LOCKHEED field service digest

This publication is a digest of the most important technical information currently available and is intended to assist our customers in the service, maintenance, and operation of their Lockheed transport aircraft.

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Vol. 8, No. 3
November-December 1961

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COVER PICTURE: Commencing in January of 1959, ***Eastern Air Lines*** was the first Lockheed customer to begin scheduled operations with the prop-jet ***Electra***. A total of 40 of these airplanes were delivered to EAL, and scheduled daily departures on the order of 257 soon became a daily routine.

The ***Electras*** have been used on the major portion of Eastern's route structure, including stations where only the smaller two-engine airliners were previously operated. In the past three years the EAL ***Electra*** fleet has amassed some 271,853 flying hours, and the aircraft has more than proven its ability to operate successfully in both the short and medium-haul markets.

LOCKHEED
field service digest

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ELECTRA FLIGHT CONTROLS

part one

IN THE PERIOD prior to World War 2, flight controls on conventional airplanes were relatively simple and a mechanic, a pilot, or anyone who was interested could readily understand the theory of their operation 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 restricted to trimming devices utilizing trim tabs or an adjustable spring bias.

The modern airliner—to take just one category of airplane—has advanced a long way since that time, both in size and performance, and flight controls have become correspondingly more complex. A control system on a modern air transport can contain any number of bewildering arrays 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 Electra, in common with its contemporary airplanes, has its fair share of the above devices. Some are necessary in order to obtain desirable flying characteristics, while others can be classified as

refinements. Necessary or not, these complications are hard to justify to someone, such as an airline mechanic, who may not possess the knowledge and appreciation of an aerodynamicist or an experienced pilot. On the other hand, the reports of pilots who fly the Electra leave no doubt that the excellent flying qualities of the airplane are ample justification for the added complexity.

Few of us are ever likely to fly the Electra from the pilot's seat, and fewer of us would be in a position to judge, even if we had the opportunity. We thought it appropriate therefore to begin this discussion by quoting from an article, which was written by a well known senior pilot of one of the world's largest airlines. The article was published in February, 1959.* Unfortunately, space limitations prohibit us from quoting other than excerpts from the article, but we have selected those items that are particularly concerned with flying characteristics — the prime consideration in any flight control system. It will also be noted that, in effect, many of the basic requirements governing flight control design are discussed from a practical viewpoint. Where text has been omitted from the original article it is noted by means of a double asterisk (**). This will explain any discontinuities which may become apparent to the reader.

**

"Speaking solely from an operational viewpoint, a very fine job has been done on the Electra control system. I have flown most of the US commercial transports, both single and multi-engined, from the Tri-Motor Ford to the Boeing 707, together with several British aircraft and I know none that had or has a control system operationally superior to the Electra's and very few, if any, of them are its equal."

**

"If it is necessary for the pilot to keep his attention constantly on the instruments, it is extremely fatiguing. The aircraft should have stability characteristics such that if the pilot's attention is diverted from the flight instruments for a few seconds to look at his radio map, to observe the engine instruments, to set up a new radio facility, to talk to the stewardess to order a cup of coffee, or to answer some questions regarding the flight, when he again looks at the instruments the aircraft should still be at the same altitude and still headed in the same direction. It must not have so much stability built into it, however, that it is hard to maneuver."

"An aircraft that requires constant attention is extremely fatiguing to fly and is hard to fly smoothly and give the customer a good ride during critical maneuver periods such as instrument approaches."

"The Electra is excellent with respect to all of these items. The controls require a minimum of physical effort to move and the aircraft is quite stable. Of course, it is recognized that the faster an aircraft the greater is the altitude change for a given change in pitch attitude, and the Electra is no exception. If at cruising speed the pitch attitude is changed slightly because of a center of gravity change caused by the passengers' moving, a considerable altitude change can result in a matter of seconds. This can be prevented by careful attention on the part of the pilot doing the flying, or the autopilot can be used. The Eclipse-Pioneer PB20 auto-pilot does an excellent job in flying the aircraft and in maintaining a constant altitude when on altitude control. While on altitude control, even when making maximum banked turns, the altitude is quite precisely maintained."

"A second important flight characteristic is the action of the controls and the aircraft's response to control movement. If a control is moved out of its neutral position and the actuating force removed, it should of its own accord return to neutral. It should not have to be moved back. Also, when a control is moved the aircraft should respond immediately and in a positive manner. My observation to date is that here also the Electra is excellent."

**

"In-flight maneuverability is no less outstanding than maneuverability on the ground. One check on a pilot's general flying ability is his ability to make smooth reversed turns with a minimum of change in altitude, or rate of climb if this maneuver is being accomplished during the climb or descent. The Electra is one of the best aircraft I

Published originally in Shell Aviation News, "Flight Evaluation" was written by Captain F. E. Davis, Director, Engineering Flight Test, Eastern Air Lines. Captain Davis approved this republication (3 years after the original publication date) with the comment: "I still consider that, from a flight standpoint, the Electra is the nicest-flying large airplane it has ever been my privilege to operate."

***One or more paragraphs have been omitted from the original article.*

have ever flown in this respect. During the climb or at cruising speed, 45° banked reverse turns can be made with a minimum of attention being necessary in order to keep from gaining or losing altitude or changing the rate of climb during the maneuver, as long as the aircraft is properly trimmed for the normal flight condition before entry into the turns and as long as there are no great changes in the center of gravity during the maneuver."

**

"Fifth are the take-off and landing characteristics. I have been flying since 1924 and have flown quite a large number of different types, some 120 or more. After a while, flying — or I should say piloting — becomes quite a normal job, but there are some aspects of it which will never cease to thrill me. No matter how long I fly, I don't think I'll ever lose the personal satisfaction of executing a good smooth take-off or a near-perfect landing. The Electra exhibits as good landing characteristics as those of any aircraft I have ever flown, if not better. No one who has ever flown any of the large transport aircraft should have any trouble in landing the Electra, unless they have never been able to make consistently good landings with other aircraft."

**

"The action during a wave-off from a missed approach is extremely satisfactory. Even when the application of power is delayed almost until touchdown with the aircraft in the proper landing attitude, with the airspeed just a few knots above minimum for touchdown, and with the gear down and flaps in the full down position, power application results in immediate rapid acceleration with practically no change in attitude, nor is there much change in the control forces or trim as the gear and flaps are retracted."

**

"Summing up all of these facts from a pilot's viewpoint, there are three main considerations of importance regarding the way an aircraft performs and handles; the ability of the pilot to keep the aircraft out of questionable flight conditions — this includes all performance parameters; the ability to recover safely from questionable conditions if they are inadvertently entered; and the physical ease with which the aircraft may be operated and maneuvered. In my opinion, the Electra merits no less than 'A-Plus' on all three counts."

**

It is acknowledged that the extremely gratifying remarks by Captain Davis are one expert's opinion, but nevertheless it does seem that the results justify the means. In the following pages, we shall endeavor to explain how these results are achieved and why they are necessary. One question in particular always comes to the fore:

Why Boosted Controls? 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 performance of airplanes in the transport category, for example, have progressed to the point where the pilot requires additional power assistance and artificial "feel" built into the system, and where a wide speed range—in which the maximum speed frequently exceeds the landing speed by four or five hundred percent—creates additional control problems.

Figure 1 lists performance figures and other data of some typical transports, from the pre-war period up to the present time. During the early 1940's, it was apparent that air transport design had advanced to the point where the incorporation of some form of power assistance to the flight controls was necessary. Most manufacturers of large airplanes in this period gained this 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, even before the war in 1938, decided to take a long term view of this situation and develop hydraulic booster assisted controls which, although more complicated, showed several major advantages over the aerodynamic control system. Most important, hydraulic boosters showed promise of future development for more advanced versions of the Constellation and later transport designs such as the C-130, Starliner, and the Electra. This was quite apart from the application of boosters to high performance military aircraft, where hydraulic power assistance had already been used to a limited extent to solve the new control problems arising with these airplanes.

This proved to be a sound policy. No major modification was required to the basic flight control system throughout the entire range of Constellation

YEAR	AIRCRAFT	TAKE-OFF H. P. OR EQUIVALENT	MAX SPEED (APPROX.)	GROSS WEIGHT
1934	LOCKHEED MODEL 10	900	200 M.P.H.	10,500 LB.
1937	LOCKHEED MODEL 14	1,700	250	17,500
1945	LOCKHEED MODEL 049	8,800	300	90,000
1948	LOCKHEED MODEL 749	10,000	320	107,000
1955	LOCKHEED MODEL 1049G	13,600	340	137,500
1957	LOCKHEED MODEL 1649	13,600	345	160,000
1958	LOCKHEED MODEL 188	15,000	420	116,000
1958	LARGE JET		550+	250,000 +

Figure 1 Progress of Air Transport Performance

and Super Constellation aircraft, even though this evolutionary line of aircraft 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 current jet transports. From the first flight tests, the Electra has not undergone any major rework of the flight controls, while other transports, designed by other manufacturers with other types of control power assistance, have in several cases had to finally resort to hydraulic boosters as a result of subsequent flight evaluation, or in-service handling experience.

At this point we shall postpone further discussion on boosters. The following descriptions of various flight control systems (excluding the flap control system) take into account the assistance given to the pilot by the boosters, but a fuller description of their advantages and operation will be given in a forthcoming issue of the Digest. The flap controls will also be described in a future issue.

CONTROL SYSTEM DESCRIPTION — GENERAL

The Electra was designed as a short and medium range airliner. Short range operations demand excellent airport performance with fast climb and descent speeds. Minimum distance take-off and landing capabilities are also necessary in order to take advantage of the smaller "commuter" type airports. On the other hand, a fast enroute speed is the primary consideration of the medium range airliner.

The flight performance requirements of these two categories of airline operation are conflicting. A more versatile airplane results from combining the two categories, but the problem is to do this without compromising the airplane's capability of competing with other airliners designed specifically for either short or medium-haul operations. Resolving this problem successfully was largely the task of the aerodynamicists and flight controls designers after the basic aircraft configuration had been established. We might briefly review the Electra's basic statistics, which inevitably influence the flight characteristics, but which are established by many factors—not necessarily aerodynamic.

The General Arrangement of the Electra (see Figure 2) follows what might be considered classic lines for this type of aircraft. The fuselage, thoroughly practical, rather than following the familiar aerodynamic form of the Constellation, maintains a cylindrical shape for most of its length, the actual length and diameter of the fuselage being largely deter-

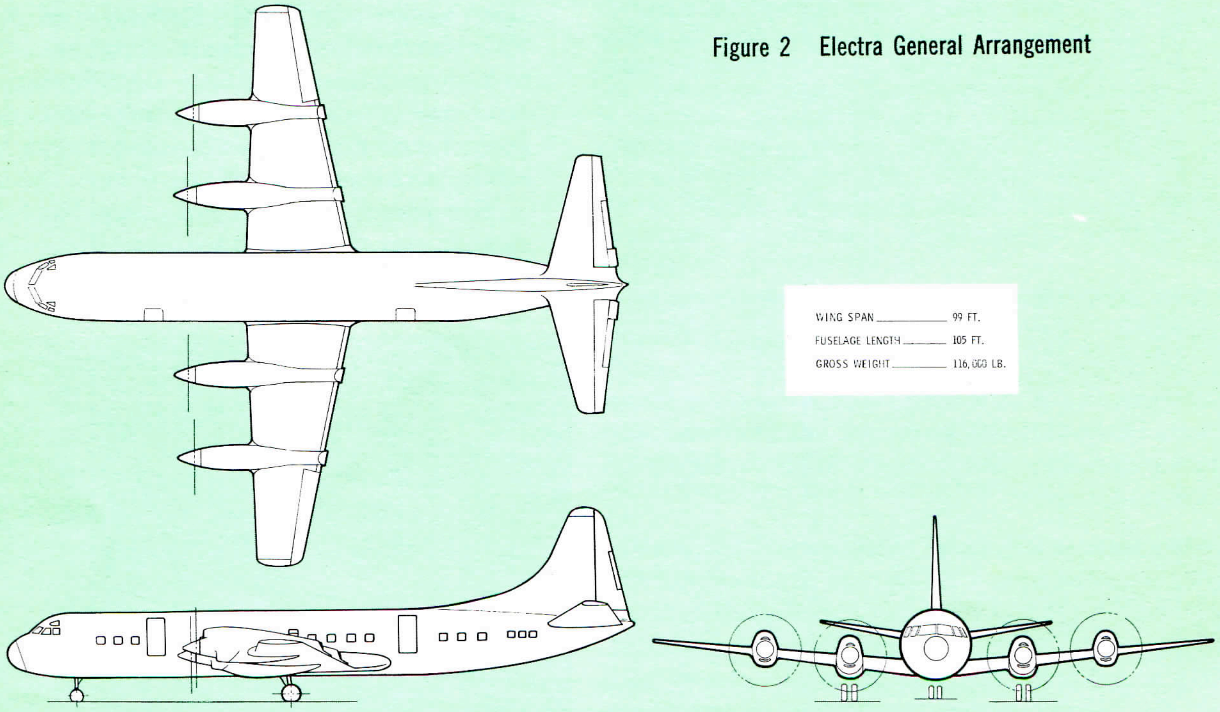


Figure 2 Electra General Arrangement

WING SPAN	99 FT.
FUSELAGE LENGTH	105 FT.
GROSS WEIGHT	116,000 LB.

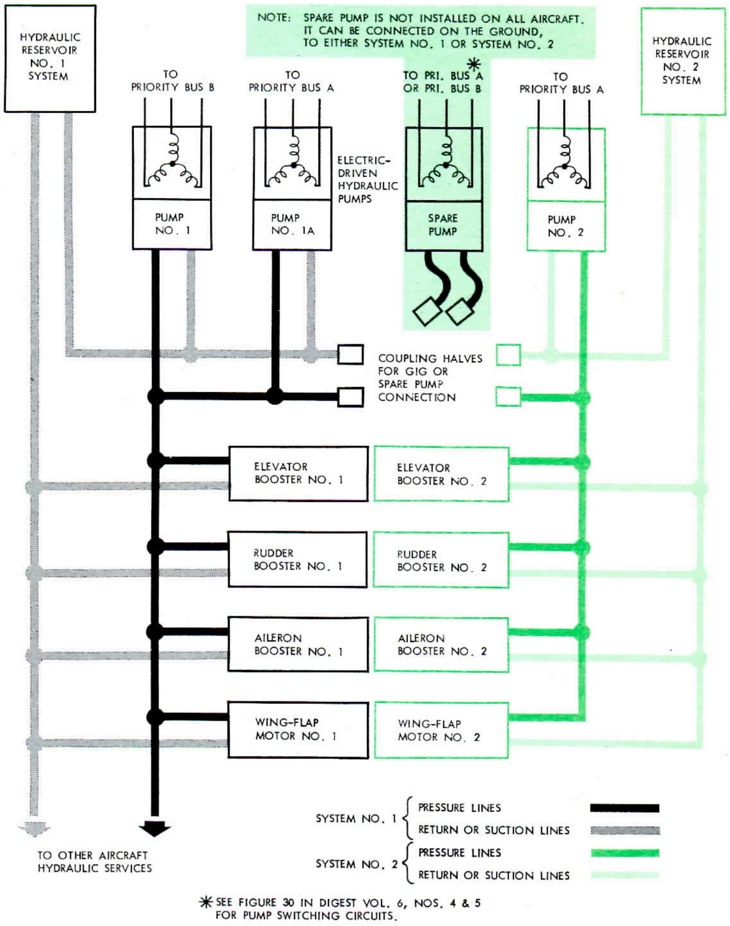
mined by its ability to accommodate varying numbers of passengers in different interior configurations.

The wings, outwardly conventional, have a relatively short span; a moderately high speed airfoil section with an average thickness-to-chord ratio of 13 percent contributes to the fast en route speed requirements, while still leaving enough available space inside the wing box beam for storing fuel. Excluding the center section, the wing integral fuel tanks provide ample capacity for medium ranges up to 2500 or 3000 miles depending upon individual customer requirements. Of particular interest in this discussion, the straight wing design gives good stalling and landing characteristics. It also simplifies fuel management inasmuch as all the tanks are located along the lateral axis and fuel usage therefore has the minimum effect on fore and aft change of c.g.

Another interesting feature of this wing design is that almost the complete span is swept by the slipstream from the propellers. This fact coupled with the unusual constant-speed characteristics of the Allison prop-jet engine results in the Electra's excellent "wave-off" capabilities. Any requirement for a sudden gain in altitude is not completely dependent upon either the engines increasing in speed, or upon a gain in forward speed of the aircraft. As fast as the fuel supply to the engines is increased and the propellers change pitch to utilize the increased power, the resulting propeller slipstream produces lift from the wing.

This almost instantaneous "recovery and climb" capability of the Electra is of course an extremely desirable feature but can create some stability problems. Specifically, the slipstream also increases the angle of downwash from the wing and changes both the wing and horizontal tail pitching moments or, in other words, causes a sudden change in longitudinal trim, if not provided for in the controls design. The effects of the propeller slipstream also affect the longitudinal stability over the entire operating range of the aircraft, and this aspect will be discussed in Part Two of this article. Yet another consideration is that the large power output available on the Electra as compared to older propeller-driven airplanes results in a corresponding increase in the effects of propeller torque.

There are many other factors involved, many of them conflicting, but the above will suffice to show that the design of the flight controls is essentially a process of achieving the right compromise within the framework of the basic design conditions.



*SEE FIGURE 30 IN DIGEST VOL. 6, NOS. 4 & 5 FOR PUMP SWITCHING CIRCUITS.

Figure 3 Flight Controls Hydraulic Systems—Block Diagram

The Elevator, Rudder, and Aileron Control Systems on the Electra are similar in many respects. Each incorporates hydraulic booster units which are linked to the control surfaces by push-pull tubes. The dual flight station controls are connected to operating quadrants on the booster unit assemblies by cable systems.

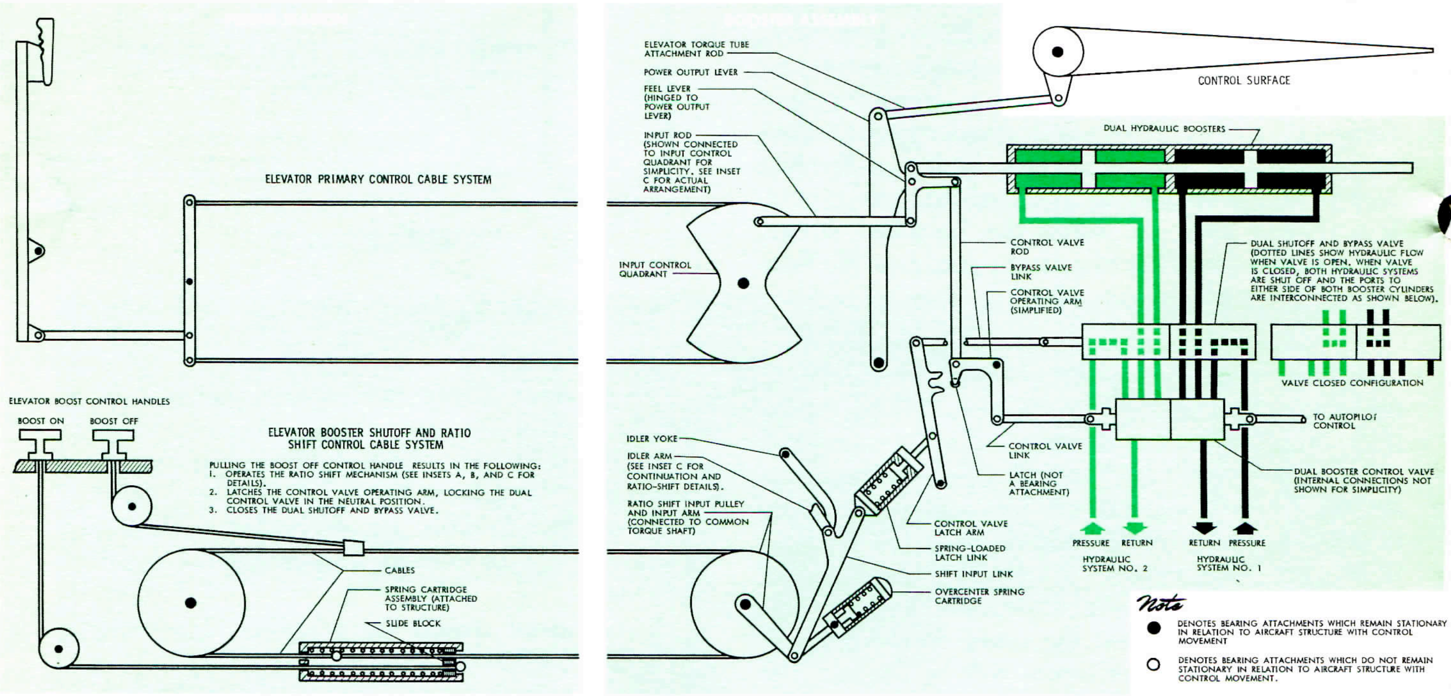
Each control system has a primary configuration in which the pilot's effort is supplemented by dual hydraulic boosters to drive the control surfaces. Normally both boosters operate in tandem, each being powered by completely independent hydraulic systems (see Figure 3). The airplane can be flown "boost-on" satisfactorily with any one of the dual boosters in each control system inoperative, and no action involving the flight controls is required from the pilot in the event of such a failure.

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 sufaces. In this "boost-off" configuration 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. Figure 4 shows a simplified elevator control system, and the general arrangement is typical of all three control system configurations.

The operation of the boosters is not too apparent from the diagram as only the minimum of details are shown. Briefly, the pilot-input controls, besides being connected to the control surfaces directly, are also connected to a dual booster control valve, which controls the hydraulic flow to both booster cylinders. This same booster control valve is utilized by the autopilot, enabling the autopilot signals to be converted into control surface movement as efficiently as possible.

This is perhaps an appropriate time to mention that, should the autopilot 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 and the boost shut-off controls in the flight station are shown in Figure 5.

In any powered or boost-assisted control system, it is important to consider the hydraulic power sources. In the Electra, the hydraulic pumps are electrically driven from either of two electric power buses, and each bus can be powered by any one of three generators in the Electra's four-generator electric system. Since the Electra's generator/bus transfer system is automatic, and there are either three or four hydraulic pumps available (depending upon the customer configuration), a complete hydraulic failure is an unlikely occurrence. Further, with electrically driven



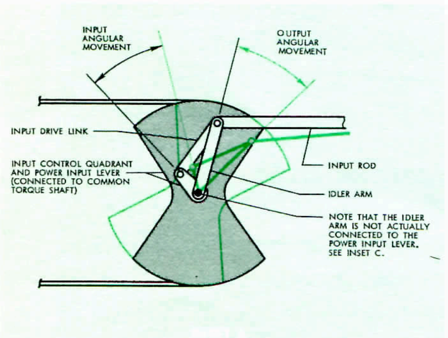
ELEVATOR BOOSTER SHUTOFF AND RATIO SHIFT CONTROL CABLE SYSTEM

PULLING THE BOOST OFF CONTROL HANDLE RESULTS IN THE FOLLOWING:
1. OPERATES THE RATIO SHIFT MECHANISM (SEE INSETS A, B, AND C FOR DETAILS).
2. LATCHES THE CONTROL VALVE OPERATING ARM, LOCKING THE DUAL CONTROL VALVE IN THE NEUTRAL POSITION.
3. CLOSES THE DUAL SHUTOFF AND BYPASS VALVE.

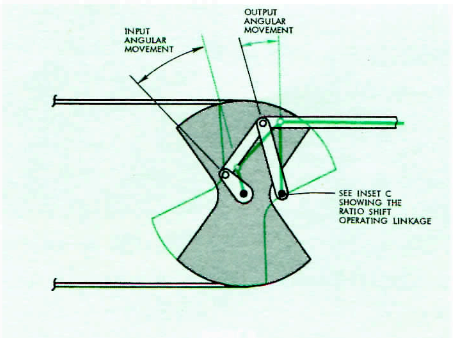
Note

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

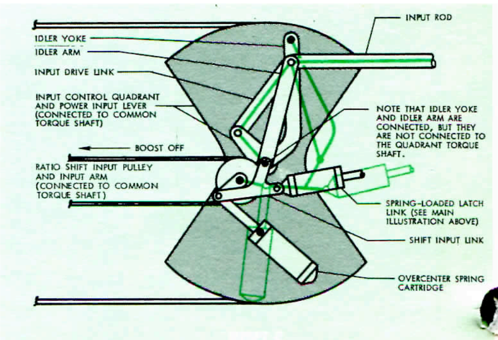
○ DENOTES BEARING ATTACHMENTS WHICH DO NOT REMAIN STATIONARY IN RELATION TO AIRCRAFT STRUCTURE WITH CONTROL MOVEMENT.



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 INSET A. NOTE THAT THE ANGULAR OUTPUT MOVEMENT IS NOW CONSIDERABLY LESS.



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.

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. In fact both hydraulic systems and all hydraulic pumps are available with any two engines in operation (see Figure 6).

Minimizing friction in the cable systems to the boosters was a primary design objective. The most direct and straight cable runs were established in the early design stages before fuselage structure and equipment from other aircraft systems compromised this concept. Particularly where pulleys are necessary, conventional flexible cable is used, but wherever long straight runs make its use advantageous, Lockclad cable is preferred. Lockclad cable consists of normal cable, pre-stretched, with aluminum tubing swaged around it while the cable is still in tension. This manufacturing process results in a control cable with a coefficient of expansion basically similar to that of the airframe structure, and the effect of ambient temperature changes on the flight controls are thereby lessened considerably. The aluminum sheath also gives the additional benefits of protecting the steel cable and reducing its sagging characteristics.

Cable slack take-up units are used in all the primary control cables, located close to the operating quadrants of the booster units. Figure 7 shows the construction of these assemblies. The aileron and rudder control systems have a single unit for each cable (four in all), while the elevator system has two dual units. These components should not be confused with cable tension regulators. When each control system is rigged with the correct cable tensions, 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 7), 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 high tension loads during control operation.

