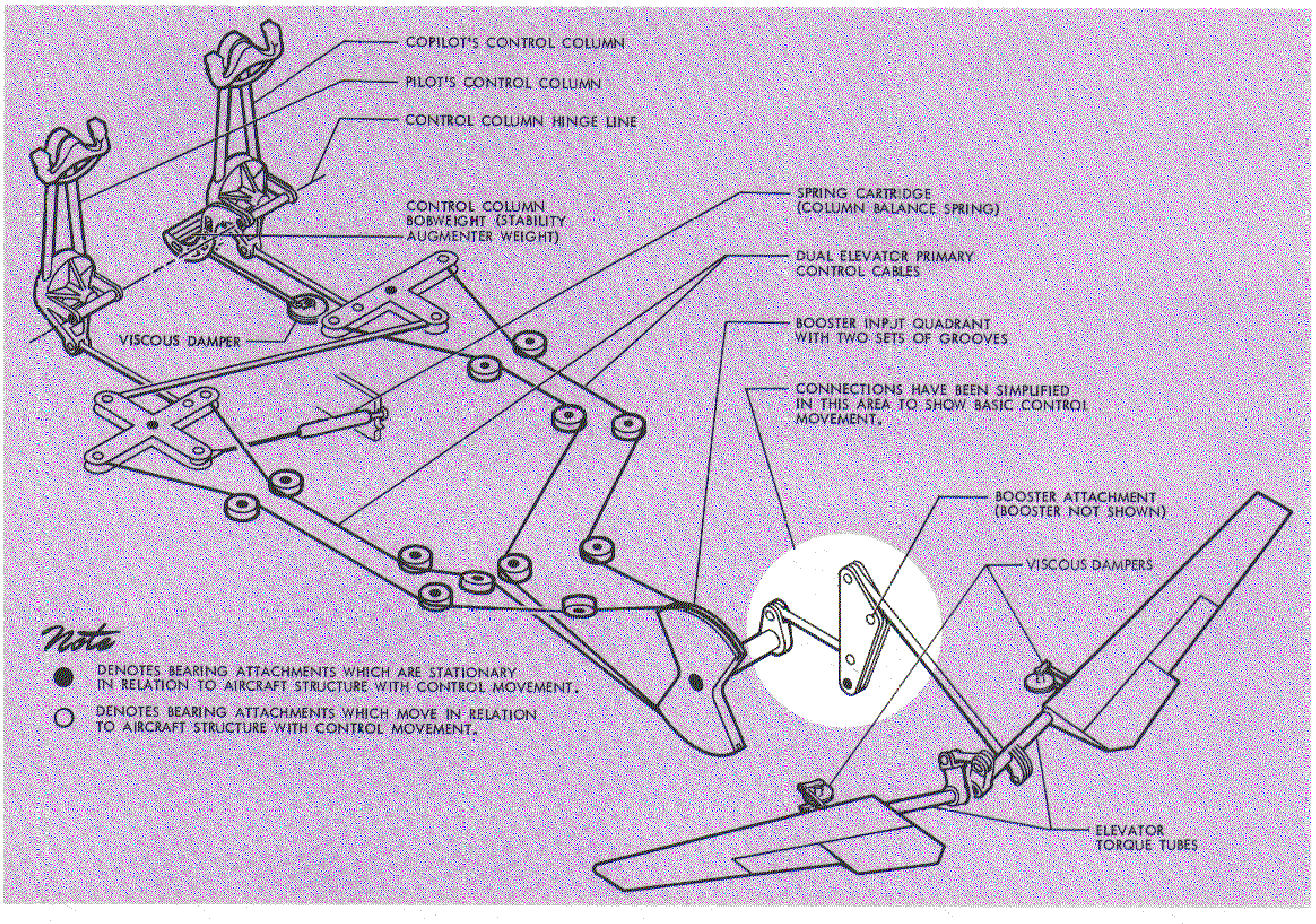


Figure 31
Sketch of
Elevator Control System
— Booster not shown

as well as cable slack absorbers. The complete dual assembly (including four slack absorbers) is shown in Figure 32, while Figure 33 is a simplified diagram of one of the two identical units showing the principle of operation.

Rigging instructions for the installed regulator are given in the Maintenance Instruction Manual, and they are accomplished with the elevator booster in the "boost-on" position. Briefly, with the spindle and drive arm in the neutral position (rig pin installed in booster) and the flight station controls in neutral (rig pins installed in both elevator bellcranks), the cables are then adjusted to the correct tension. It should be noted that, unlike other cable systems on the aircraft, tensiometers are not used to obtain the correct tension on the elevator primary cables. Instead, the cables are rigged by reference to the pointers and scales on the regulators (see Figure 32) and to the pertinent tension chart in the MIM (NAVWEPS 01-75PAA-2-2).

The tension is actually supplied by two rig-load compression springs, and, when rigging the regulators as outlined above, the crosshead should be free to slide on the spindle of the drive arm. It follows that when both the primary cables (see Figure 33a) are similarly loaded, the rig load springs maintain an almost constant tension on the cables regardless of the effect of temperature changes on the aircraft structure or other influences.

However any movement of the controls—whether initiated from the flight station or by air loads on the control surfaces—will cause the cables to be unevenly loaded with the result that the crosshead is tilted and becomes locked on the spindle. This action is depicted in Figure 33b. The clearance between the crosshead and the spindle is of course highly exaggerated in these drawings and the clearance is actually such that the movement required to lock the assembly as a rigid unit is less than 0.030 in. measured at the cable attachment. Needless to say, no lubricant of any kind should be applied to the drive arm spindle but it should be noted that the crosshead incorporates a wiper, which is lubricated during assembly of the unit.

It will be noted in Figure 32 that the attachment of the crosshead to each quadrant half incorporates another spring assembly (section B-B). These assemblies were omitted from Figure 33 for the sake of clarity. They are actually cable slack absorbers and, although attached to the cable quadrant rather than the cable, they have the same purpose and principle of operation as the similar units attached to the aileron and rudder primary cables.

