ORION SERVICE DIGEST

LOCKHEED
CALIFORNIA • COMPANY

issue 10 july-september 1964

ORION

editor DON WADSWORTH

assistant editors WAYNE CRADDUCK : EUGENE DRICKEY

art VIRGINIA ROBINS : IRENE FRIEDMAN

FRONT AND BACK COVERS PATRON NINE found themselves supporting Marine attack sorties in the thick of the Korean conflict less than a year after being commissioned as a "Privateer" Squadron in 1951. Becoming veterans in their first year may account for the air of professional self-reliance they have exhibited in acquiring competence with ASW equipment, and in taking their wares and setting up practice on short notice wherever and whenever needed. Before the Korean hostilities ceased, they returned to the States and transitioned to the Neptune — with pilot training administered by four PATRON NINE pilots with previous Neptune experience—and achieved an Operational Readiness Inspection rating of "Excellent". Although many of their newly qualified personnel were promptly returned to inactive status in the first days after the cessation of combat, the squadron deployed, on schedule, to Atsugi, Japan.

Since then, the Squadron, or Detachments thereof, has participated in fleet exercises of all kinds (and practically everywhere) in the Pacific, including such spectaculars as "POTSHOT" and "PEACHTREE", and during the Nautilus' Polar cruise they even befriended a submarine. To PATRON NINE personnel, "home" is a transitory concept, for although the Squadron has been based chiefly at NAS Alameda, "home" for some or for all has shuttled like an industrious spider from Kodiak to Iwakuni to Alameda to Kodiak to Alameda to Kodiak/Adak to Oahu to Midway to Alameda to San Diego to Oahu to San Diego to Kodiak/Adak to Alameda to Oahu to Alameda to Oahu, to supplementing other squadrons on the Alaskan Sea Frontier, and coincidentally transitioning to Orions at Moffett Field.

Their itinerary proves PATRON NINE is certainly the readiest possible ASW Ready Squadron, and they even managed the transition to the P-3 without once losing their status as an operational ASW unit.

With their complement of new Orions, they are presently assigned to the Seventh Fleet as the first operational P-3 Squadron in the Far East.

COPIES REQUIRED OR CHANGE OF ADDRESS —Please send your name; present address; occupation; your organization's name; and, if applicable, your old address as imprinted on a Digest envelope to:

LOCKHEED SERVICE DIGEST
BURBANK, CALIFORNIA 91503

part two

P-3 ORION FLIGHT CONTROLS

longitudinal stability and the force link tab

PART ONE of the Orion flight controls was published in Orion Digest #8. The three primary booster-assisted flight control systems were described in some detail in that issue, except that certain unconventional features of the elevator control system were given only cursory attention. These unconventional features are described in this second part of the article.

An item on the Orion that continually raises questions regarding its purpose and operation is the force link tab. There are many reasons that this device is so poorly understood. The linkage and other mechanism associated with the force link tab appears complicated—due principally to the severe space restrictions for its installation—and to understand why it is necessary and how it achieves its purpose requires a basic knowledge of aerodynamics and flight control design. Further, the two force link tabs on the aircraft are interrelated, either mechanically or aerodynamically, with several other devices, including the trim tab controls, the elevator downspring, and the teeter-totter balance weights, which all tend to make explanation that much more difficult.

The purpose of this article is not only to explain the mechanics and the interrelationship of these devices, but also to present the larger view, that is, the factors which necessitated the design, and its great contribution to the excellent overall flying qualities of the P-3 Orion.

DESIGN HISTORY. A full history and description of the force link tab requires that we go back in time to the early design stages of the Electra, for the Orion inherited this device from its commercial antecedent, and the tabs perform exactly the same function on both airplanes.

One basic overall aerodynamic consideration in a new airplane design concerns longitudinal changes in the center of lift throughout the complete speed range of the airplane. In this regard, designing flight controls with "natural" feel characteristics 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 (c.g. range)—a necessary feature of transport airplanes, if they are going to be operationally competitive.

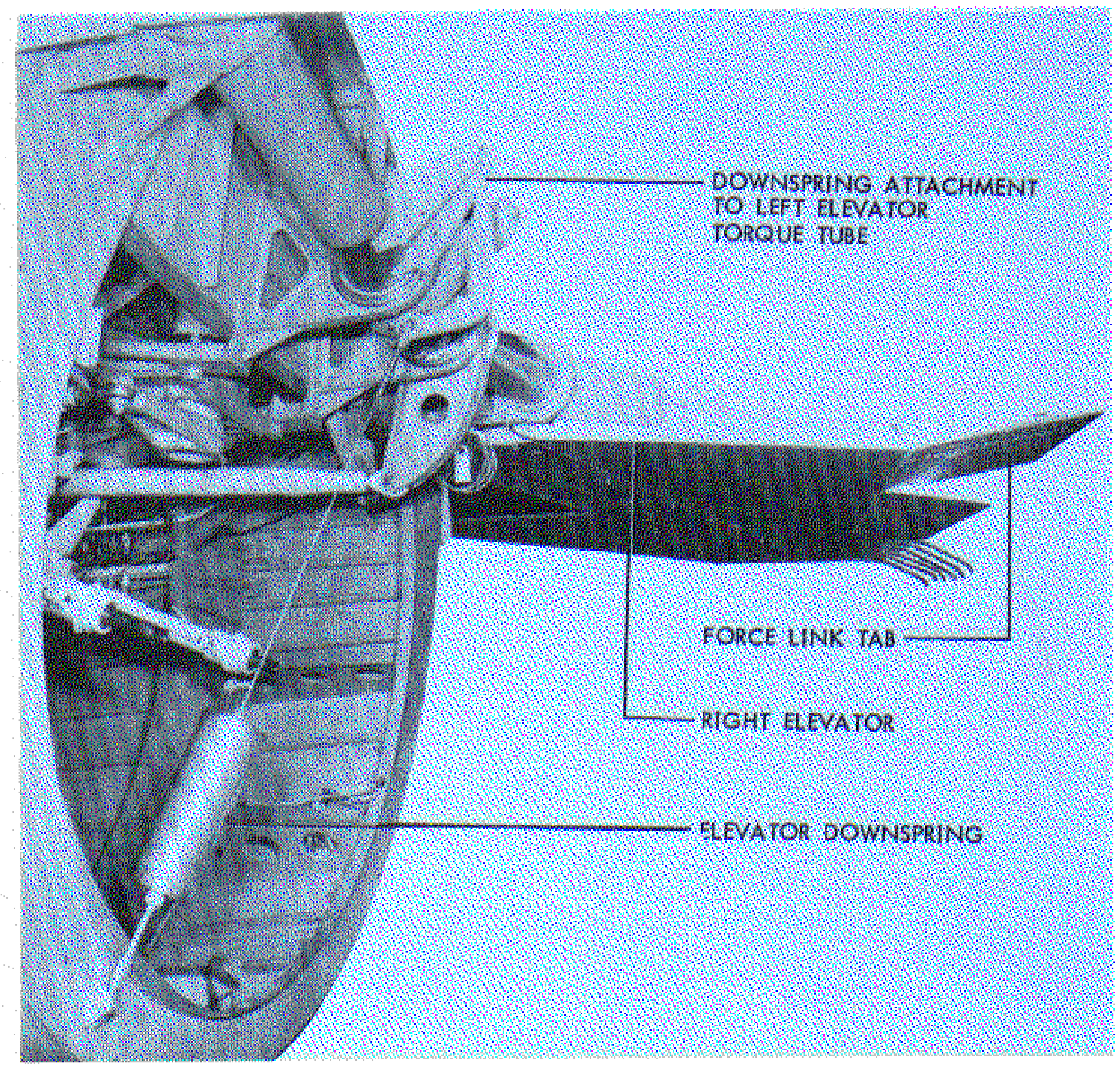
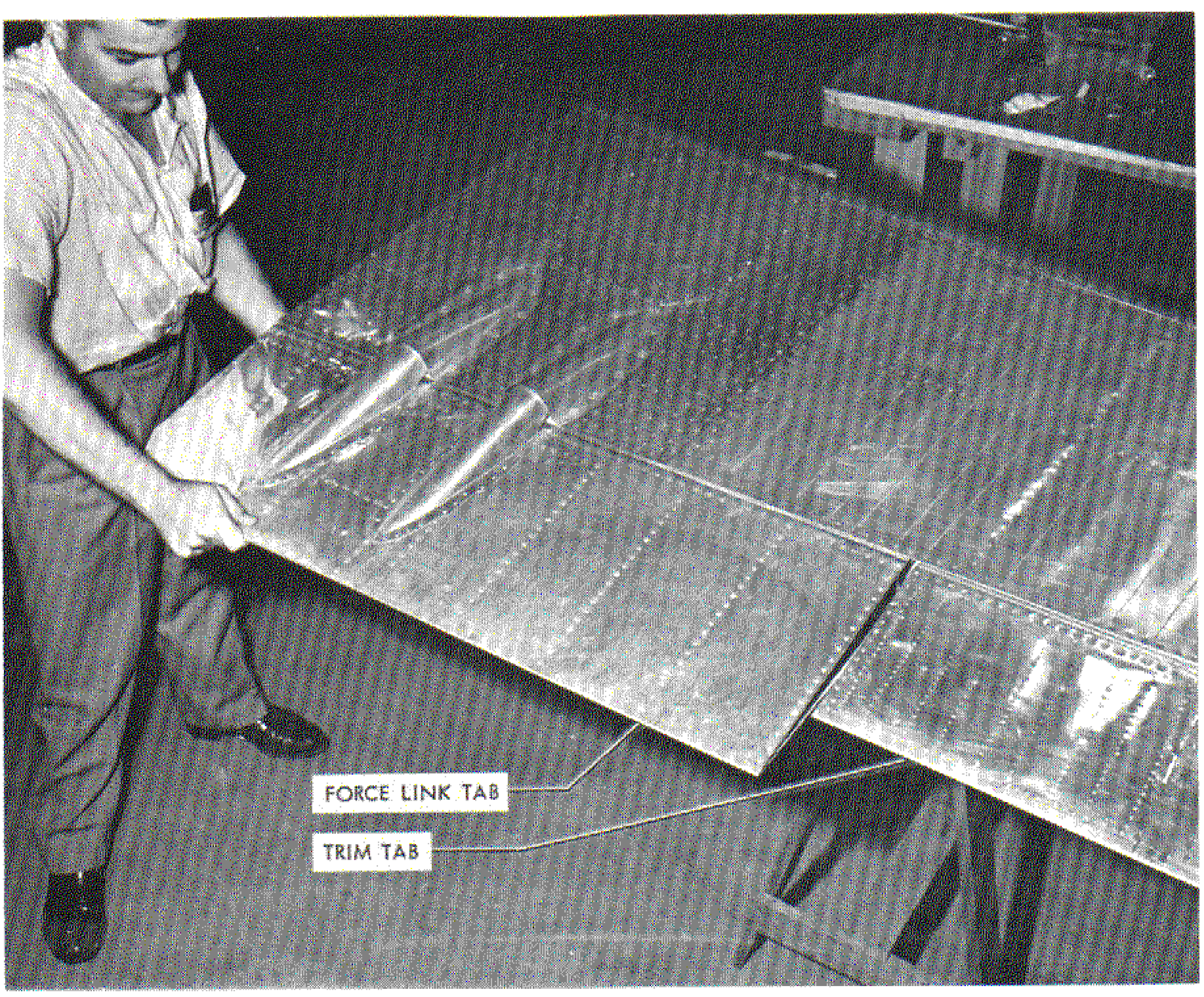


Figure 1 Force Link Tab and Elevator Downspring

The relatively large c.g. range of both the Electra and the Orion is indirectly related to the ability of these aircraft to virtually lift their own weight in fuel and payload. For aircraft of this size and performance, this is an exceptional achievement. However, in the early design stages of the Electra it appeared that this capability would be seriously compromised by possible changes in the basic design, necessitated by the longitudinal stick-free stability requirements. (These requirements are explained later.)

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 aft of the wing would have to be lengthened,* thus increasing the size and structural weight of the airframe. Either of these alternatives would have resulted in a loss in useful load. However, 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 within the allowable range and throughout the entire flight spectrum, to meet the longitudinal stick-free stability requirements.



**The dimension from wing to stabilizer is the important consideration here. This dimension, and the basic wing and stabilizer configurations, are the same for both the Electra and the Orion. Thus, even though they may differ in other respects, certain characteristics involving longitudinal stability are common to both aircraft.*

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 elevator movements correspond to a lower flight speed and a higher flight speed respectively, and, if an airplane has stick-free stability, 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 and Military Air Regulations in regard to stick-free stability have to be demonstrated in flight tests. These tests are conducted at various trimmed speeds throughout the complete operating range of the airplane, and under the most adverse conditions of configuration, c.g., and loading. The results of two typical flight tests on the Orion (with the force link tab and downspring installations) are shown in Figure 2.

For the test depicted by the white curve the aircraft had a gross weight of 121,500 lb., a forward c.g. of 21.8 percent M.A.C. (Mean Aerodynamic Chord), and was initially trimmed at 283 knots at an altitude of 8,450 feet. The plot was obtained by measuring the stick force required to hold the aircraft at various speeds, both above and below 283 knots. The naval test requirement called only for a test-range of plus and minus 15% of the original trimmed speed, but these two tests were carried over to about twice this

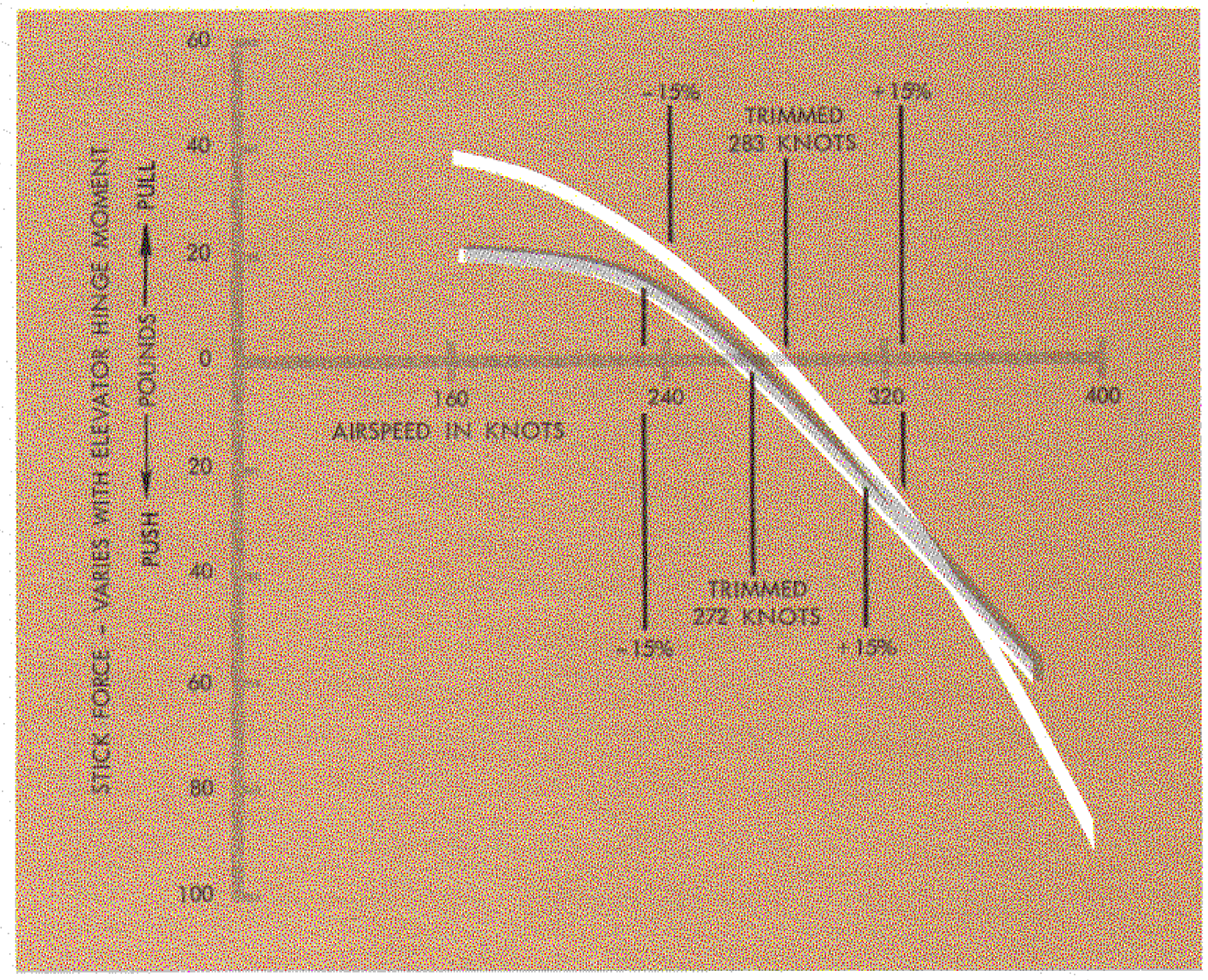


Figure 2 Graph Showing Results of 2 Stick-Free Stability Flight Tests on the Orion

range. 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 down to about 160 knots. It also shows that a steadily increasing push force is required from the trim condition up to 400 knots—close to the design limit dive speed of 405 knots.*