Plain hinged control surfaces are used throughout and no aerodynamic balancing is employed. Metal skin and ribs are built upon one or two spar beams with hinge brackets attached to the forward beam. The elevators and ailerons are balanced to varying

Figure 4 Typical Electra Control System (Elevator Shown)

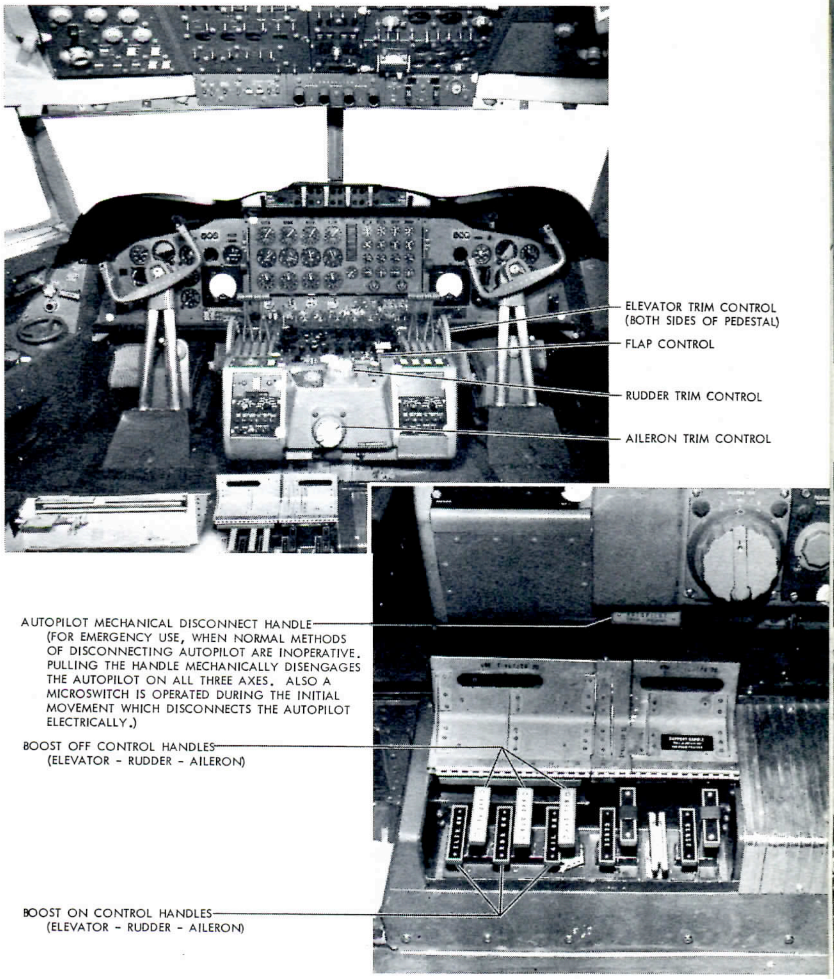


Figure 5 Electra Flight Station

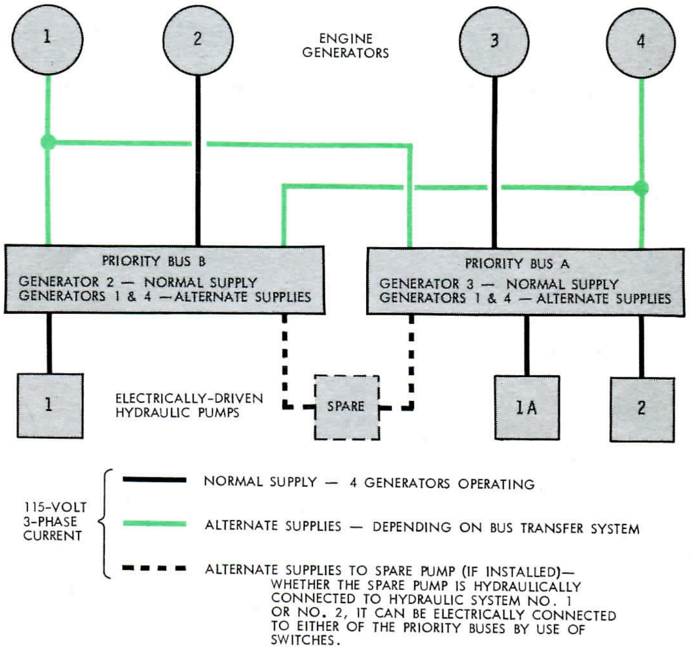
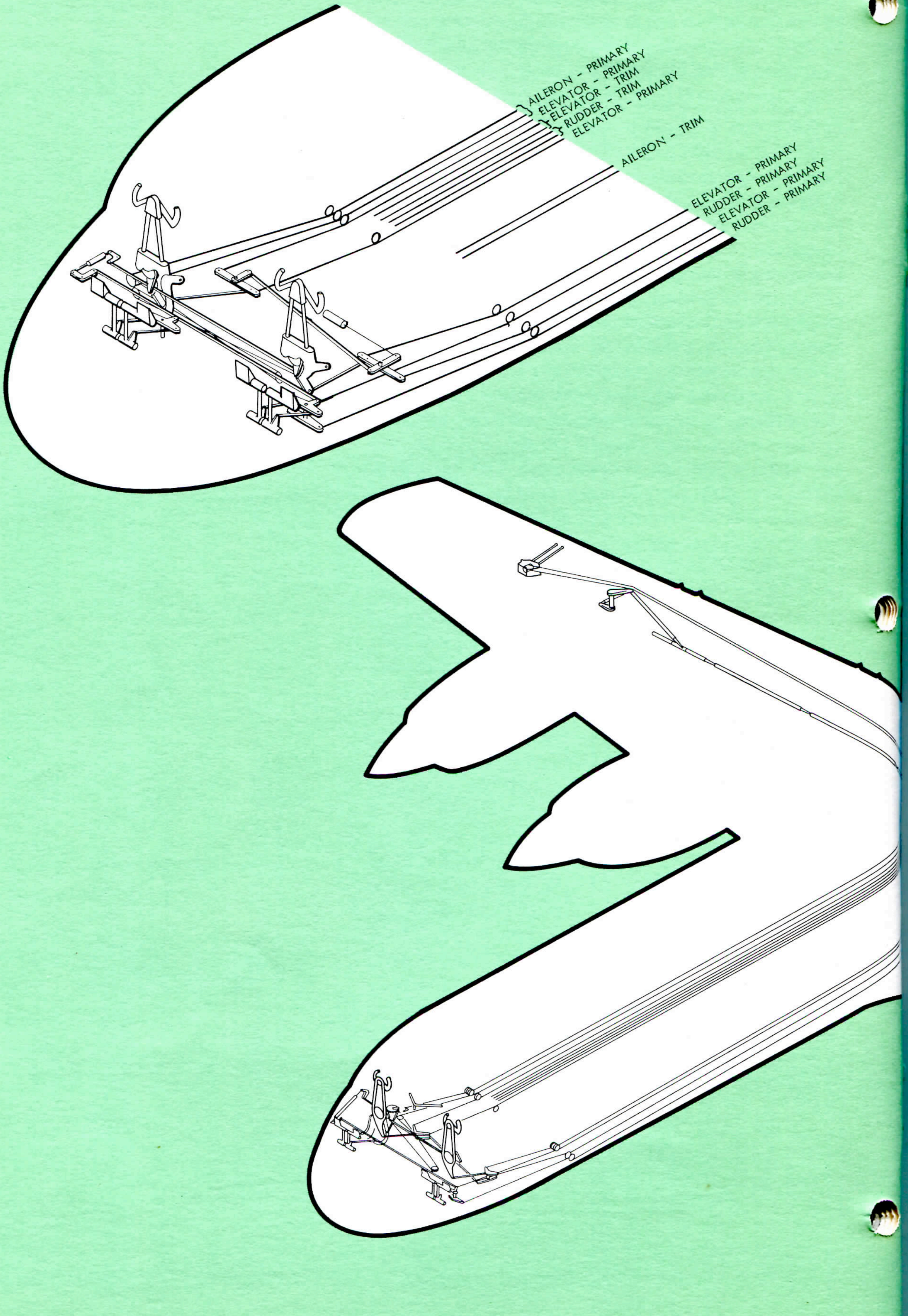


Figure 6 Electric Power Supplies to Hydraulic Pumps


AILERON - PRIMARY
ELEVATOR - PRIMARY
ELEVATOR - TRIM
RUDDER - TRIM
ELEVATOR - PRIMARY
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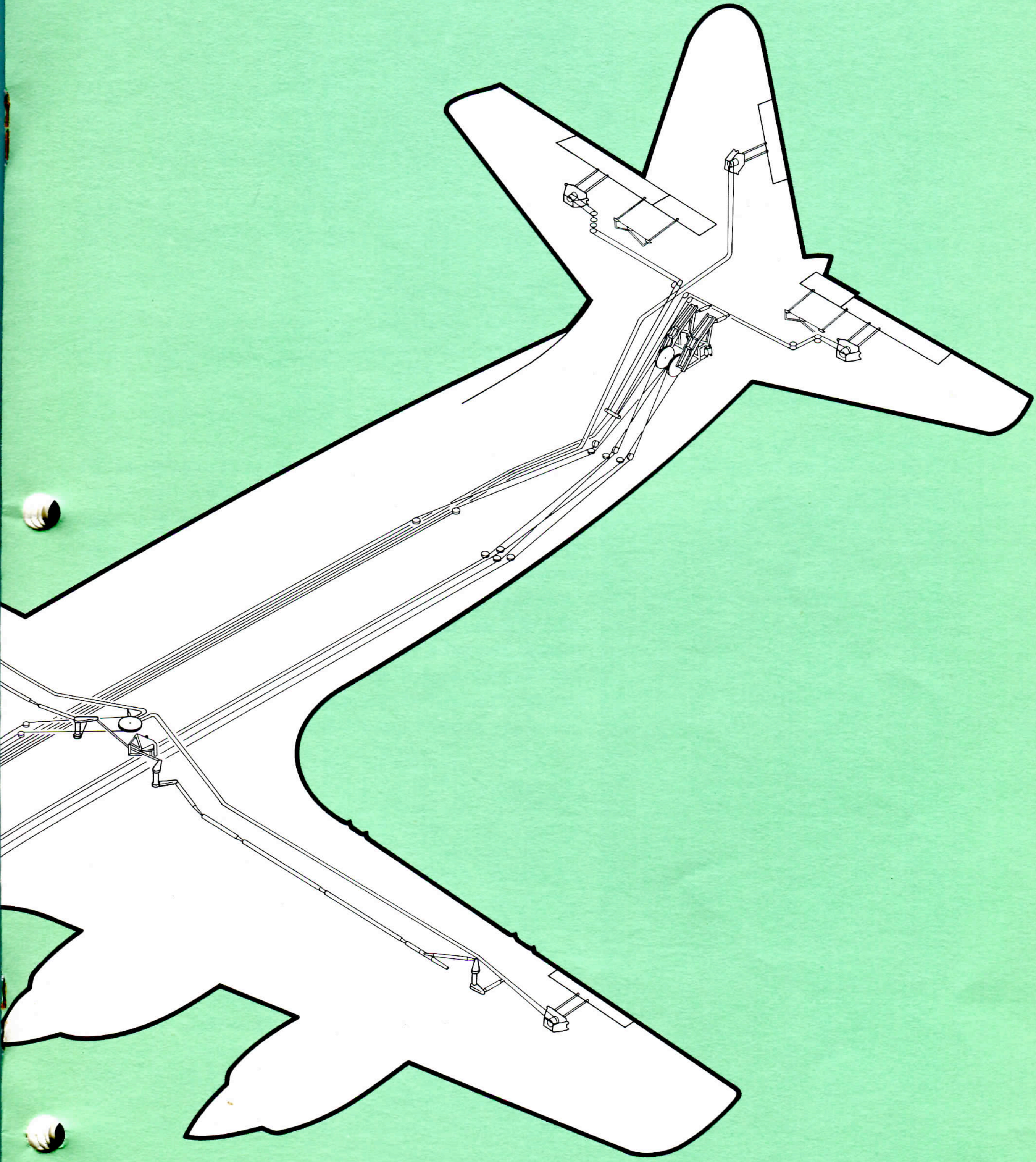
General Arrangement of
Electra Flight Controls



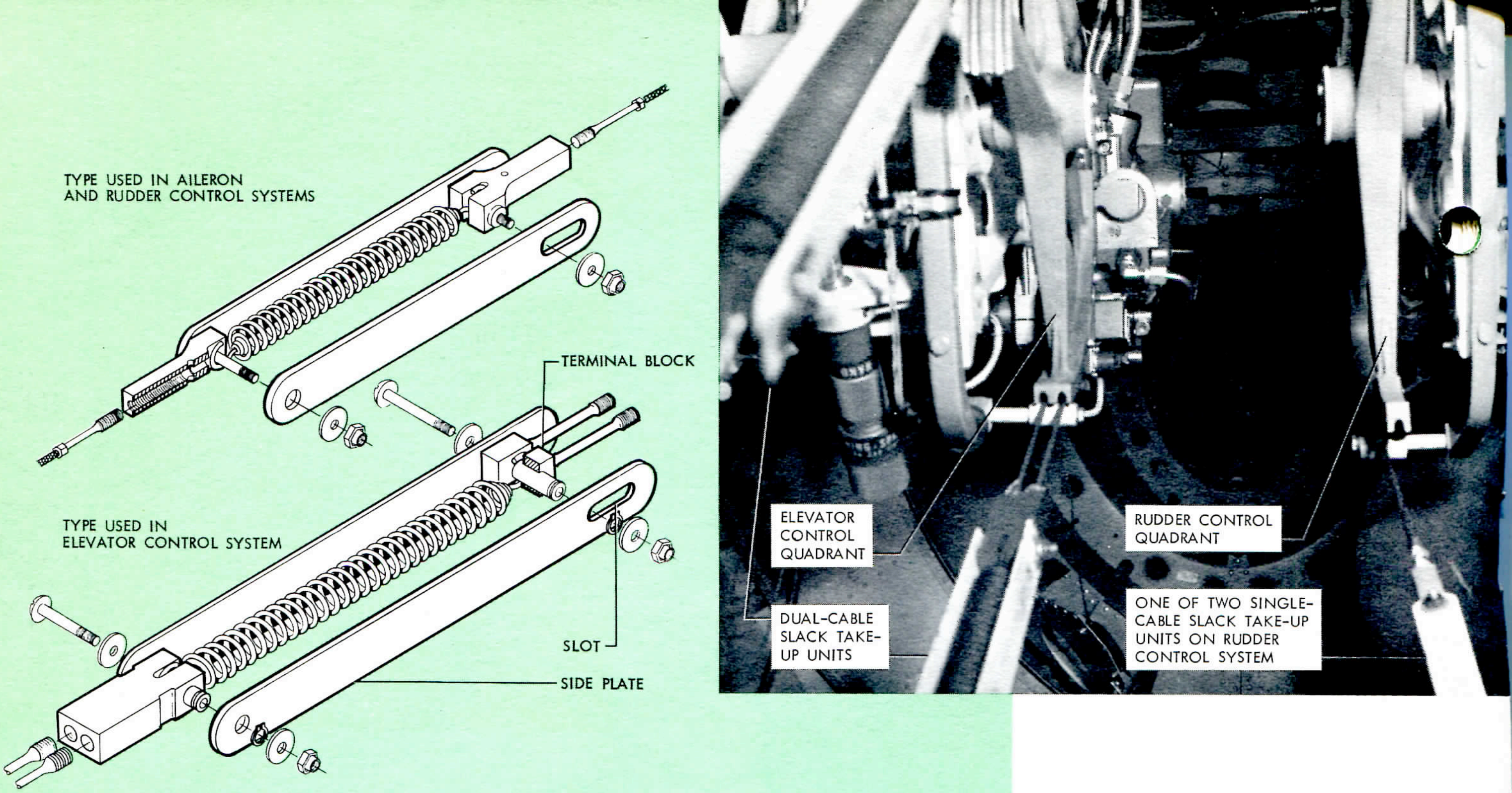
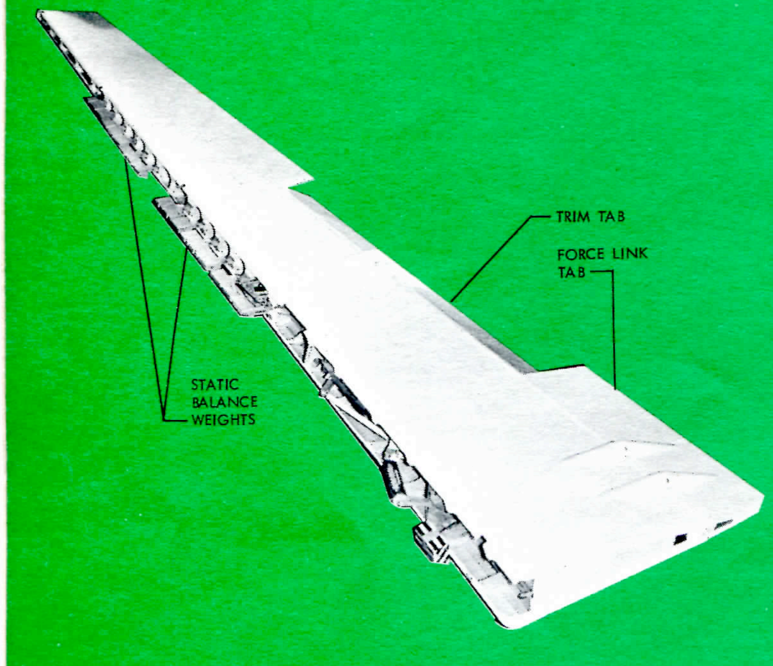


Figure 7
Cable Slack Take-up Units

Figure 8 View of Elevator Showing Tabs and Balance Weights



degrees by static balance weights also attached to the control surface front spar (see Figure 8).

Conventional mechanically-operated trim tabs, which have no servo action, are provided on all control surfaces. An additional tab of unique design is installed inboard of each elevator trim tab to tailor the elevator control forces to the desired magnitude. These two tabs, called force link tabs, are linked to, and are monitored by, the elevator trim tab controls so as to provide optimum control forces throughout the flight spectrum of the airplane.

At this point we are back where we started in the introduction. We have now returned to items which cannot be described as conventional or common to all three control axes, and it is now necessary to describe each of the flight control systems individually.

THE 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 moment, and a bobweight (called a stability augmenter weight), installed on the copilot's column, increases the total moment of the columns to a nominal value of 21.5 pounds stick force in terms of pilot effort. The purpose of this stick force

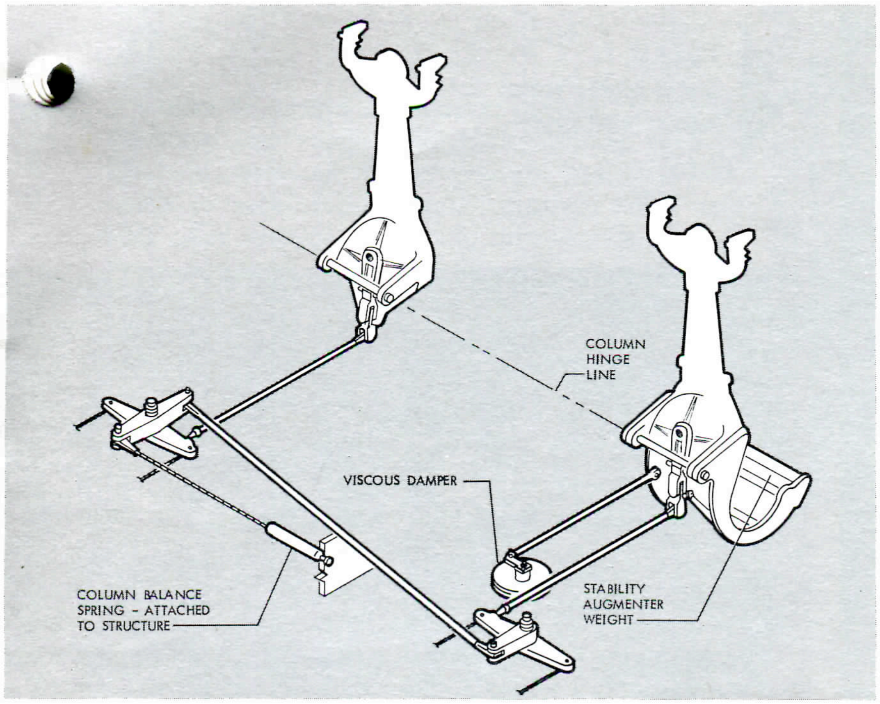


Figure 9 Sketch Showing Control Columns, Stability Augmenter Weight. and Balance Spring

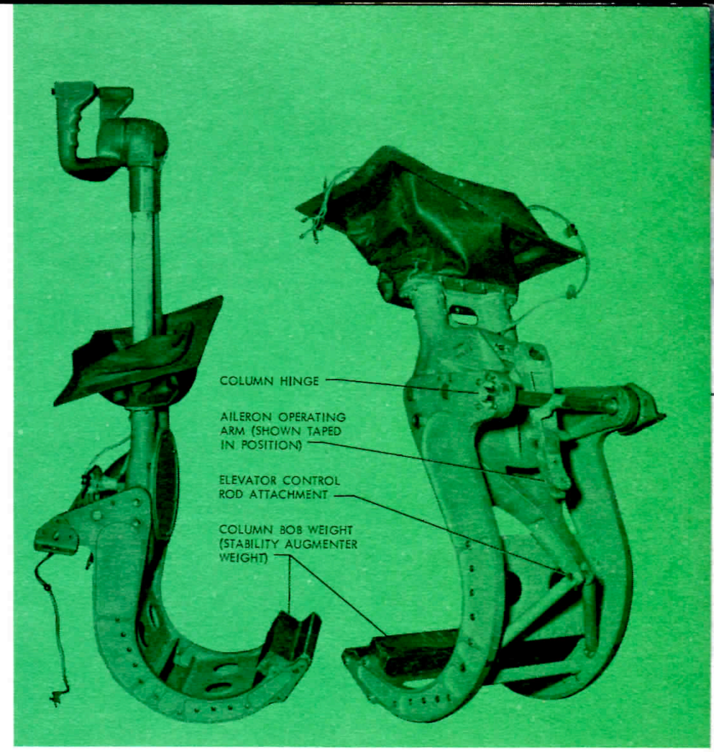


Figure 10 Copilot's Control Column

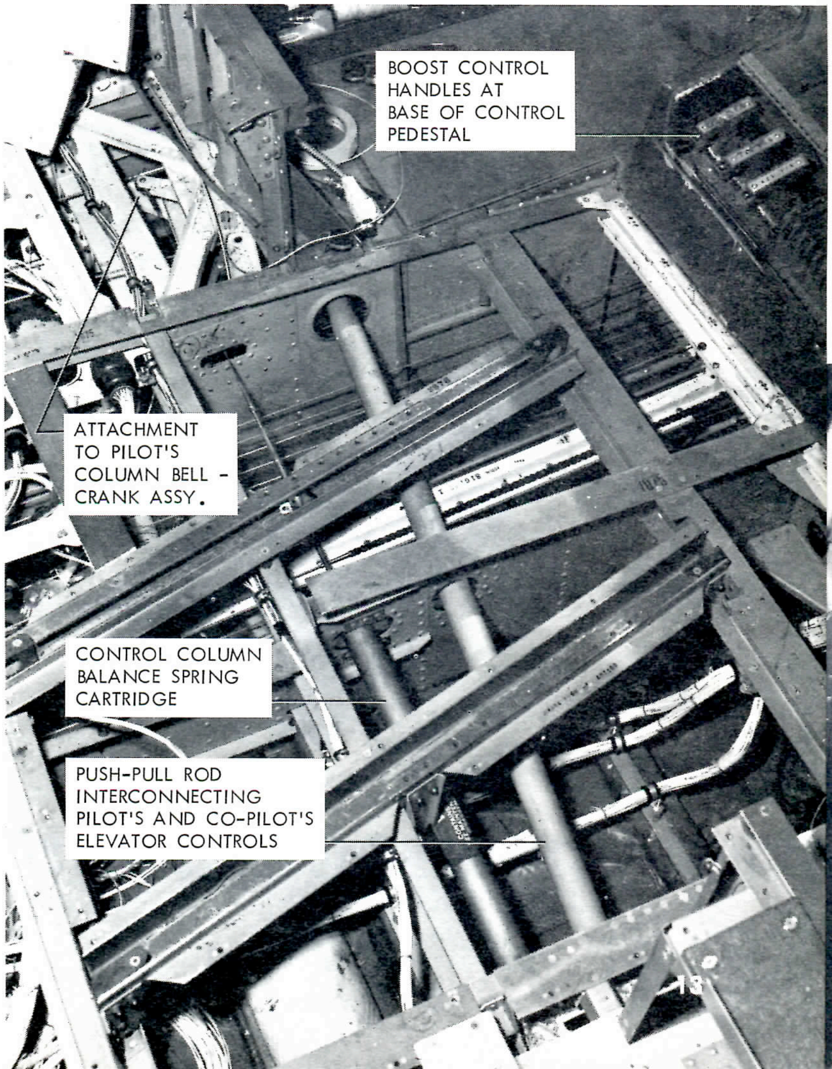
is explained later but, under static conditions, it remains essentially constant with elevator position and is statically balanced by a spring cartridge so that the columns would assume a neutral position if they were not connected to the rest of the control system (see Figures 9, 10, and 11).

A Viscous Damper is installed in the elevator control system to damp oscillations in the system, which might possibly result from a rapid movement of the control columns at high air speeds. It is attached to the bottom of the copilot's control column by a pushrod and crank assembly (see Figure 12). Friction is provided in the damper by rotating a disc in a viscous fluid (Dow Corning 200 fluid). For extremely rapid column movements (maximum rate allowed by booster unit), the stick force is increased by approximately 1.25 pounds, but the viscous damper has practically no effect in normal flight maneuvering. As a safeguard against a seizure occurring in the damper, the lever at the top of the unit is attached to the damper shaft with a rivet, which acts as a shear pin. Needless to say it is important to ensure that any replacement rivet is to the same specification.*

**Originally an AN470DD6 rivet. However, Service Bulletin 188/SB-525 allowed the use of a larger rivet (MS20470AD7-22) should inspection reveal looseness in the existing rivet attachment.*

(Continued on page 15)

Figure 11 Control Column Balance Spring Installation



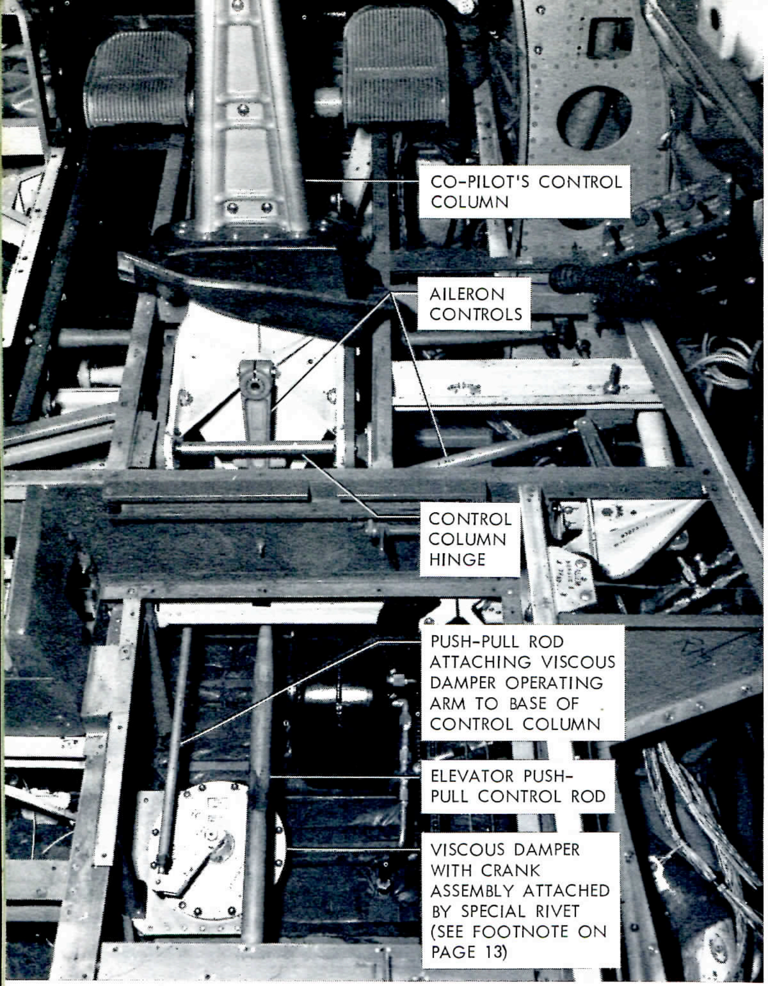


Figure 12
Control Column Viscous
Damper Installation

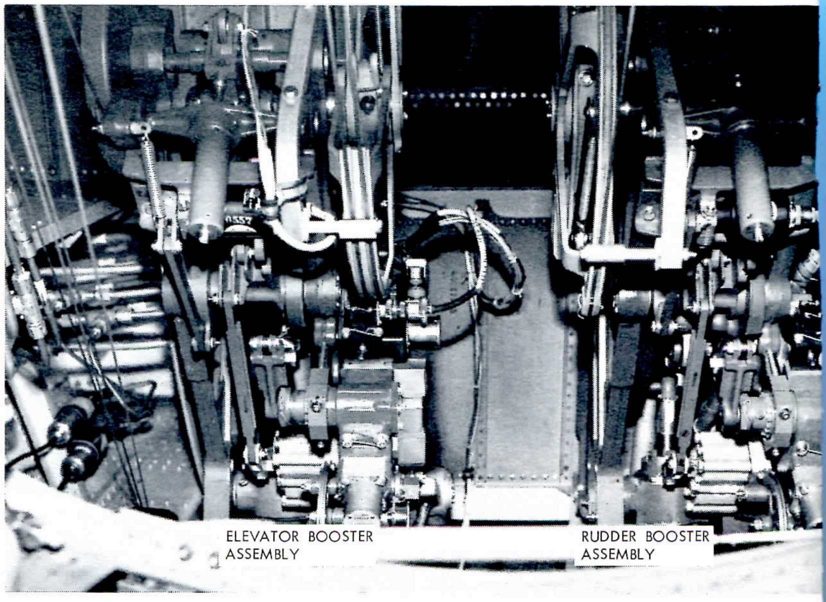
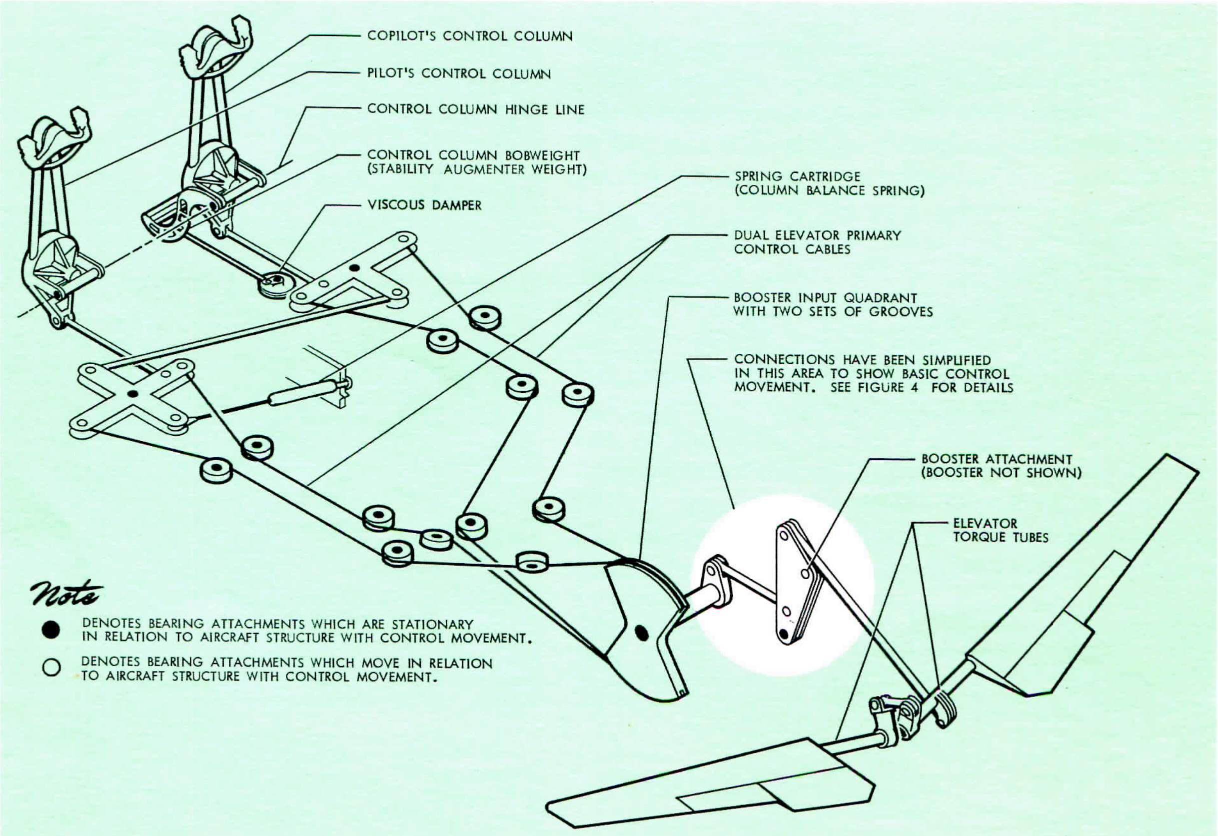
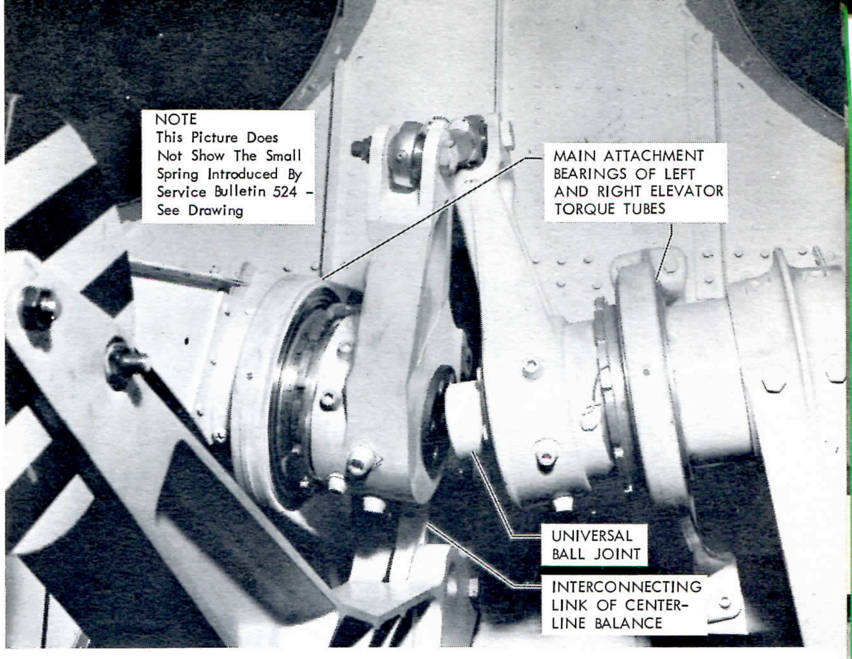