Aft of the elevator booster assembly, the booster power output lever is connected to the right elevator torque-tube input arm by a push-pull tube. The horizontal stabilizer has an appreciable amount of dihedral so that a universal ball joint and other intercon-

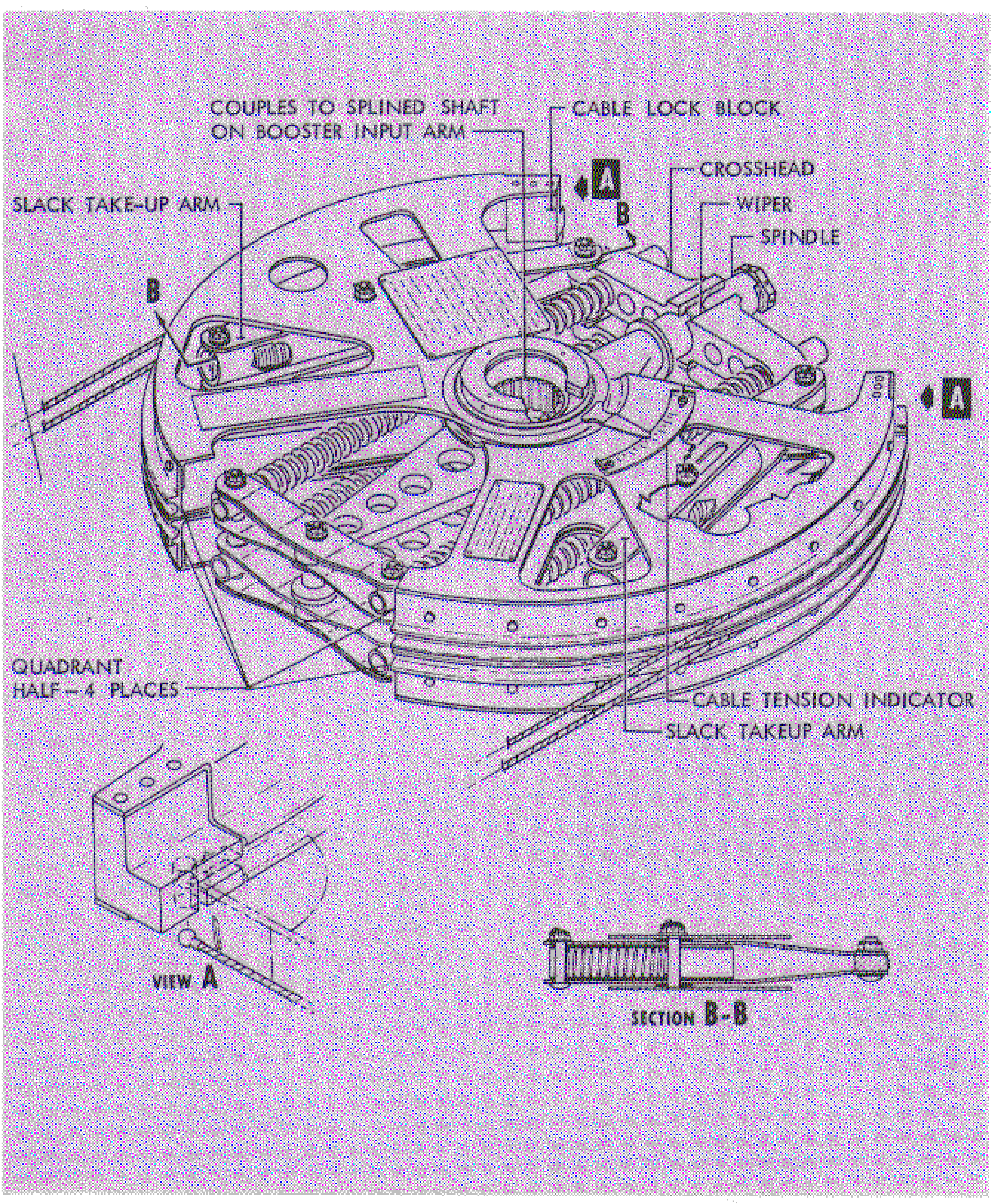


Figure 32 Elevator Cable Tension Regulator

necting linkage is necessary at the juncture of the two elevator torque tubes (see Figure 34).

The elevator viscous damper installation — one for each elevator — is shown in Figure 35. This damper installation differs from the others on the airplane inasmuch as the body of the damper is not fixed to the aircraft structure but incorporates an attachment arm which, like the arm on the rotating disc, is also connected to the moving elevator control surface. For any particular installation, assuming the control geometry cannot be varied, the relative movement of the disc in the fluid is doubled compared to the "body-fixed" configuration. This has obvious advantages in some design situations—the elevator installation being one of them.

In the elevator control and surface couplings, consideration must be given to possible failure of the principal linkages—namely the boost output connection to the right elevator, and the interconnect link between the elevator torque tube arms. The principal role of the elevator viscous dampers, therefore, is to provide fail-safe capability against flutter of the elevator control surfaces in the event of such a failure. It should be noted also that should both elevators ever become completely disconnected from the control system, the airplane can still be successfully controlled longitudinally by means of the elevator trim tabs.