The grey curve on Figure 2 shows the test results of an Orion which had a gross weight of 131,800 lb and an aft c.g. of 31.2 percent M.A.C. The aircraft was initially trimmed at 272.5 knots at 8,160 feet. These conditions, particularly the aft c.g. location, are far more exacting than the forward c.g. test conditions, and this is reflected in the two curves—the white curve being nearly ideal, while the grey curve tends to flatten out below 200 knots. This is satisfactory, in that the pull force did continue to increase, but it is less desirable than the almost linear increase that resulted with the forward c.g. loading. Vertical lines on Figure 2 mark the required speed range (plus and minus 15%) for each of the two test cases, and the portions of the curves within these limits depict excellent results.

***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.*

**Called V_D or M_D, this is the maximum speed that the airplane should be flown in service, and is the speed on which the design structural analysis is based.*

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 a subsonic 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.

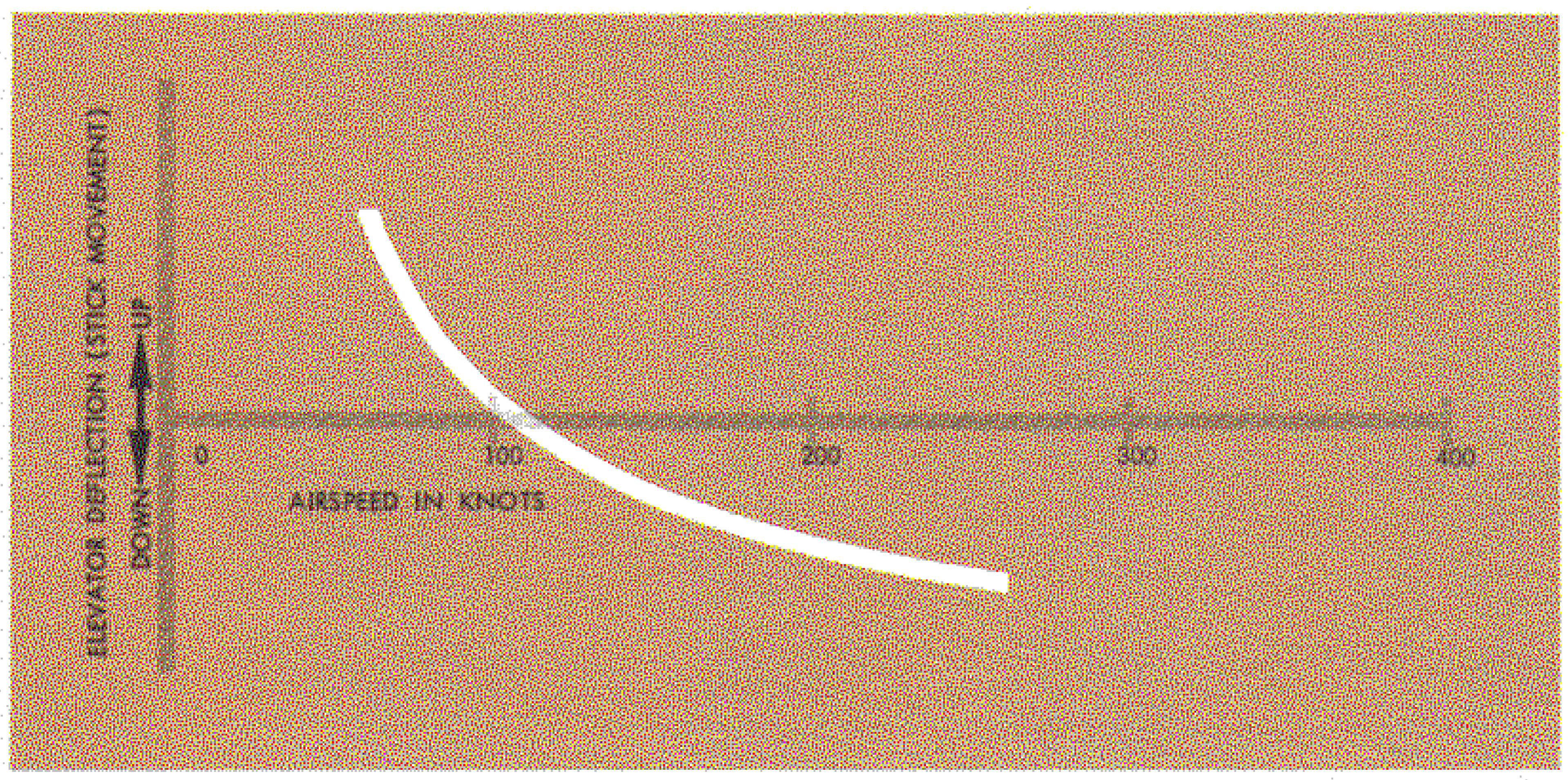


Figure 3a Graph Showing Elevator Deflection Variation with Airspeed—Typical 250-knot Transport

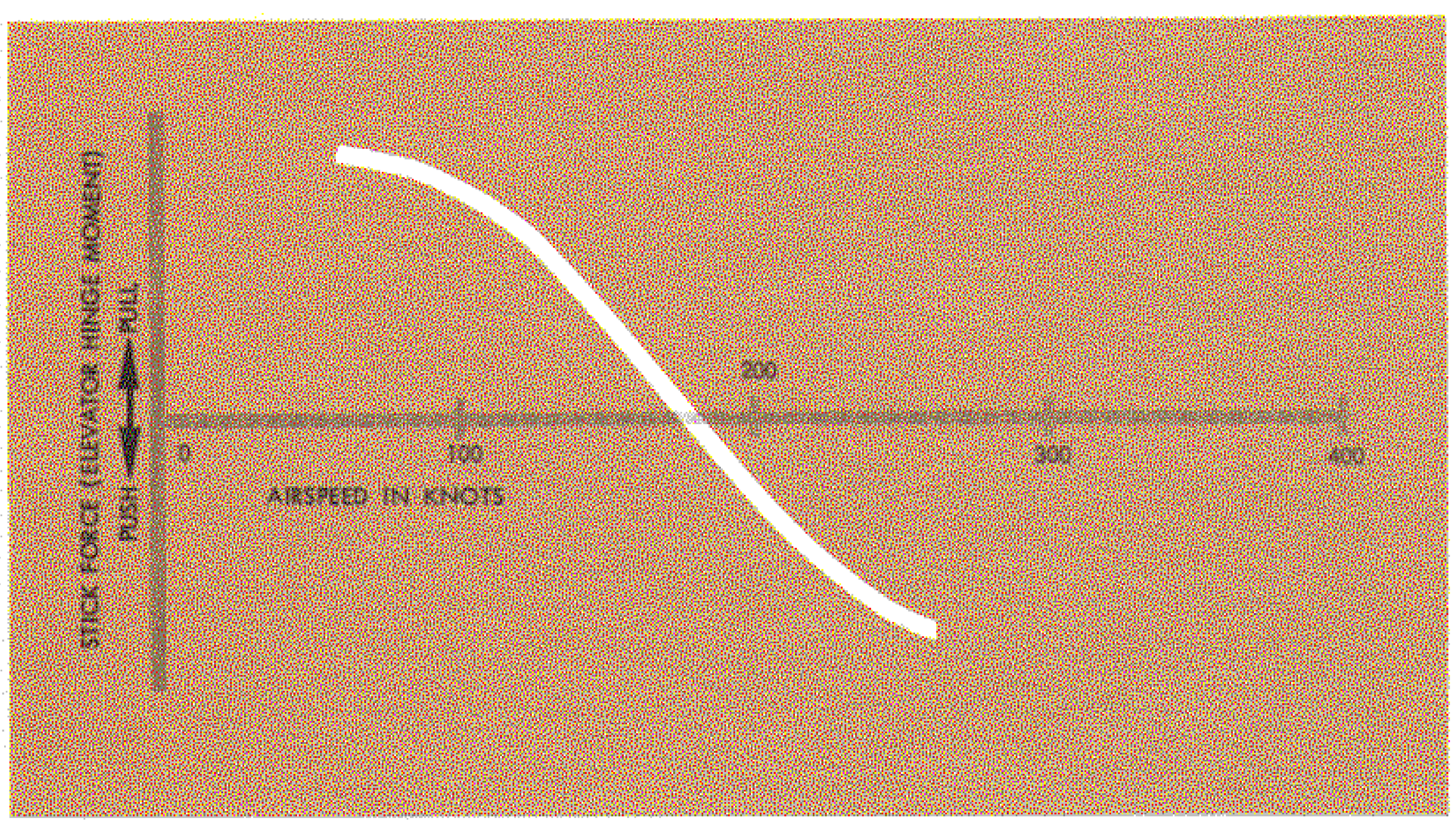


Figure 3b Graph Showing Stick-Force Characteristics—Typical 250-knot Transport

Based on the Orion's performance,* it will be noted 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 approaching the design limit dive speed (V_D), the elevators are actually deflected in the opposite direction. It should be expected that these characteristics would produce a stick force curve similar to 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 and Orion's specifications. The primary reason — and the only one causing the flattened-out portion of the curve—is due to what is called the "slipstream effect". One of the Orion'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 propellers 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 aero-

**At this point we should emphasize that a large proportion of the following information is only based on the Orion's flight characteristics and should not be regarded as an accurate record of actual 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.*

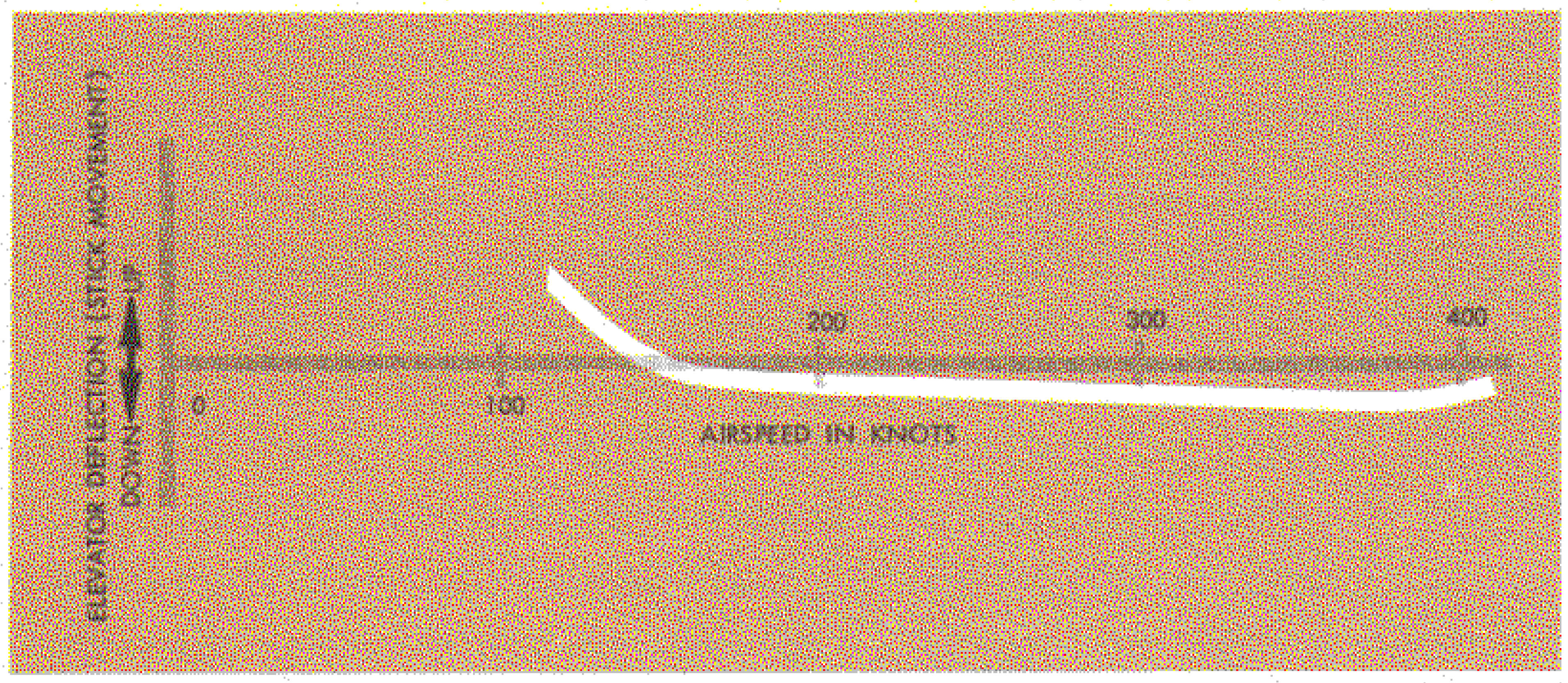


Figure 4a Graph Showing Elevator Deflection Variation with Airspeed—Based on Orion Performance