Figure 13 View Inside Fuselage Looking Aft Towards Elevators

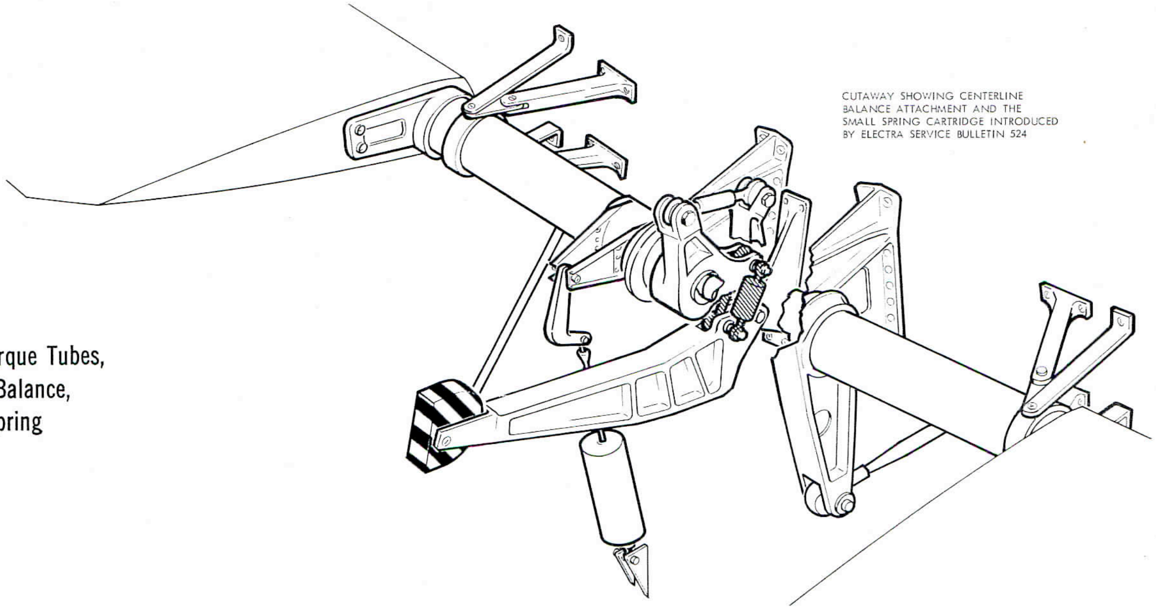
Figure 14
Sketch of Elevator
Control System
— Booster not shown



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. From here both cable systems extend aft, on opposite sides of the fuselage, to a common input quadrant 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 forward of the boosters in the aft fuselage, would still leave the elevators operable by either or both pilots (see Figures 13 and 14).

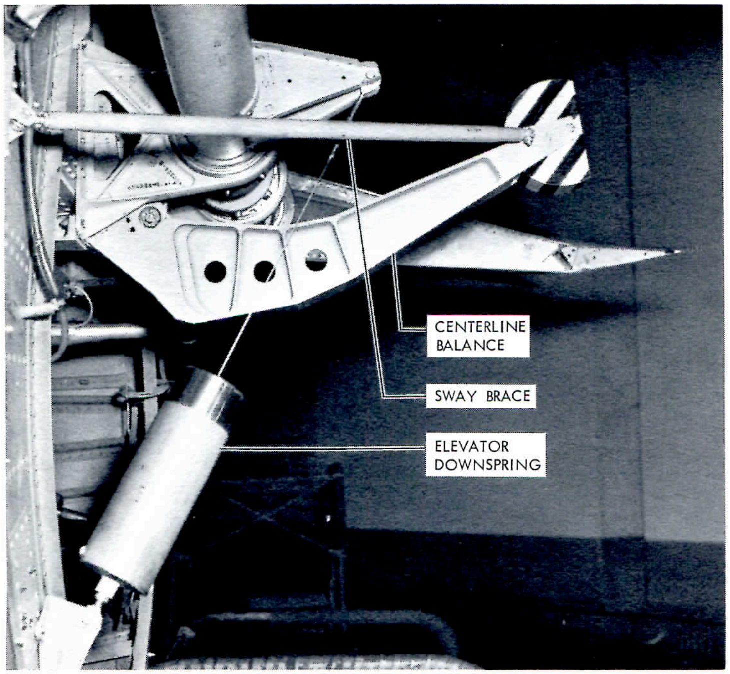


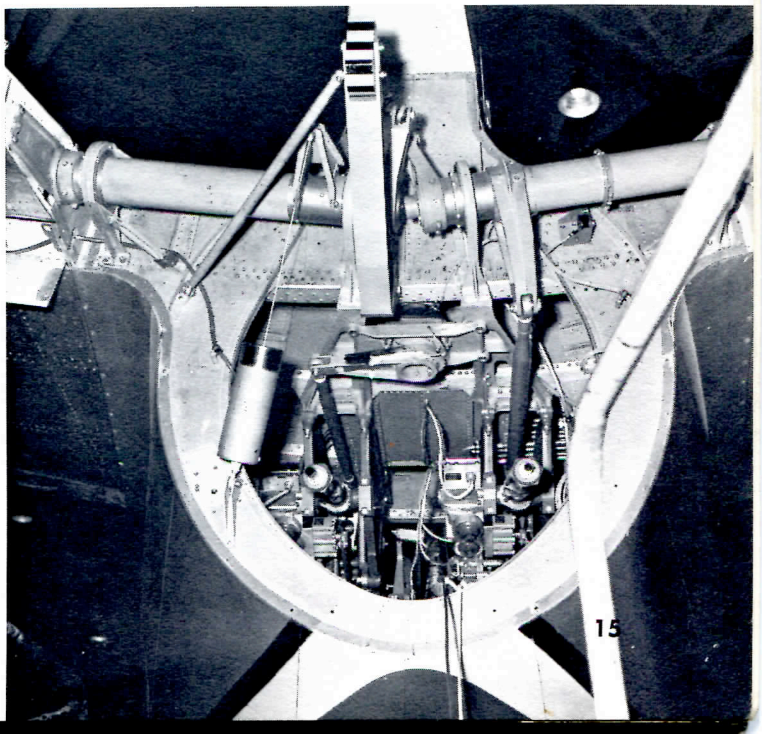
NOTE
This Picture Does Not Show The Small Spring Introduced By Service Bulletin 524 - See Drawing



CUTAWAY SHOWING CENTERLINE BALANCE ATTACHMENT AND THE SMALL SPRING CARTRIDGE INTRODUCED BY ELECTRA SERVICE BULLETIN 524

Figure 15
Elevator Torque Tubes,
Centerline Balance,
and Downspring





The booster output is connected to the right elevator torque-tube input arm by levers and push-pull tubes, some of which are incorporated in the elevator booster assembly. The horizontal stabilizer has an appreciable amount of dihedral so that a universal ball joint and other interconnecting linkage is necessary at the juncture of the two elevator torque tubes (see Figure 15).

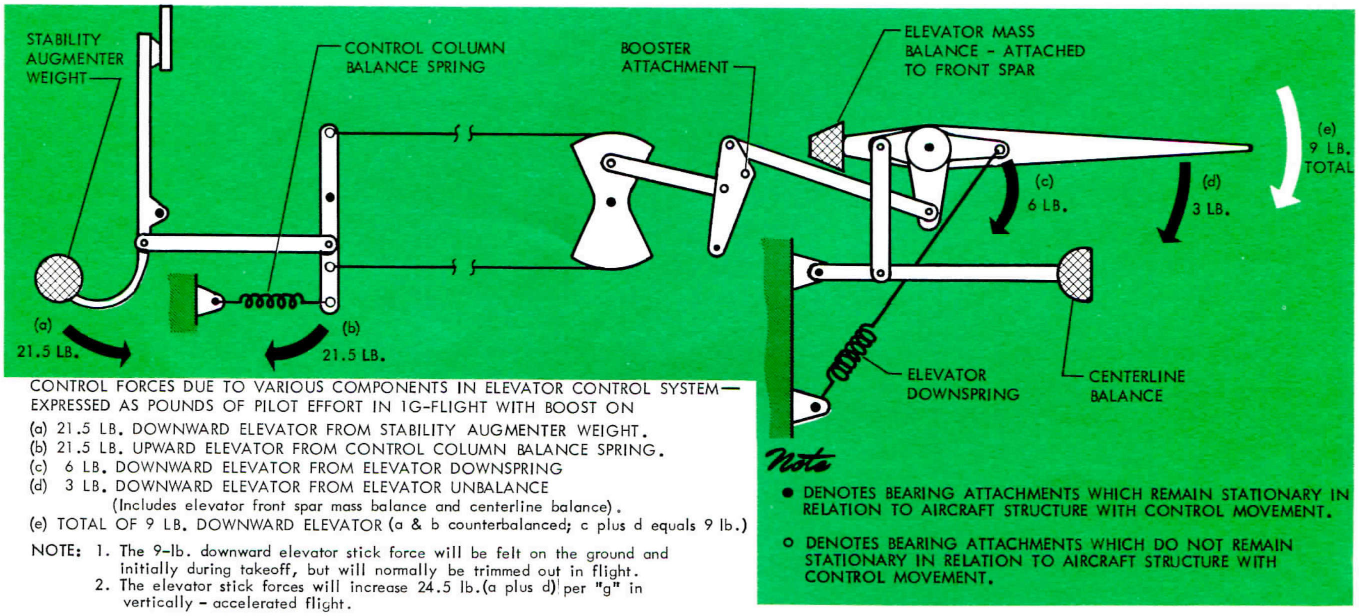
Both elevators are partially balanced by static weights attached to the control surface front spar, and a linked weight, attached to the left elevator torque tube and called the centerline balance, has a similar effect to the static weights so that the total elevator mass unbalance amounts to 3 pounds in terms of pilot effort (see Figure 16). Also attached to the left elevator torque tube is a downspring, which further increases the total elevator hinge moment to about 154 ft. lb. with the elevators in a faired position. This total corresponds to approximately 9 pounds in terms of pilot stick force.

Besides having a self-centering action in combination with the balance spring, the flight station stability augmenter weight also adds a constant increment of stick force per g for vertically-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 (21.5 plus 3) 24.5 pounds in pilot effort (see Figure 16), and a 3-g pull-up would require 49 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 combined effect of the downspring and the mass unbalance of the elevator improves the stick force stability characteristics of the airplane over its whole speed range in straight or 1-g flight. This will be further explained in the "Longitudinal Stability" section in Part Two of this article.

The principal role of the centerline balance — besides adding to the mass balance of the elevators — is to provide fail-safe capability against flutter of the elevator control surfaces, and the left elevator in particular. 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.

Normally the booster unit, which is connected to the right elevator torque tube, and the centerline balance on the left elevator torque tube would both act to prevent oscillations developing in the control surfaces. However, a failure of either of the above principal linkages would leave the centerline balance remaining to damp either both elevators or the left surface alone should the elevator interconnection fail. It should be noted that in the event of a failure, which leaves the elevators completely disconnected



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

(a) 21.5 LB. DOWNWARD ELEVATOR FROM STABILITY AUGMENTER WEIGHT.
(b) 21.5 LB. UPWARD ELEVATOR FROM CONTROL COLUMN BALANCE SPRING.
(c) 6 LB. DOWNWARD ELEVATOR FROM ELEVATOR DOWNSPRING
(d) 3 LB. DOWNWARD ELEVATOR FROM ELEVATOR UNBALANCE (Includes elevator front spar mass balance and centerline balance).
(e) TOTAL OF 9 LB. DOWNWARD ELEVATOR (a & b counterbalanced; c plus d equals 9 lb.)

NOTE: 1. The 9-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 24.5 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 16 Elevator Control System Showing Pilot Forces in Level (1g) Flight from the control system, the airplane can still be successfully controlled longitudinally by means of the elevator trim tabs.

The fail-safe policy of considering various failures in the control system to ensure that they will not produce dangerous flight characteristics is particularly problematical in control design. Many failures were simulated in the wind tunnel and in flight tests. For example, one such test involved the control column balance spring. The balance spring was manually disconnected on an Electra while the airplane was trimmed under cruise conditions (Gross weight 101,940 lb., C.G. 33%, Altitude 9,100 ft, EAS 276 knots). The pilot took no corrective action for approximately four seconds to simulate pilot reaction time. The airspeed increased 2 knots and the pitch changed 5 degrees nose down with a negative acceleration to plus 0.55g. A mild pull-up to 1.5g with a 32-lb pull was made during recovery. The airplane was restabilized at 286 knots with a 15-lb pull without retrimming.

Incidentally, the centerline balance linkage incorporates a small spring, which was introduced as part of Service Bulletin 524 (see Figure 15). The function of this spring is to pre-load the linkage, eliminate any mechanical play that exists, and thus avoid any high-frequency oscillations that could develop as a result of excessive wear in the joints of the linkage.

ELEVATOR TRIM TAB CONTROL SYSTEM

There are two tabs on each elevator surface. The outboard one is the trim tab and the inboard tab, extending four inches beyond the elevator trailing edge, is the force link tab (see Figure 17). As previously mentioned, the force link tab is connected to, and monitored by, the trim tab.

The controls to the elevator surface trim tabs are completely mechanical, and the tabs are finally operated by irreversible drum-driven screw actuators at each surface. The relatively large cable travels required by the screw actuators are obtained from a flight station control unit and a series of chain and sprocket drives. Friction of the complete system is controlled during 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. A total of 9.2 revolutions of either wheel is required to move the tabs through their complete range. The control wheels drive the tab control unit (see Figure 18), 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).

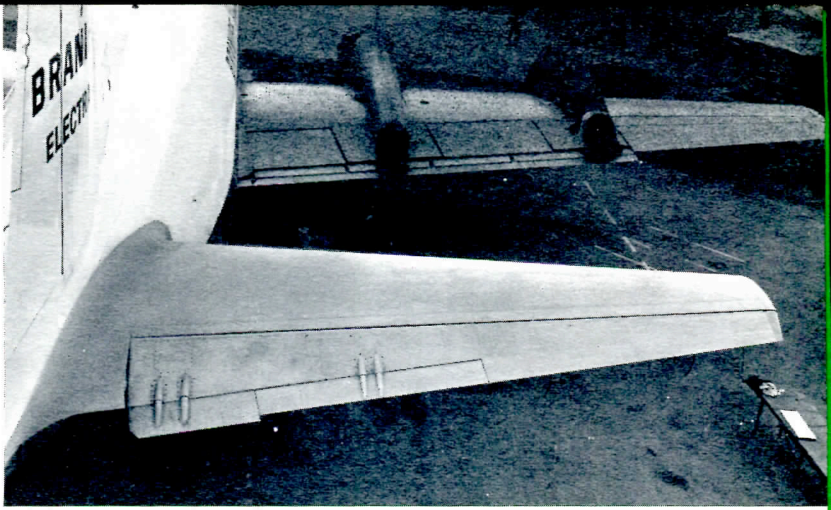


Figure 17 View of Elevator Showing Trim Tab and Force Link Tab

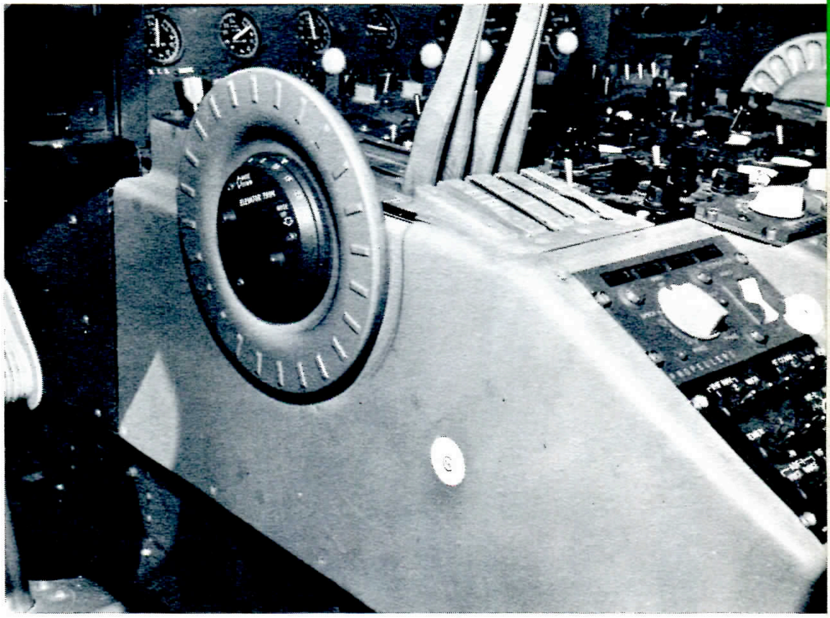


Figure 18 Flight Station Control Pedestal and Left Elevator Trim Control Wheel

From each control wheel, a chain drive goes to a sprocket on a common horizontal shaft in the control pedestal (see Figure 19). 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 of the

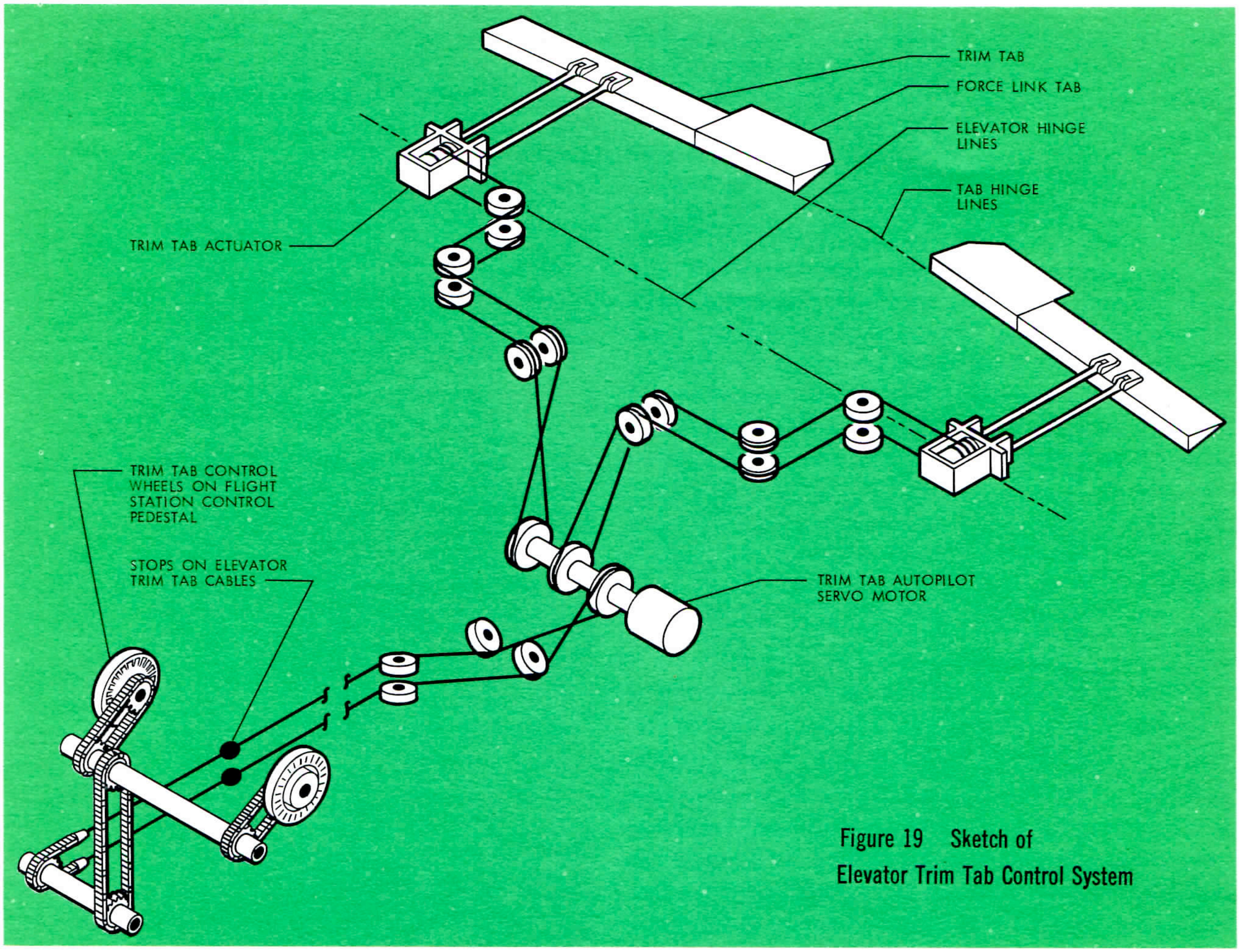


Figure 19 Sketch of Elevator Trim Tab Control System

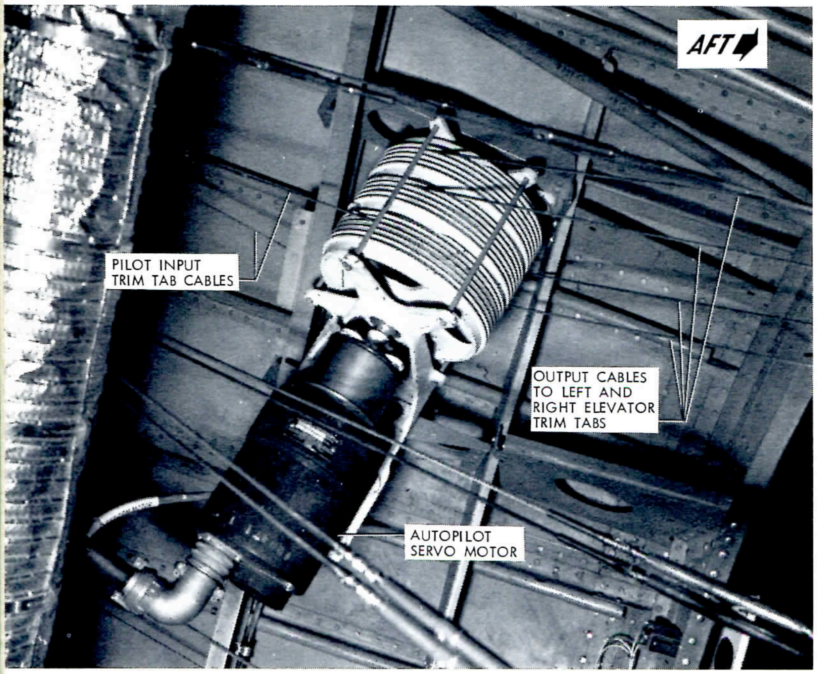


Figure 20 Autopilot Elevator Trim Tab Servo Motor Installation

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 aft of Fuselage Station 288 engage swaged ball fittings on the cable to limit total cable travel to 60.74 inches.

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 1024, where a pulley cluster permits change of direction toward the center 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 20).

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 cable ends 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 21).

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 shut down, as well as manual over-ride by holding the flight station trim wheel.

The Elevator Trim Tab Actuators are interchangeable with similar units which are used on the aileron and rudder tabs — a total of five per airplane. On each system the cable lengths attached to the drums differ according to requirements.

The actuator assembly consists of a cast aluminum alloy main housing, which supports a fixed Acme screw shaft (see Figure 22). 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.

The operating cable is wound around grooves on the drum and two swaged ball fittings on the cable prevent slippage. The Acme screw thread equals the pitch 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 .22 in, of axial travel. At cable load of 45 pounds, minimum axial load output is specified as 570 pounds.

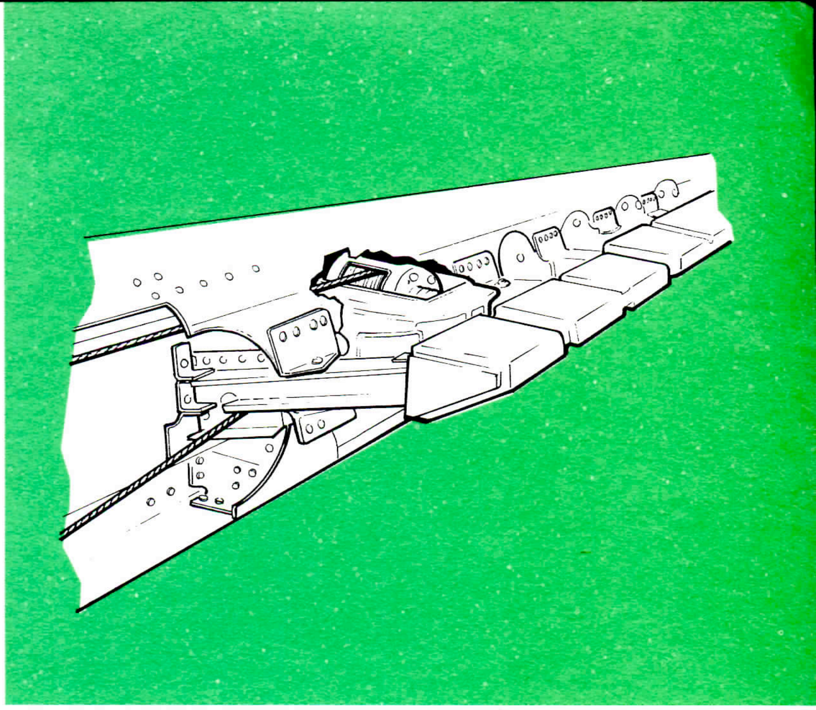


Figure 21 Elevator Trim Tab Actuator
Installation in Left Elevator

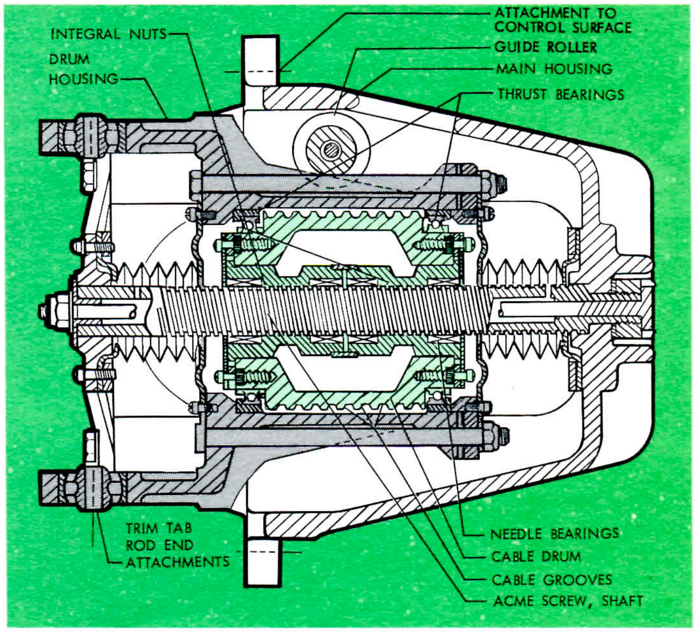


Figure 22 Trim Tab Actuator — Cross Section

The elevator tab actuators are mounted by four bolts to the structure of each elevator control surface front spar. Actuating 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.