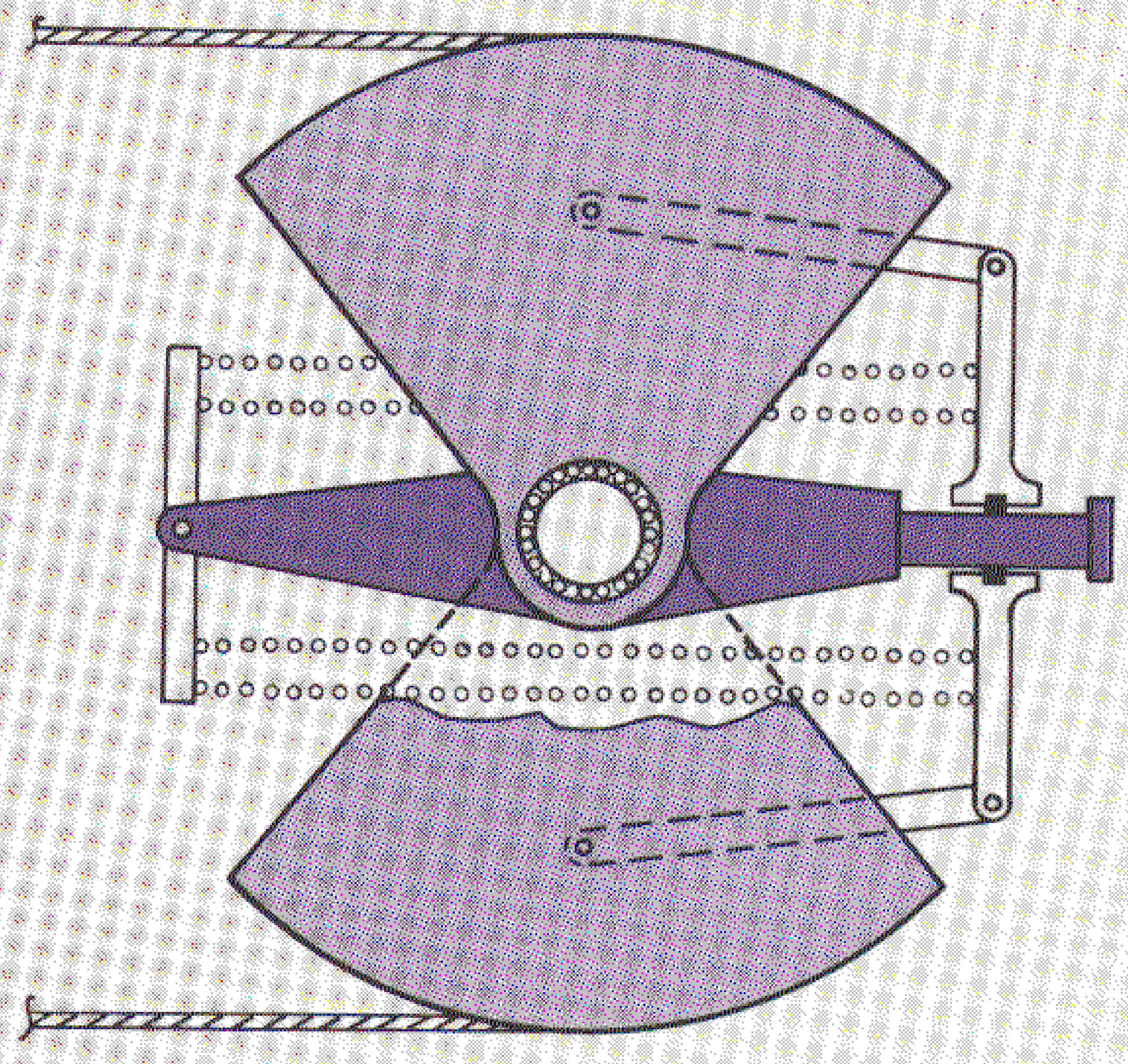


Figure 33a Cables Have Equal Tension and Crosshead is Free to Slide on Spindle

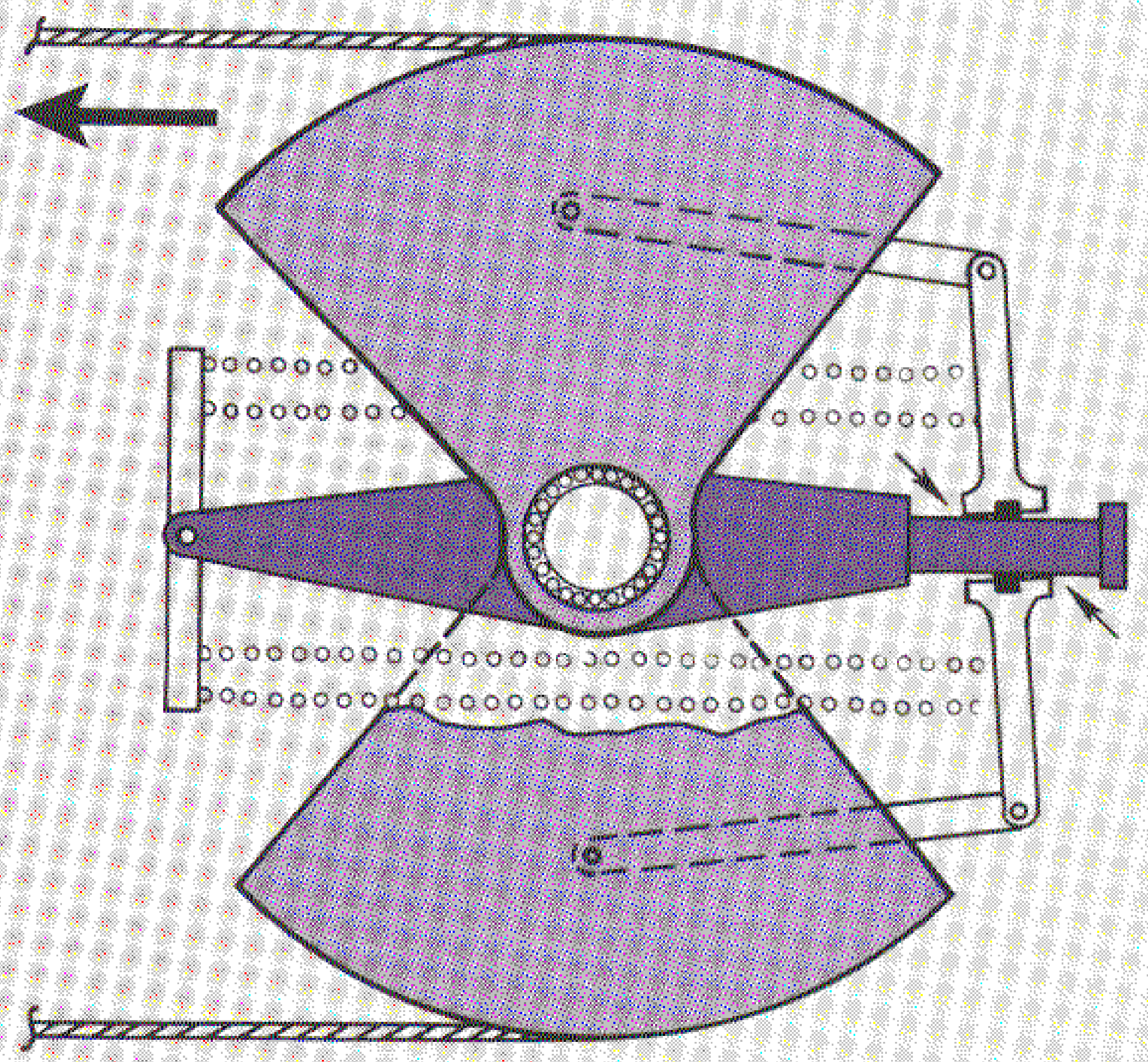


Figure 33b Tension Load on Top Cable Causes Crosshead to Lock on to Spindle

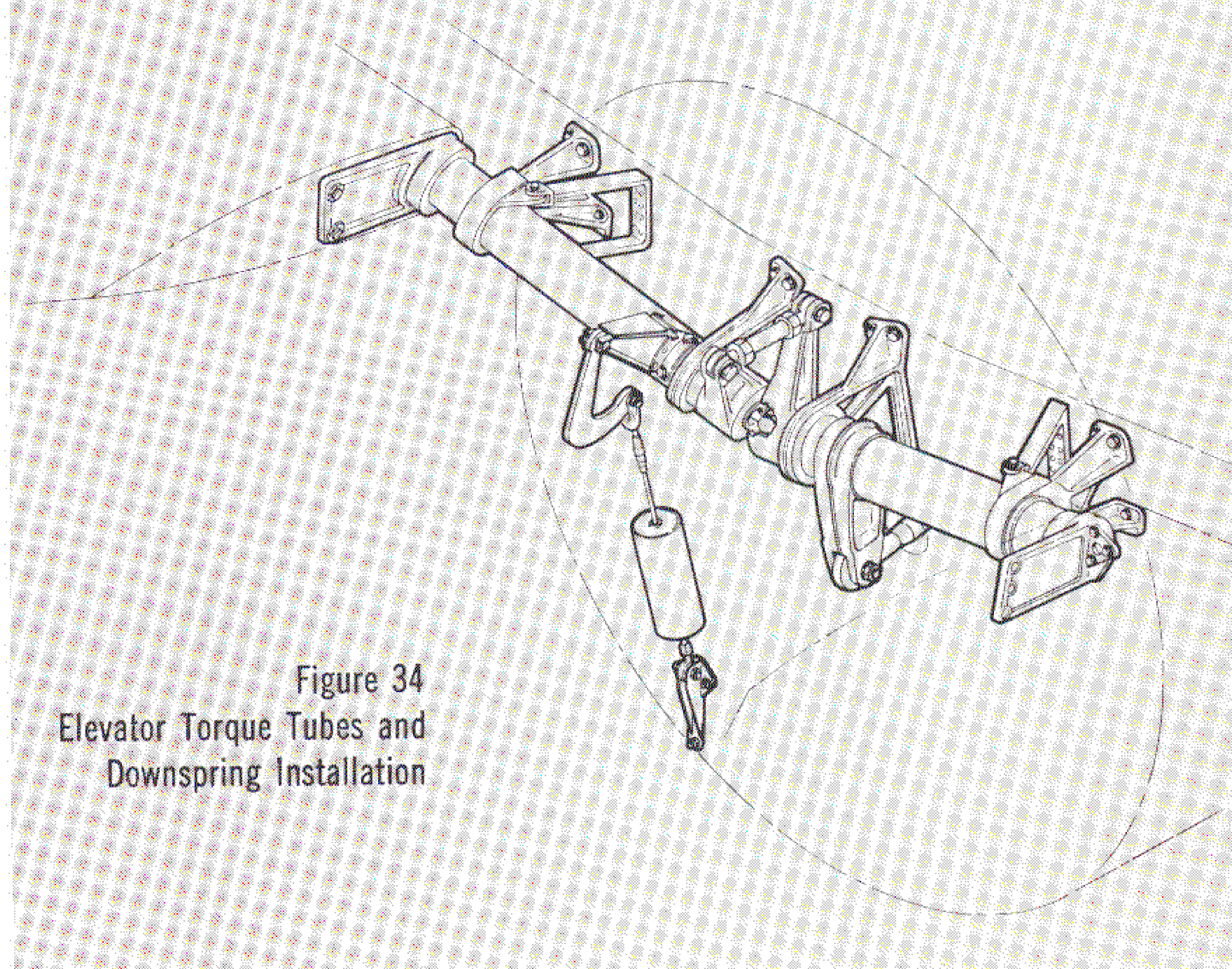


Figure 34
Elevator Torque Tubes and
Downspring Installation

Elevator Control Forces. Each elevator is partially balanced by static weights attached to the control surface front spar, and the total mass unbalance of both elevators amounts to 96 ft. lb. hinge moment or 5.7 pounds in terms of pilot effort with the elevators faired (see Figure 36). Also attached to the left elevator torque tube is a downspring, which further increases the total elevator hinge moment to about 168 ft. lb. with the elevators in a faired position. This total corresponds to approximately 10 pounds in terms of pilot stick force.