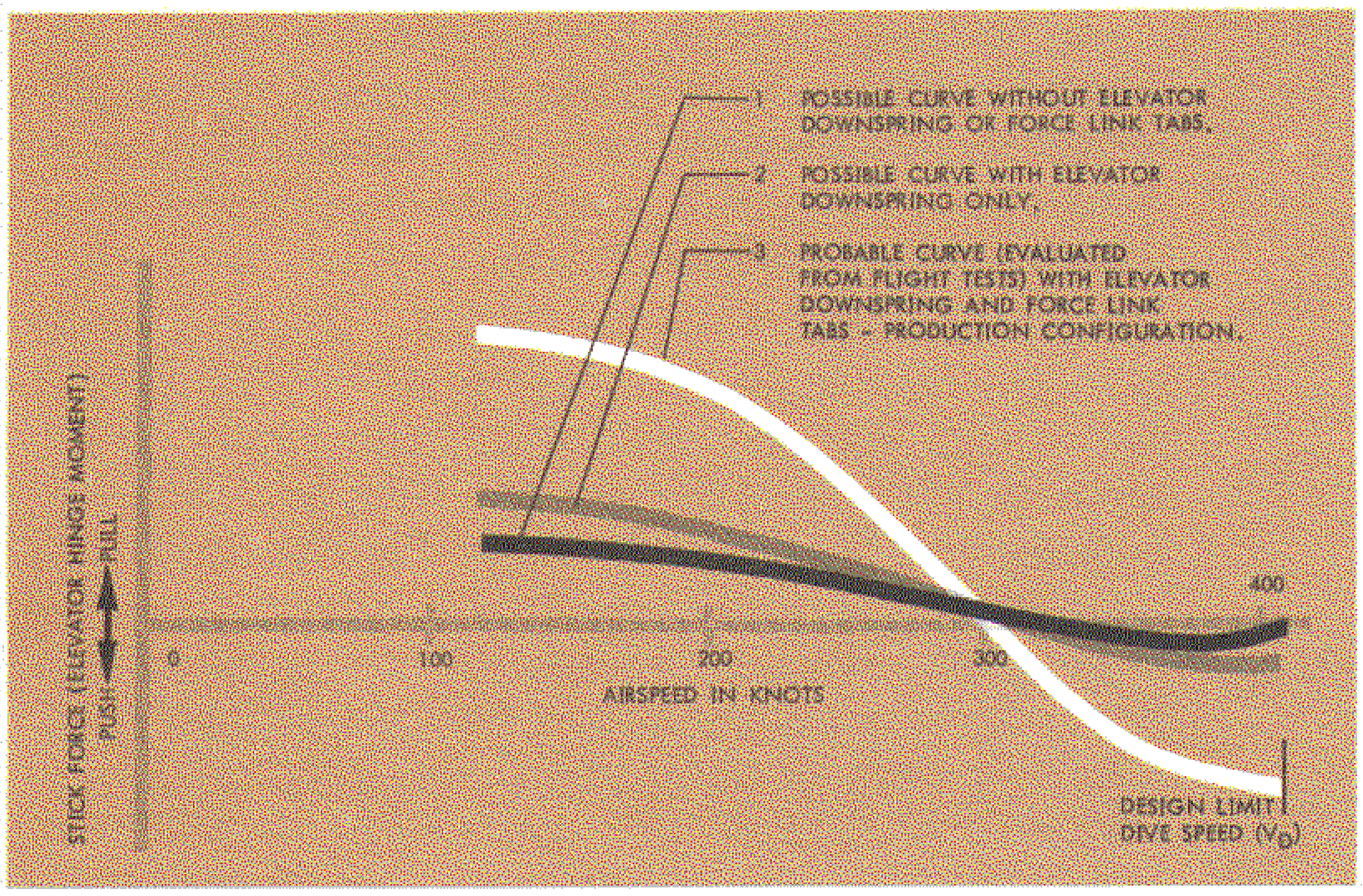


Figure 4b Graph Showing Stick-Force Characteristics When Initially Trimmed at 305 knots—Based on Orion Performance

dynamicist 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 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.

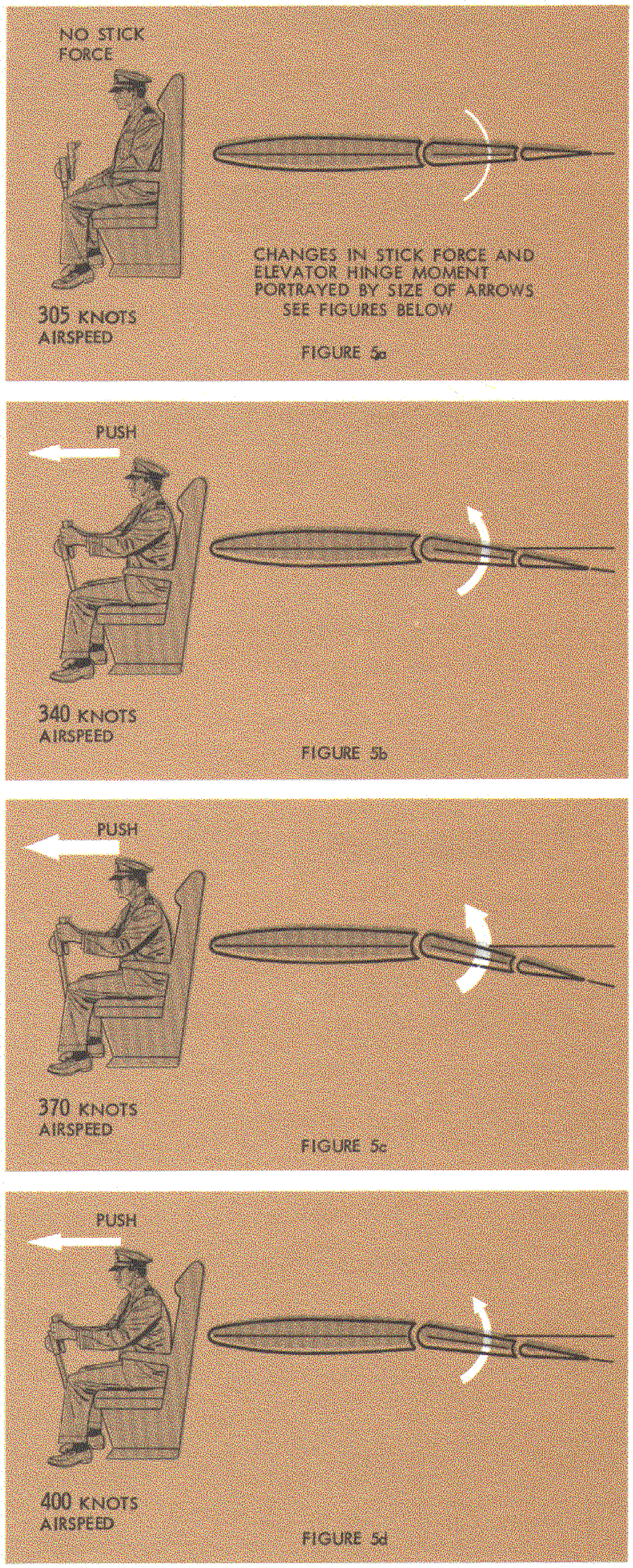


Figure 5 High-Speed Stick-Force Characteristics Without Elevator Downspring and Force Link Tab Installations—Based on Orion Performance

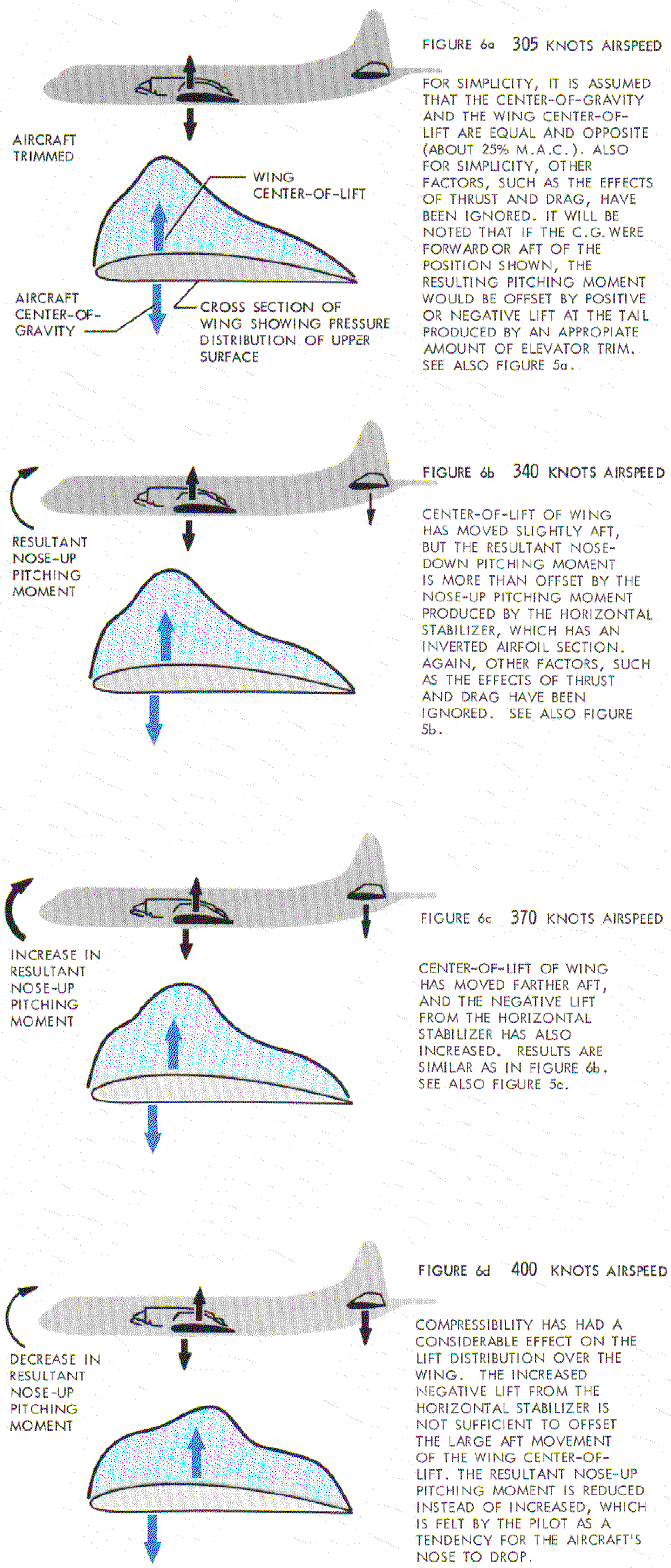


Figure 6 How Compressibility Affects a Typical Subsonic Wing to Cause Tuck—Based on Performance of Orion Without Elevator Downspring and Force Link Tab Installations

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 and the Orion, 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).

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/Orion wing is about as thin as practicable, while still maintaining good landing characteristics and the necessary fuel storage capacity. It is interesting to note that the depth-to-chord ratio of the Electra/Orion wing compares to that of the Lockheed P-80 Shooting Star. 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 this specification. However, the "tuck" problem on the Electra and Orion is of far less concern than the "slipstream" problem—particularly since the aircraft 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 one of the stick-force curves, Curve 3, is an "averaged" approximation of statistics obtained during the numerous flight tests described previously in connection with Figure 2. Curve #3, of course, includes the effect of both the elevator downspring and the force link tabs. 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.

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

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.

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 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 Orion. 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 280 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.