This concludes Part One of the Electra Flight Controls. The next issue of the *Digest* will describe the aileron and rudder control systems, and a description of the elevator force link tabs will be included in a section which discusses longitudinal stability. ▲▲

LOCKHEED field service digest

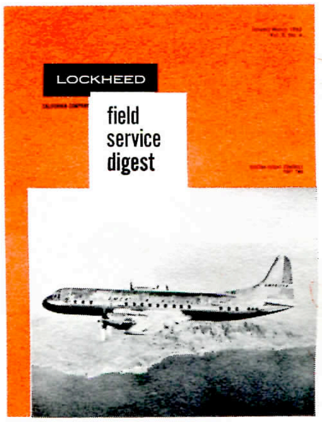
This publication is a digest of the most important technical information currently available and is intended to assist our customers in the service, maintenance, and operation of their Lockheed transport aircraft.

CONTENTS

Vol. 8, No. 4
January-March 1962

COVER PICTURE: It is probably not very well known that the ***Electra*** evolved from Lockheed's CL-303 preliminary design, which was undertaken in 1954 to meet an ***American Airlines*** specification for a four-engined prop-jet airliner. The CL-303 developed into a larger aircraft, the CL-310, which in turn became the basic design of the ***Electra*** as we know it today.

American Airlines took delivery of 35 of the prop-jets and many of them have now acquired 7,000 flying hours. Used primarily on ***AA's*** short-haul operations, the ***Electra*** vies with the pure jets in speedy, comfortable service; and equals the best of the piston-engined aircraft in dependability, ease of maintenance, and operational flexibility.



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part two

ELECTRA FLIGHT CONTROLS

longitudinal stability and the force link tab

SATISFYING THE flight control requirements and achieving good flying characteristics is essentially a process of choosing the right compromise. In addition to meeting the more basic requirements, some of which were described in Part One of this article, the airplane also has to have satisfactory handling characteristics under such operational conditions as: trim changes due to power application, one or more engines out, landing gear and flaps extended, boost off and boost on, take-off, landing, and so forth. One basic overall consideration concerns longitudinal changes in the center-of-lift throughout the complete speed range of the airplane. In this regard, designing flight controls to account for all possible variables can be especially problematical on airplanes with specifications similar to that of the Electra. With such aircraft, the situation is usually complicated further by a widely varying center-of-gravity — a necessary characteristic of transport airplanes, if they are going to be operationally competitive.

The Electra has a relatively large center-of-gravity range and this fact is indirectly related to the ability of this airplane to virtually lift its own weight in fuel and payload. For a transport of this size and

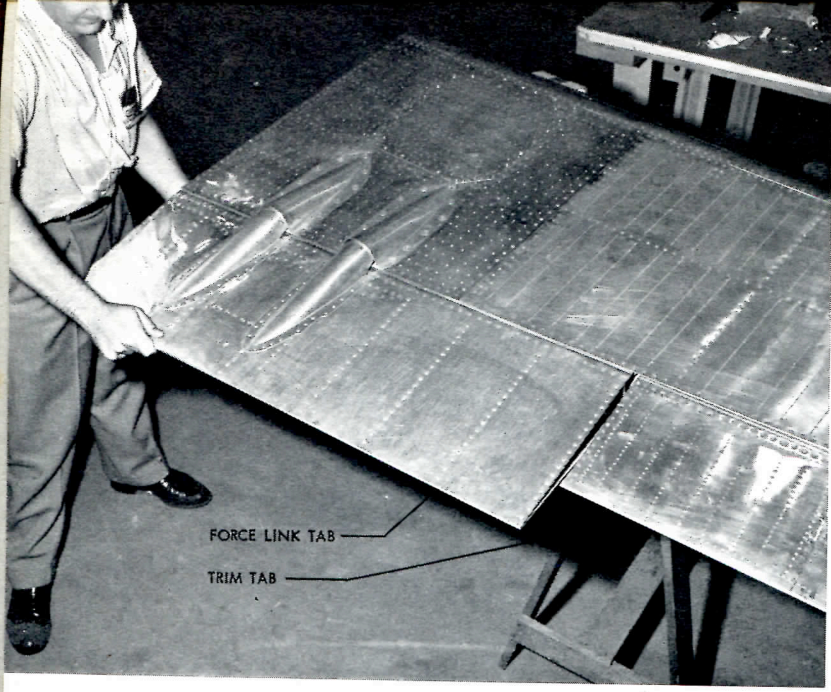
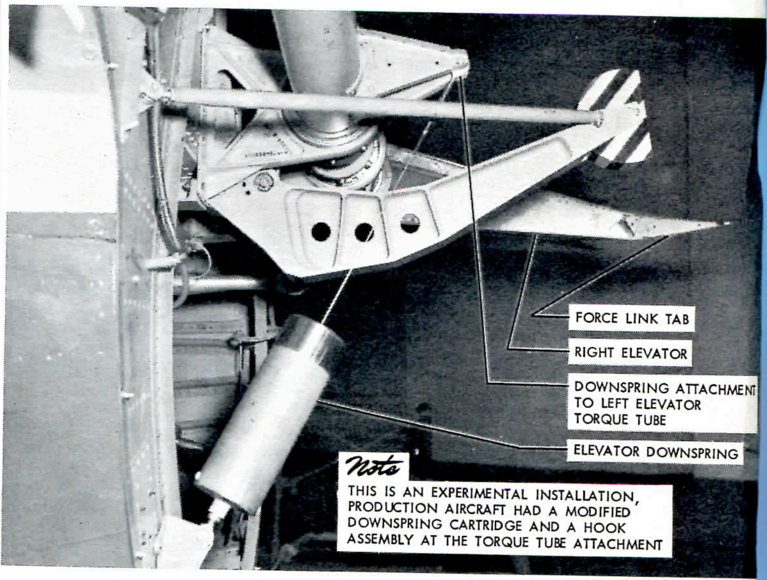


Figure 1 Force Link Tab and Elevator Downspring



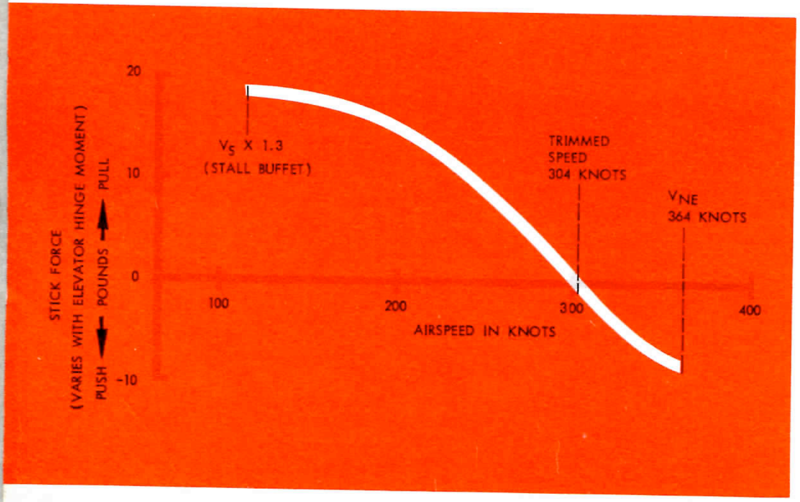


Figure 2 Graph Showing Results of a Stick-Free Stability Flight Test on the Electra

performance, this is an exceptional achievement. However, in the early design stages, it appeared that this achievement or goal would be seriously compromised by possible changes in the basic design, necessitated by the longitudinal stick-free stability requirements. (See the heading below for a brief explanation of this tongue twister).

Specifically, it seemed that there were two choices open to the designers: Either the planned c.g. range would have to be reduced, or the fuselage would have to be extended aft, thus increasing the size and weight of the airplane. Either of these alternatives would have resulted in a loss in useful load for, to put it simply, the Electra would no longer have been able to lift its own weight in fuel, passengers, freight, and so forth. However, the Electra still has this claim to fame as there was a third less obvious choice, which had no serious disadvantages — other than being an added complication. The elevator force link tabs, in combination with the elevator downspring (see Figure 1), tailor the elevator control forces, under all c.g. conditions and throughout the entire flight spectrum, to meet the longitudinal stick-free stability requirements.

The Longitudinal Stick-Free Stability of an airplane in flight is apparent to the pilot through its influence on the variation of elevator control force (elevator hinge moment) with speed.* If an airplane is initially trimmed hands-off in level flight at cruise speed, a stable airplane normally requires a rearward motion of the control stick to achieve a higher angle of attack and a forward motion of the control stick to achieve a lower angle of attack. These stick or

---

**It should be noted that the forces exerted on the control surface hinges are transmitted to, and are felt by the pilot through the flight station controls. In fact, for any one particular aircraft type with manual or boost-assisted controls, it is possible to make an approximation and state that so many foot-pounds of elevator hinge moment, for example, are equivalent to one pound of pilot effort at the control column. Throughout the article, we have used whatever term (control surface hinge moment, pilot effort, or stick force) seemed most appropriate to the context. The reader is requested to appreciate the above relationship.*

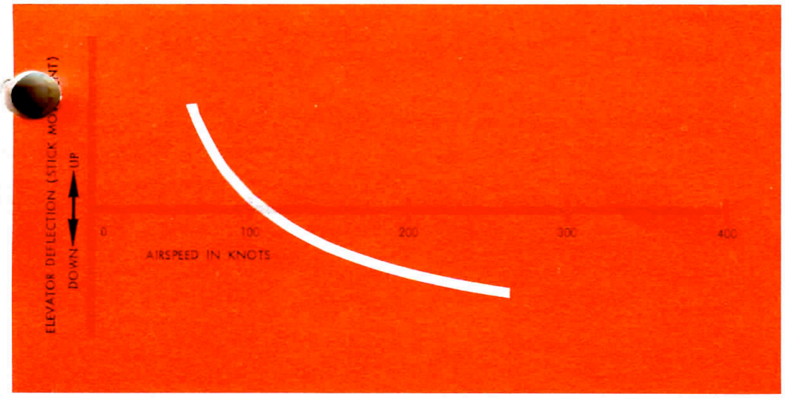


Figure 3a Graph Showing Elevator Deflection Variation with Airspeed — Typical 250-knot Transport

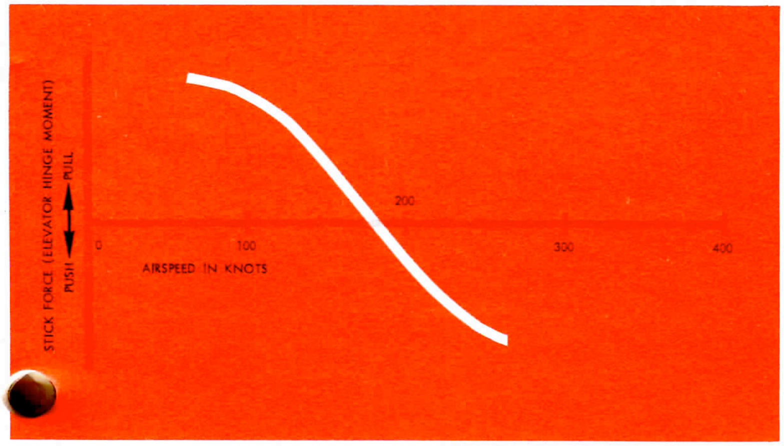


Figure 3b Graph Showing Stick-Force Characteristics — Typical 250-knot Transport

elevator movements correspond to a lower flight speed and a higher flight speed respectively, and, if an airplane is stable with stick-free, a *pull force* is required to fly the airplane at a lower flight speed and a *push force* is required to fly at a higher flight speed — both actions by the pilot being instinctive. If the stick force is maintained the airplane should stabilize at the new flight speed, and, further, when the stick is released on a stable airplane, the stick should return to its original position and the airplane should return to its original trimmed speed.

The Civil Air Regulations in regard to stick-free stability have to be demonstrated in flight tests. These tests are conducted throughout the complete operating range of the airplane, and under the most adverse conditions of c.g. or loading. The result of a typical flight test on the Electra (with the force link tab and downspring installations) is shown in Figure 2. For this test the airplane had a gross weight of 114,000 lb. and an aft c.g. of 33% M.A.C. It was initially trimmed in level flight (2.9 degrees tab down) at 304 knots I.A.S. at an altitude of 9,000 feet with maximum cruise power on all four engines. The stick force required to vary the speed from trim was measured at several stable speeds down to the edge of stall buffet and up to V_{NE} (Never Exceed speed — the maximum placard speed for operation of the airplane). The stick was released slowly from each extreme to determine that, within certain limits, the aircraft returned to the original trimmed speed. The graph shows that a steadily increasing pull force is required to decrease the speed from the trimmed condition to near the stall (V_S times 1.3). It also shows that a steadily increasing push force is required from the trimmed condition up to the Electra's maximum operational speed.

From the pilot's point of view it should be appreciated that stick force (elevator hinge moment) is more important than stick movement (elevator deflection) in regard to sensing varying speeds and aircraft attitudes from a given trimmed condition. However, it usually follows that the stick-force requirements will be met on an airplane that has suitable elevator deflection variation with speed — although there are many other considerations and the result may not necessarily be ideal. Aircraft of the pre-war period were normally of such size and performance that they came into the above category. Figure 3a depicts a typical curve for a transport airplane with a maximum speed of about 250 knots. The elevator deflection angle is plotted against speed for a given center-of-gravity position, gross weight, and so forth.

Figure 3b depicts what might be considered desirable stick force characteristics which could result from an airplane designed with the elevator deflection angle/speed characteristics shown in Figure 3a. It should be noted that aircraft of this pre-war period were of such size and performance that any form of power assistance to the controls was unnecessary, and the control surfaces were usually plain with no aerodynamic balancing.

Based on the Electra's performance,* it will be noted

**At this point we should emphasize that a large proportion of the following information is only based on the Electra's flight characteristics and should not be regarded as an accurate record of the aircraft's performance. For example, some flight characteristics have been purposely exaggerated on the graphs, and the speed/control-movement relationships have been chosen merely to simplify the discussion. It should also be noted that the incorporation of Service Bulletin 88/SB-262 (Uptilting of the Electra's powerplants) changed some of the airplane's original characteristics slightly — particularly at the higher airspeeds. These changes were considered to be insignificant and have not been brought out in the article.*

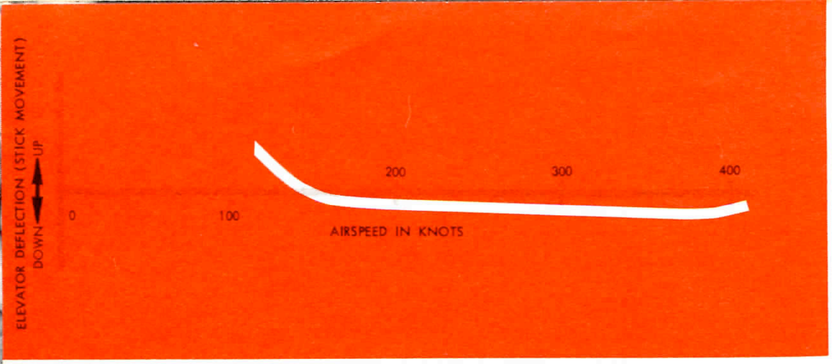


Figure 4a Graph Showing Elevator Deflection Variation with Airspeed — Based on Electra Performance

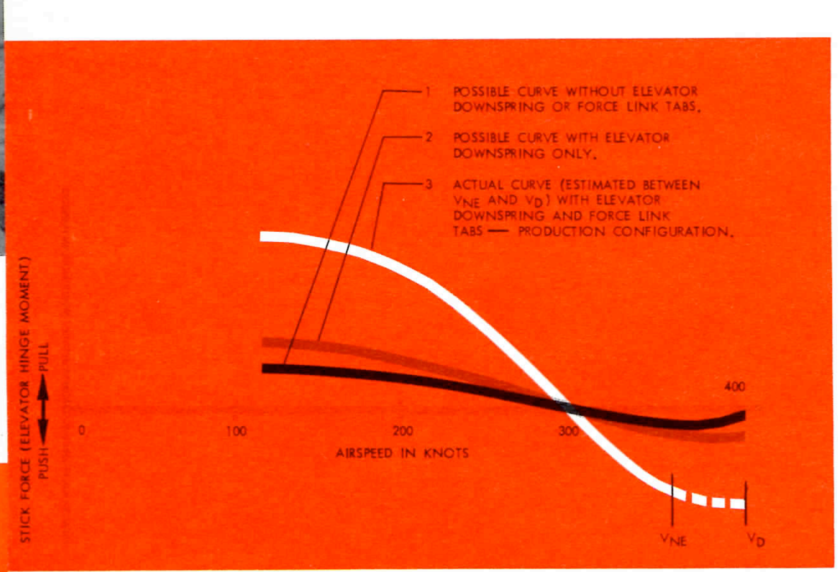


Figure 4b Graph Showing Stick-Force Characteristics When Initially Trimmed at 305 knots — Based on Electra Performance

that the elevator-deflection/airspeed curve (Figure 4a) is only comparable with the typical pre-war transport curve (Figure 3a) at speeds approaching the stall. Above about 150 knots the curve flattens out, as very little elevator movement is required, and eventually, at speeds well above the operational speed range of the Electra, the elevators are actually deflected in the opposite direction. It should be expected that these characteristics would produce a stick force curve similar to that shown by curve #1 in Figure 4b — assuming a control system without benefit of the elevator downspring or the force link tabs.

There are two reasons for the characteristics shown in Figure 4a. Neither of them is avoidable in an airplane of the Electra's specification. The primary reason — and the only one causing the flattened-out portion of the curve — is due to what is called the "slipstream effect." As previously mentioned in Part One of this article, one of the Electra's most desirable features is the aircraft's almost instantaneous power response resulting from the unusual characteristics of the engines, and due in large part to the lift generated by the slipstream from four large propel-

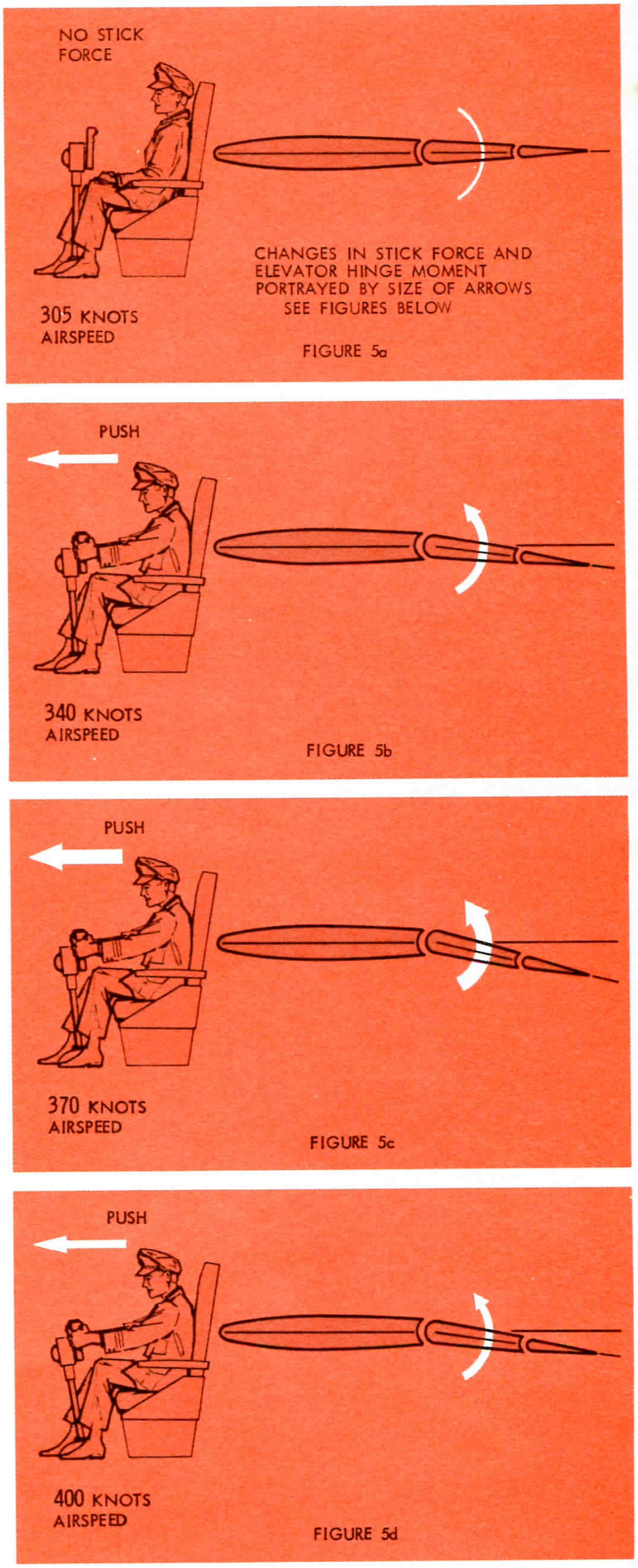


Figure 5 High-Speed Stick-Force Characteristics Without Elevator Downspring and Force Link Tab Installations — Based on Electra Performance

lers washing over almost the entire wing. However, this slipstream also causes a change in the lift characteristics of the wing and the tail, which causes a nose-down pitching moment and opposes the more normal nose-up pitching moment associated with increase in airspeed. One result of these two counteracting forces is that there is little change in elevator deflection with airspeed. Without some special control design, there would also be little change in elevator hinge moment with airspeed, and the pilot would consequently experience little change in stick force compatible with the change in airspeed. This is depicted in Figures 5a and 5b.

A secondary reason for the high speed section of the curve in Figure 4a is called "tuck" by the aerodynamicist and explains the control force reversal at speeds close to 400 knots — a phenomenon, incidentally, which is common to all jet transports which have performance capabilities up to the transonic speed range.* Figures 5c and 5d depict the effect on the pilot of further increasing speed from the initially trimmed speed of 305 knots. At 370 knots (Figure 5c) there again would be a slight increase in elevator hinge moment as the pilot pushed on the stick, but if he pushed on the stick to achieve a speed of 400 knots he would sense an unnatural feel to the elevator controls; he would have to relax the push force he is applying to the control column in order to prevent the airplane's tendency to nose over and gain speed.

In the tuck regime the airflow over the wing reaches, or exceeds, the speed of sound (Mach 1). The resultant compressibility effects are such that the center-of-lift of the wing moves aft a large amount compared to the speed increase.

At subsonic speeds, as Figures 6a, 6b, and 6c depict, the center-of-lift of the wing gradually moves aft, but there is no tendency for the aircraft nose to drop. There are several factors involved, but the nosing-down tendency is more than offset by the increased negative lift from the horizontal stabilizer, which, on the Electra, has an inverted airfoil section.† Thus the aircraft's nose actually rises with increased speed and this is counteracted by a steadily increasing push force on the stick by the pilot.

At transonic speeds, however, the negative lift from the horizontal stabilizer is not sufficient to offset the large aft movement of the center-of-lift of the wing and the aircraft's nose has a tendency to drop or tuck under (see Figure 6d). *(Continued on next page)*

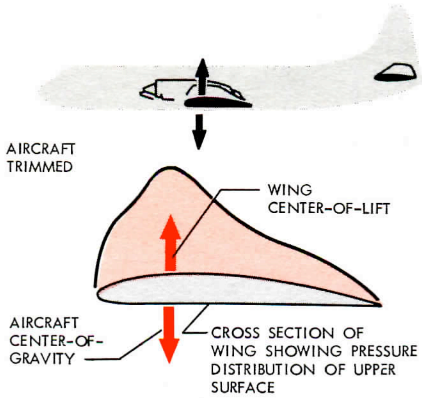


FIGURE 6a 305 KNOTS AIRSPEED

FOR SIMPLICITY, IT IS ASSUMED THAT THE CENTER-OF-GRAVITY AND THE WING CENTER-OF-LIFT ARE EQUAL AND OPPOSITE (ABOUT 25% M.A.C.). ALSO FOR SIMPLICITY, OTHER FACTORS, SUCH AS THE EFFECTS OF THRUST AND DRAG, HAVE BEEN IGNORED. IT WILL BE NOTED THAT IF THE C.G WERE FORWARD OR AFT OF THE POSITION SHOWN, THE RESULTING PITCHING MOMENT WOULD BE OFFSET BY POSITIVE OR NEGATIVE LIFT AT THE TAIL PRODUCED BY AN APPROPRIATE AMOUNT OF ELEVATOR TRIM. SEE ALSO FIGURE 5a.

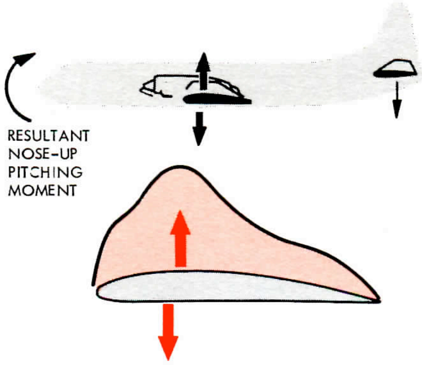


FIGURE 6b 340 KNOTS AIRSPEED

CENTER-OF-LIFT OF WING HAS MOVED SLIGHTLY AFT, BUT THE RESULTANT NOSE-DOWN PITCHING MOMENT IS MORE THAN OFFSET BY THE NOSE-UP PITCHING MOMENT PRODUCED BY THE HORIZONTAL STABILIZER, WHICH HAS AN INVERTED AIRFOIL SECTION. AGAIN, OTHER FACTORS, SUCH AS THE EFFECTS OF THRUST, AND DRAG HAVE BEEN IGNORED. SEE ALSO FIGURE 5b.

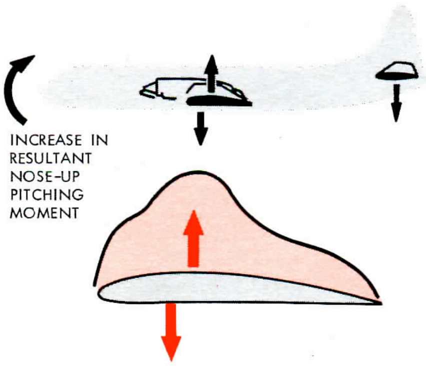


FIGURE 6c 370 KNOTS AIRSPEED

CENTER-OF-LIFT OF WING HAS MOVED FARTHER AFT, AND THE NEGATIVE LIFT FROM THE HORIZONTAL STABILIZER HAS ALSO INCREASED. RESULTS ARE SIMILAR AS IN FIGURE 6b. SEE ALSO FIGURE 5c.

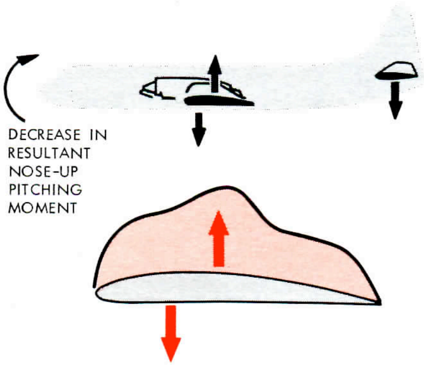


FIGURE 6d 400 KNOTS AIRSPEED

COMPRESSIBILITY HAS HAD A CONSIDERABLE EFFECT ON THE LIFT DISTRIBUTION OVER THE WING. THE INCREASED NEGATIVE LIFT FROM THE HORIZONTAL STABILIZER IS NOT SUFFICIENT TO OFFSET THE LARGE AFT MOVEMENT OF THE WING CENTER-OF-LIFT. THE RESULTANT NOSE-UP PITCHING MOMENT IS REDUCED INSTEAD OF INCREASED, WHICH IS FELT BY THE PILOT AS A TENDENCY FOR THE AIRCRAFT'S NOSE TO DROP.

Figure 6 How Compressibility Affects a Typical Subsonic Wing to Cause Tuck — Based on Performance of Electra Without Elevator Downspring and Force Link Tab Installations

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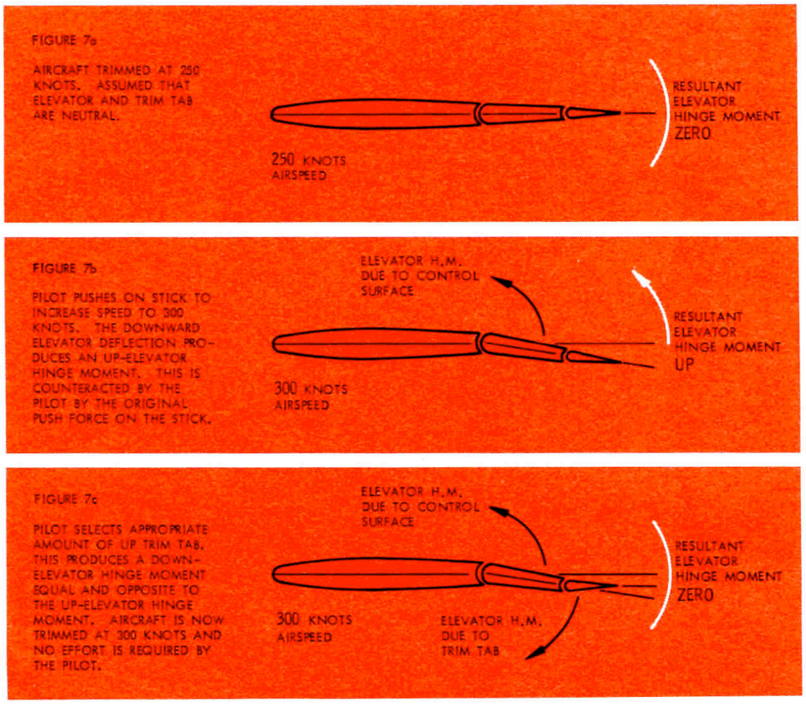
**In this range some parts of the airplane are at, or exceed, the speed of sound. This will usually begin to occur between Mach 0.7 and 0.9 depending on the particular airplane under consideration.*

†*An airfoil which has the maximum curvature on the underside so that the lift acts downwards.*



AIRCRAFT TRIMMED AT 250 KNOTS. ASSUMED THAT ELEVATOR AND TRIM TAB ARE NEUTRAL.