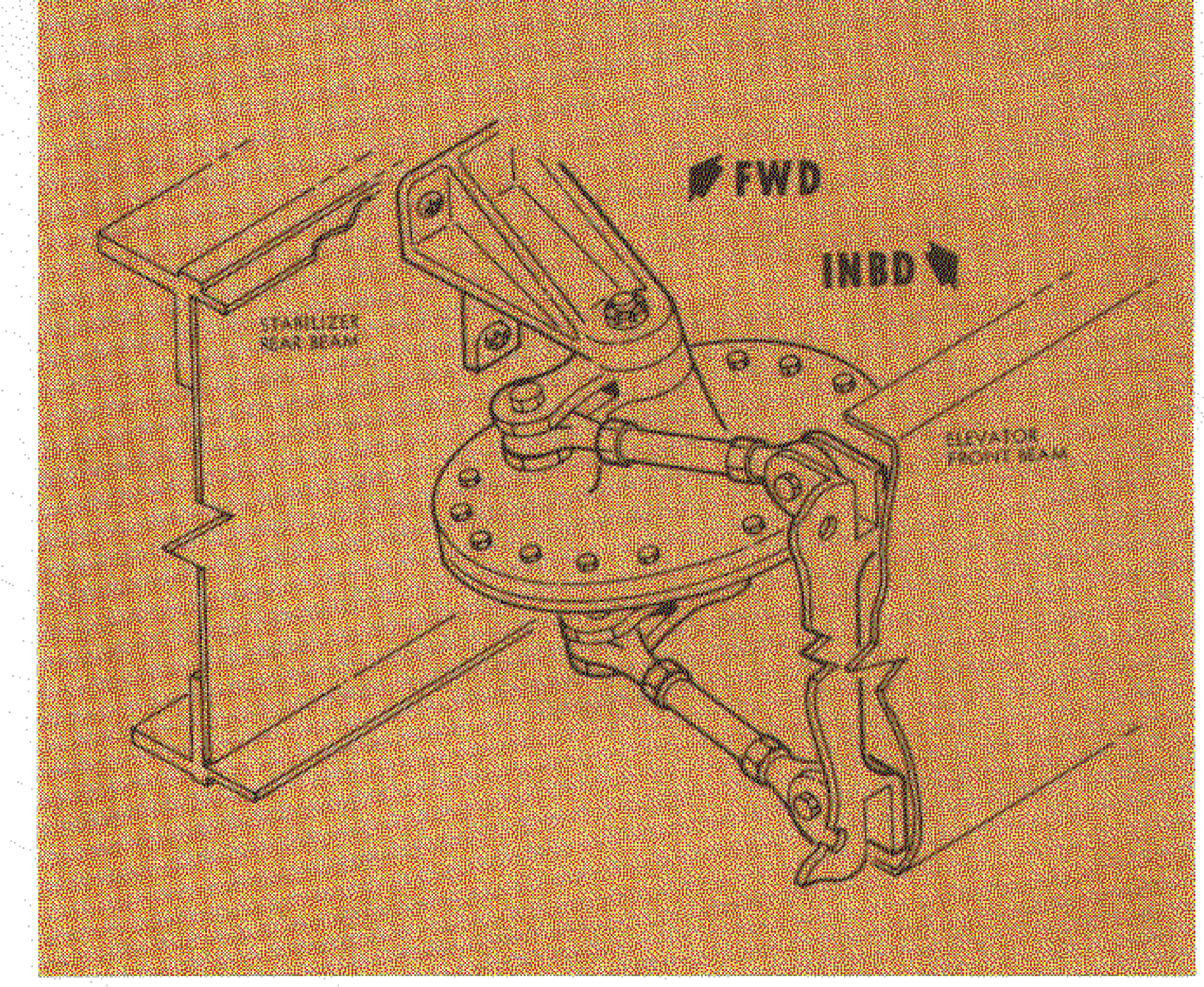
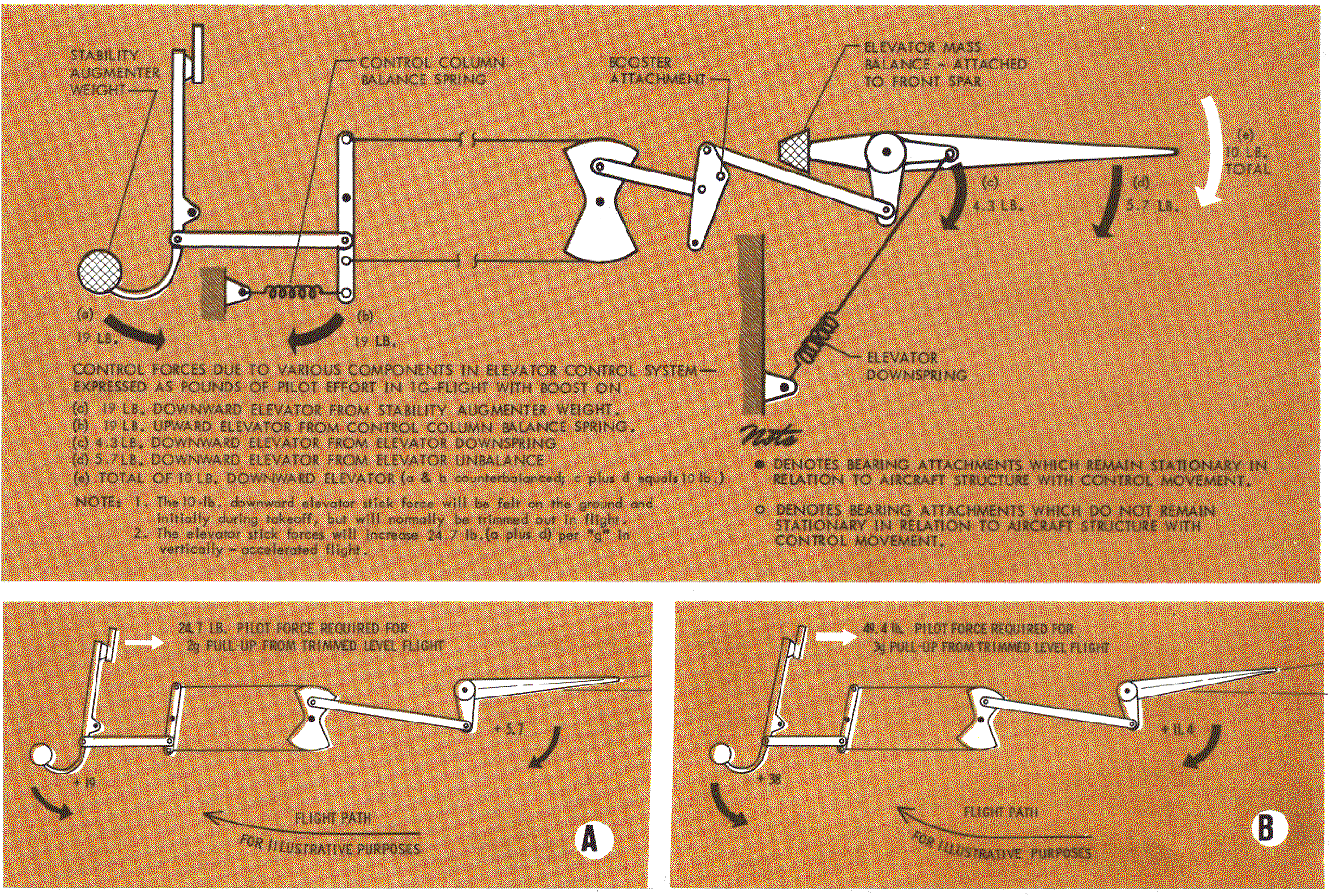


Figure 35 Viscous Damper Installation on Each Elevator

The flight station control columns and stability augmenter weight add a constant increment of stick force per g for accelerated flight conditions. The elevator mass unbalance also has a similar effect so that in a 2-g pull-up, for example, the stability augmenter weight and elevator unbalance would add (19 plus 5.7) 24.7 pounds in pilot effort (see Figure 36), and a 3-g pull-up would require 49.4 pounds in pilot effort in addition to normal flight loads. It will be noted that the stability augmenter weight and the mass unbalance of the elevators produce control forces that are essentially linear with variation of normal acceleration and—most important—these forces do not vary with airspeed. This is a desirable control characteristic both from the point of view of protecting the airframe structure from stresses due to excessive accelerations, and from the pilot's viewpoint of recognizing an undesirable flying situation through the feel of the controls.

The reason for the elevator downspring is not brought out in Figure 36 and the force link tabs are not even shown on this diagram. These components and their role in the elevator control system will be discussed in Part Two of this article.



CONTROL FORCES DUE TO VARIOUS COMPONENTS IN ELEVATOR CONTROL SYSTEM—EXPRESSED AS POUNDS OF PILOT EFFORT IN 1G-FLIGHT WITH BOOST ON

(a) 19 LB. DOWNWARD ELEVATOR FROM STABILITY AUGMENTER WEIGHT.
(b) 19 LB. UPWARD ELEVATOR FROM CONTROL COLUMN BALANCE SPRING.
(c) 4.3 LB. DOWNWARD ELEVATOR FROM ELEVATOR DOWNSPRING
(d) 5.7 LB. DOWNWARD ELEVATOR FROM ELEVATOR UNBALANCE
(e) TOTAL OF 10 LB. DOWNWARD ELEVATOR (a & b counterbalanced; c plus d equals 10 lb.)

NOTE: 1. The 10-lb. downward elevator stick force will be felt on the ground and initially during takeoff, but will normally be trimmed out in flight.
2. The elevator stick forces will increase 24.7 lb. (a plus d) per "g" in vertically - accelerated flight.