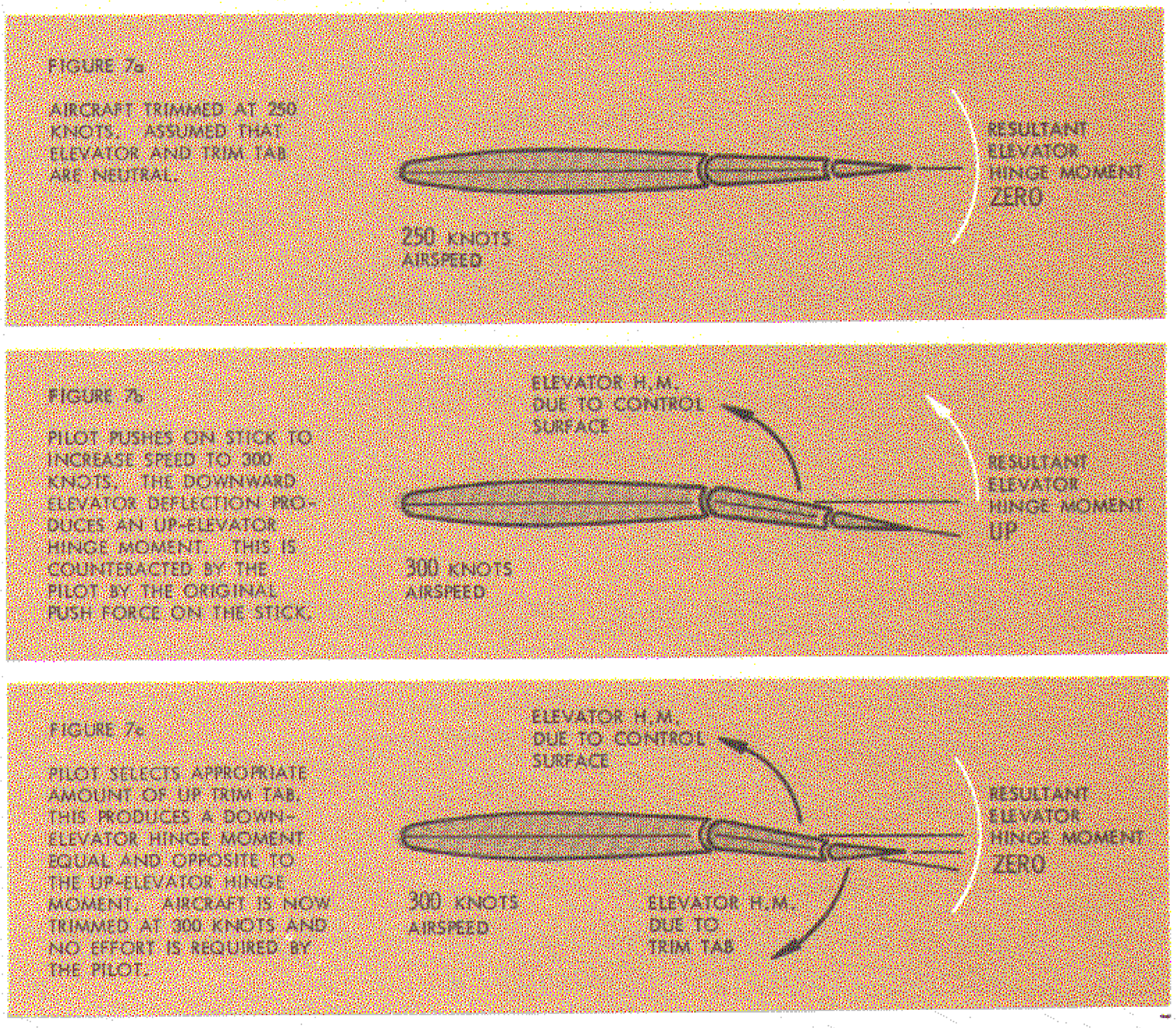


Figure 7 Principle of Trimming an Aircraft by Means of a Trim Tab

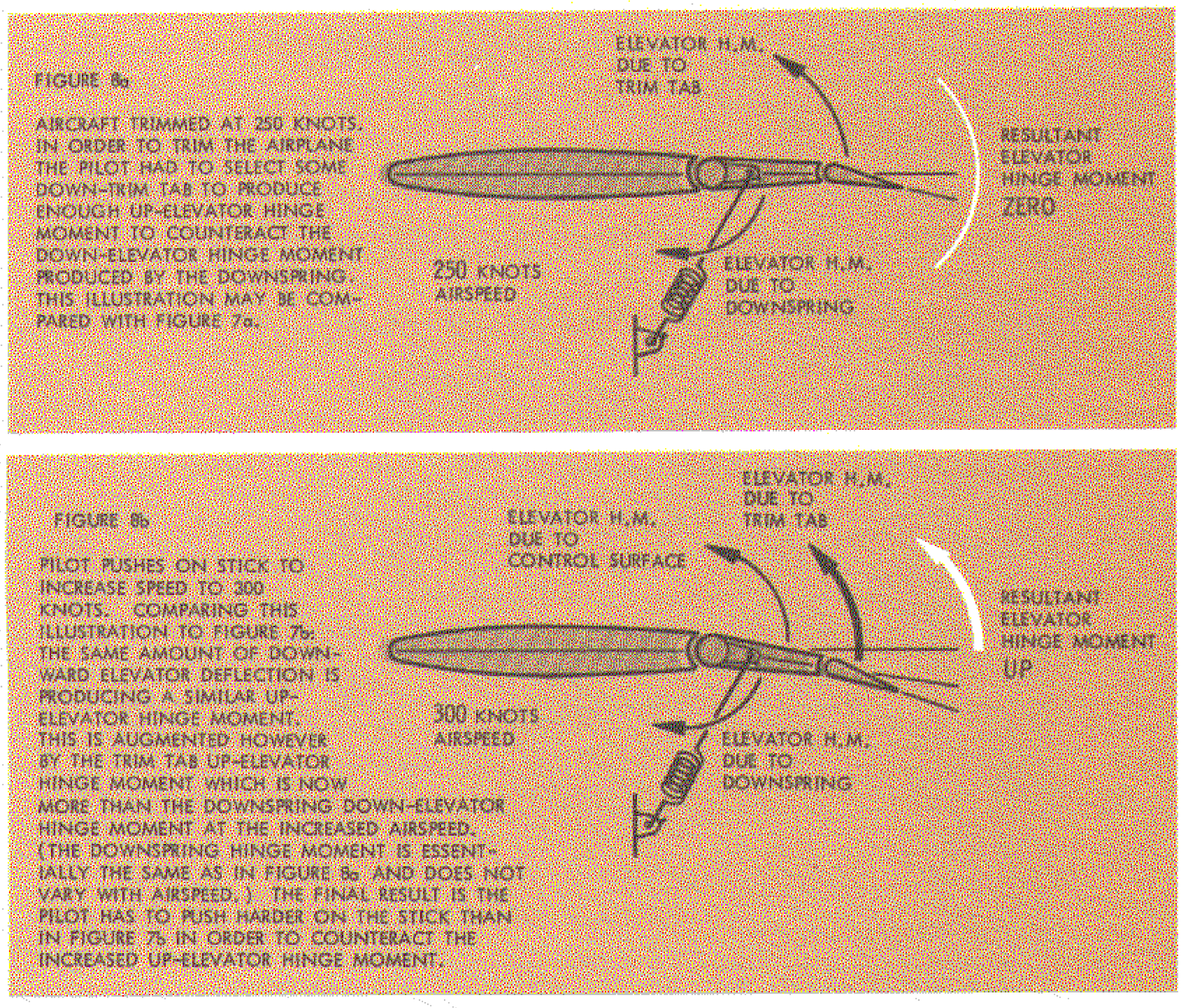


Figure 8 Effect of a Downspring on the Elevator Hinge Moment

On the other hand, the force link tabs 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.

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

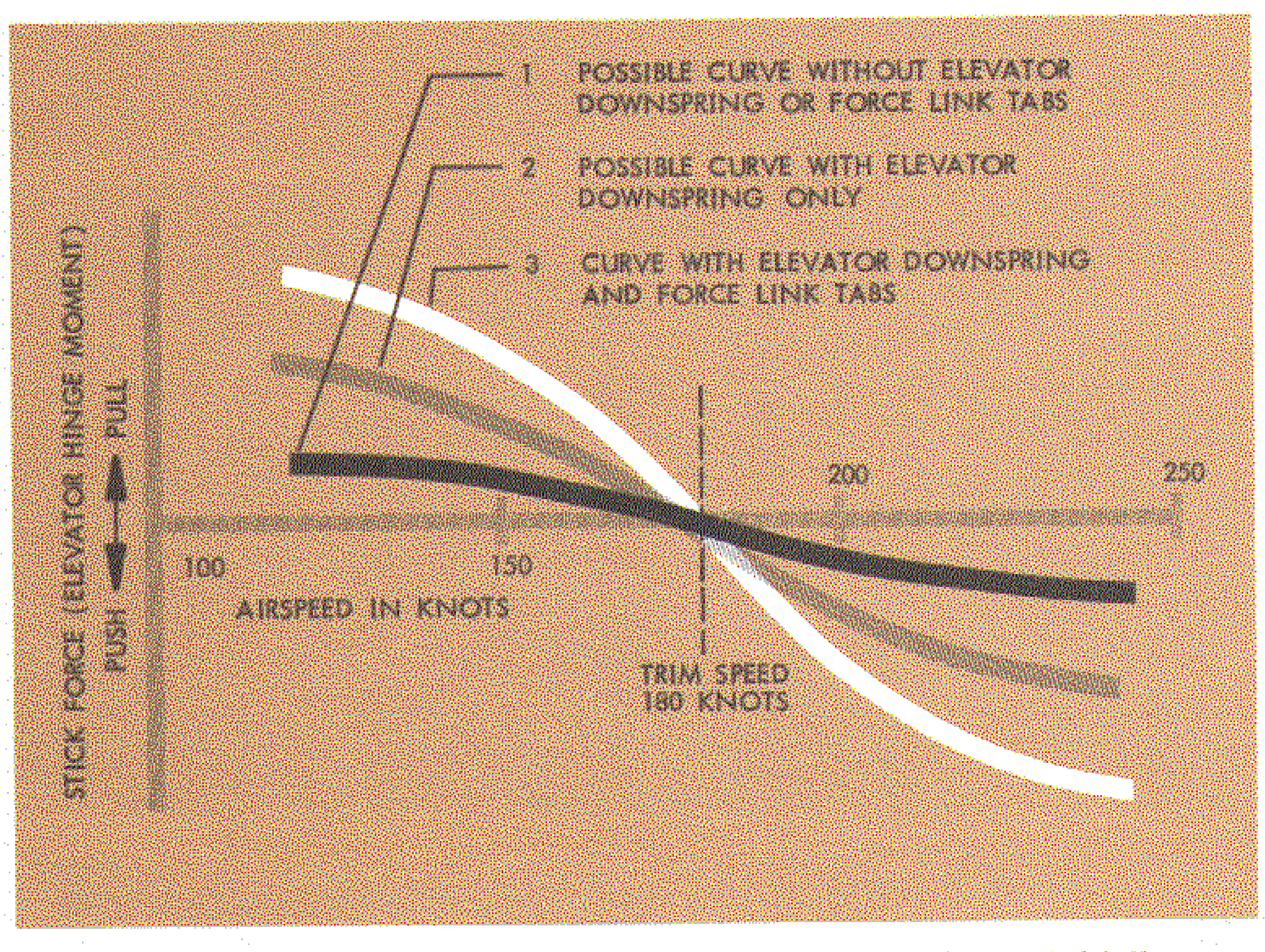


Figure 9 Graph Showing Stick-Force Characteristics When Initially Trimmed at 180 knots—Based on Orion Performance

movement and speeds are not necessarily factual and only serve to further the discussion.

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. At 280 knots and 360 knots the resultant up-elevator hinge moment has steadily increased (portrayed by size of arrows), but not enough to be representative of the conditions. At 400 knots the resultant up-elevator hinge moment has actually decreased slightly as the aircraft enters the tuck regime, and the pilot has had 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 aircraft of the Electra and Orion's specifications 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.

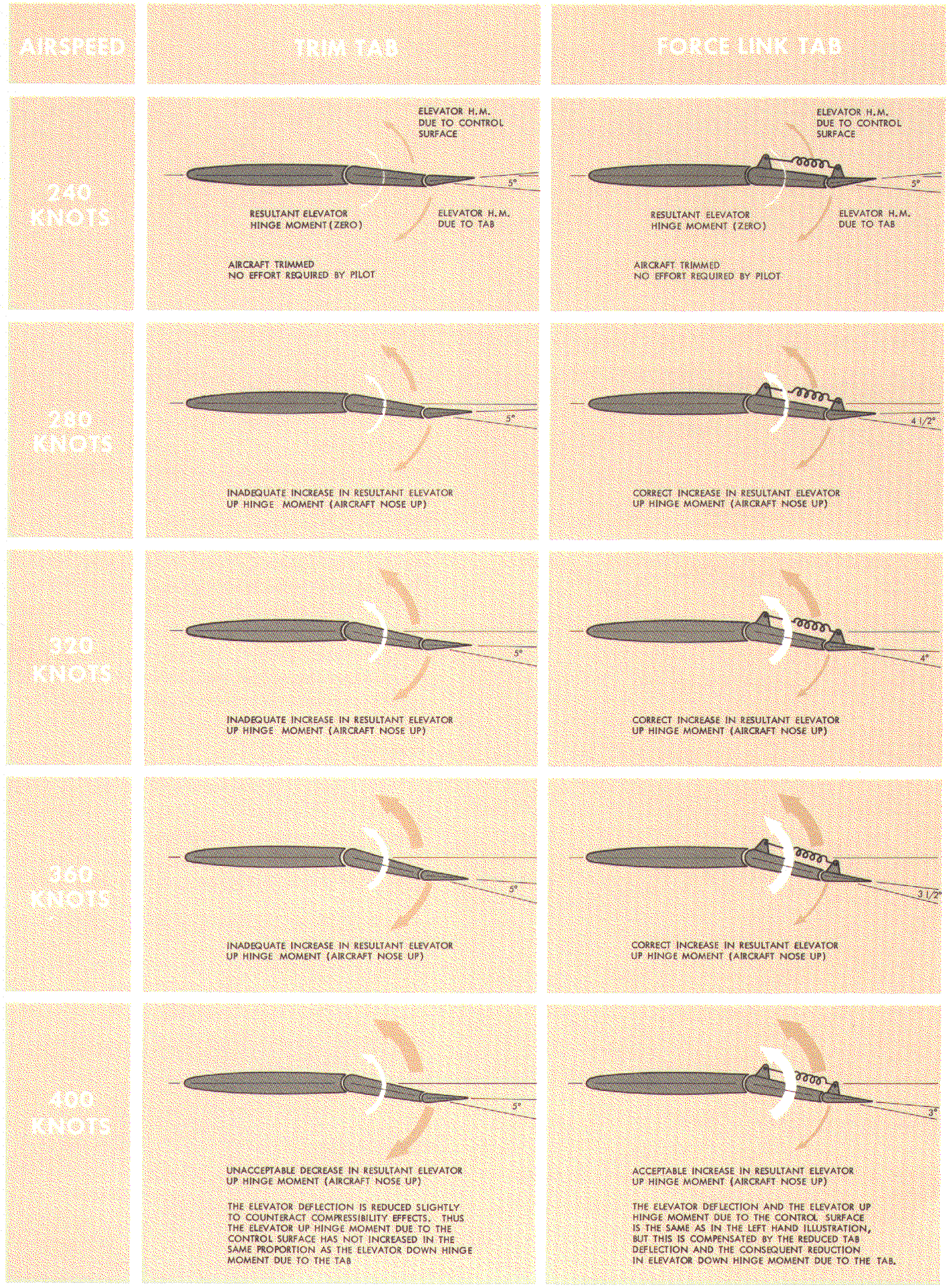


Figure 10 Effect of a Force Link Tab Compared with a Fixed Trim Tab at Different Airspeeds to show Force Link Tab Principle of Operation

The interconnection of the elevator tab controls on the Orion 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.

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 is 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.

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

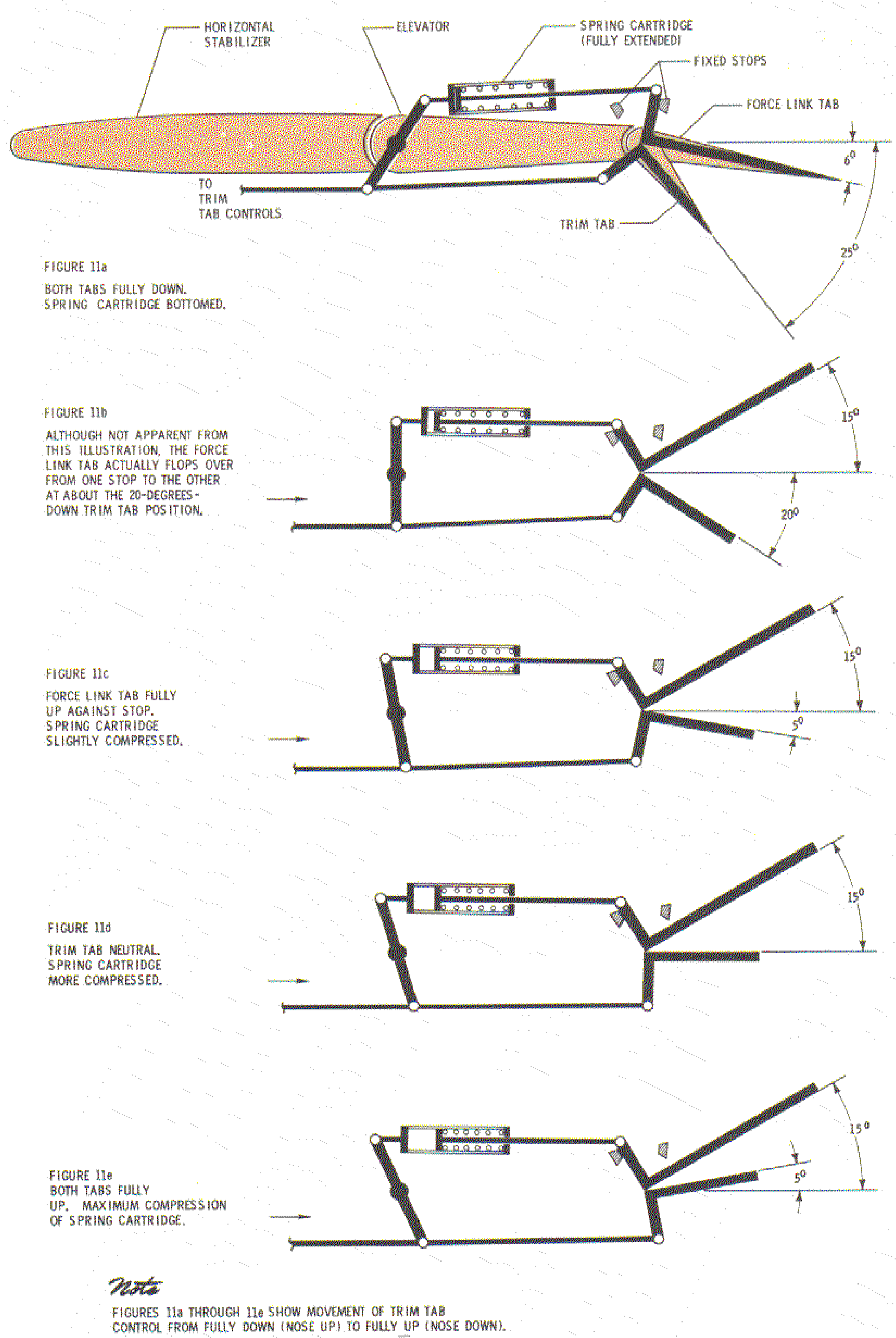


Figure 11 Basic Arrangement of Trim Tab and Force Link Tab Interconnecting Linkage