PILOT PUSHES ON STICK TO INCREASE SPEED TO 300 KNOTS. THE DOWNWARD ELEVATOR DEFLECTION PRODUCES AN UP-ELEVATOR HINGE MOMENT. THIS IS COUNTERACTED BY THE PILOT BY THE ORIGINAL PUSH FORCE ON THE STICK.

PILOT SELECTS APPROPRIATE AMOUNT OF UP TRIM TAB. THIS PRODUCES A DOWN-ELEVATOR HINGE MOMENT EQUAL AND OPPOSITE TO THE UP-ELEVATOR HINGE MOMENT. AIRCRAFT IS NOW TRIMMED AT 300 KNOTS AND NO EFFORT IS REQUIRED BY THE PILOT.

Figure 7 Principle of Trimming an Aircraft by Means of a Trim Tab

Airplane tucking became a fairly common phenomenon with fighter aircraft at the end of World War 2 and was counteracted to some extent, or delayed, by the employment of thin laminar-flow wings and then later, swept-back wings. The Electra wing is about as thin as practicable, while still maintaining good landing characteristics, and carrying enough fuel for its role as a short to medium haul airliner — even so it interesting to note that the depth-to-chord ratio of the Electra wing compares to that of the Lockheed P-80 Shooting Star. Further, the use of sweepback, while introducing undesirable complications in fuel management, would also have introduced many low-speed stability and control problems, which were considered to be unacceptable on an airplane designed to the Electra's specification. However, the "tuck" problem on the Electra is of far less concern than the "slipstream" problem — particularly since the Electra only enters the tuck regime at speeds close to its Design Diving Speed of 405 knots (Mach .711).*

Returning now to Figure 4b, it will be noted that the stick-force curve of an actual flight test on the Electra (see Figure 2) has been plotted on this diagram for comparison purposes (Curve #3). Based on Electra flight characteristics, this curve has been extended beyond the V_{NE} speed and up to V_D speed (note the dotted line). Curve #3, of course, includes the effect of the elevator downspring and the force link tab. Curve #2 on this diagram is a theoretical estimate and gives some idea of the effect of the downspring alone on the stick force characteristics of the Electra.

Both devices — the downspring and the force link tab — utilize the same basic principle of the operation of a trim tab in which, if the tab is moved up, for example, airflow acting on it will force the elevator down, and the control surface movement, in turn, will force the aircraft nose down. Trim tabs of course are used to relieve the pilot of work in maintaining the attitude and speed of an airplane. The example in Figures 7a, 7b, and 7c illustrates the principle involved (somewhat exaggerated) of trimming an airplane by means of the trim tab controls.

**Called* V_D *or* M_D*, this is the maximum speed for which the airplane is designed and is used only in design structural analysis. Operationally, the Electra should never exceed 364 knots (*V_{NE}*). However, it is interesting to note that the Electra has been flight tested up to a mach number of .724 and no compressibility effects were apparent to the pilots.*

In Figure 7 and in the following discussion, it is assumed that we are in steady flight conditions and that the stick force experienced by the pilot is directly proportional to the elevator hinge moment. Thus if there is zero elevator hinge moment, then the aircraft is trimmed and no effort is required by the pilot; and if there is an upward elevator hinge moment, then the pilot is having to push on the stick to force the elevators down.

As discussed earlier, we know that we want some means of increasing the push-force the pilot is exerting on the stick in Figure 7b. This is the same thing as increasing the up-elevator hinge moment. One way of achieving this is by adding an elevator downspring as shown and explained in Figures 8a and 8b. These two illustrations may be compared with Figures 7a and 7b respectively.

Compared to the force link tabs, the downspring is a simple device, but there are drawbacks to using this method alone for achieving the objective. Referring back to Figure 4b: curve #2 gives some indication of the effect of the present downspring installation on the Electra. It will be noticed that the force link tabs are about five times more effective than the downspring in this instance, where the airplane was trimmed initially at about 300 knots. An exceptionally large downspring would be required to equal the performance of the force link tabs and, quite apart from the increase in size and weight, the control forces on the ground and during takeoff would be prohibitive.

On the other hand, the force link tab cannot entirely replace the downspring. Figure 9 shows a similar set of curves to Figure 4b, except that the airplane in this instance was trimmed initially at about 180 knots. It will be noted that the downspring is now comparatively more effective than in Figure 4b. Thus it is apparent that, while both devices achieve similar results, they actually complement each other, particularly when considering both low and high-speed operational conditions.

THE FORCE LINK TAB In order to simplify the explanation of the theory of operation of the force link tab we shall consider it first of all as a unit separated from the trim tab controls. As shown in Figure 10, it can be represented as a tab which is spring loaded in the up position. Its operation is similar to a device called a springy tab, which was used to solve the tuck problem of World War 2 fighters with performances in the transonic range.

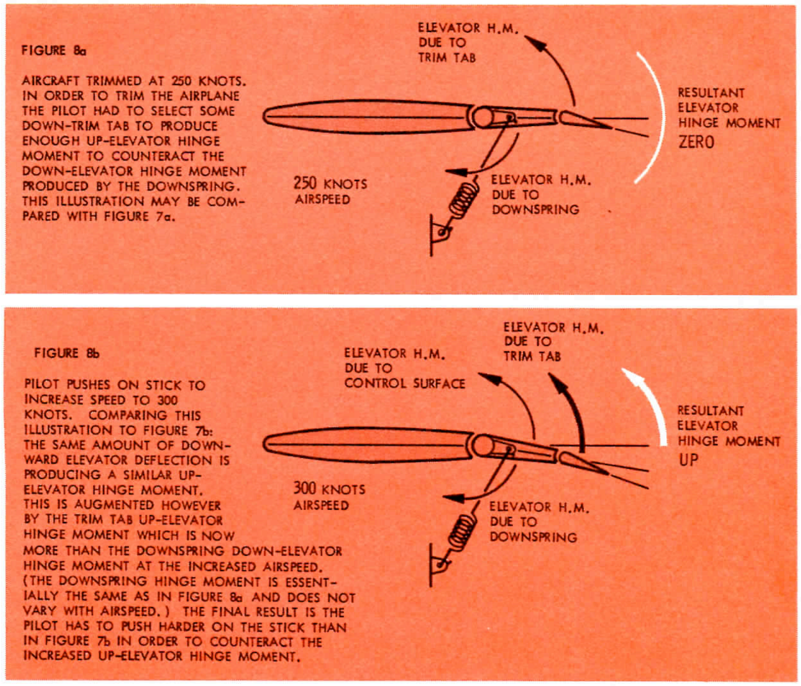


FIGURE 8a

AIRCRAFT TRIMMED AT 250 KNOTS. IN ORDER TO TRIM THE AIRPLANE THE PILOT HAD TO SELECT SOME DOWN-TRIM TAB TO PRODUCE ENOUGH UP-ELEVATOR HINGE MOMENT TO COUNTERACT THE DOWN-ELEVATOR HINGE MOMENT PRODUCED BY THE DOWNSPRING. THIS ILLUSTRATION MAY BE COMPARED WITH FIGURE 7a.

FIGURE 8b

PILOT PUSHES ON STICK TO INCREASE SPEED TO 300 KNOTS. COMPARING THIS ILLUSTRATION TO FIGURE 7b: THE SAME AMOUNT OF DOWNWARD ELEVATOR DEFLECTION IS PRODUCING A SIMILAR UP-ELEVATOR HINGE MOMENT. THIS IS AUGMENTED HOWEVER BY THE TRIM TAB UP-ELEVATOR HINGE MOMENT WHICH IS NOW MORE THAN THE DOWNSPRING DOWN-ELEVATOR HINGE MOMENT AT THE INCREASED AIRSPEED. (THE DOWNSPRING HINGE MOMENT IS ESSENTIALLY THE SAME AS IN FIGURE 8a AND DOES NOT VARY WITH AIRSPEED.) THE FINAL RESULT IS THE PILOT HAS TO PUSH HARDER ON THE STICK THAN IN FIGURE 7b IN ORDER TO COUNTERACT THE INCREASED UP-ELEVATOR HINGE MOMENT.

Figure 8 Effect of a Downspring on the Elevator Hinge Moment

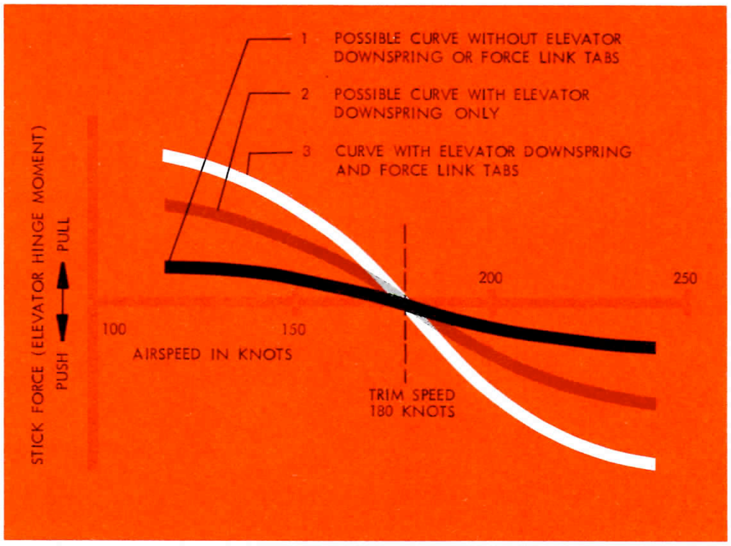
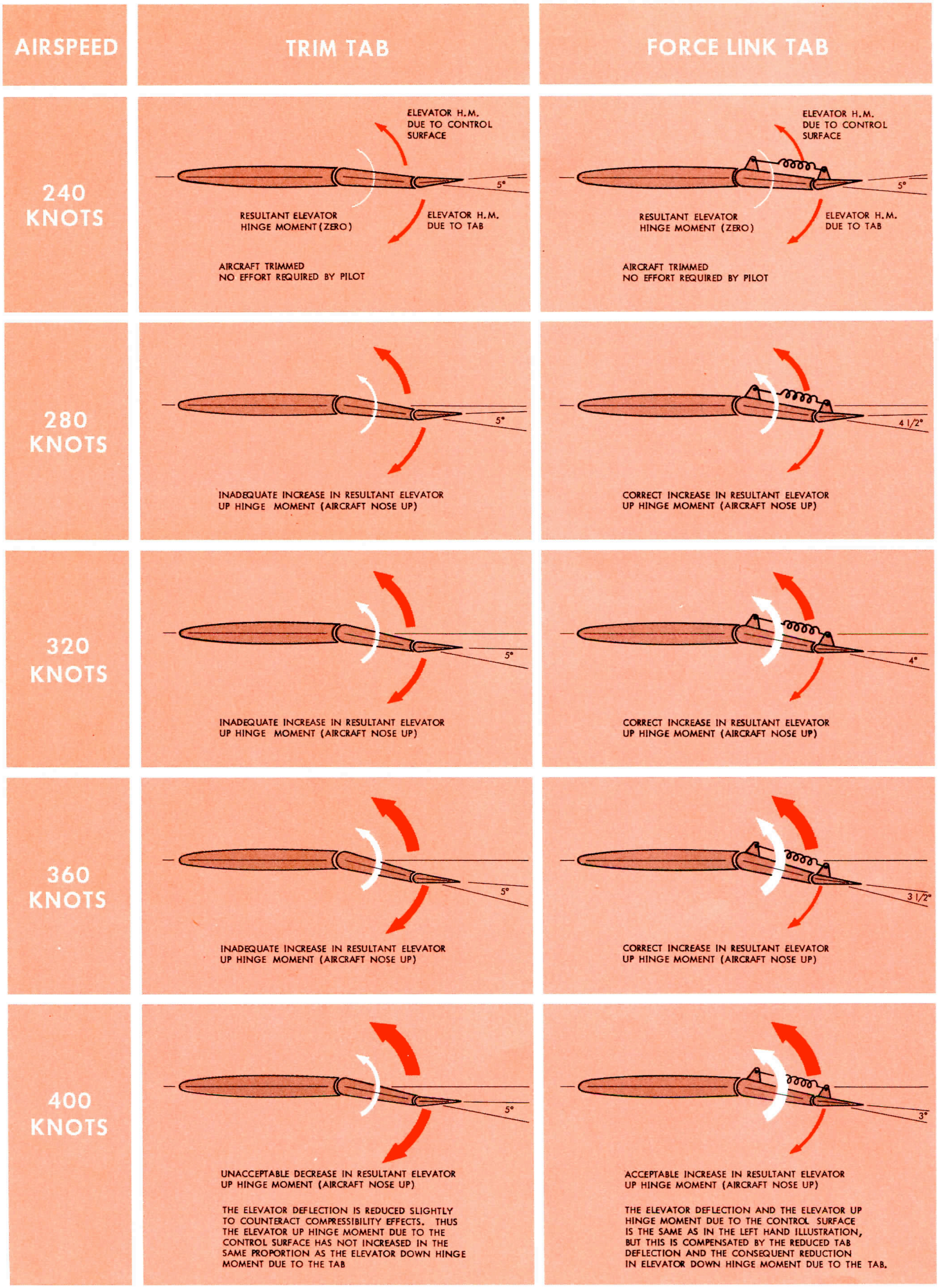


Figure 9 Graph Showing Stick-Force Characteristics When Initially Trimmed at 180 knots — Based on Electra Performance

In Figure 10 the operation of the force link tab is compared to the operation of a trim tab under similar conditions. The resultant elevator hinge moments of the trim tab and force link tab at various speeds may be compared with the similar results shown on curves #1 and #3 respectively of Figure 4b, although the initial trimmed speed (240 knots) is lower and curve #3 also includes the effect of the downspring. As previously stated, the angles of tab movement and speeds are not necessarily factual and only serve to further the discussion.

(Continued on page 11)



AIRSPEED	TRIM TAB	FORCE LINK TAB
240 KNOTS	AIRCRAFT TRIMMED NO EFFORT REQUIRED BY PILOT	AIRCRAFT TRIMMED NO EFFORT REQUIRED BY PILOT
280 KNOTS	INADEQUATE INCREASE IN RESULTANT ELEVATOR UP HINGE MOMENT (AIRCRAFT NOSE UP)	CORRECT INCREASE IN RESULTANT ELEVATOR UP HINGE MOMENT (AIRCRAFT NOSE UP)
320 KNOTS	INADEQUATE INCREASE IN RESULTANT ELEVATOR UP HINGE MOMENT (AIRCRAFT NOSE UP)	CORRECT INCREASE IN RESULTANT ELEVATOR UP HINGE MOMENT (AIRCRAFT NOSE UP)
360 KNOTS	INADEQUATE INCREASE IN RESULTANT ELEVATOR UP HINGE MOMENT (AIRCRAFT NOSE UP)	CORRECT INCREASE IN RESULTANT ELEVATOR UP HINGE MOMENT (AIRCRAFT NOSE UP)
400 KNOTS	UNACCEPTABLE DECREASE IN RESULTANT ELEVATOR UP HINGE MOMENT (AIRCRAFT NOSE UP) THE ELEVATOR DEFLECTION IS REDUCED SLIGHTLY TO COUNTERACT COMPRESSIBILITY EFFECTS. THUS THE ELEVATOR UP HINGE MOMENT DUE TO THE CONTROL SURFACE HAS NOT INCREASED IN THE SAME PROPORTION AS THE ELEVATOR DOWN HINGE MOMENT DUE TO THE TAB	ACCEPTABLE INCREASE IN RESULTANT ELEVATOR UP HINGE MOMENT (AIRCRAFT NOSE UP) THE ELEVATOR DEFLECTION AND THE ELEVATOR UP HINGE MOMENT DUE TO THE CONTROL SURFACE IS THE SAME AS IN THE LEFT HAND ILLUSTRATION, BUT THIS IS COMPENSATED BY THE REDUCED TAB DEFLECTION AND THE CONSEQUENT REDUCTION IN ELEVATOR DOWN HINGE MOMENT DUE TO THE TAB.

Figure 10 Effect of a Force Link Tab Compared with a Fixed Trim Tab at Different Airspeeds to Show Force Link Tab Principle of Operation

Referring to the Trim Tab column in Figure 10: at 240 knots the aircraft is trimmed and the up-elevator hinge moment is opposed by an equal down-elevator hinge moment produced by five degrees of trim tab. The resultant hinge moment is therefore zero and no effort is required by the pilot. From 280 knots to 360 knots the resultant up-elevator hinge moment steadily increases (portrayed by size of arrows), but not enough to be representative of the conditions. At 400 knots the resultant up-elevator hinge moment actually decreases slightly as the aircraft enters the tuck regime, and the pilot has to relax the push-force on the stick.

It will be noted that throughout this sequence the five degrees of up trim tab gives a down-elevator hinge moment which increases with increase in airspeed. Comparing each illustration in the "Trim Tab" column with its counterpart in the "Force Link Tab" column, it will be noted that at 240 knots the conditions are the same with both tabs set at five degrees up. With increase in speed, however, the down elevator hinge moment from the force link tab remains the same, as the tab deflection is reduced by the increase in airloads. The resultant elevator hinge moment is therefore increased in an upwards direction with increase in airspeed and the pilot therefore experiences an increasing push force on the stick throughout the whole speed range, which is more representative of the conditions.

Although Figure 10 draws a comparison, the force link tab does not of course replace the trim tab or vice versa; both are required since they have different functions. A further complication exists: employing these two tab systems as separate entities would be sufficient for an airplane, such as a fighter, with a relatively stable center-of-gravity. An airliner though has a c.g. which varies widely according to the loading of the airplane, and it follows that the effect of the force link tab should vary to suit this variation in c.g. Since the position of the trim tab is also a function of the aircraft's c.g., we can simplify the whole arrangement by linking these two tabs to the same control linkage. It should also be pointed out at this stage that the force link tab has this additional advantage over an elevator downspring — that it can be easily varied to suit the airplane's c.g. position.

The interconnection of the elevator tab controls on the Electra is illustrated in Figure 11. The angular movements shown are for the static condition and do not take air loads into account.

As previously mentioned, the force link tab was designed primarily to improve the stick-free longitudinal stability throughout the speed range, but it also has another function. The trim tab/force tab interconnecting linkage is designed so that as the trim tab moves from the full-up towards the fully down position (nose up), the force tab spring compression is reduced. Basic airplane stability increases with forward c.g. travel and the effectiveness of the force link tab is therefore progressively lessened with forward c.g. movement. Further movement of the trim tab down relaxes the force tab spring compression until the cartridge is bottomed. The tab moves past the faired position, and it then functions as another rigid trim tab (see Figure 11). This additional trim effectiveness is particularly useful during approach and landing maneuvers when the force link tab will ordinarily vary between zero and 6 degrees down and the trim tab will vary between 21 and 25 degrees down.

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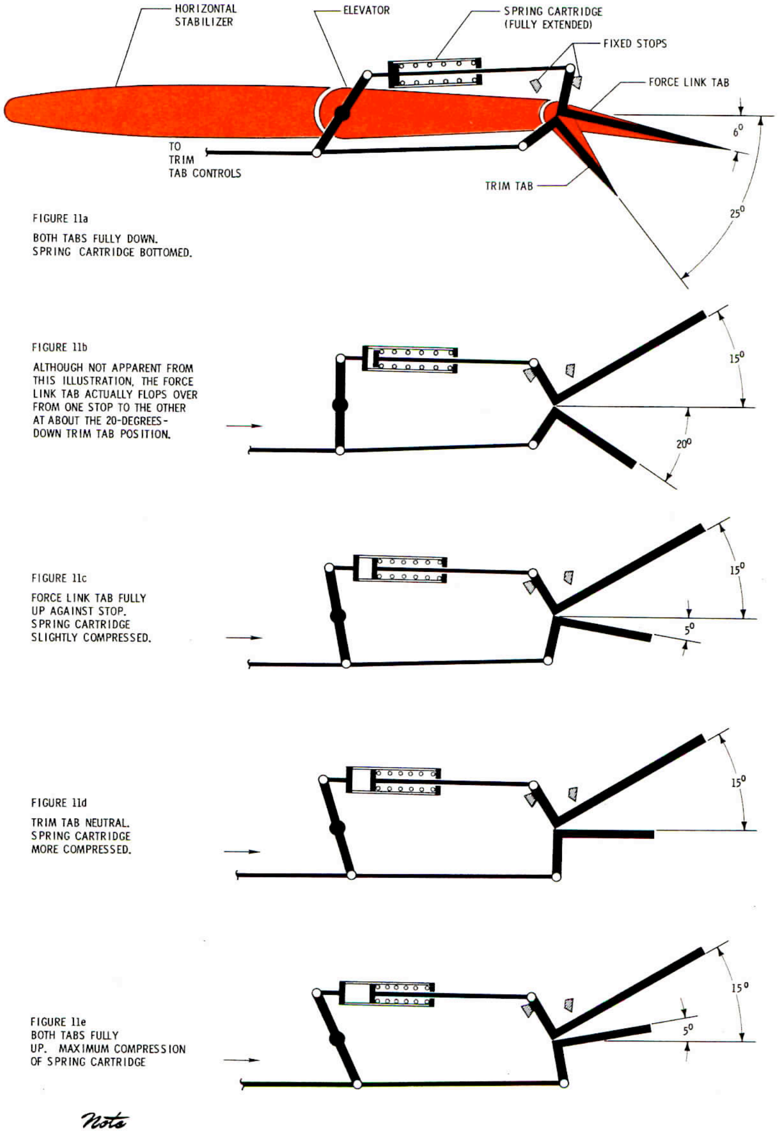

FIGURE 11a
BOTH TABS FULLY DOWN.
SPRING CARTRIDGE BOTTOMED.

FIGURE 11b
ALTHOUGH NOT APPARENT FROM THIS ILLUSTRATION, THE FORCE LINK TAB ACTUALLY FLOPS OVER FROM ONE STOP TO THE OTHER AT ABOUT THE 20-DEGREES-DOWN TRIM TAB POSITION.

FIGURE 11c
FORCE LINK TAB FULLY UP AGAINST STOP.
SPRING CARTRIDGE SLIGHTLY COMPRESSED.

FIGURE 11d
TRIM TAB NEUTRAL.
SPRING CARTRIDGE MORE COMPRESSED.

FIGURE 11e
BOTH TABS FULLY UP. MAXIMUM COMPRESSION OF SPRING CARTRIDGE

Note
FIGURES 11a THROUGH 11e SHOW MOVEMENT OF TRIM TAB CONTROL FROM FULLY DOWN (NOSE UP) TO FULLY UP (NOSE DOWN).

Figure 11 Basic Arrangement of Trim Tab and Force Link Tab Interconnecting Linkage

In conclusion, Figures 12a, b, and c demonstrate schematically the interaction of the trim tab and force link tab under flight conditions in the upper speed range. Aerodynamically, the force tab position, for any one trim tab position, is mainly a function of the airspeed and slightly affected by the elevator position. For simplicity, however, the following example assumes that the elevator position stays constant and the spring input to the force tab also remains constant. Again it should be noted that the angles and loads given are hypothetical and not necessarily factual.

Figure 12a shows the relative positions of the elevator tabs with the airplane initially trimmed (hands off) at 300 knots.

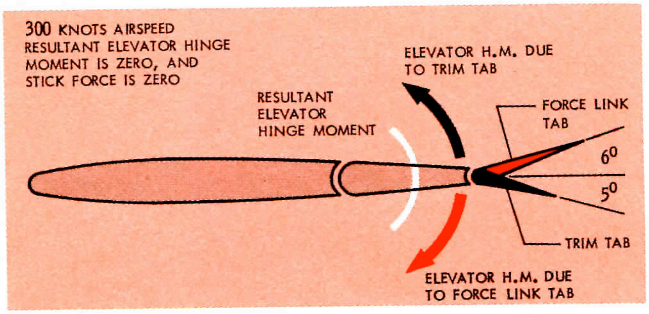

Figure 12a. Interaction of the Trim Tab and Force Link Tab in Flight — Aircraft Trimmed at 300 knots

It will be noted that the trim tab is five degrees down, which is the same setting shown in Figure 11c. The force link tab, however, is not hard up against the stop (as shown in the static condition in Figure 11c); it has assumed an intermediate position of six degrees up between the two stops, where the spring load counterbalances the aerodynamic load at 300 knots. Pilot stick force is a function of the elevator hinge moment and, since the aircraft is trimmed, the elevator hinge moment in Figure 12a is zero, and therefore the stick force is zero. It will also be noted that, ignoring other factors, the zero elevator hinge moment is the resultant of the hinge moments of the trim tab and the force link tab, which, we have assumed counterbalance one another at these particular angular settings.

With the airplane still trimmed at 300 knots, the pilot should, in order to reduce speed, *pull* on the stick to lift up the nose of the airplane. Figure 12b shows schematically how, at a lower speed of 250 knots, the down angle of the trim tab is still five degrees, but the up angle of the force link tab has increased to eight degrees due to a lowering of the aerodynamic force. The clockwise elevator hinge moment due to the force link tab is now greater than the reduced counter-clockwise hinge moment generated by the trim tab. The resultant elevator hinge moment from these two forces is therefore clockwise, forcing the elevator down, and the aircraft's nose down. The pilot must therefore *pull* on the stick to keep the nose up and maintain the lower speed of 250 knots.

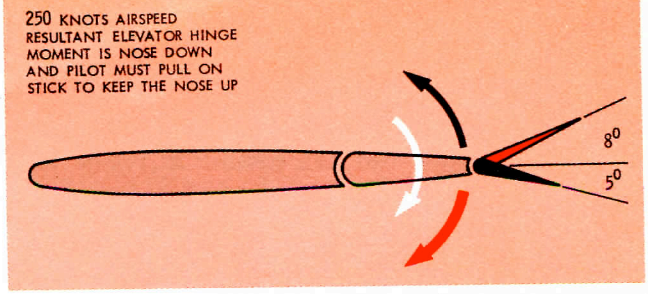

Figure 12b Airspeed Decreased to 250 knots

Conversely, in Figure 12c, at a higher speed of 350 knots, the angle of the force link tab has decreased to four degrees due to the greater aerodynamic force. The clockwise elevator hinge moment due to the force link tab is now less than the increased counter-clockwise trim tab hinge moment. The resultant elevator hinge moment is now counter-clockwise, forcing the elevator up, and the aircraft's nose up. The pilot must therefore *push* on the stick to maintain the higher speed.

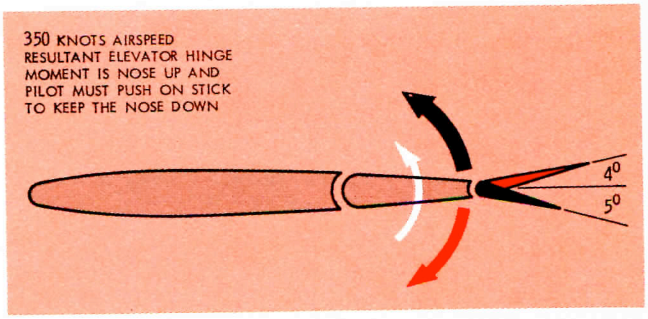

Figure 12c Airspeed Increased to 350 knots

The above effect can be summarized by saying that the force link tab produces essentially constant elevator hinge moment with airspeed (actually it varies slightly with force tab position due to mechanical linkage), while the hinge moment produced by the trim tab varies directly with the aerodynamic force. The difference in the two hinge moments gives the pilot positive stick feel.

The Force Link Tab Linkage and its interconnection with the trim tab is shown in Figures 13, 14, 15, and 16. Although operated by movement of the trim tab, the force tab linkage is almost independent of the trim tab control system, its only connection being with the trim tab itself by means of a single push-pull rod. As a fail-safe provision against flutter occurring from a disconnected tab, dual push-pull rods connect the force link tab to the teeter-totter balance and the trim tab to its actuator. In these instances either of the dual push-pull rods is capable of carrying the load.

Figure 13 View of Elevator Showing Force Link Tab Control Mechanism

The two extreme positions of the force tab linkage are shown schematically on Figures 15a and 15g and these diagrams may be compared with Figures 11a and 11e respectively. It will be noted that contact of the aft counterweight of the teeter-totter balance with the upper and lower surfaces of the elevator limits the full-down and full-up travel of the force tab itself, and corresponds to the "stops" shown in Figure 11.

There are actually two spring cartridges in the linkage of each force tab. The program spring cartridge on Figures 14 and 15 is the main one, and corresponds essentially to the spring on Figure 11. The other spring is called the roll-off spring cartridge and it remains in a slightly varying pre-loaded condition during trim control operation, and opposes the effect of the program spring only slightly, due to the low leverage angle on the inboard bellcrank. It has least effect in the tab up position (high-speed range) when the roll-off spring cable contacts and fulcrums about the cable stop.

The roll-off spring cartridge improves the force tab characteristics in high-speed flight, but is designed primarily to reduce the pilot forces required to move the flight station tab control wheels. It also eliminates a great deal of the backlash in the linkages, particularly when the program spring cartridge is bottomed and the force link tab is in process of transition from its role as a springy tab to that of a trim tab.