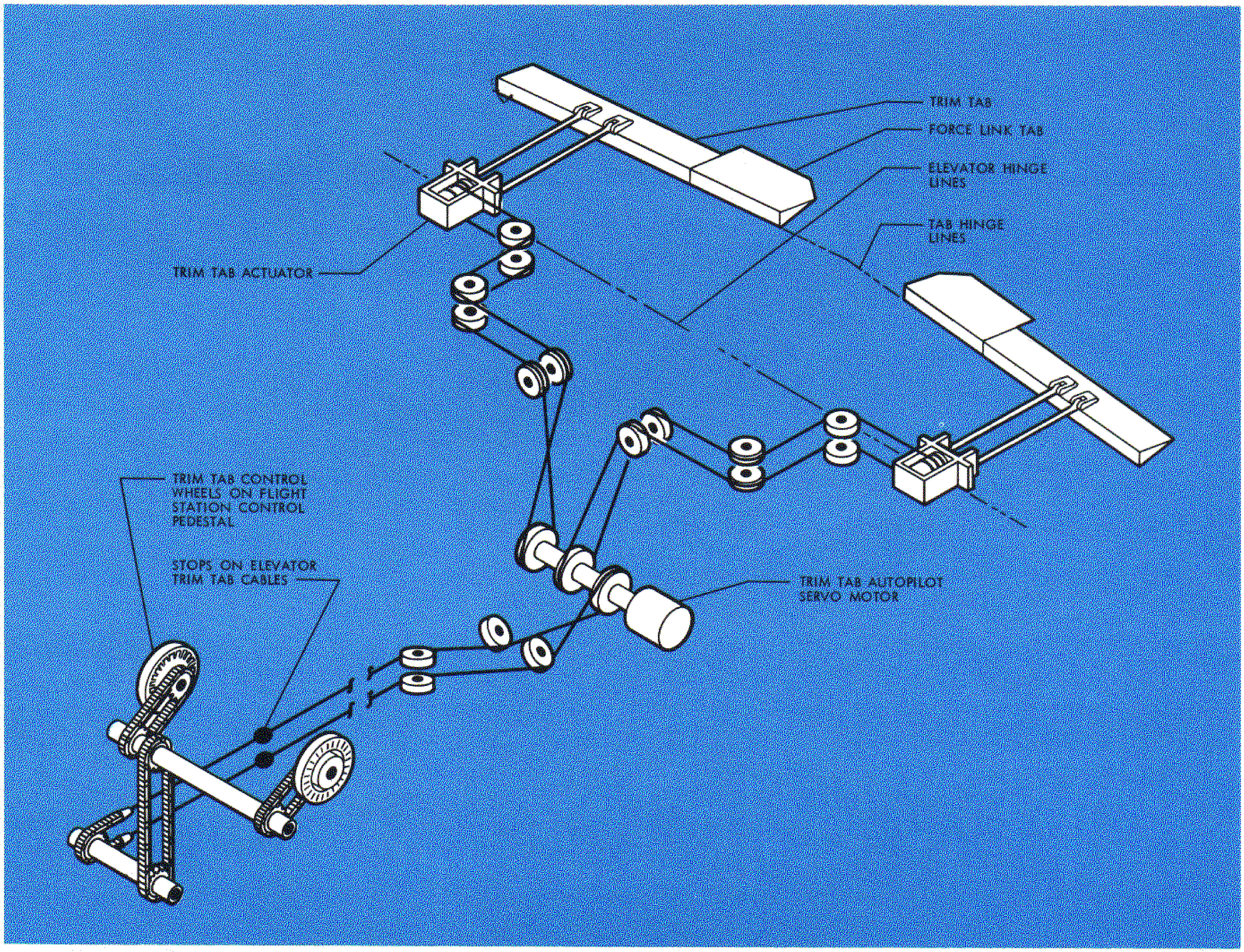
Note

● DENOTES BEARING ATTACHMENTS WHICH REMAIN STATIONARY IN RELATION TO AIRCRAFT STRUCTURE WITH CONTROL MOVEMENT.

○ DENOTES BEARING ATTACHMENTS WHICH DO NOT REMAIN STATIONARY IN RELATION TO AIRCRAFT STRUCTURE WITH CONTROL MOVEMENT.

Figure 36 Elevator Control System Showing Pilot Forces in Level (lg) Flight.
Pilot Forces in a 2g Maneuver are Shown in A and a 3g Maneuver in B.

Figure 37 Sketch of Elevator Trim Tab Control System



ELEVATOR TRIM TAB CONTROL SYSTEM

There are two tabs on each elevator surface. The outboard one is the trim tab and the inboard tab, which extends four inches aft of the elevator trailing edge, is the force link tab (see Figure 37).

As shown in Figure 37, the controls to the elevator trim tabs are completely mechanical and consist of a cable system running from the flight station to two trim tab actuators which were described in the "General" section. The relatively large cable travels required by the screw actuators are obtained from a flight station control unit through a series of chain and sprocket drives. Friction of the complete system is controlled through careful design and manufacture so that a force of not more than 0.72 lb. at either of the two control wheel rims will initiate motion of all the elevator tabs, including the force link tabs.

The two trim control wheels are located on each side of the flight station control pedestal, and their movement is conventional. When the top of either wheel is rotated forward, the tabs are moved up—giving a nose down trim condition—and vice versa. About 9 revolutions of either wheel are required to move the tabs through their complete range. The control wheels drive the tab control unit (see Figure 38), and also drive an edge-lighted tab position indicator through an independent unloaded planetary gear mechanism. The trim tab position indicators are installed in the hub of each wheel, and show the range of tab travel from 25 degrees down (nose up) to 5 degrees up (nose down).