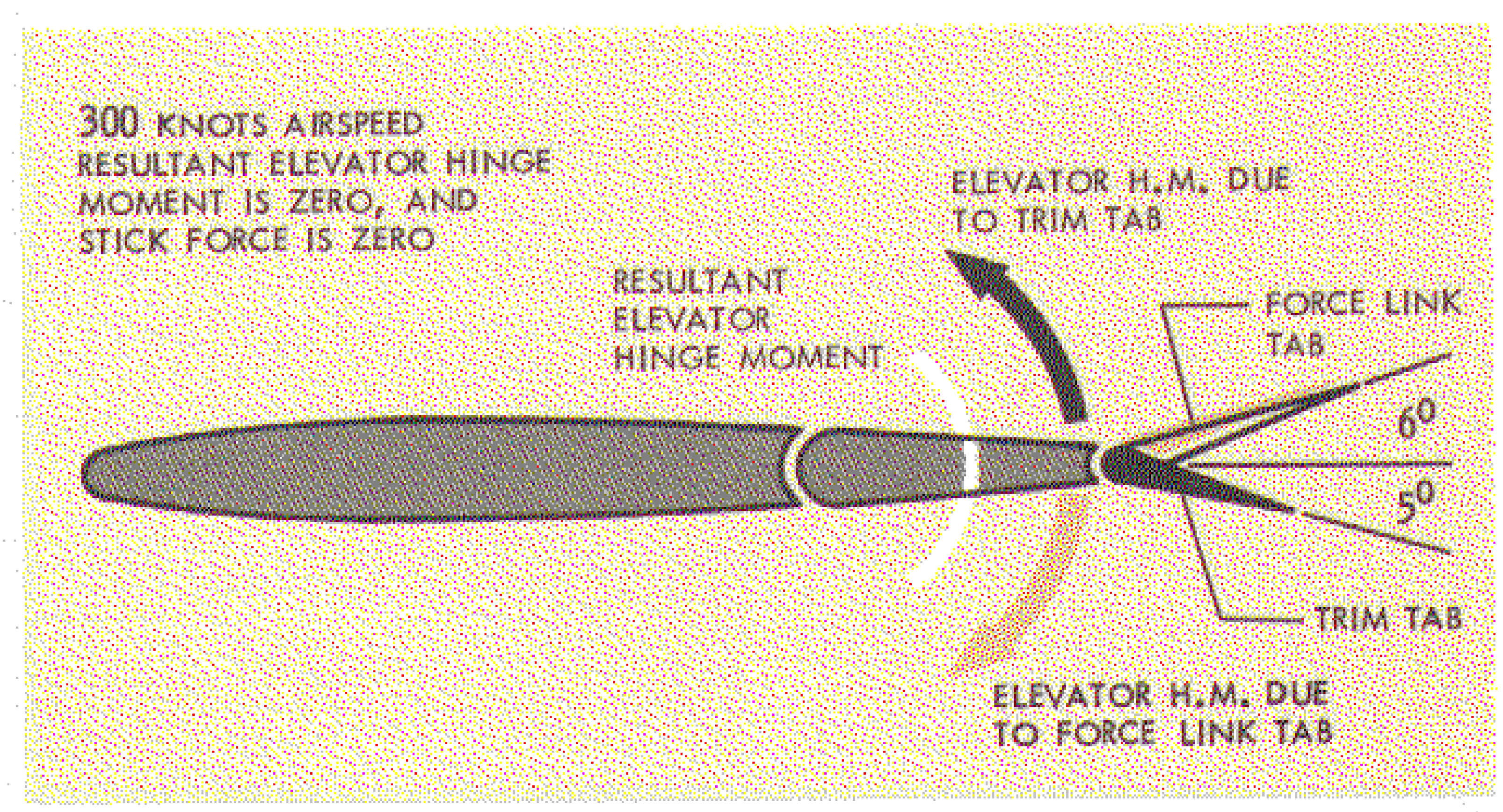


Figure 12a Interaction of the Trim Tab and Force Link Tab in Flight—Aircraft Trimmed at 300 knots

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

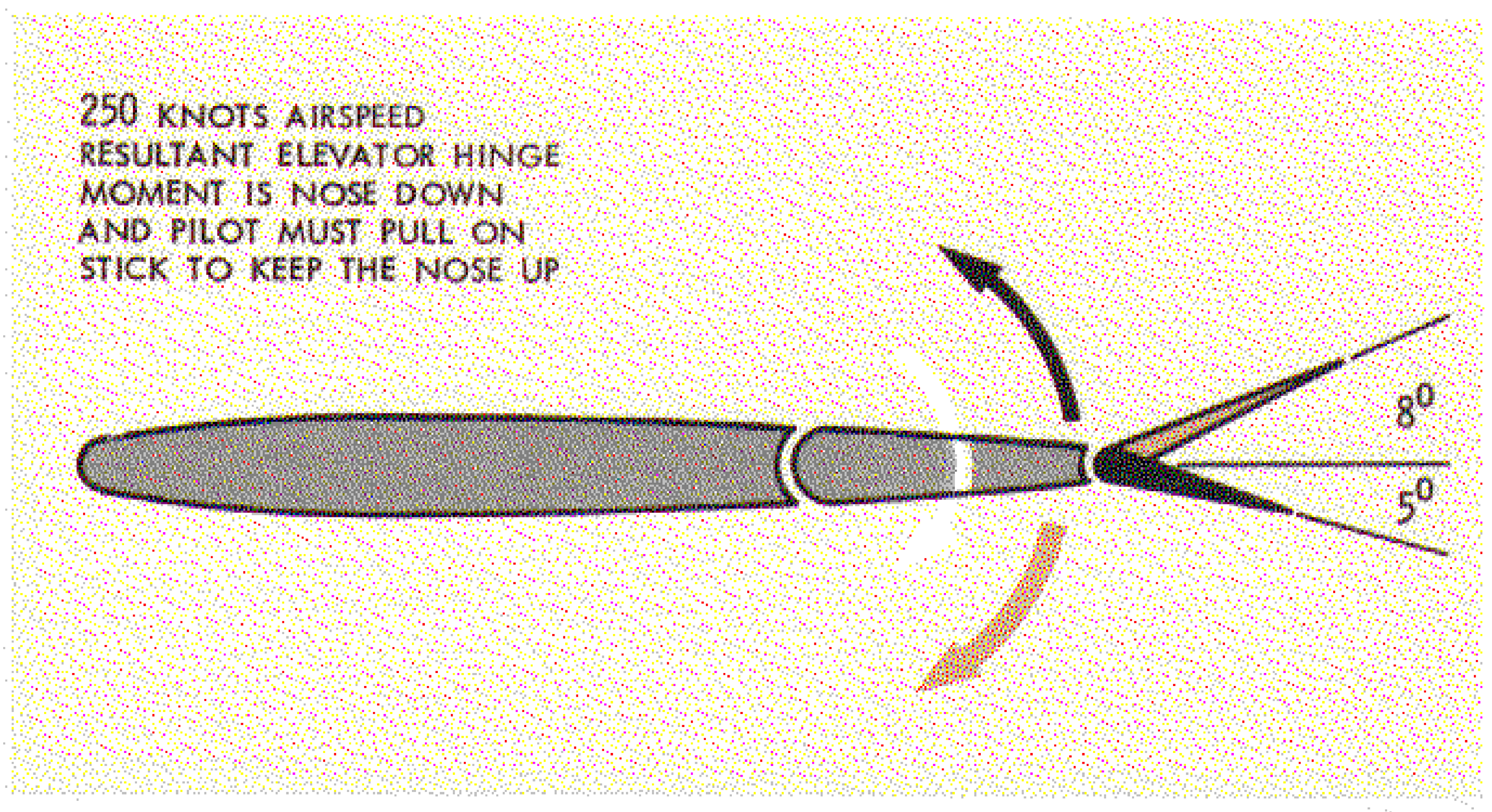


Figure 12b Airspeed Decreased to 250 knots

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.

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.

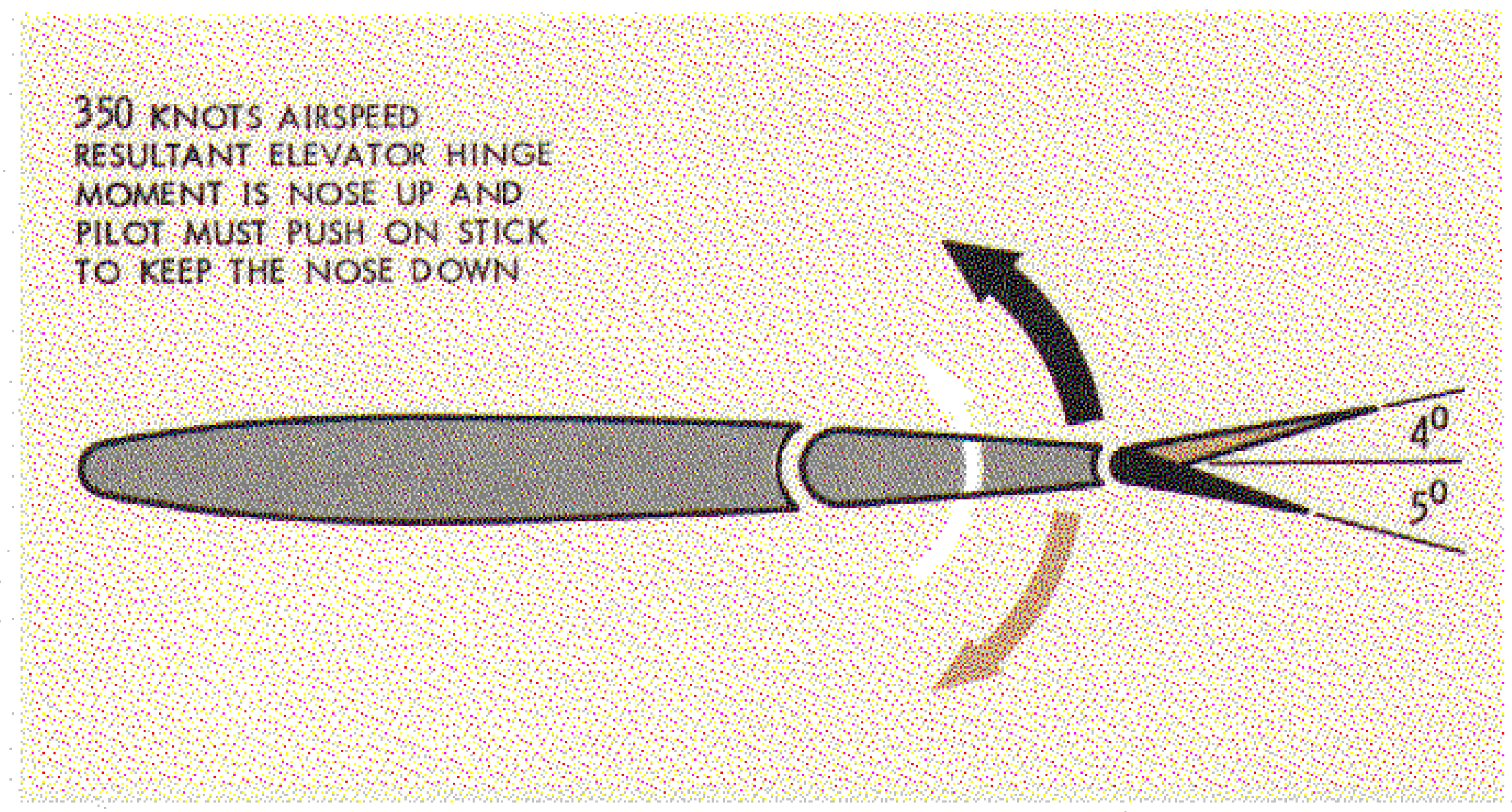
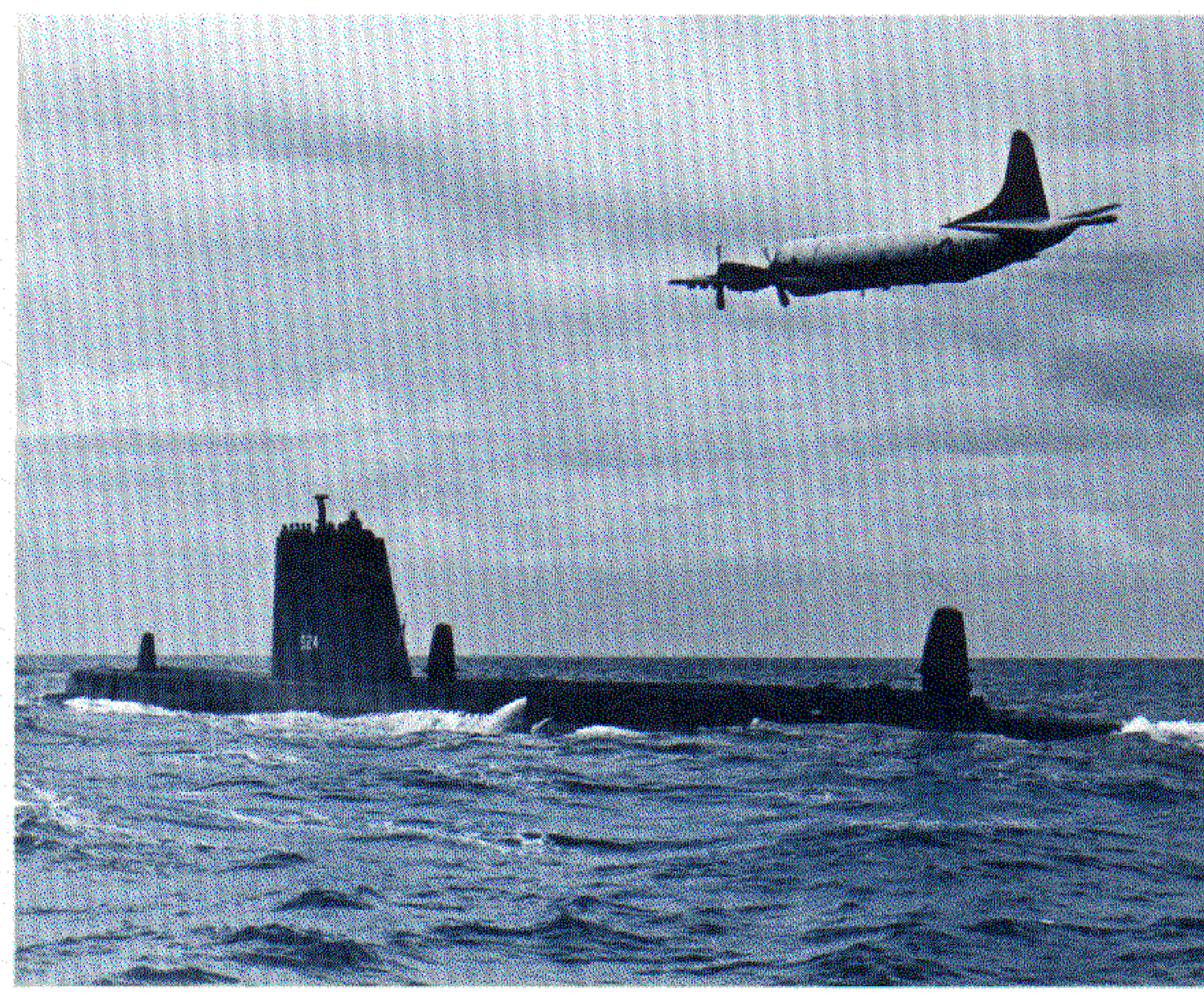


Figure 12c Airspeed Increased to 350 knots

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.