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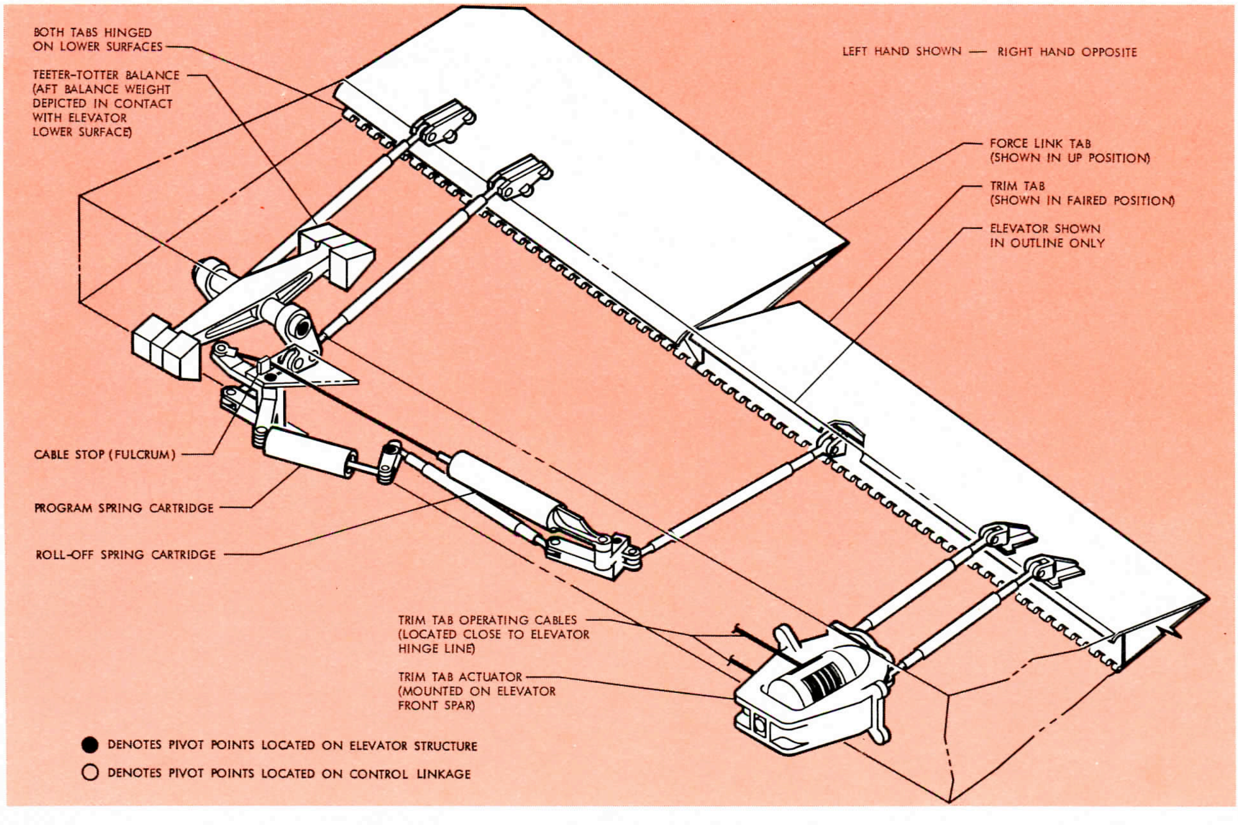
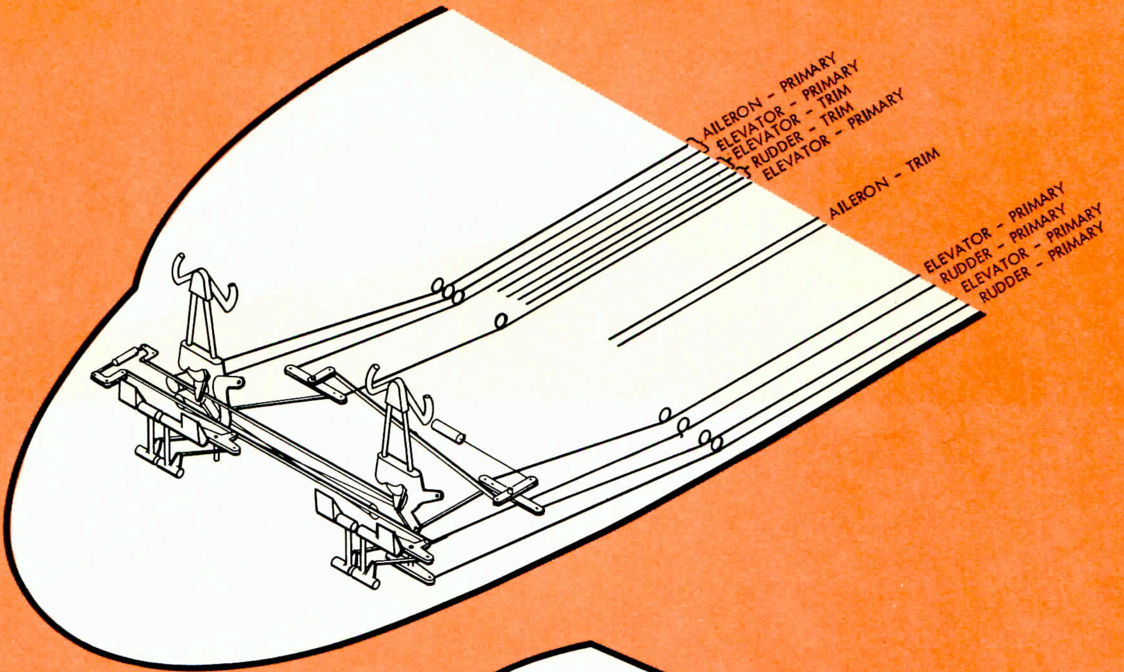


Figure 14 Schematic Showing Trim Tab/Force Link Tab Control Linkage


AILERON - PRIMARY
ELEVATOR - PRIMARY
ELEVATOR - TRIM
RUDDER - TRIM
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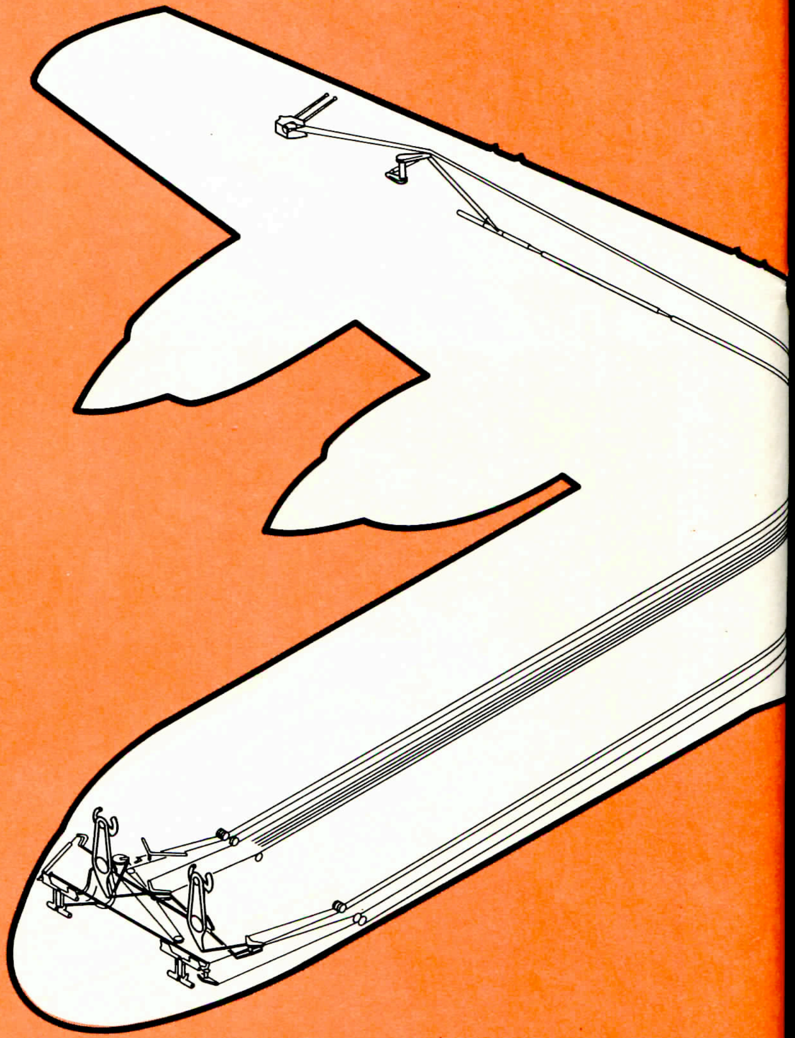


General Arrangement of
Electra Flight Controls

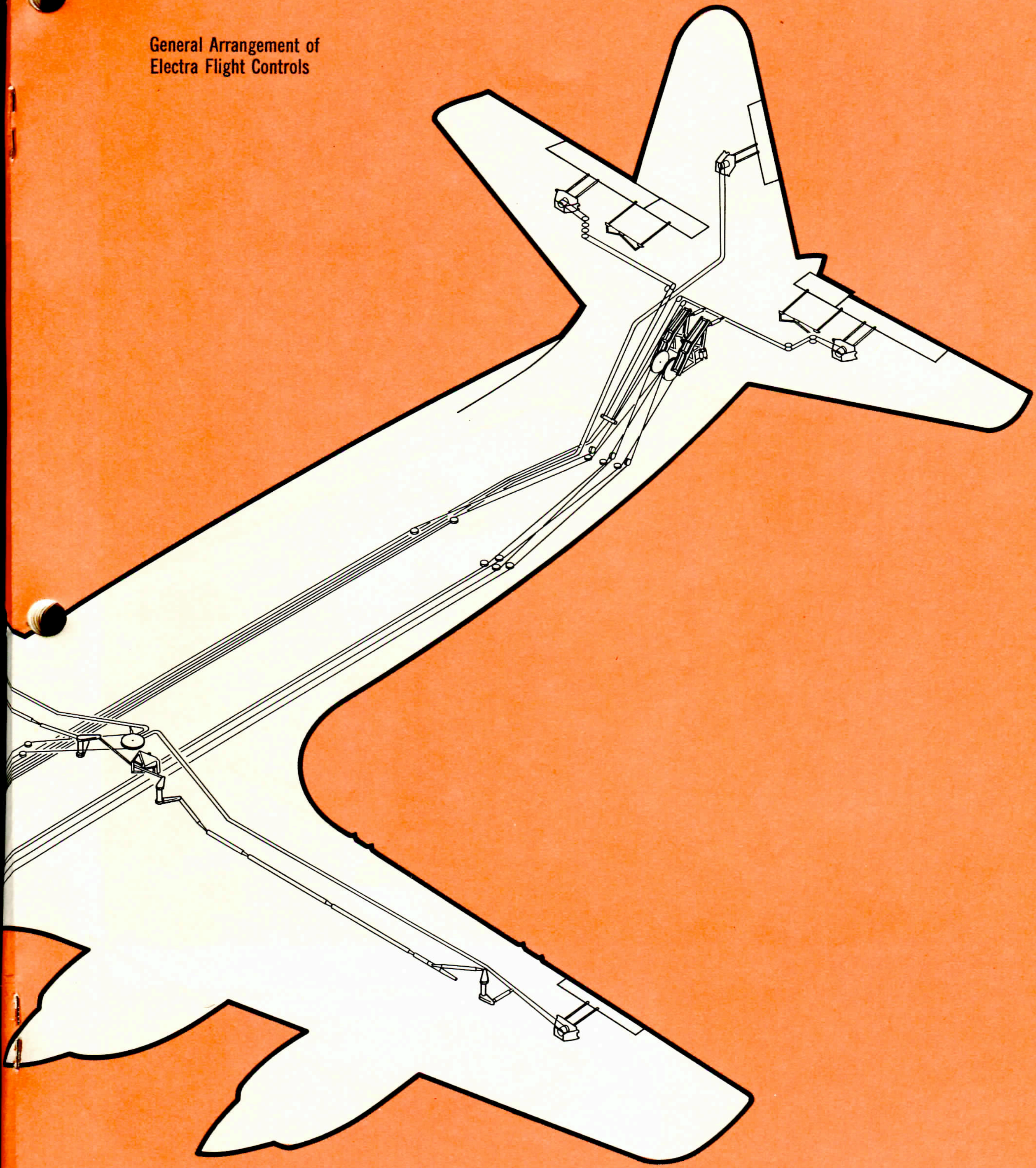


Figure 15 Revised Force Link Tab Rigging Procedure and Schematics Showing Full Up and Down Positions of Force Link Tab Control Linkage (Figures 15a and 15g)

FORCE LINK TAB RIGGING PROCEDURE

The following is an alternative rigging procedure to that given in the Electra Maintenance Manual. It was approved at the time of publication, but reference should be made to any applicable Electra Service Information Letter for changes which may affect this procedure. Refer to the Electra Maintenance Manual (Sections 27-4-5 through 27-4-8) for rigging of the elevator trim tab controls.

It is preferable and easier to check the force link tab rigging when the elevators are removed from the aircraft. Each elevator trim tab can then be operated by pulling the trim tab operating cables at each trim tab actuator.

If the elevators are installed, the controls should be moved to the elevator UP position with the boost ON (see Note 1). The control columns should be secured or lashed in this position and the hydraulic power switched OFF. Suitable warning placards should be placed on the flight station elevator and elevator trim controls to prevent movement of them by persons not concerned with the rigging. It should be particularly noted that, apart from the danger of injuring personnel, movement of the trim tab flight station control wheels when rig pins are installed in the force tab linkages can impose high stresses on the trim tabs.

NOTE 1.

Rigging cannot be accomplished or checked on the aircraft with the elevators in the down position. At this control setting the front counterweight of each teeter-totter balance can contact the stabilizer structure when the tab controls are moved towards up, and the full movement of the force link tab is therefore restricted. Another consideration is that maximum accessibility to the force tab linkages can be obtained when the elevators are selected to full up with boost on. (Note that elevator up travel is reduced with boost off.)

NOTE 2.

The spring cartridges (E and G) are loaded to varying degrees at certain rigging positions. Follow the pertinent instruction below (steps 2, 3, 7, or 8) for safe cartridge removal or installation.

NOTE 3.

Spring Cartridge E (P/N 834802) may be adjusted at overhaul by the addition of shims (P/N 830866-1). A maximum of 7 shims may be distributed between both ends of the spring (see Figure 15f) to obtain the maximum starting load as called out on drawing #834802, or to satisfy the tab hinge moment requirement in step 10 below. If this maximum number of 7 shims does not restore the spring cartridge to the minimum starting load, a new spring should be installed.

CHECK/ADJUST FORCE LINK TAB RIGGING AS FOLLOWS:

1. a. Operate elevator trim tab to the fully down position and check items i through vii as listed below and on Figure 15a.
   - i. Install a rig pin in bellcrank assembly B. It is permissible to move the controls slightly so that the rig pin is a sliding fit.
   - ii. Install a rig pin in bellcrank assembly D.
   - iii. Install a rig pin in bellcrank assembly F.
   - iv. Check that piston in cartridge E is bottomed.
   - v. Check that piston in Cartridge G is visible in the inboard witness hole of the two holes about one inch apart.
   - vi. Check that aft counterweight of teeter-totter balance is contacting the elevator upper surface.
   - vii. Check that trim tab is 25 degrees down (4.34 plus or minus 0.12 in. measured at outboard end of trim tab trailing edge).

   b. If items i through vii on Figure 15a check out satisfactorily, remove the rig pins from bellcranks B, D, and F and continue with steps 9, 10 and 11 below.

   c. If items i through vii on Figure 15a do *not* check out satisfactorily; either make any minor adjustment that is necessary with caution (see Note 2 above), and continue with steps 9, 10, and 11 after removal of the rig pins; or remove the rig pins from bellcranks B, D, and F and continue with steps 2 through 11 below. Steps 2 through 11 detail a rigging sequence which safeguards the operator from any preloaded linkages by first disconnecting the spring cartridges.

2. DISCONNECT OR REMOVE SPRING CARTRIDGE G AS FOLLOWS:
   a. With the elevator trim tab in the down position, insert a 1/4-inch diameter bolt in the outboard witness hole of the cartridge. If necessary, place adhesive tape over the bolt head to hold it in position.
   b. Operate trim tab to up so that the piston (spring retainer) of cartridge G rests on the bolt and the cartridge cable is slack.
   c. Disconnect the cartridge cable from spring cartridge G, or disconnect and remove spring cartridge G completely.

3. DISCONNECT OR REMOVE SPRING CARTRIDGE E AS FOLLOWS:
   a. Operate elevator trim tab towards the fully down position until a rig pin can be easily installed in bellcrank assembly B.
   b. Ensure that spring cartridge E is bottomed (see inset on Figure 15a). Adjust the cartridge if necessary, and disconnect it or remove it completely.

4. Check that trim tab is 25 degrees down (4.34 plus or minus 0.12 in.) from the tab faired position—measured at the outboard end of the trim tab. If necessary, disconnect push rod A, operate trim tab to 25 degrees down position, and adjust and reconnect push rod A.

5. Adjust push rod C if necessary and insert rig pin into bellcrank assembly D.

6. Insert rig pin into bellcrank assembly F and check that the aft counterweight of the teeter-totter balance is against the elevator upper surface. Adjust push rod H as necessary.

7. INSTALL OR RE-CONNECT SPRING CARTRIDGE E AS FOLLOWS:
   a. With the elevator trim tab in the fully down position and the rig pins installed in bellcranks B, D, and F, adjust spring cartridge E as necessary and re-install.
   b. After installation, check that spring cartridge E is still bottomed (see inset on Figure 15a).
   c. Remove rig pins from bellcranks B, D, and F.

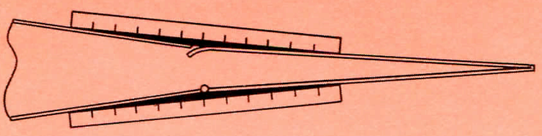
8. INSTALL OR RE-CONNECT SPRING CARTRIDGE G AS FOLLOWS:
   a. Operate elevator trim tab to the up position.
   b. Install spring cartridge G or reconnect cable to spring cartridge G.
   c. Operate elevator trim tab to the fully down position and remove the bolt from the outboard witness hole of spring cartridge G (if previously placed there in step 2 above).
   d. Check that the piston of cartridge G is visible in the inboard witness hole of the two holes about one inch apart (see inset on Figure 15a). Adjust cartridge cable as necessary.
   e. Operate elevator trim tab to the fully up position (0.87 plus or minus 0.12 in. measured at outboard end of trim tab trailing edge) and check that the piston of cartridge G is visible in the outboard witness hole (see inset on Figure 15g).

9. CHECK FORCE LINK TAB RANGE OF MOVEMENT AS FOLLOWS (SEE FIGURE 15b):
   a. Operate elevator trim tab to about the 17 degrees down position (approx. 3.0 in. down from the trim tab faired position). It should now be possible to move the force link tab easily by hand, although it will be slightly spring-loaded in the up position.
   b. Determine the faired position of the force link tab. A suitable method is shown in Figure 15c. Take an angular reading at this force tab setting.
   c. Ensure that the aft counterweight of the teeter-totter balance is against the elevator lower surface and check that the force link tab is 15 degrees (plus or minus one degree) up from the faired position. Adjust push rods J and K as necessary.
   d. Move the force link tab by hand to the down position. Ensure that the aft counterweight of the teeter-totter balance is against the elevator upper surface and check that the force link tab is 6 degrees (plus or minus one degree) down from the faired position.

10. CHECK FORCE LINK TAB HINGE MOMENT AS FOLLOWS (SEE FIGURE 15d):
    a. Operate elevator trim tab to the faired position.
    b. Make up a suitable device so that a spring scale can be attached at the trailing edge of the force link tab. Figure 15e, for example, shows how a strong sling can be easily manufactured from some 2-inch adhesive cloth tape and some cord or thin rope.
    c. Using a spring scale and pulling perpendicularly to the chord of the force link tab, the force required to move the tab from the UP position to the FAIRED position should be 37 to 46 pounds. This represents a hinge moment of 582 in. lb. (plus or minus 10 percent).
    d. If the force link tab hinge moment is *not* within these limits, recheck steps 1 and 9 in this procedure. If steps 1 and 9 are satisfactory, remove and replace spring cartridge E as described in steps 3 and 7 (see Note 3 above). After cartridge replacement, carry out procedure beginning with step 1, although step 9 may be omitted at the operator's discretion, if checked previously.

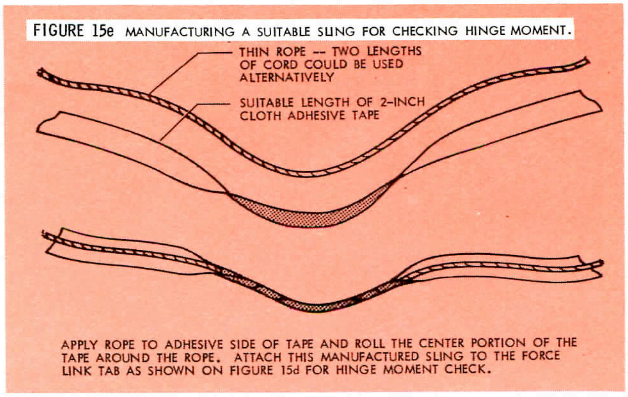
11. If steps 1, 9, and 10 are satisfactory, recheck all adjustments for safety and locking. Ensure that all rig pins are removed.

FIGURE 15c DETERMINING FORCE LINK TAB FAIRED POSITION

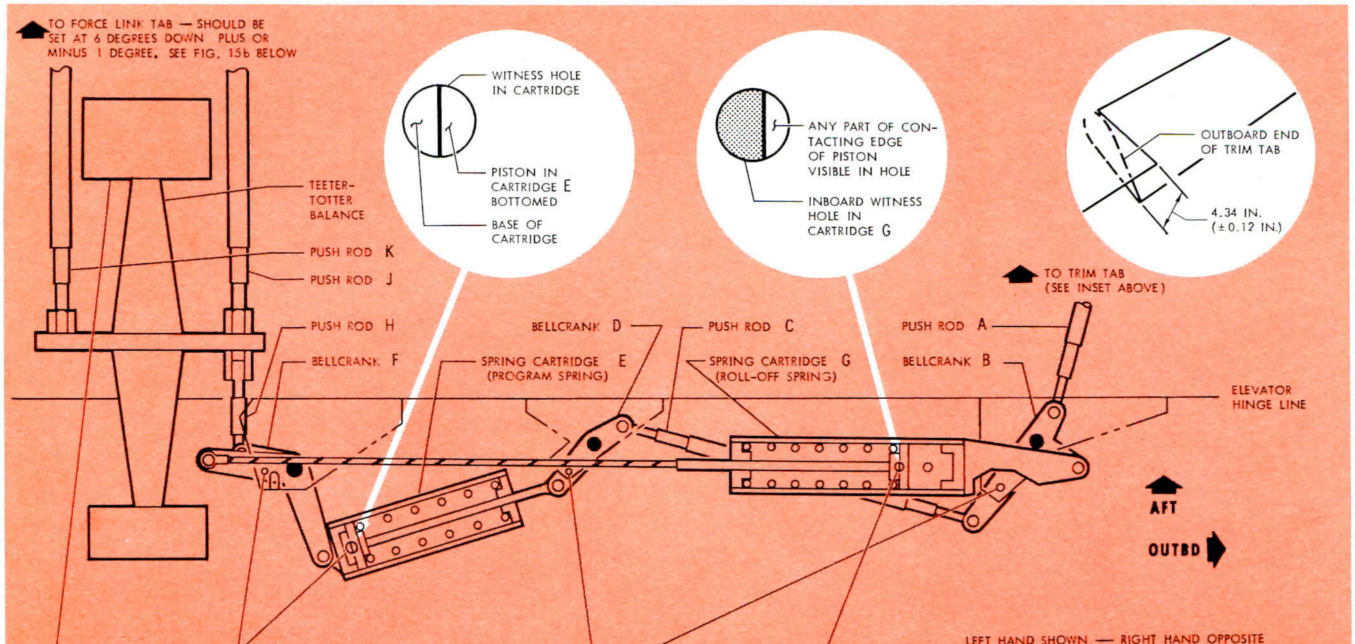


NOTE THAT, UNLIKE THE TRIM TAB, THE FORCE LINK TAB DOES NOT FOLLOW THE GENERAL AIRFOIL SECTION OF THE STABILIZER AND ELEVATOR. THE FAIRED POSITION OF THE FORCE LINK TAB (POSITION 'A' ON FIGURE 15B) MAY BE DETERMINED BY APPLYING A 12-INCH STRAIGHT EDGE TO THE UPPER AND LOWER SURFACES AS SHOWN, AND VISUALLY CHECKING THAT THE GAPS (FILLED-IN IN BLACK) ARE EQUAL.

FIGURE 15e MANUFACTURING A SUITABLE SLING FOR CHECKING HINGE MOMENT.



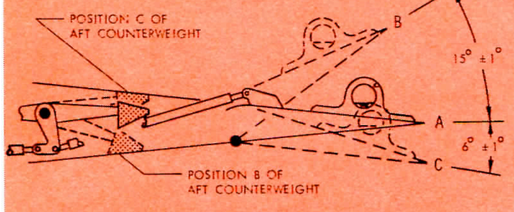
APPLY ROPE TO ADHESIVE SIDE OF TAPE AND ROLL THE CENTER PORTION OF THE TAPE AROUND THE ROPE. ATTACH THIS MANUFACTURED SLING TO THE FORCE LINK TAB AS SHOWN ON FIGURE 15d FOR HINGE MOMENT CHECK.



i RIG PIN INSTALLED IN BELLCRANK B
ii RIG PIN INSTALLED IN BELLCRANK D
iii RIG PIN INSTALLED IN BELLCRANK F
iv PISTON IN CARTRIDGE E BOTTOMED - SEE INSET
v PISTON IN CARTRIDGE G VISIBLE IN INBOARD WITNESS HOLE - SEE INSET
vi AFT COUNTERWEIGHT CONTACTING ELEVATOR UPPER SURFACE
vii TRIM TAB 25 DEGREES DOWN (4.34 PLUS OR MINUS 0.12 IN.)-SEE INSET

FIGURE 15a POSITION OF FORCE LINK TAB MECHANISM WHEN TRIM TAB IS FULLY DOWN 25 DEGREES

FIGURE 15b FORCE LINK TAB ANGULAR MOVEMENT

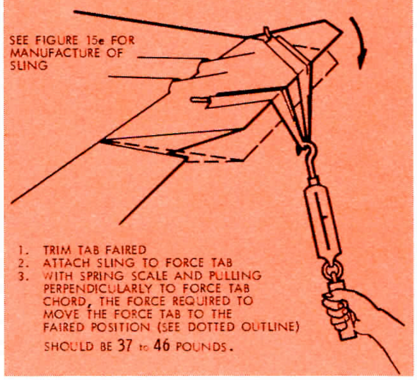


USING A SUITABLE DEVICE, SUCH AS A PROTRACTOR FROM A COMBINATION SET, MEASURE:

1. ANGLE AT POSITION A WITH FORCE LINK TAB FAIRED (SEE FIGURE 15d)
2. ANGLE AT POSITION B WITH AFT COUNTERWEIGHT CONTACTING LOWER SURFACE OF ELEVATOR
3. ANGLE AT POSITION C WITH AFT COUNTERWEIGHT CONTACTING UPPER SURFACE OF ELEVATOR

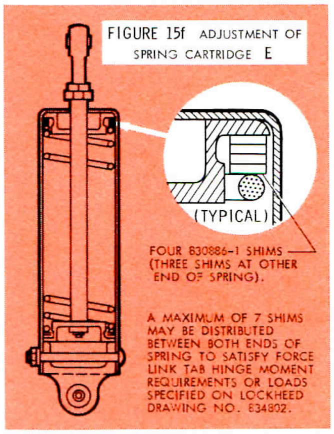
FORCE TAB UP MOVEMENT (B MINUS A) SHOULD BE 15° ±1°.
FORCE TAB DOWN MOVEMENT (C MINUS A) SHOULD BE 6° ±1°.

FIGURE 15d FORCE LINK TAB HINGE MOMENT CHECK



1. TRIM TAB FAIRED
2. ATTACH SLING TO FORCE TAB
3. WITH SPRING SCALE AND PULLING PERPENDICULARLY TO FORCE TAB CHORD, THE FORCE REQUIRED TO MOVE THE FORCE TAB TO THE FAIRED POSITION (SEE DOTTED OUTLINE) SHOULD BE 37 to 46 POUNDS.

FIGURE 15f ADJUSTMENT OF SPRING CARTRIDGE E



FOUR 830886-1 SHIMS (THREE SHIMS AT OTHER END OF SPRING).

A MAXIMUM OF 7 SHIMS MAY BE DISTRIBUTED BETWEEN BOTH ENDS OF SPRING TO SATISFY FORCE LINK TAB HINGE MOMENT REQUIREMENTS OR LOADS SPECIFIED ON LOCKHEED DRAWING NO. 834802.