From each control wheel, a chain drive goes to a sprocket on a common horizontal shaft in the control pedestal (see Figure 37). A closed chain on a third sprocket on this shaft is connected to a sprocket on another horizontal shaft, located below the floor. This lower shaft transmits torsion to the right side

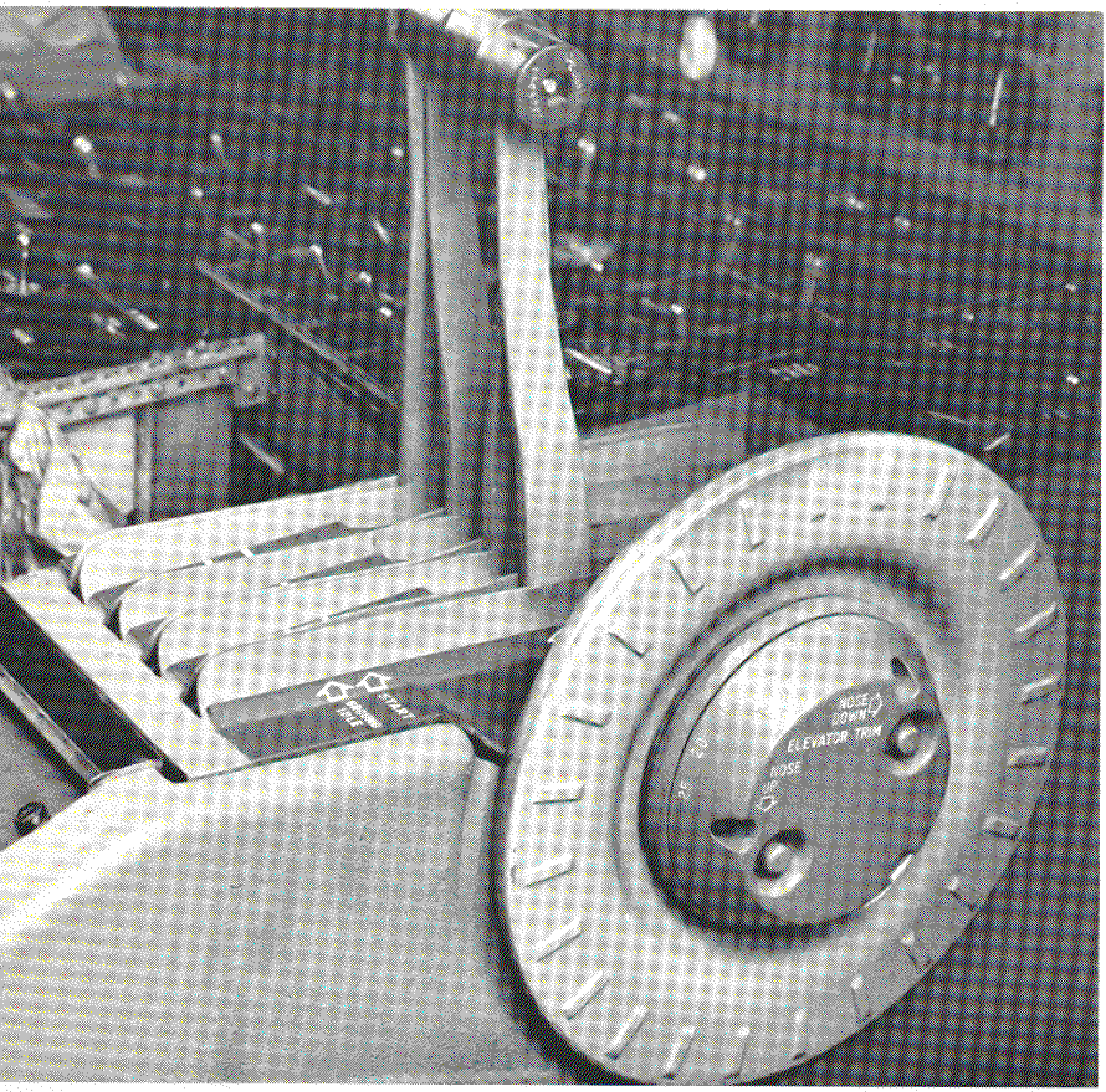


Figure 38 Flight Station Control Pedestal Showing One of Two Trim Control Wheels

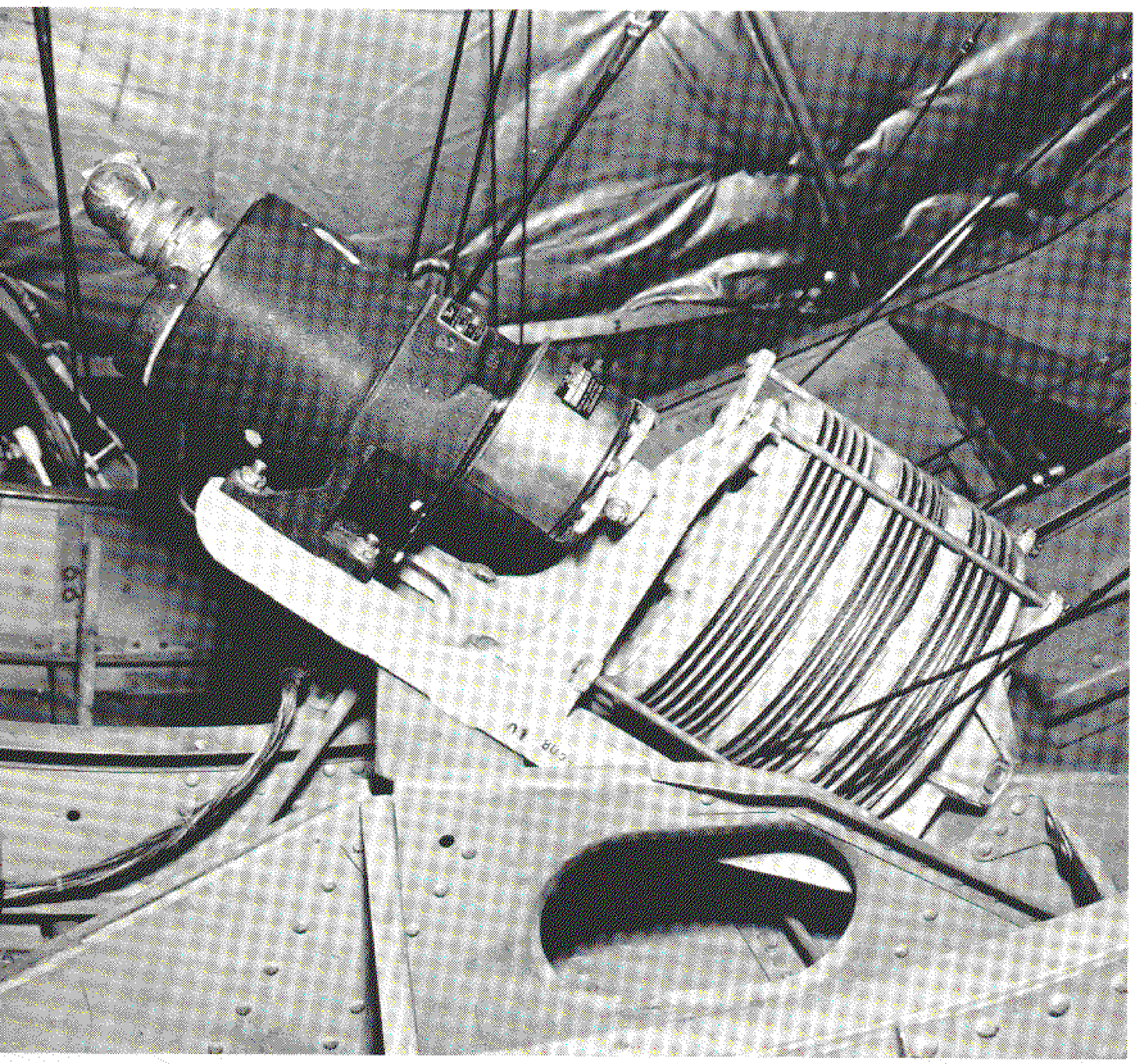


Figure 39 Autopilot Trim Tab Servo-Motor Unit

of the flight station where another sprocket drives a link chain, the ends of which are attached to 3/32-in. diameter cables. Mechanical stops in structure at Fuselage Station 288 engage swaged ball fittings on the cable to limit the total cable travel.