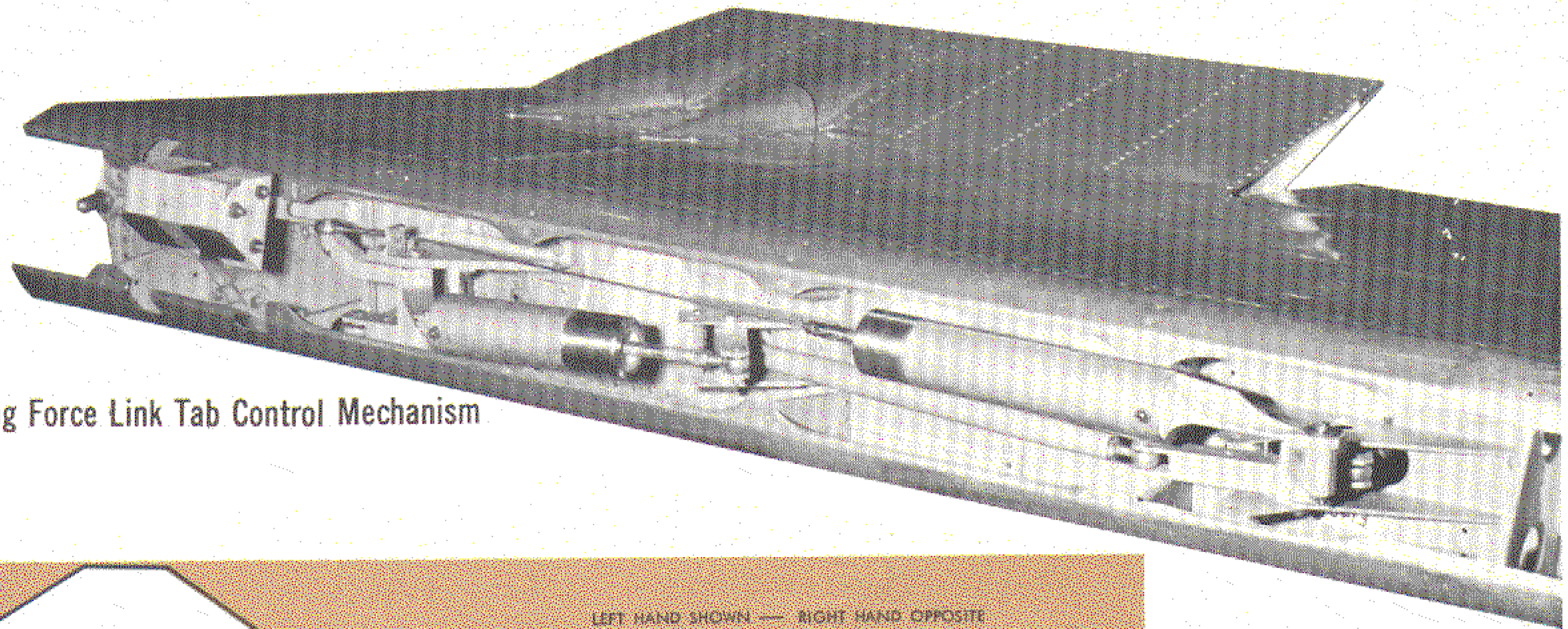


Figure 13
View of Elevator Showing Force Link Tab Control Mechanism

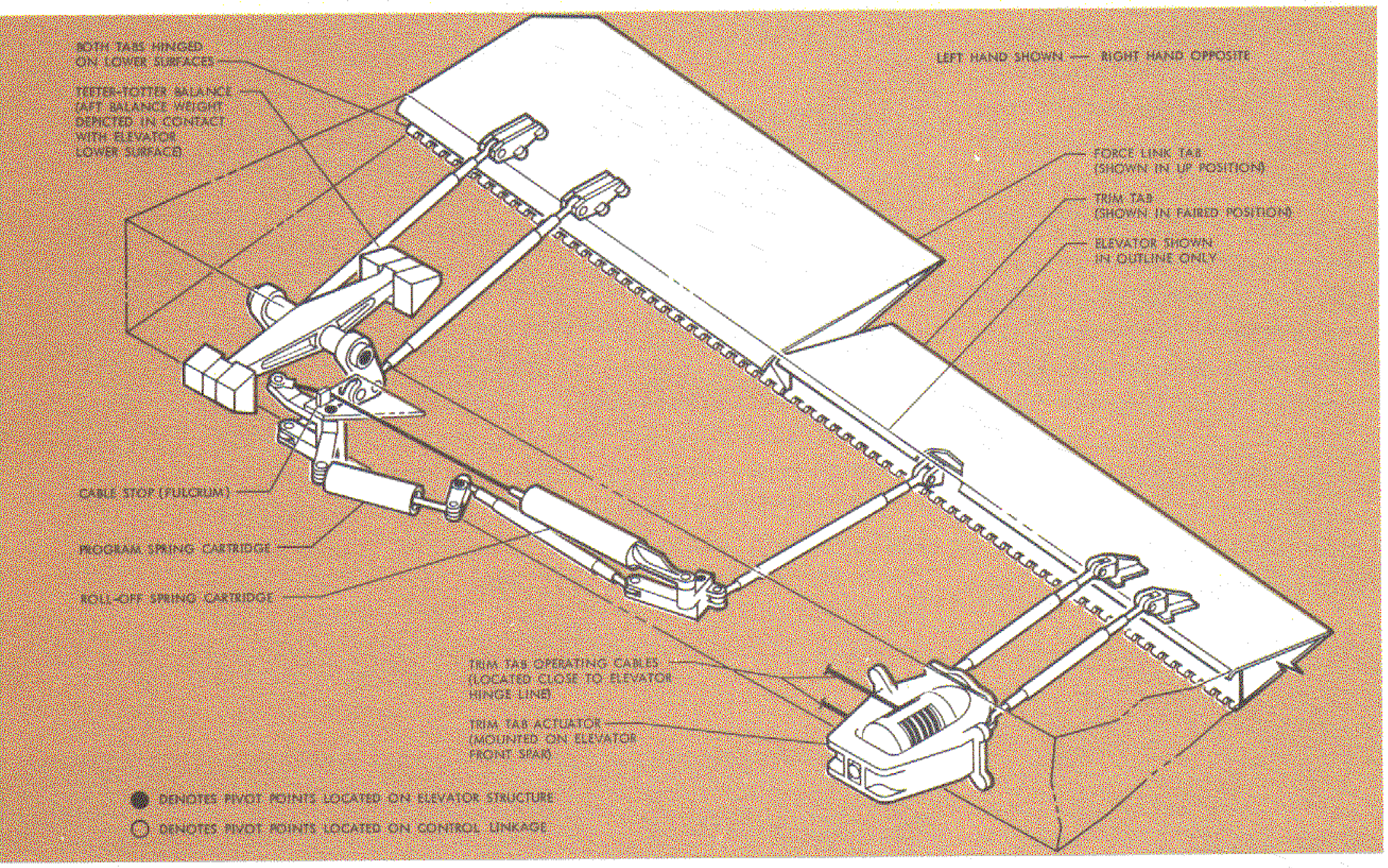


Figure 14
Schematic Showing
Trim Tab/Force Link Tab
Control Linkage

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.

The two extreme positions of the force tab linkage are shown schematically on Figures 16a and 16g 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 16 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 when the roll-off spring cable contacts the cable stop.

The roll-off spring cartridge improves the force tab characteristics in high-speed flight and reduces 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.

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 15. 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. It is worth a digression to explain this rather enigmatic 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.

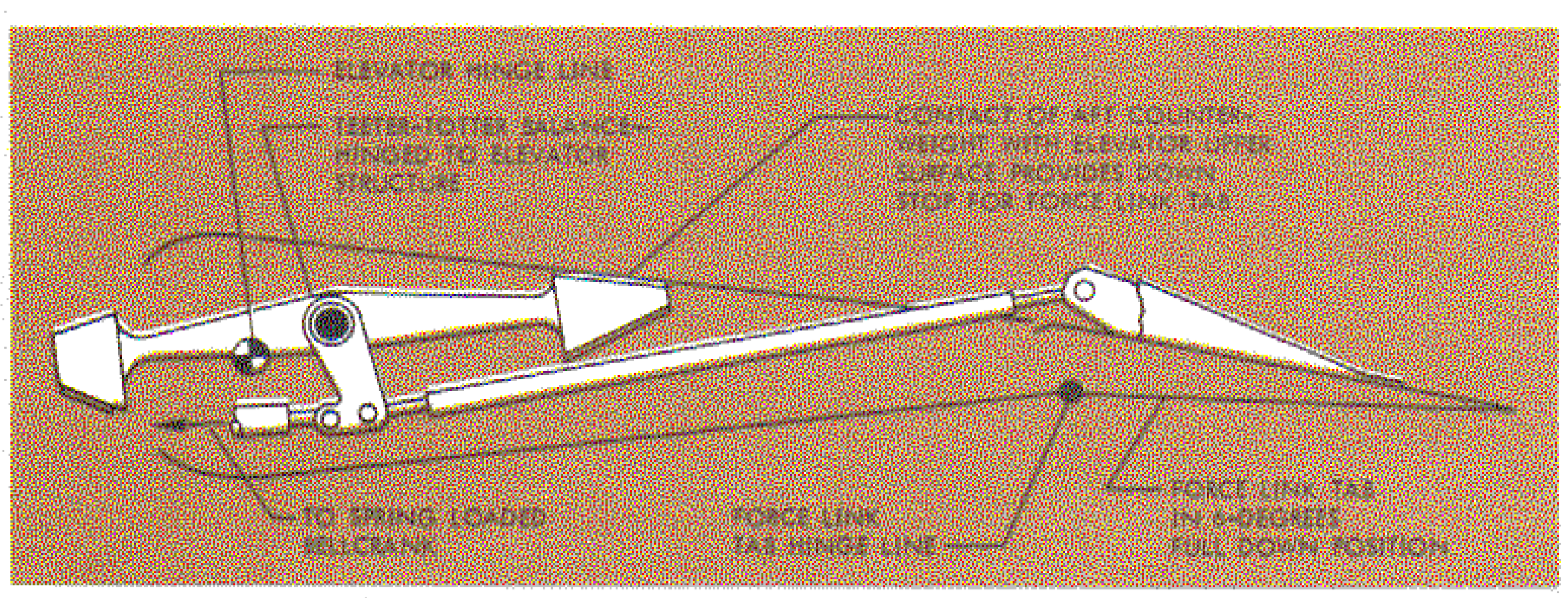


Figure 15 Section Through Elevator and Force Link Tab Showing Teeter-Totter Balance Weight

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 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 Orion 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 Orion—it is actually impossible. The Orion'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 16 Force Link Tab Rigging Summary, and Control Linkage Schematics showing Full-up (16a) and Full-Down (16g) Configurations

ABSTRACT

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.

Figure 16a shows the check points of the preliminary configuration that must exist (or be obtained by adjustment) before proceeding to verify force and travel. The ways and means to verify force and travel are illustrated in Figures 16 b, c, d, e, g, and h. Figure 16f shows means of altering spring force in Cartridge E, but note that the cartridge must be removed and disassembled, and a restraining fixture (described in the MIM) is required for safe disassembly.

The force link tab on each elevator is to be rigged separately, and forces and throws are to be verified separately. Since tolerances are allowed for both the force and the travel criteria, it is entirely possible and permissible that the maximum up and down movements of the left and right force link tabs differ by as much as 2 degrees and the hinge moments vary by twenty percent. To answer another query regarding the comparison of force link tab settings on the same airplane: the flop-over point for the left and right force link tabs can vary considerably due to peculiarities in the geometry of the linkage. Such variation is of no significance, however, as the force link tabs have little if any effect on elevator control when the trim tabs are within a few degrees either way of the 20-degrees down setting.

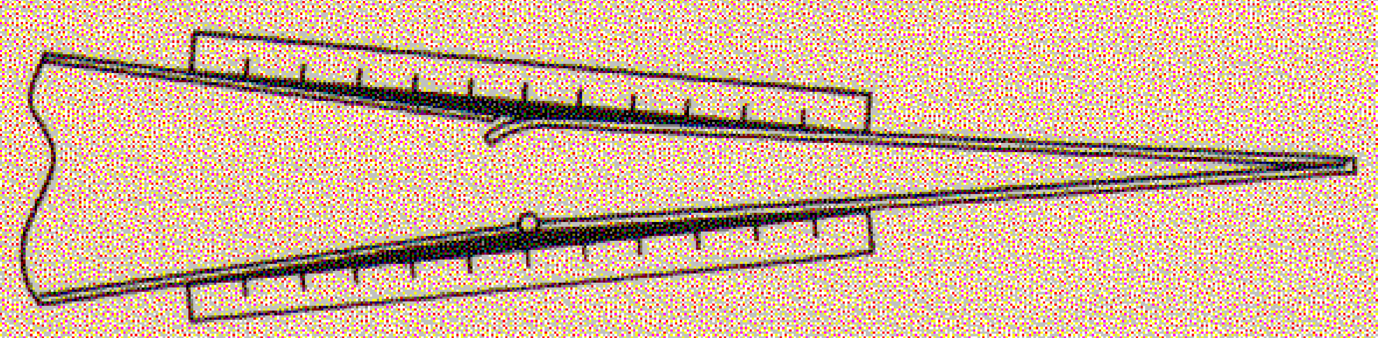
NOTE 1. Rigging cannot be accomplished or checked on the aircraft with the elevators in the down position. At this control setting the front counterweight of each teeter-totter balance can contact the stabilizer structure when the tab controls are moved towards up, and the full movement of the force 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. When removing and installing these cartridges, follow the step-by-step procedures in the MIM carefully to ensure against injury.

NOTE 3. Due to the difference in moment arm, the hinge moment test requirement for readings taken with "push" scale (Figure 16h) are higher than for readings taken with "pull" scale (Figure 16d) at the trailing edge of the force link tab.

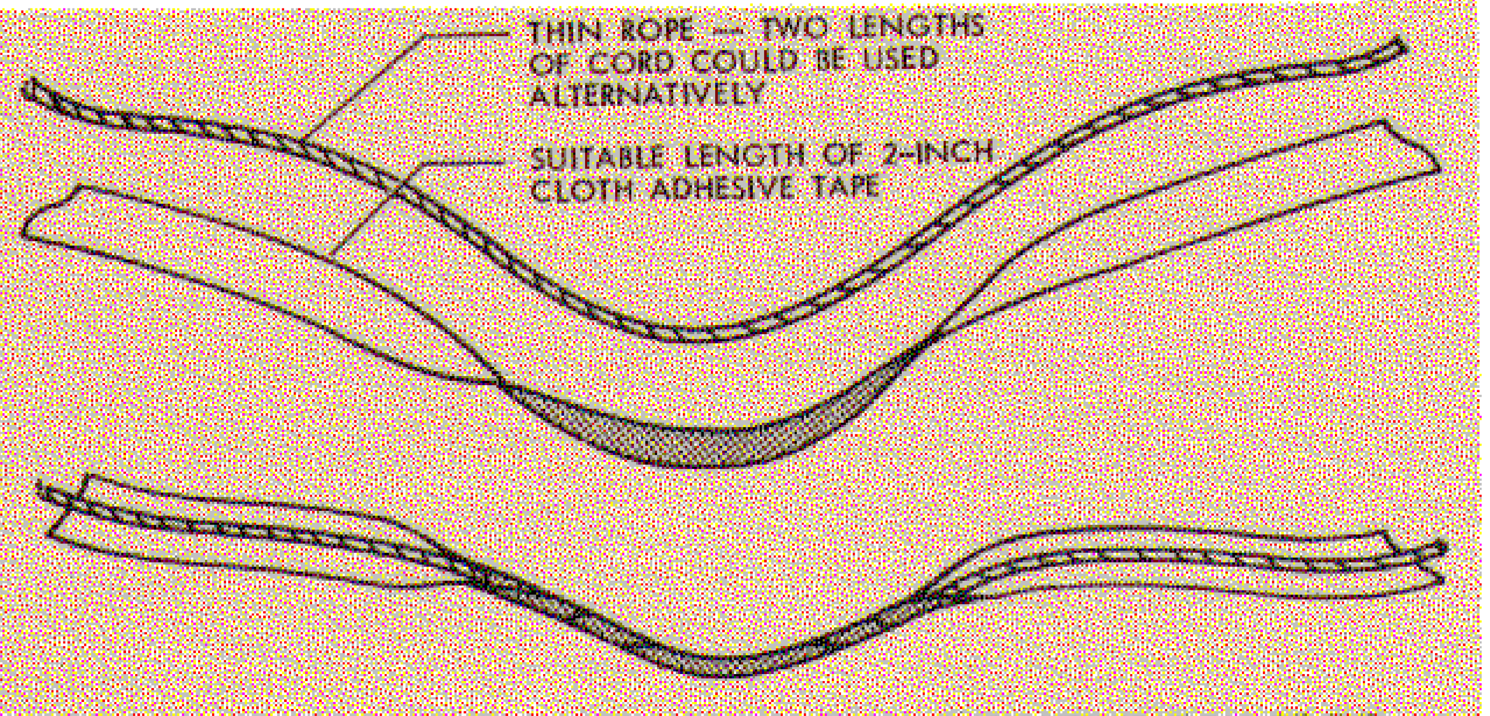
NOTE 4. Spring Cartridge E may be adjusted at overhaul by the addition of shims (P/N 830886-1). A maximum of 4 shims may be distributed between both ends of the spring to obtain the maximum starting load required in MIM overhaul-test instructions if this is necessary to satisfy the tab hinge moment requirement (see Figures 16d and 16h). If this maximum number of 4 shims does not restore the spring cartridge to the minimum starting load, a new spring should be installed.