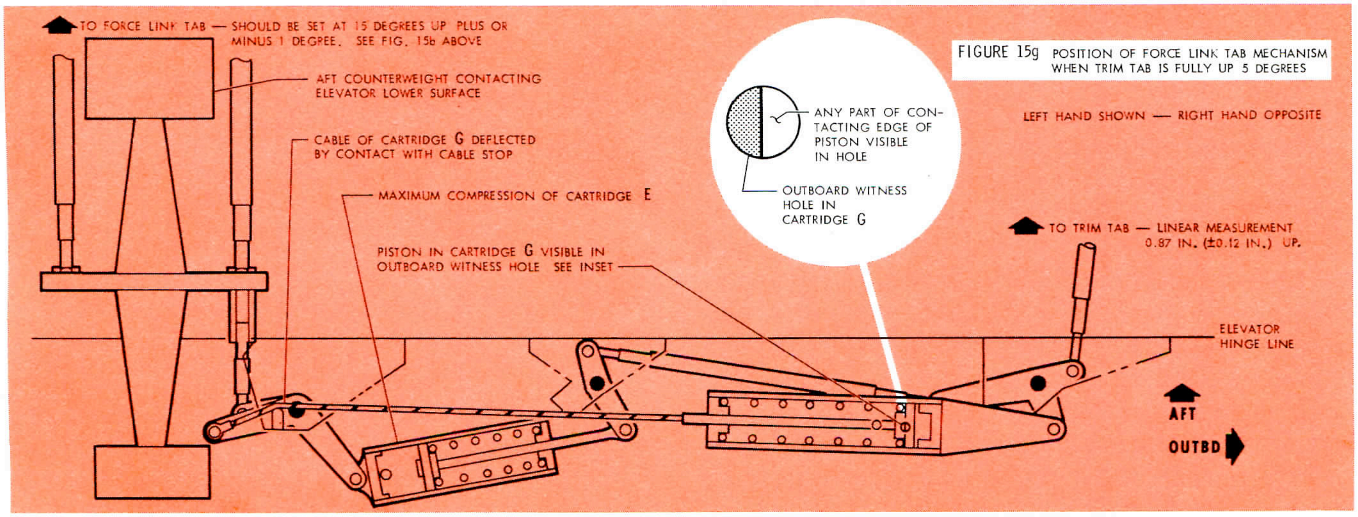


FIGURE 15g POSITION OF FORCE LINK TAB MECHANISM WHEN TRIM TAB IS FULLY UP 5 DEGREES

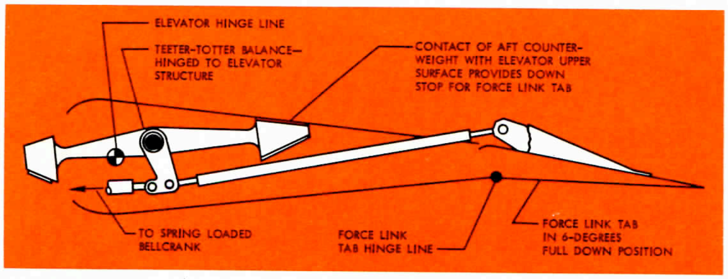


Figure 16 Section Through Elevator and Force Link Tab Showing Teeter-Totter Balance Weight

The Teeter-Totter Balance Weight is one item which has not been fully discussed. Its connection to the force link tab can best be seen in Figure 16. An engineer specializing in flutter analysis would say that this seesaw arrangement of mass balance provides the force link tab with 75 percent static balance and 125 percent dynamic balance. This sounds like a good trick and is worth a digression at this point to explain this statement more fully.

Flutter, and similar vibrations of an airplane in flight, can be induced by many outside agencies such as acceleration forces, changes in air flow with increased speed, air gusts, maneuvering loads, wing and stabilizer deflections, and so forth. Particular attention must be paid to the design of certain parts of the aircraft structure to prevent the occurrence of flutter, and this is especially true of the control surfaces. On these components, prevention of flutter is usually obtained by attaching weights to the surface itself, forward of the hinge line, so as to achieve a desired condition of balance or unbalance about the hinge axis. Flutter prevention is the primary consideration in the selection of the desired amount of weights, but it should perhaps be mentioned that other considerations are: the reduction of the surface hinge moment, the attainment of certain control characteristics (change of hinge moment under acceleration loads, for example), and of course the actual increase in the structural weight of the airplane.

In the case of primary control surfaces, we are usually only concerned with flutter of the surface relative to motion of the airplane as a whole. With some types of control surface *tabs* however the problem is more complex, and we also have to consider flutter of the tab while the primary control surface, to which it is attached, is moving. A fluttering elevator, for example, is considered as oscillating about its hinge line, which is fixed in relation to the aircraft structure. On the other hand, if we consider a free tab attached to the elevator (a tab connected by hinge only): when the tab is fluttering, the tab hinge could be fixed in relation to the airplane or it could be moving in an arc, depending upon whether the elevator is stationary or moving.

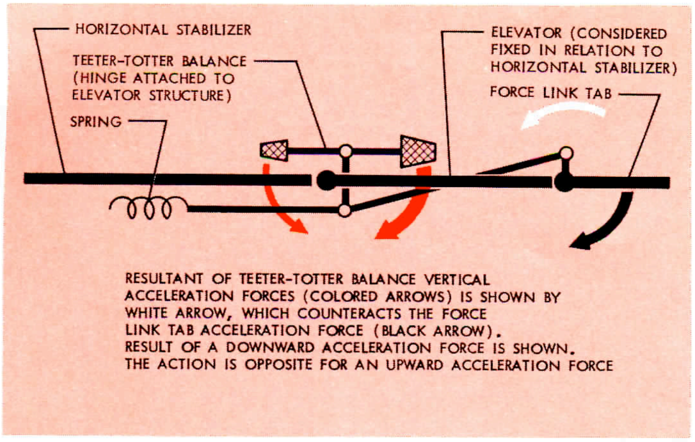
The adding of weights to the tab surface for the prevention of flutter in either of these instances is called static balancing for the stationary elevator case and dynamic balancing for the moving elevator case. The optimum amount of weight required in either instance is written as a percentage of the amount required to exactly balance the tab—either statically or dynamically.

Most types of control surface tabs do not usually require the addition of mass balance to prevent flutter, because of their control system design. For example, trim tabs commonly have irreversible control units located close to the tabs, and other tab systems often incorporate connecting linkage which is stiff and free from backlash. Because of their particular application, however, spring tabs cannot derive similar benefits from a stiff or rigid control system, and must be balanced to avoid flutter problems.

Considering a sudden movement of an Electra elevator about its hinge line, will give some idea of other factors involved in the balancing of spring tabs: the force link tab would initially have a tendency to lag (the associated spring would not oppose this tendency) and then, when the elevator movement was stopped, the force link tab would tend to overshoot and carry on moving. It should be noted that this relative movement of the force link tab about its hinge line would alternately assist and oppose the movement of the elevator, so that the elevator and tab also have to be considered in combination when determining flutter characteristics.

However, when considering spring tabs, a flutter analysis is undertaken to determine the optimum values for both static balancing and dynamic balancing. On some aircraft installations, similar to the force link tab installation, it is then possible to achieve a compromise and attach a suitable amount of mass balance directly to the tab so that both the static balance and the dynamic balance requirements are within acceptable limits. In other instances, particularly where the springy tab is large in relation to the elevator, such a compromise is difficult to achieve by this method. And where the percentage dynamic balance exceeds the percentage static balance — as in the case of the Electra — it is actually impossible. The Electra's apparently impossible optimum requirements of 75 percent static and 125 percent dynamic balance can, however, be met by the use of a device such as the teeter-totter balance.

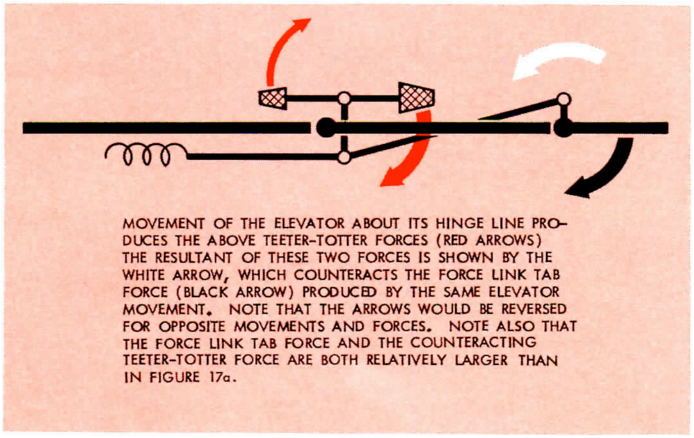
Figure 17a shows the action of the teeter-totter balance when the aircraft is subjected to a downward acceleration force. In this event, the stabilizer, elevator, and the force link tab would all be moving in



RESULTANT OF TEETER-TOTTER BALANCE VERTICAL ACCELERATION FORCES (COLORED ARROWS) IS SHOWN BY WHITE ARROW, WHICH COUNTERACTS THE FORCE LINK TAB ACCELERATION FORCE (BLACK ARROW). RESULT OF A DOWNWARD ACCELERATION FORCE IS SHOWN. THE ACTION IS OPPOSITE FOR AN UPWARD ACCELERATION FORCE

Figure 17a Action of Teeter-Totter Balance in Achieving Static Balance for the Force Link Tab

the same direction. Assuming the elevator remains stationary about its hinge line, the force link tab would tend to rotate clockwise about its hinge line — against the action of the spring. However, both weights of the teeter-totter would also be subjected to the downward acceleration force, and since the rear weight (right on the diagram) is the heavier of the two, there would be a resultant clockwise hinge moment about the teeter-totter hinge axis. This would be felt as a counterclockwise moment about the force tab hinge, opposing the hinge moment due to the force link tab.



MOVEMENT OF THE ELEVATOR ABOUT ITS HINGE LINE PRODUCES THE ABOVE TEETER-TOTTER FORCES (RED ARROWS) THE RESULTANT OF THESE TWO FORCES IS SHOWN BY THE WHITE ARROW, WHICH COUNTERACTS THE FORCE LINK TAB FORCE (BLACK ARROW) PRODUCED BY THE SAME ELEVATOR MOVEMENT. NOTE THAT THE ARROWS WOULD BE REVERSED FOR OPPOSITE MOVEMENTS AND FORCES. NOTE ALSO THAT THE FORCE LINK TAB FORCE AND THE COUNTERACTING TEETER-TOTTER FORCE ARE BOTH RELATIVELY LARGER THAN IN FIGURE 17a.

Figure 17b Action of Teeter-Totter Balance in Achieving Dynamic Balance for the Force Link Tab

Figure 17b shows the action of the teeter-totter balance when the elevator controls are moved so as to move the elevator up about its hinge axis. Any resultant movement up or down of the force link tab will be counteracted by the hinge moments of both weights of the teeter-totter balance as this device tends to rotate about its axis.

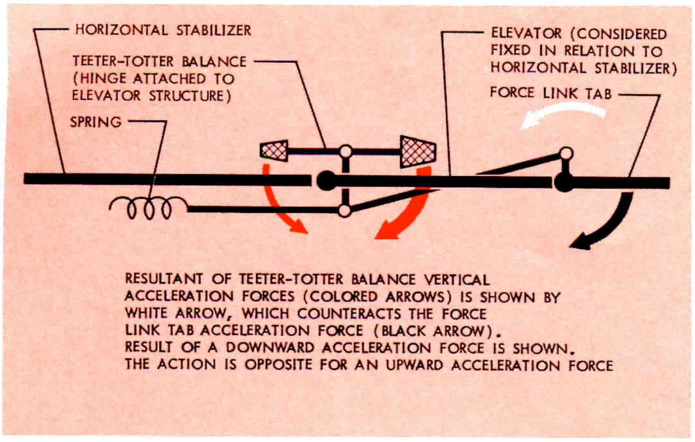
It should be noted in Figure 17b that the movement of the elevator would also result in a general movement of the stabilizer, elevator, and tab in a downward direction. However the resultant tab hinge moment from this cause would be counteracted in a similar way to the example in Figure 17a. In effect, movement of the primary control surface results in a combination of the above counter forces, but essentially the action of the teeter-totter balance can be summarized as follows: The 75 percent static balance is provided by the *difference* of the moments of the two balance weights, and the 125 percent dynamic balance is provided by the *sum* of the moments of the two balance weights.

It is also of interest to note that the force link tabs, being only 75 percent statically balanced, are slightly deflected by g forces on the airplane and the resulting aerodynamic moment on the elevators acts like a small increase in the static balance of the elevators, which is felt as less than ½ lb. per g at the stick.

Having discussed the force link tab at some length, this is perhaps an opportune time to emphasize the importance of correctly rigging this device. Reports from the field indicate that there have been several instances where vibration or buffeting in the elevator controls has been eliminated by re-rigging of the force link tab control linkages. The correct rigging procedure is summarized in Figure 15 and it includes some additional information not given in Section 27-4-9 of the Electra Maintenance Manual. This revised procedure will shortly be presented in an Electra Service Information Letter.

This is also a convenient point in this discussion to re-emphasize the importance of adhering to the recommended operating procedures contained in the Electra Crew-Operating Manual. Specifically, we would like to point out the setting of the elevator trim tabs prior to take-off (ten degrees nose-up, regardless of c.g. position), and the operation of the hydraulic pumps (all three should be operable and ON for take-off).

Electra Operating Information Letter number 18, dated 5 June 1961, reported an incident where elevator control difficulty was experienced during gear retraction after take-off. Tests carried out during the subsequent investigation determined that, with only one hydraulic pump operating, and with an initial trim tab setting of zero degrees instead of ten degrees nose-up, it was possible for stick forces to increase from 40 pounds prior to gear retraction to over 100 pounds during gear retraction. This is possibly an exceptional example, but serves to emphasize the importance of the "cockpit check." Such a build-up of elevator control forces during take-off could be disconcerting to say the least. *(Continued on next page)*



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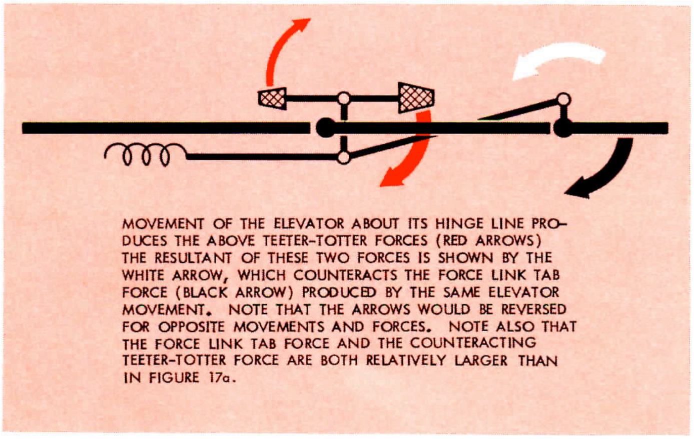

MOVEMENT OF THE ELEVATOR ABOUT ITS HINGE LINE PRODUCES THE ABOVE TEETER-TOTTER FORCES (RED ARROWS) THE RESULTANT OF THESE TWO FORCES IS SHOWN BY THE WHITE ARROW, WHICH COUNTERACTS THE FORCE LINK TAB FORCE (BLACK ARROW) PRODUCED BY THE SAME ELEVATOR MOVEMENT. NOTE THAT THE ARROWS WOULD BE REVERSED FOR OPPOSITE MOVEMENTS AND FORCES. NOTE ALSO THAT THE FORCE LINK TAB FORCE AND THE COUNTERACTING TEETER-TOTTER FORCE ARE BOTH RELATIVELY LARGER THAN IN FIGURE 17a.

Figure 17b Action of Teeter-Totter Balance in Achieving Dynamic Balance for the Force Link Tab

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AILERON CONTROL SYSTEM

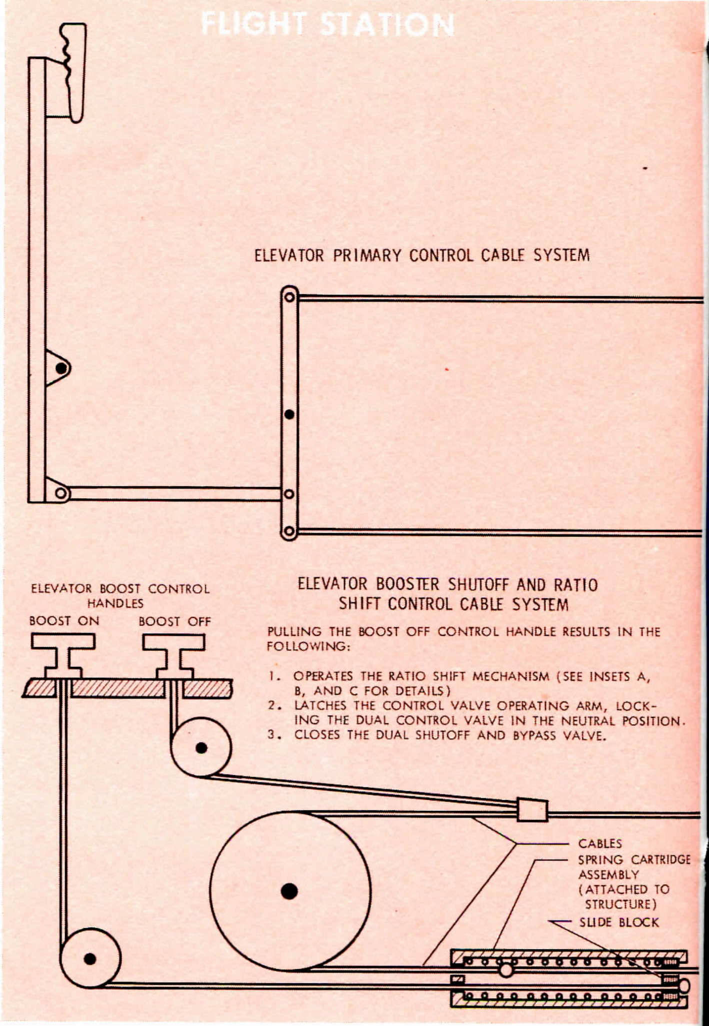
As described in Part One of this article, the flight control systems—elevator, aileron, and rudder—are similar in many respects. Each incorporates hydraulic booster units, which are linked to the control surfaces by push-pull tubes. The dual flight station controls are connected to operating quadrants on the booster unit assemblies by cable systems. Further, each control system is normally operated in a "boost-on" configuration, but can be quickly changed to a secondary manual type of control in which the pilot's effort is applied directly to the control surfaces.

Figure 18 has been reprinted in this issue from Part One to show the basic arrangement of each flight control system. The aileron control system differs from the elevator system, which is shown, only 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 18. As can be seen in Figure 19, 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 19 and 21). 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.

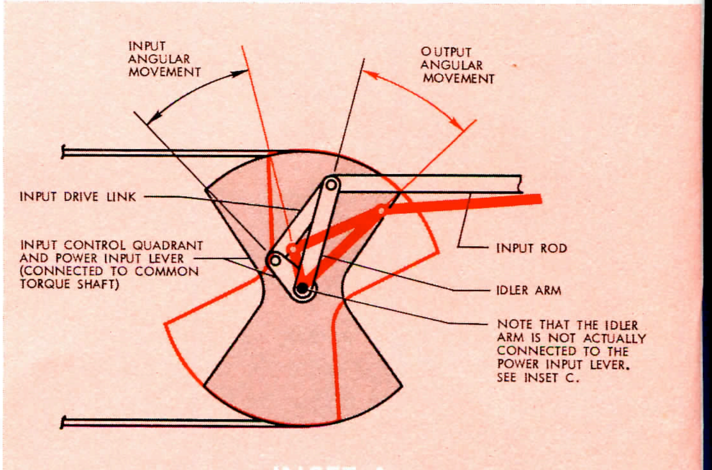
The aileron primary cables consist initially of a single pair of ⅛-inch diameter flexible steel cables routed from the control columns to the right side of the aircraft below the floor. The same type of cable constitutes the core of the Lockclad sections used in the predominantly straight runs aft. Fairlead rollers support the rigid Lockclad cable. After passing aft within the control cable tunnel above the center section, the cables break inboard (see Figure 22) to attach to the input quadrant of the aileron control booster assembly aft of the wing rear spar beam (see also Figure 23).

(Continued on page 22)



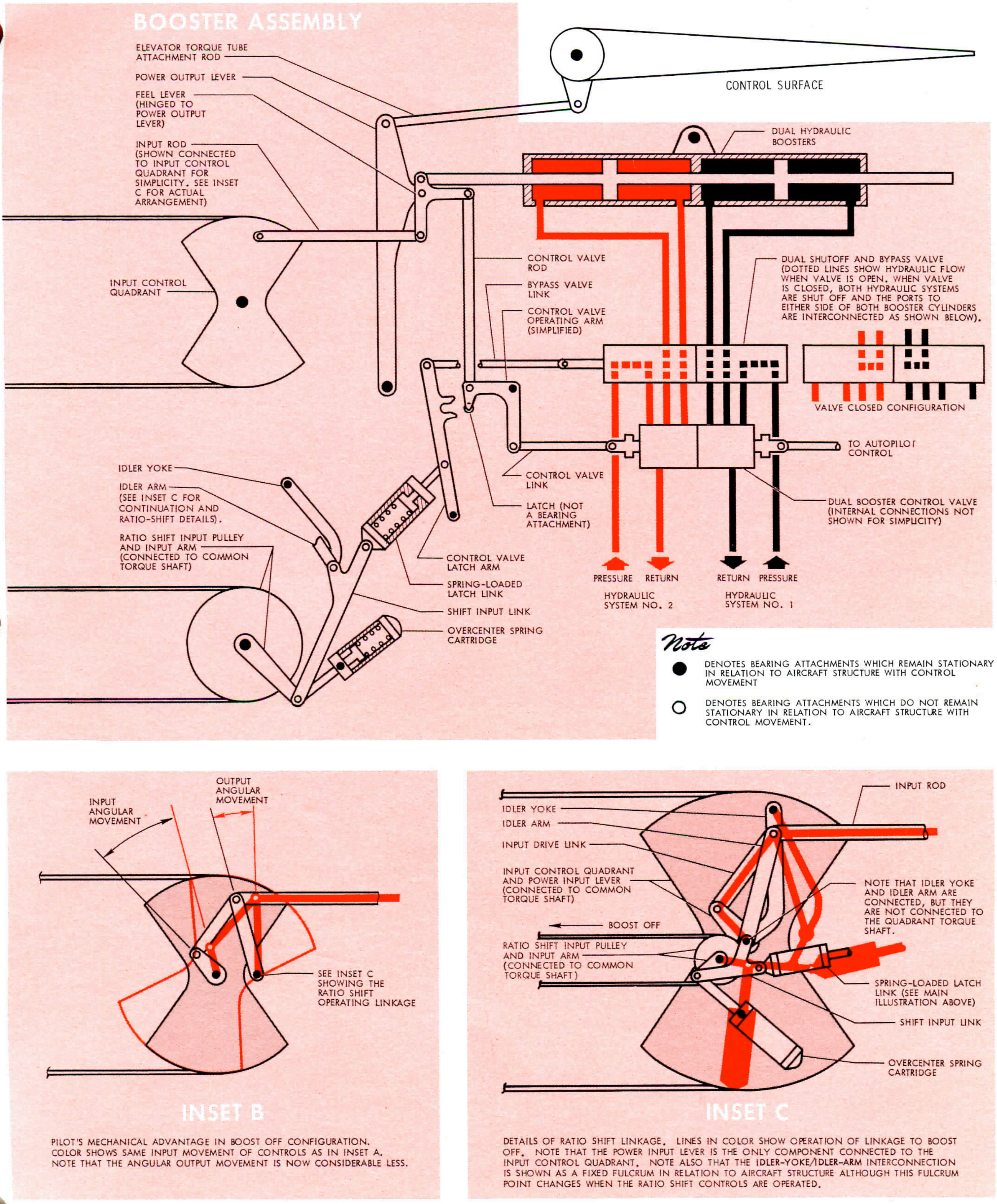
PULLING THE BOOST OFF CONTROL HANDLE RESULTS IN THE FOLLOWING:

1. OPERATES THE RATIO SHIFT MECHANISM (SEE INSETS A, B, AND C FOR DETAILS)
2. LATCHES THE CONTROL VALVE OPERATING ARM, LOCKING THE DUAL CONTROL VALVE IN THE NEUTRAL POSITION.
3. CLOSES THE DUAL SHUTOFF AND BYPASS VALVE.



INSET A

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.



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.

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

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.

Figure 18 Typical Electra Control System — Elevator shown

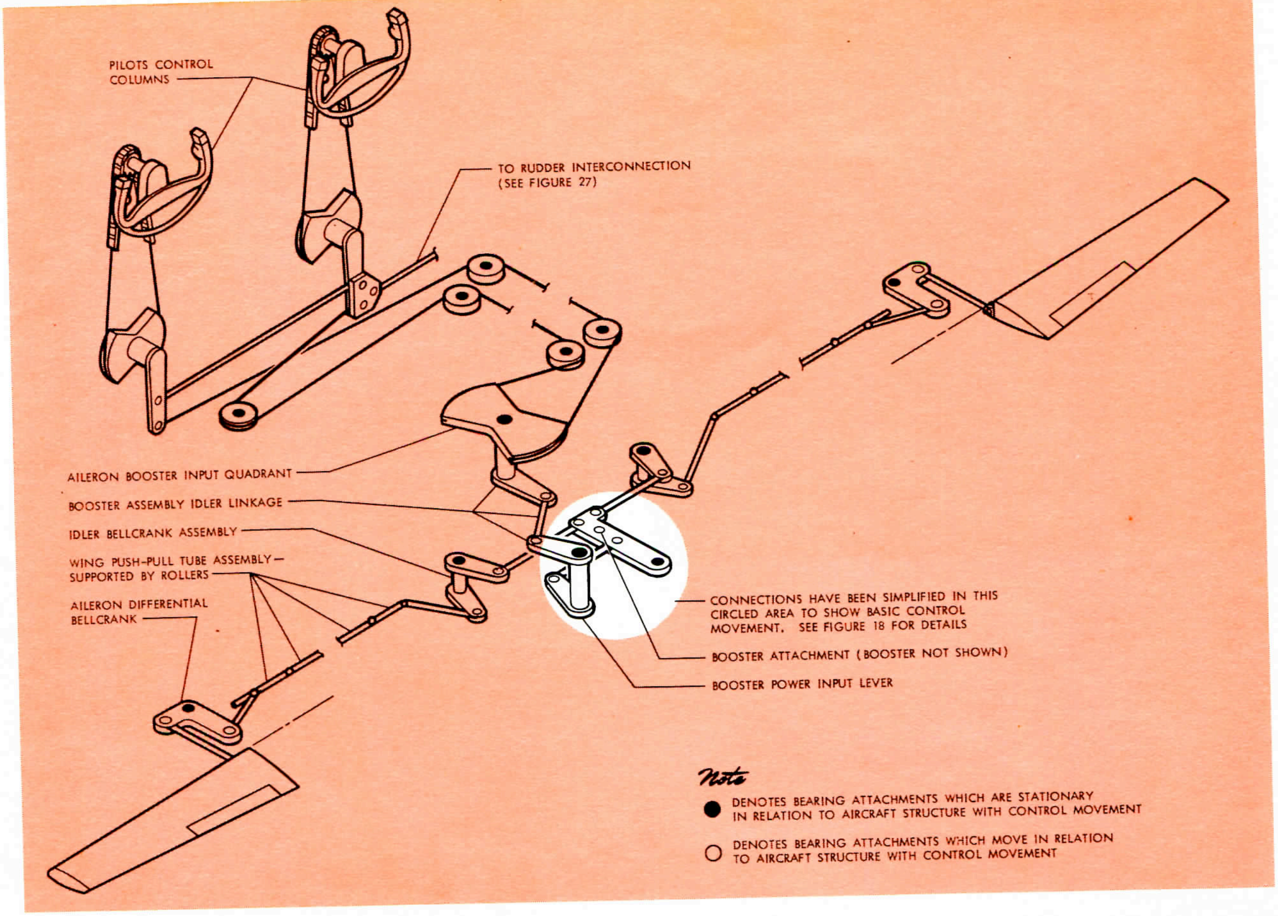


Figure 19 Sketch of Aileron Control System — Booster not shown

A cable slack absorber, similar to the elevator cable unit, is installed on each cable near to its attachment to the booster input quadrant. The aileron (and rudder) slack absorbers however have single cable terminals in each end in lieu of the dual fittings on the elevator cable units (see Part One).

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 is supported at ten points by steel rollers. At the outboard end of each wing, 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 directly to the aileron inboard end by a push rod. Figure 20 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 ambient temperature differential between steel cables and aluminum structure. 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 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 aileron surfaces 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 a faired position.

Each aileron incorporates a trim tab which is hinged at the upper surface, and the cable-driven actuator for each tab is mounted on the aileron front spar so that the tab-aileron angle is independent of aileron movement.