The long cable runs and the link chain to which they are attached make up a closed system which runs from the flight station aft to approximately Fuselage Station 1032, where a pulley cluster permits change of direction toward the centerline of the pressure bulkhead. 3/32-in. Lockclad cable is used for straight runs forward of this cluster. After passing through air-seal grommets in the pressure bulkhead, flexible cables wrap around and connect to one set of grooves in the autopilot trim tab servo motor unit (see Figure 39).

The trim tab servo consists of a rotary electric actuator driving a cable drum of about six-inches diameter with grooves for three cable systems. One of these is occupied by the long "pilot input" cable mentioned above. The other two groove sets are utilized by cables driving the left and right elevator tab actuators. All cables are secured to the drum by swaged ball fittings, and cable motion is thus transmitted via the trim tab servo to both tab actuators by cables in the leading edge of each elevator (see Figure 9).

The elevator trim tab control system is the only tab system incorporating an autopilot servo-motor unit. This component of the Bendix PB-20 Autopilot system provides automatic trimming of the aircraft in the pitch axis. The output of the electric actuator is geared down by a ratio of 11,620 to 1, and drives the cable drum through a solenoid operated clutch. The clutch is engaged when autopilot operation is selected, at which time the normal autopilot circuits are set to monitor hydraulic forces applied by the booster. A continued elevator hinge moment in one direction (as from an out-of-pitch trim condition) is felt by the hydraulic load sensors in the booster, and the resulting sensor signal, suitably amplified, actuates the trim servo motor to move the elevator tabs in the compensating direction until the sensor signal disappears. The clutch design permits disengagement when the autopilot is not in use, as well as manual over-ride by holding the flight station trim wheel.

This Concludes Part One of the Orion Flight Controls. Part Two, which will discuss Longitudinal Stability, will describe the operation of the force link tab and its connection and relationship with the elevator trim tab controls.

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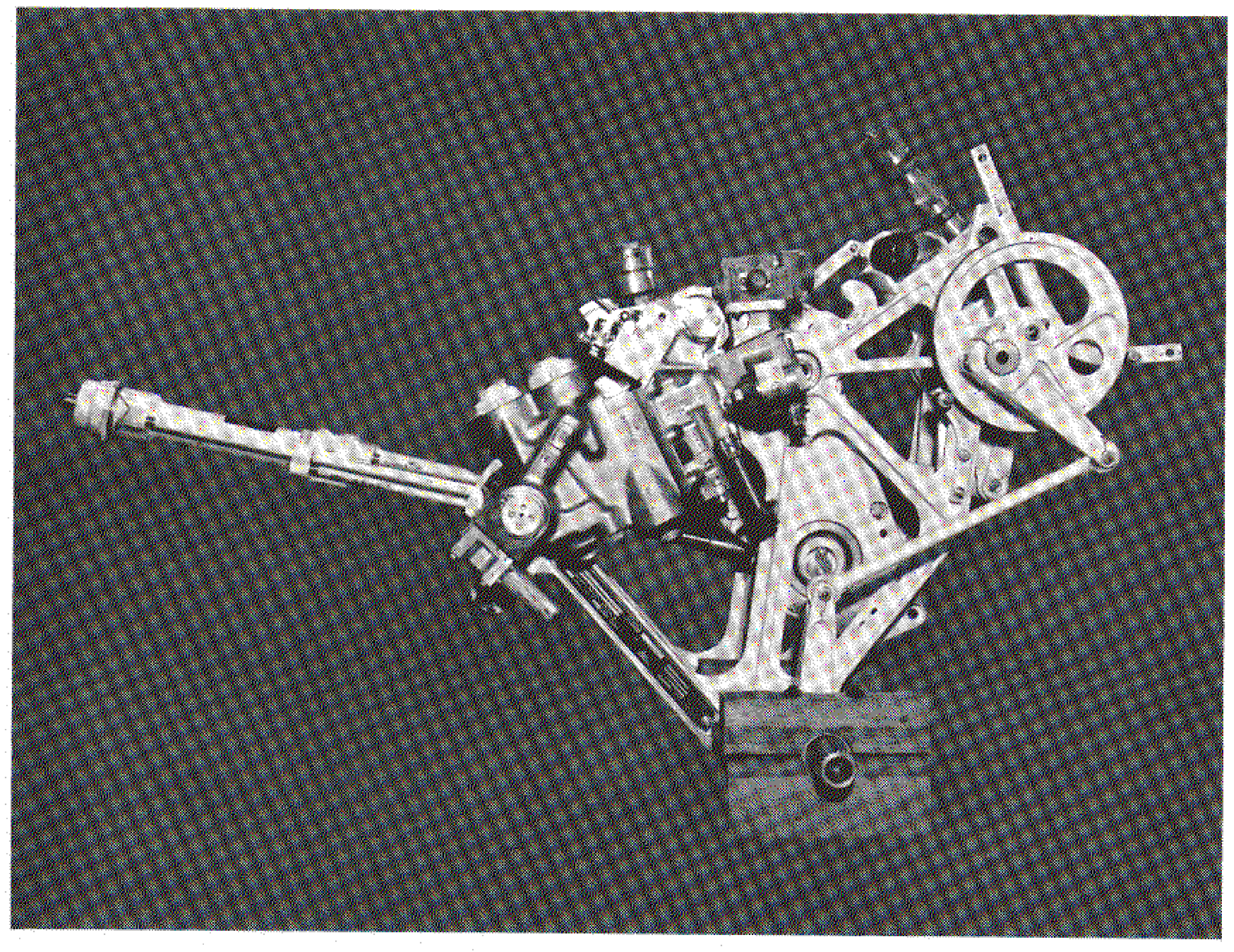

Typical Booster Unit

PATROL SQUADRON NINETEEN

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