FIGURE 16c DETERMINING FORCE LINK TAB FAIRED POSITION



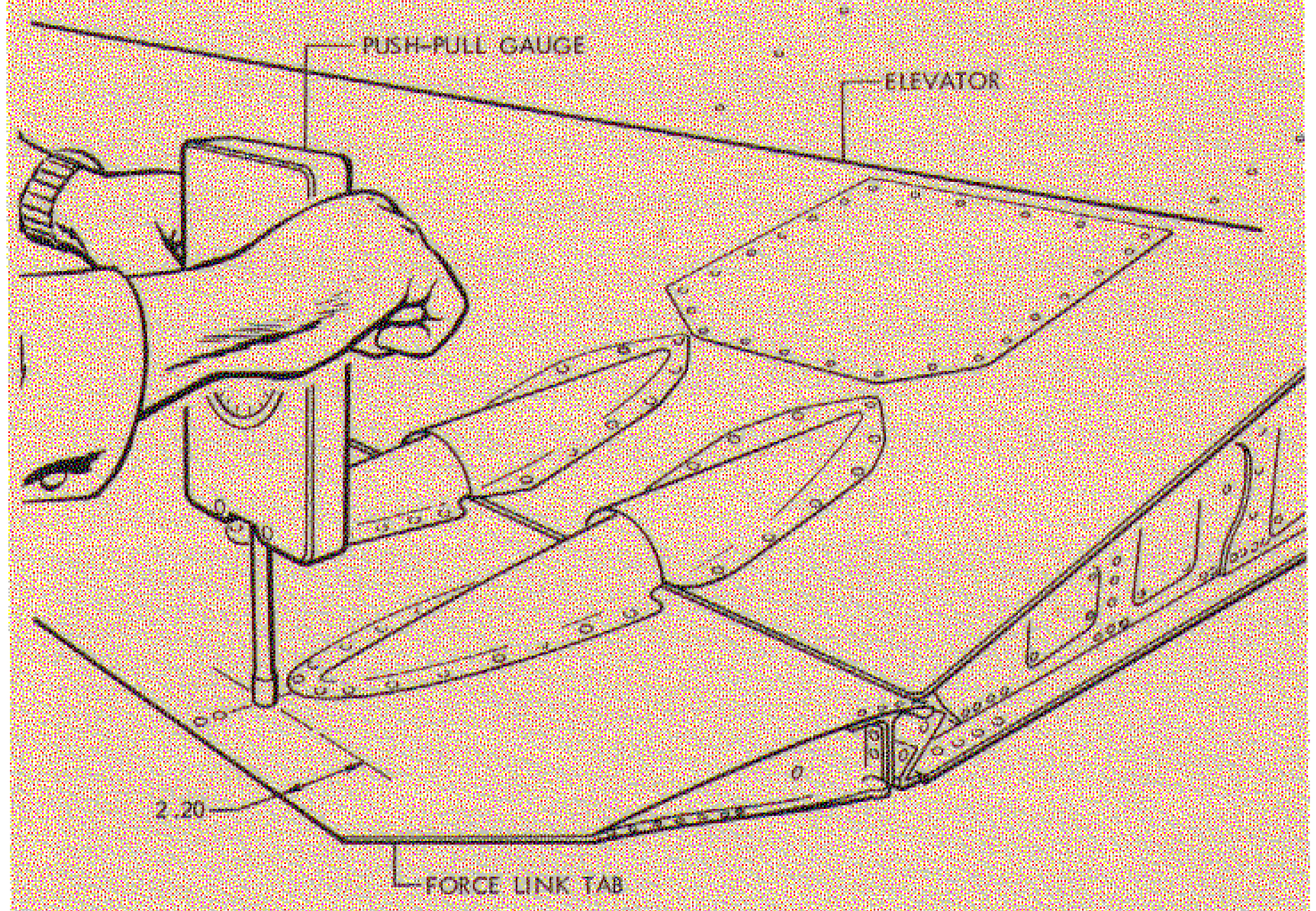
NOTE THAT, UNLIKE THE TRIM TAB, THE FORCE LINK TAB DOES NOT FOLLOW THE GENERAL AIRFOIL SECTION OF THE STABILIZER AND ELEVATOR. THE FAIRED POSITION OF THE FORCE LINK TAB (POSITION "A" ON FIGURE 16b) MAY BE DETERMINED BY APPLYING A 12-INCH STRAIGHT EDGE TO THE UPPER AND LOWER SURFACES AS SHOWN, AND VISUALLY CHECKING THAT THE GAPS (FILLED-IN IN BLACK) ARE EQUAL.

FIGURE 16e 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 16d FOR HINGE MOMENT CHECK.

FIGURE 16h FORCE LINK TAB HINGE MOMENT CHECK, ALTERNATE METHOD



1 TRIM TAB FAIRED

2 LOCATE POINT ON RIVET LINE AFT OF INBOARD PUSHROD FAIRING, 2.2 INCHES FORWARD OF FORCE LINK TAB TRAILING EDGE.

3 PROVIDE SKIN PROTECTION AT THIS POINT, CENTER PUSH-GAUGE ROD EXACTLY, AND PUSH FORCE LINK TAB DOWN TO FAIRED POSITION

4 GAUGE SHALL READ BETWEEN 43 AND 54 LBS (NOTE THAT FORCE READING IS HIGHER THAN IN 16d, DUE TO 2.2 INCH SHORTER MOMENT ARM)

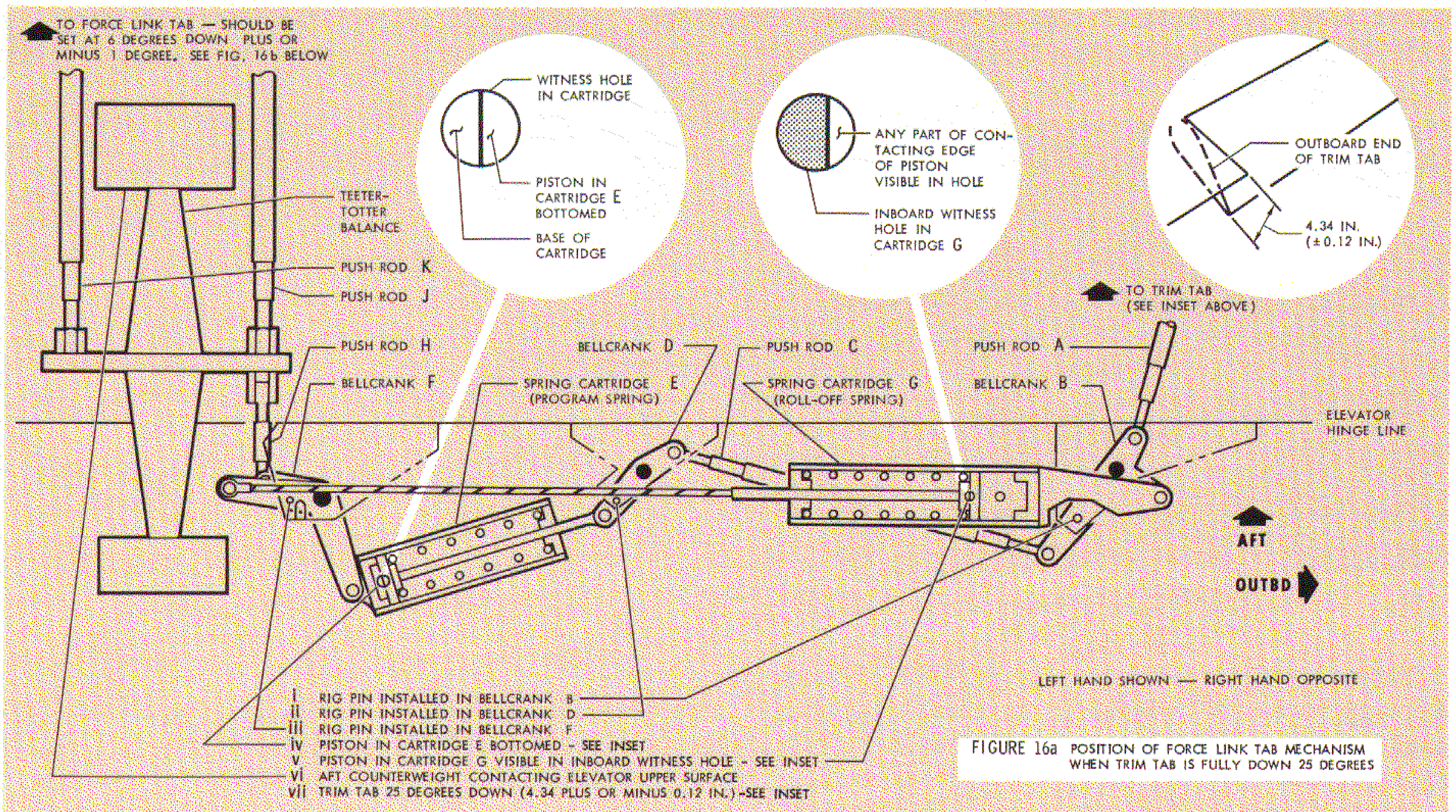
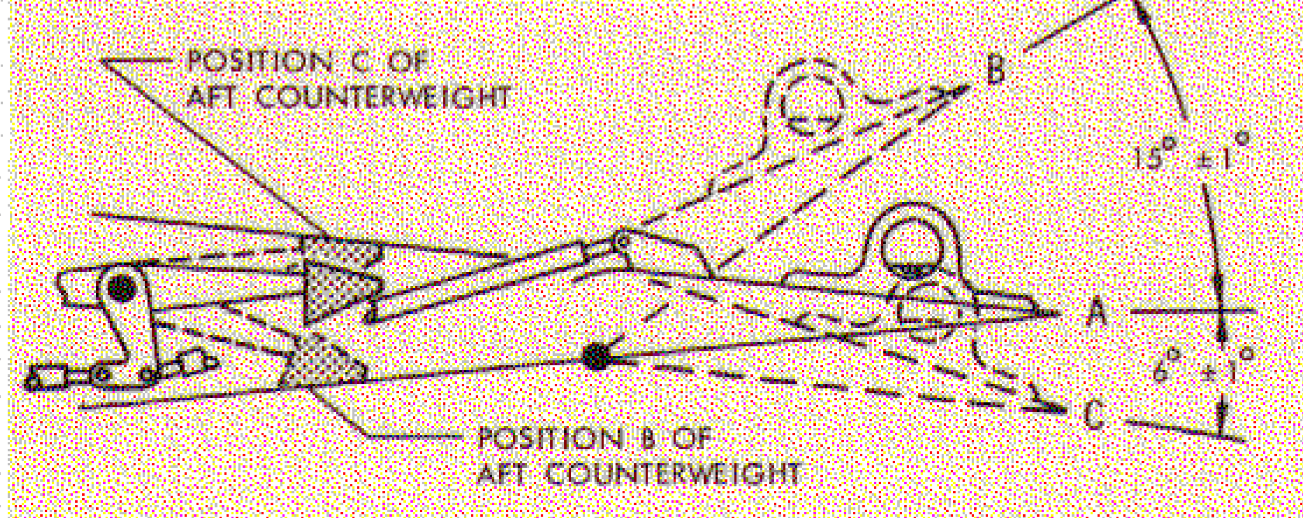


FIGURE 16a POSITION OF FORCE LINK TAB MECHANISM WHEN TRIM TAB IS FULLY DOWN 25 DEGREES

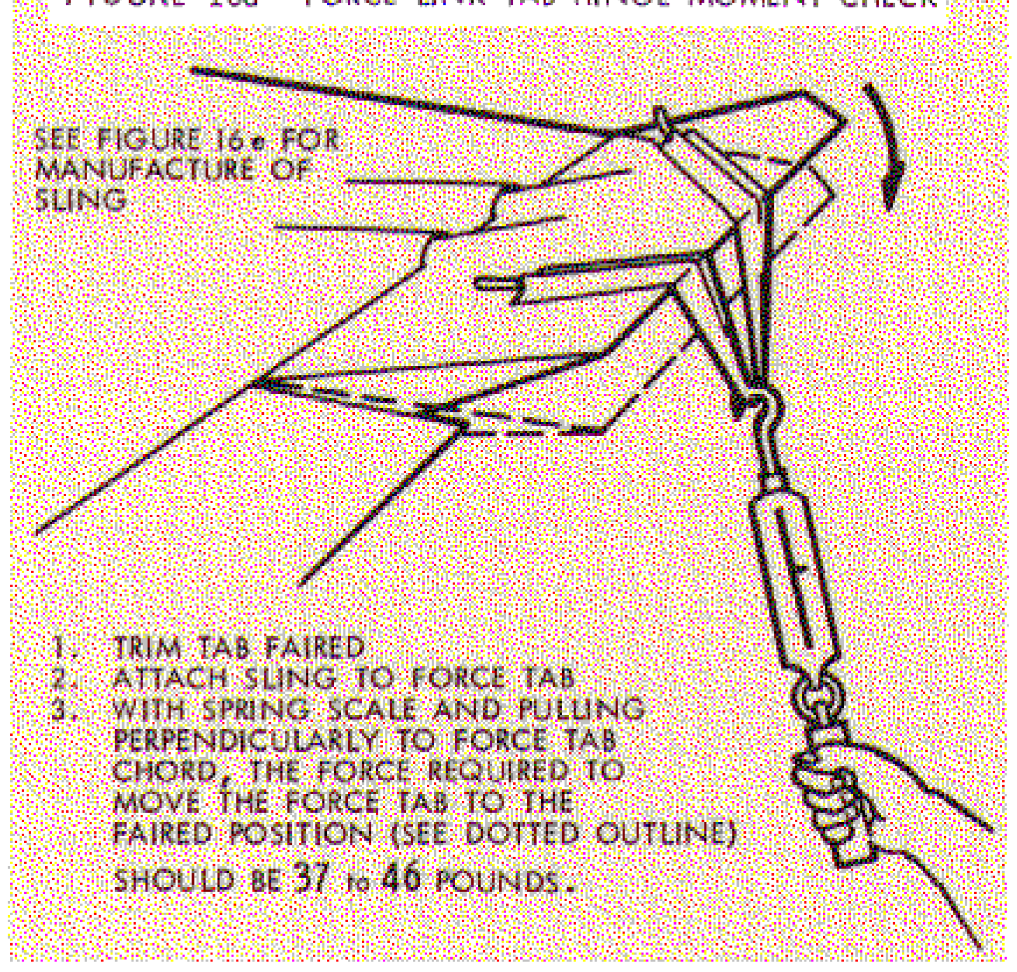
FIGURE 16b FORCE LINK TAB ANGULAR MOVEMENT