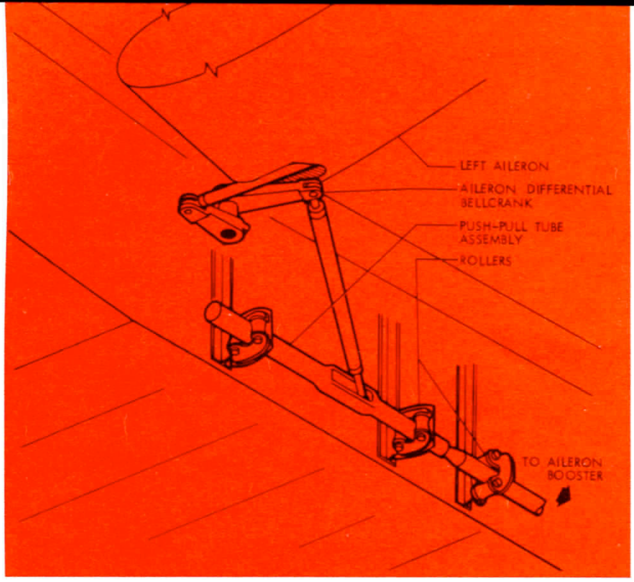


Figure 20 Detail of Aileron Push-Pull Tube Installation in Wing

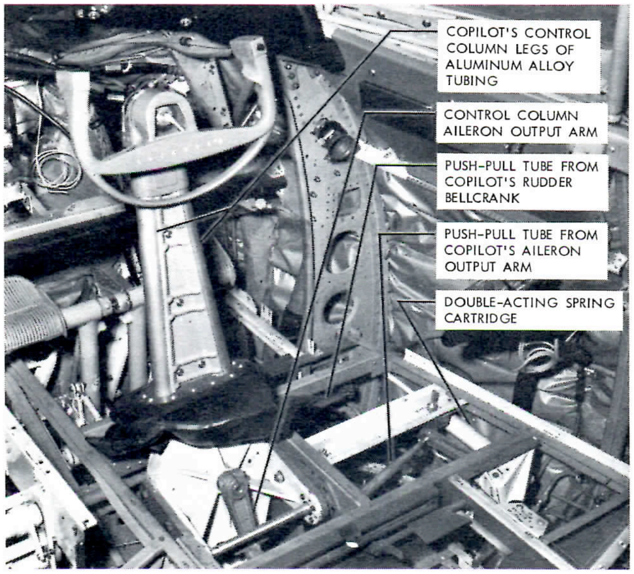


Figure 21 View of Copilot's Control Column Showing Aileron Controls

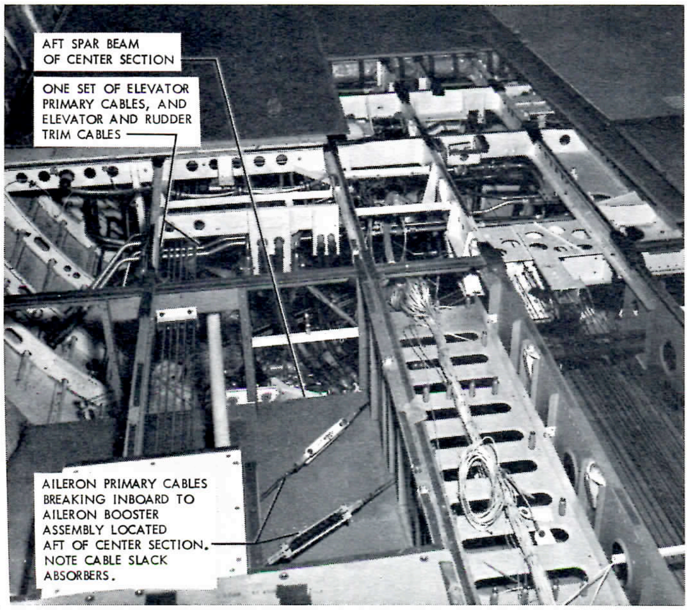
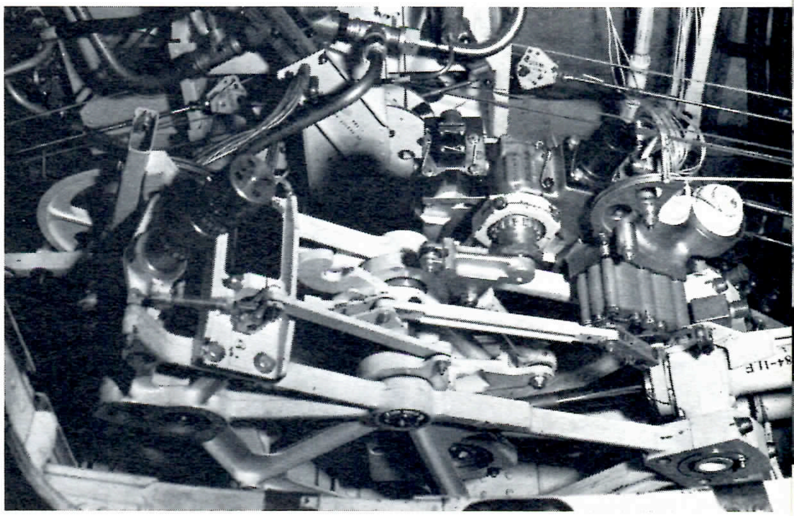


Figure 22 View Looking Aft Showing Cable Runs Below Cabin Floor and Over Center Section

Figure 23 View of Aileron Booster Assembly Installation Aft of Center Section — Looking forward through Hydraulic Service Center Access Door



RUDDER CONTROL SYSTEM

The rudder pedals extend either side of central housings which are located forward of each control column (see Figure 24). Each pedal travels in an arc about independent torque tube brackets below the flight station floor to obtain rudder control, but they may also be rotated 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 the floor or instrument panel area from falling into the sub-floor control area. The curved side-slots, through which the pedal supports travel in 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 his seat according to control column position and so forth without having to consider rudder pedal position. 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.

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 either end of

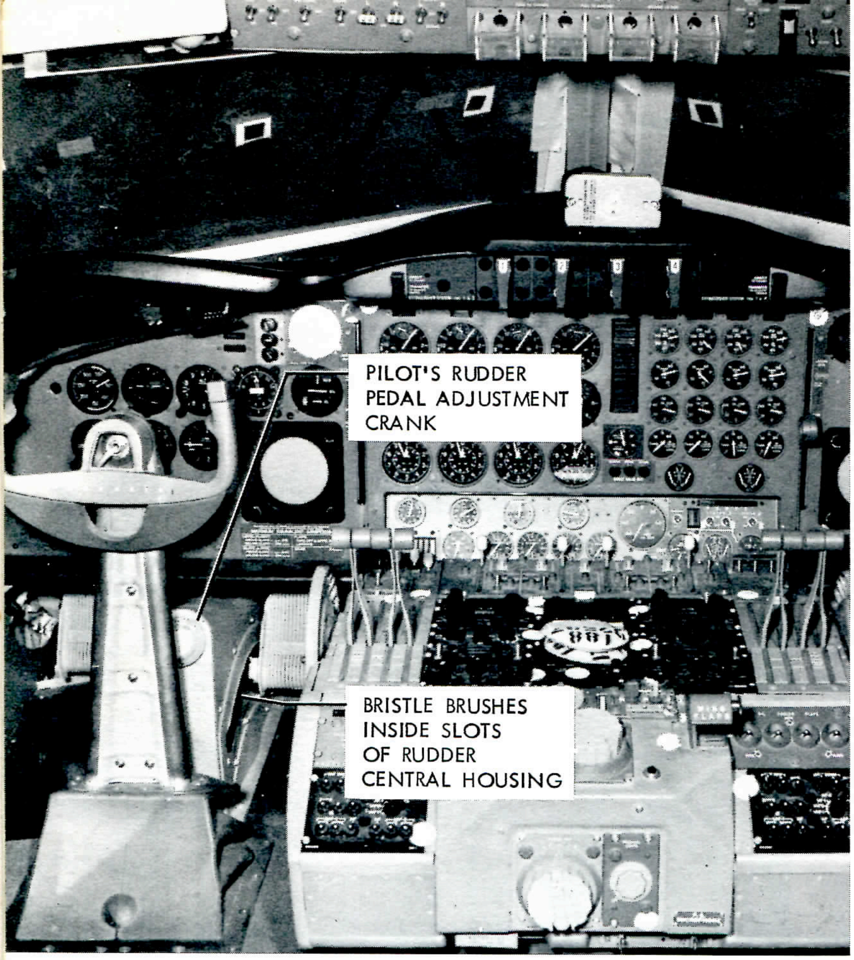


Figure 24 View of Flight Station Showing Pilot's Rudder Controls

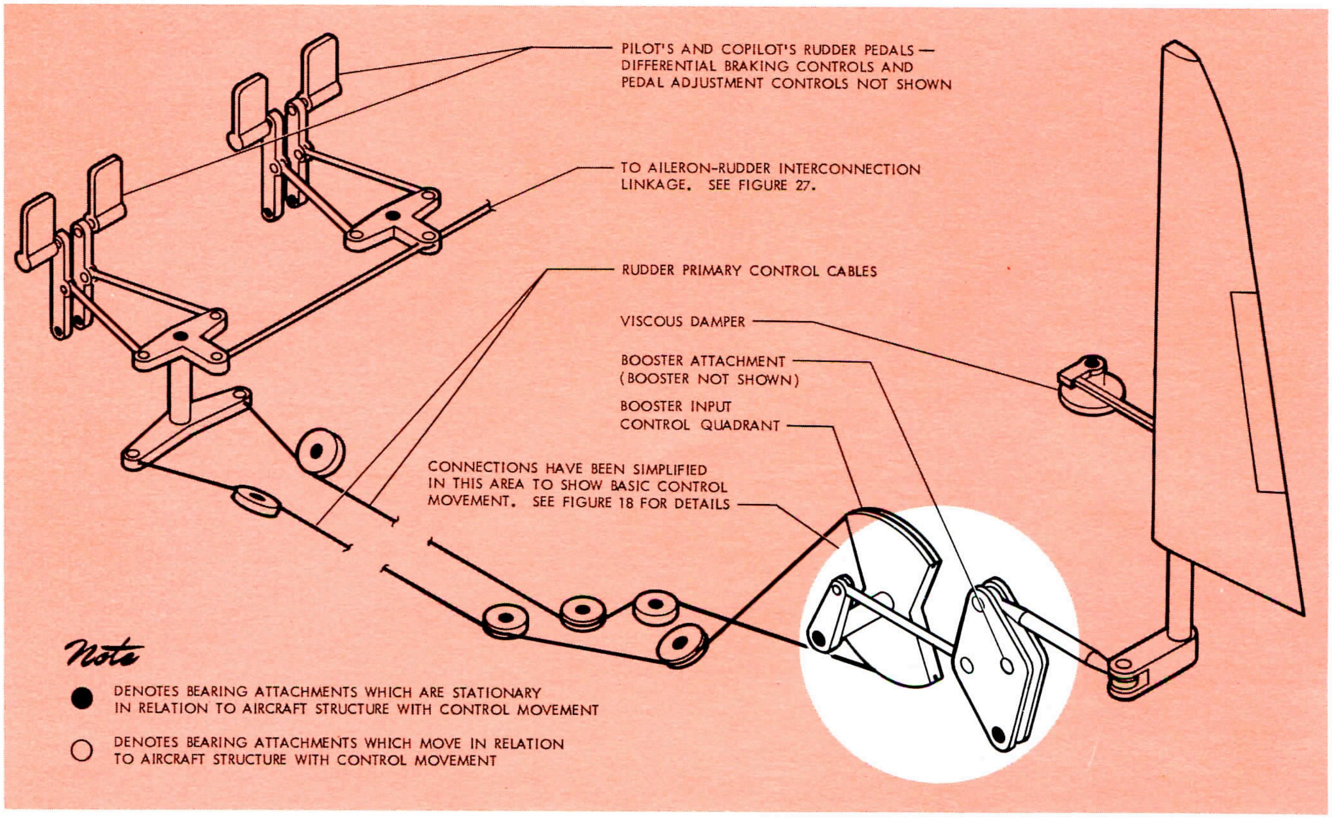
a bellcrank mounted aft of the pedals as shown in Figure 25. The two bellcranks, one for each pilot's station, are then coupled by a push-rod to coordinate pedal action. The fitting on the copilot's bellcrank, to which the connecting push-rod is attached, is also used for attachment of the aileron-rudder centering interconnection, which is explained later. The cable system is connected to arms on the pilot's bellcrank assembly.

From the pilot's bellcrank, the single pair of rudder cables are routed in a straight cable tunnel below the cabin floor structure to Fuselage Station 1024 where a cluster pulley bracket permits a bend toward the lower center of the pressure bulkhead. Aft of this bulkhead, the cables are routed upward to the rudder booster input quadrant. A cable slack absorber is installed on each cable just before attachment to the input quadrant to maintain a minimum load on the slack cable during system operation. As in the elevator control system, ⅛-inch Lockclad cable 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 fixed stabilizer center section, to the left of, and alongside, the elevator booster (see Figure 26).

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 transmits the

Figure 25 Sketch of Rudder Control System — Booster not shown



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.

A rotating disc viscous damper, similar to the one installed on the copilot's control column, is attached to the vertical fin rear spar and connected to the rudder spar by a push rod. The purpose of the damper installation is a fail-safe provision to inhibit surface oscillation in the event of failure in the booster drive rod, torque arm, or input bellcrank. The damper imposes negligible resistance to normal control motion, and incorporates a shear pin in the damper shaft and arm as a safeguard against seizure of the damper.*

AILERON-RUDDER INTERCONNECTION

This installation, shown in Figures 27 and 28, 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 bellcrank 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 27 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

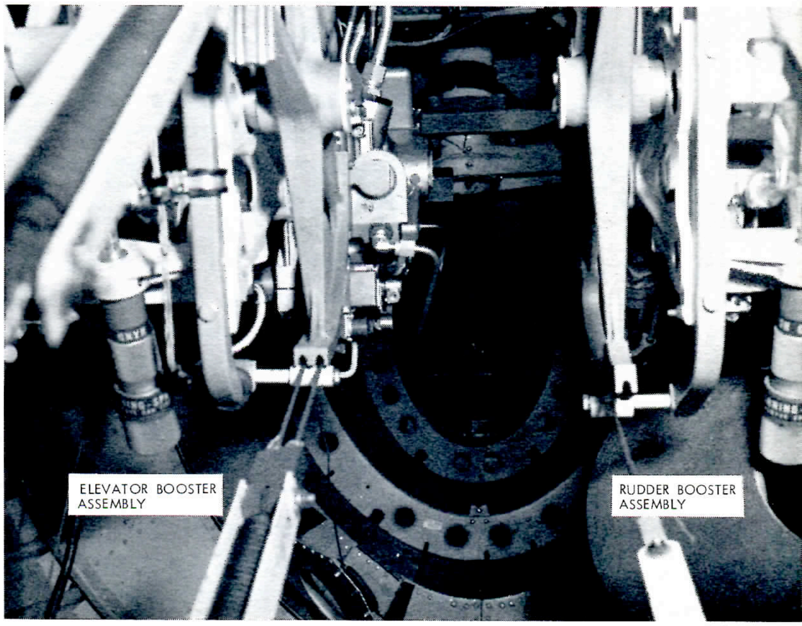
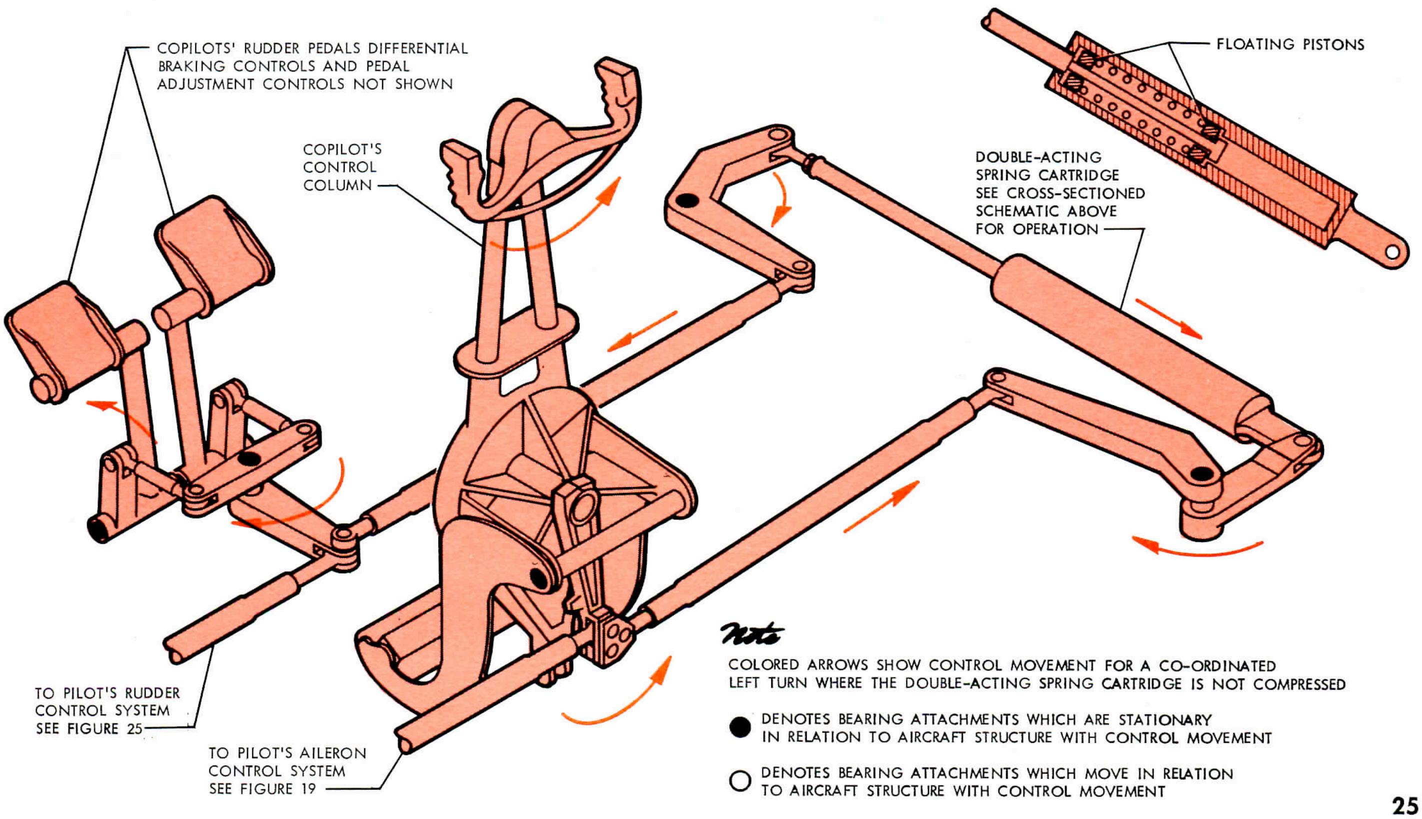


Figure 26 View Inside Fuselage Looking Aft Towards Elevator and Rudder Boosters

Figure 27 Sketch of Aileron-Rudder Interconnecting Control Linkage



**The shear pin was originally an AN470DD6 rivet. However, Service Bulletin 188/SB-525 allowed the use of a larger rivet. (MS 20470 AD7-22) should inspection reveal looseness in the existing rivet attachment.*

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 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 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 counterclockwise direction is increased to 6.7 pounds.

It is interesting to recall that the Electra was flown during flight testing with and without the coupling spring installed. It was established that aileron centering was definitely improved with the coupling installed, and the trim and normal flying characteristics (coordinated maneuvers) were unchanged.

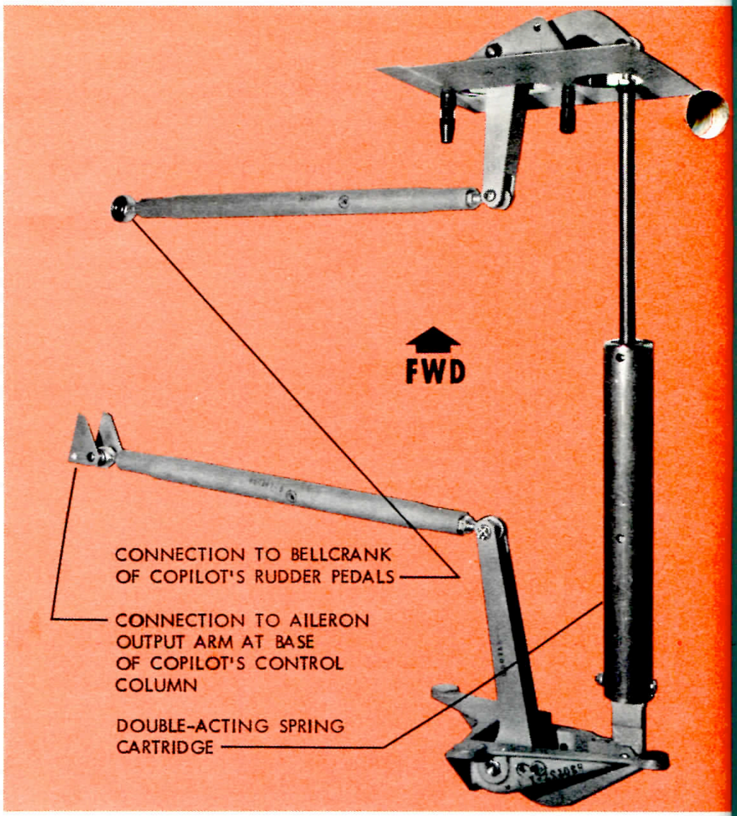


Figure 28 Aileron-Rudder Interconnection Components

AILERON TRIM TAB CONTROL SYSTEM

The aileron trim tab control unit has a 3-inch diameter fluted knob with a retractable knob-crank, and it is mounted on the aft vertical face of the flight station control pedestal (see Figure 29). 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. Seventeen full 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 30, 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. A chain with cable terminal ends is driven by this sprocket for a total travel of about 50 inches.

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 aft of Fuselage Station 280. 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 four cables are then routed to the left and right aileron tab actuators on each wing. The tab actuators are similar to those used in the elevator trim tab control system, and are described in that section in Part One.

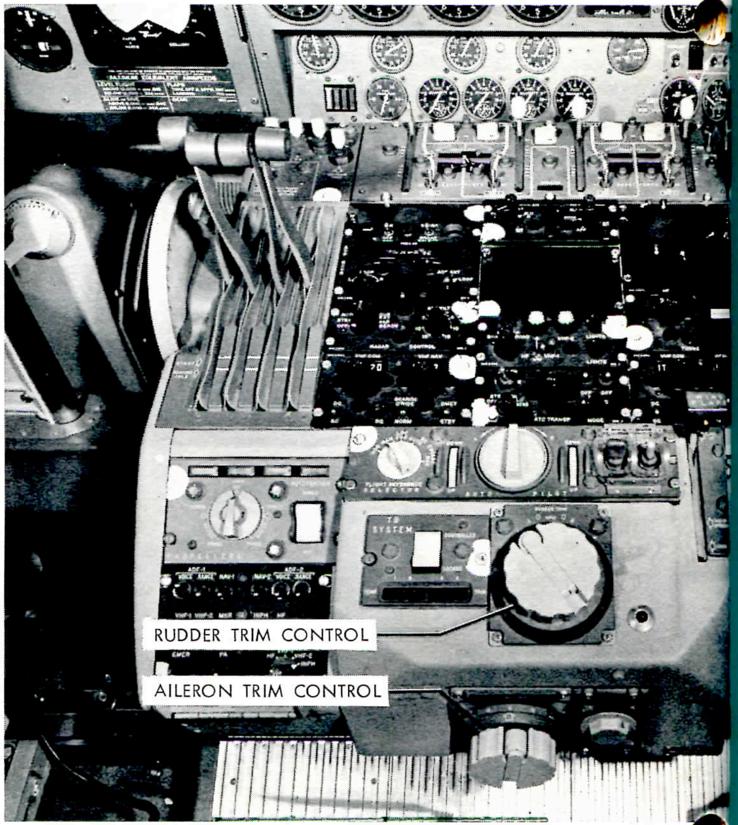


Figure 29 View of Control Pedestal Showing Aileron and Rudder Trim Controls

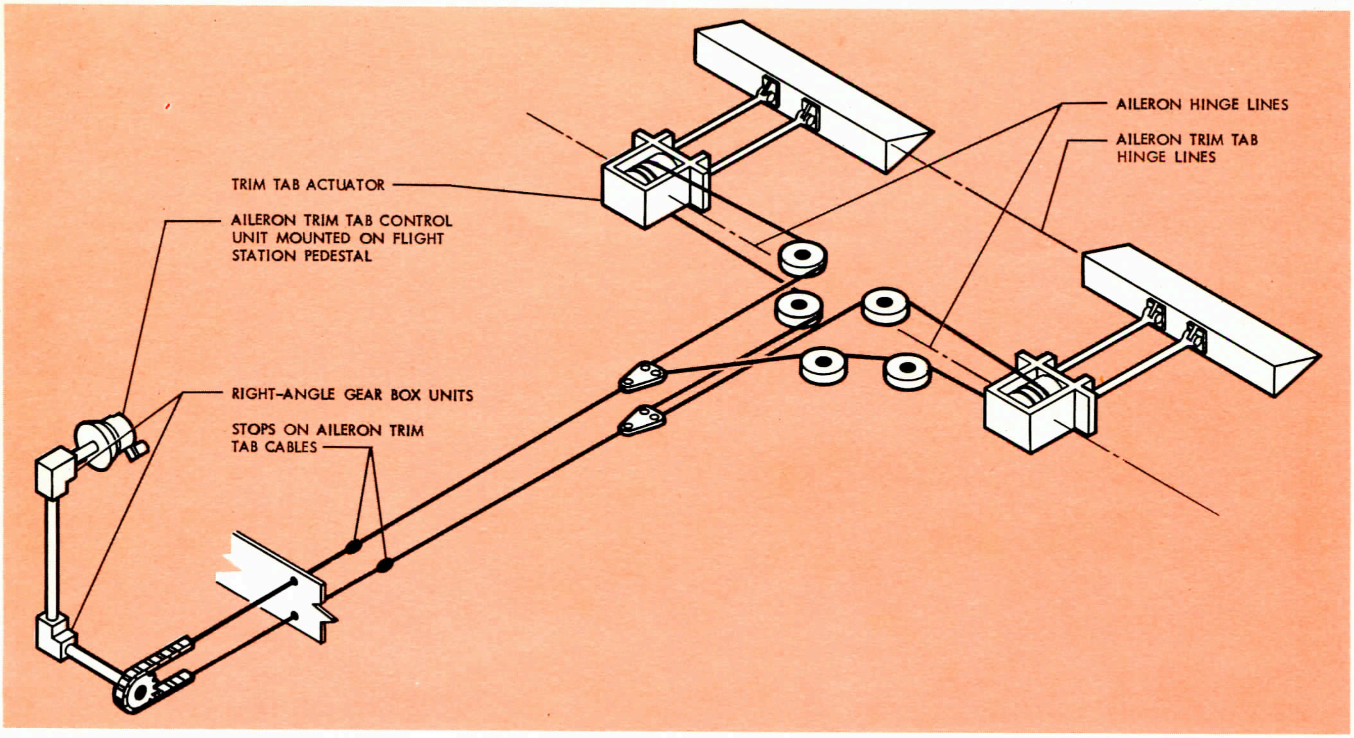


Figure 30 Sketch of Aileron Trim Control System

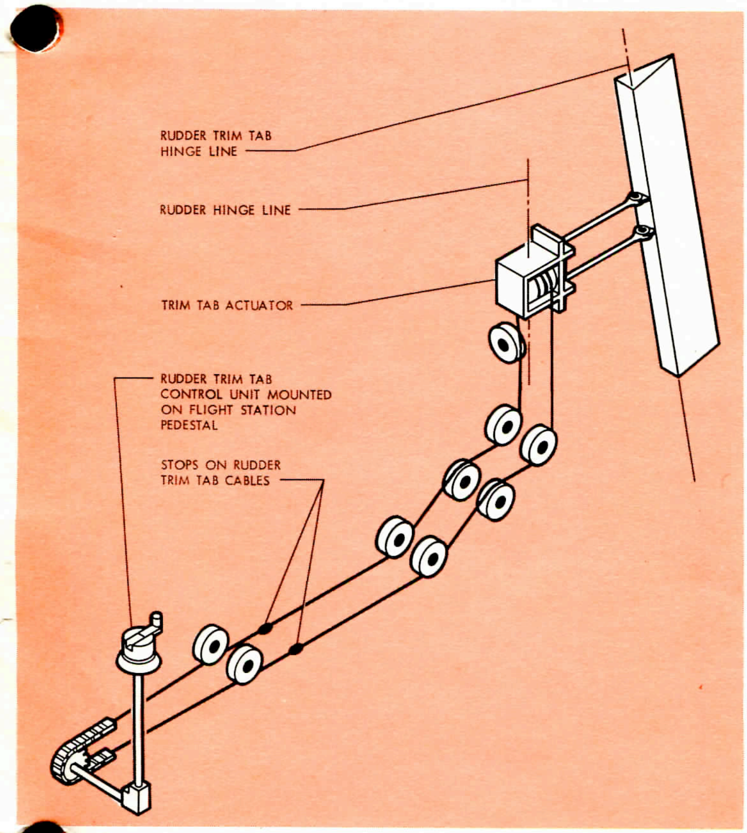


Figure 31 Sketch of Rudder Trim Control System

RUDDER TRIM TAB CONTROL SYSTEM

The rudder trim tab control unit is similar to and is mounted just above the aileron unit (see Figure 29). 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 produces 50 degrees of tab travel, which is shown on the indicator scale as 25° left and right.

Tab control input torque is transmitted from the pedestal-mounted unit downward to a right-angle gear box and then to a transverse torque shaft (see Figure 31). 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 and has a total travel of about 60 inches. Lockclad cable is used for the straight run aft to Fuselage Station 1024, and 3/32-inch diameter flexible cable for the remainder. The trim tab actuator is described in the "Elevator Trim Tab Control System" section in Part One.

This Concludes our two-part discussion on the basic flight controls of the Electra. Future issues of the *Digest* will include an article describing the 188 flap control system, and a more detailed discussion on flight control hydraulic boosters.