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 16d)
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

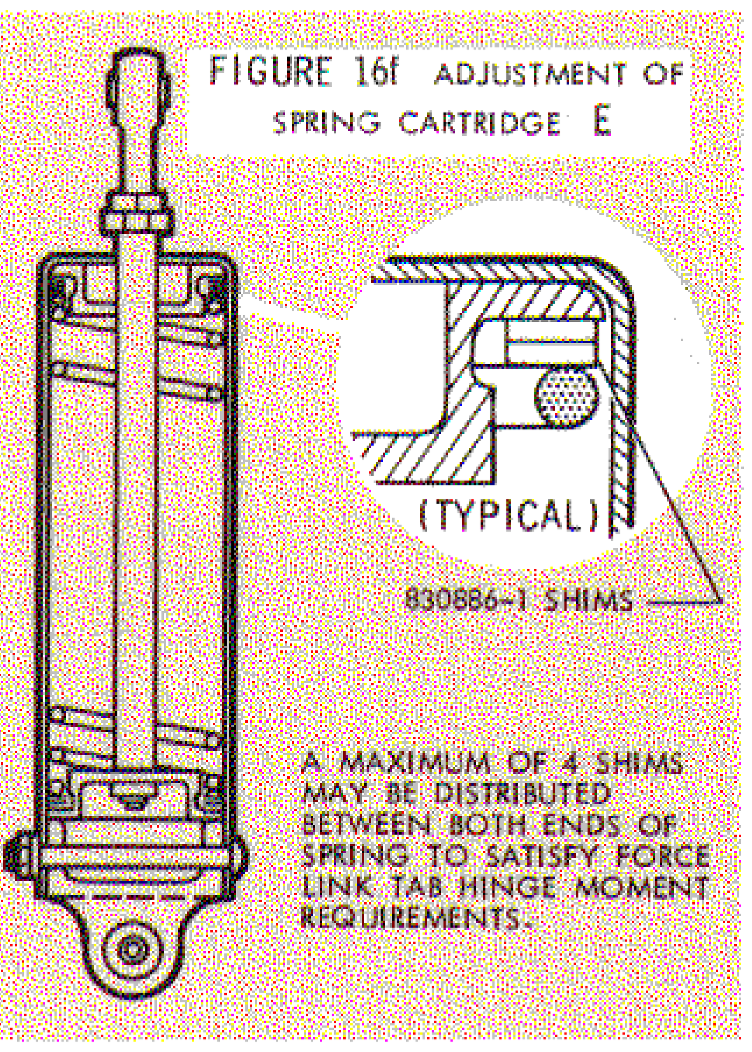
FORCE TAB UP MOVEMENT (B MINUS A) SHOULD BE 15° ±1°.
FORCE TAB DOWN MOVEMENT (C MINUS A) SHOULD BE 6° ±1°.

FIGURE 16d 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 16f ADJUSTMENT OF SPRING CARTRIDGE E



A MAXIMUM OF 4 SHIMS MAY BE DISTRIBUTED BETWEEN BOTH ENDS OF SPRING TO SATISFY FORCE LINK TAB HINGE MOMENT REQUIREMENTS.

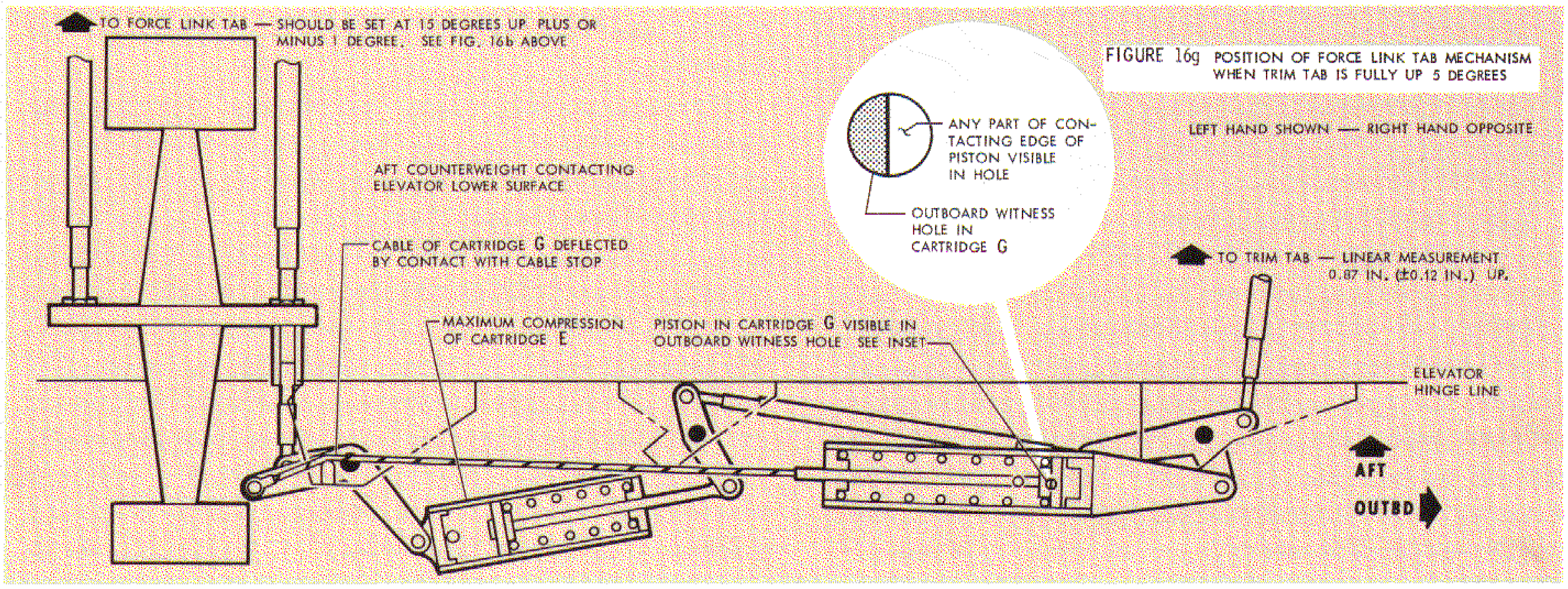


FIGURE 16g POSITION OF FORCE LINK TAB MECHANISM WHEN TRIM TAB IS FULLY UP 5 DEGREES

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

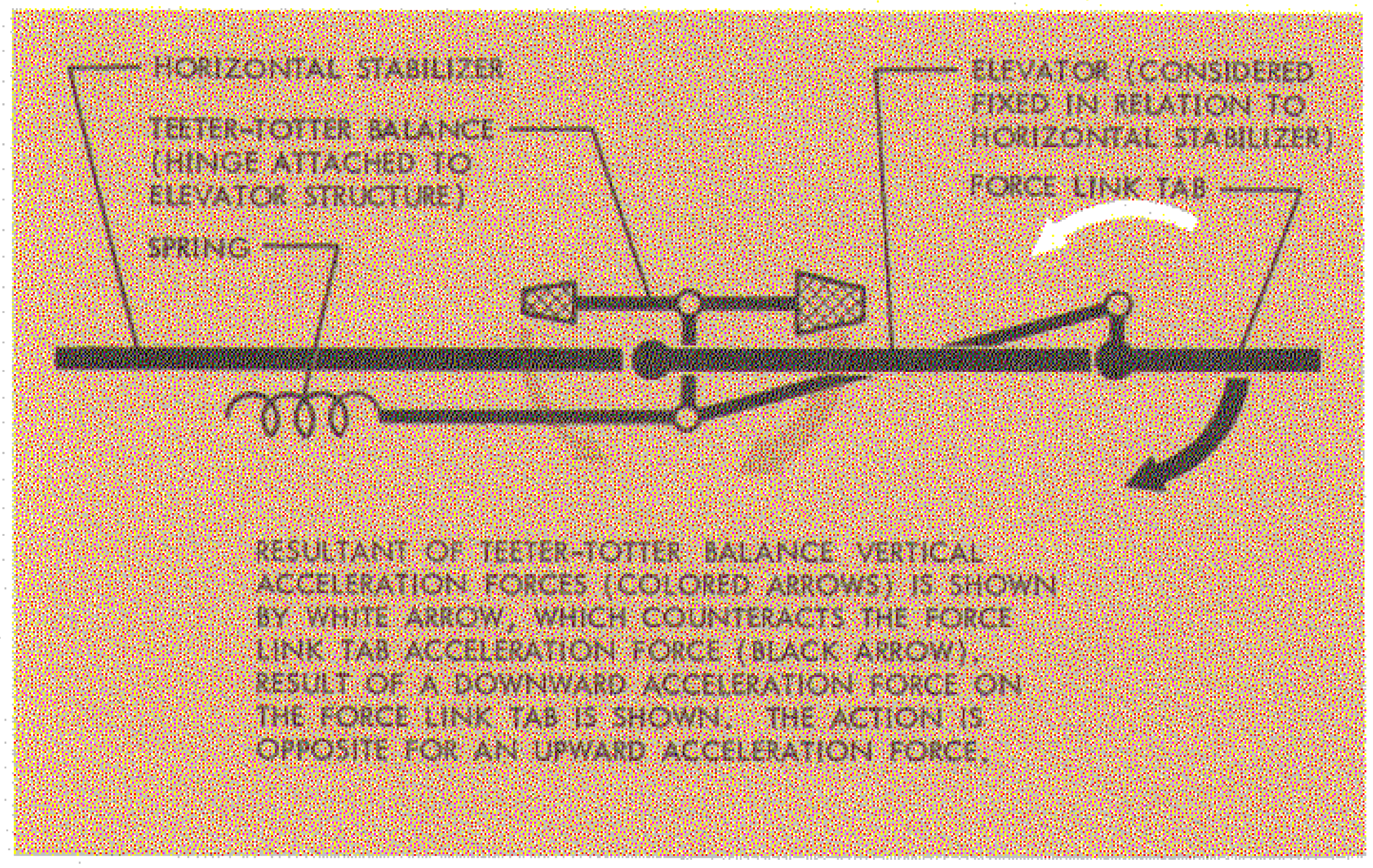


Figure 17a Action of Teeter-Totter Balance in Achieving Static Balance for the Force Link Tab

the same direction. Assuming the elevator remains stationary about its hinge line, the force link tab, subject to a downward acceleration force, has a tendency to rotate clockwise about its hinge line against the action of the spring. 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.

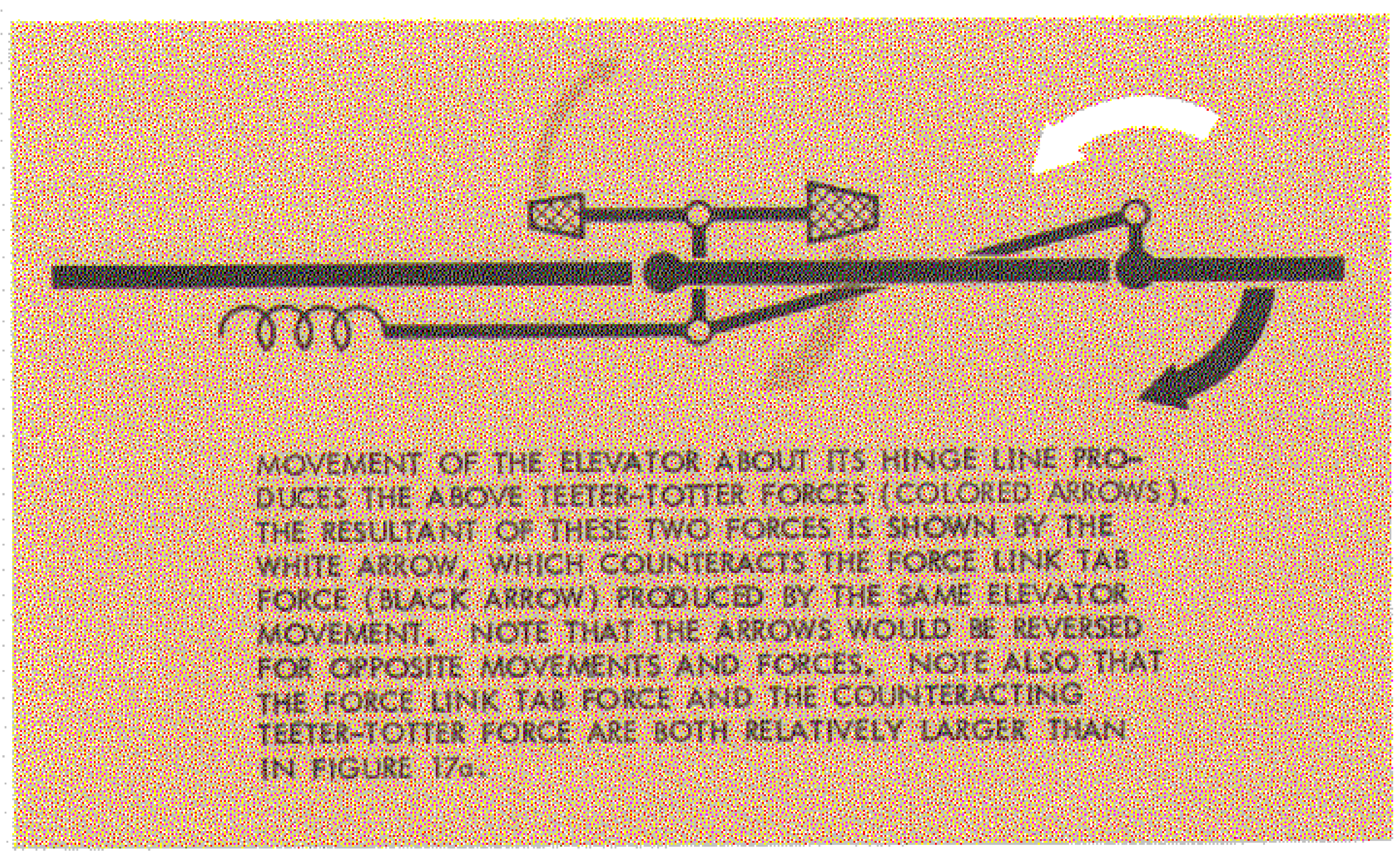


Figure 17b Action of Teeter-Totter Balance in Achieving Dynamic Balance for the Force Link Tab

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.

FORCE LINK TAB RIGGING. 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 in the past indicated 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 16 for information purposes only. When actually rigging these devices, reference should of course be made to the pertinent section of the Maintenance Manual (NAVWEPS 01-75PAA-2-2).

This is also a convenient point in this discussion to re-emphasize the importance of adhering to the recommended operating procedures contained in the NATOPS Flight Manual. Specifically, we would like to point out the setting of the elevator trim tabs prior to take-off, and the operation of the hydraulic pumps (all three should be operable and ON for take-off).

Deviations from these procedures can lead to elevator control difficulty being experienced during gear retraction after take-off. For example, flight tests have determined that, with only one hydraulic pump operating, and with an initial trim tab setting varying by as little as ten degrees from the take-off setting it is possible for stick forces to increase from 40 pounds prior to gear retraction to over 100 pounds during gear retraction. Perhaps this is an exceptional example, but it 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. ▲ ▲

The Lockheed Product Support Organization

W. J. Wayman, Director

W. A. Marco, Asst. to Dir.

Support System Planning . . . I. L. Larson
F-104 Support System Mgmt. . . E. V. Whaley
P-3 Support System Mgmt. . . M. Foster

CUSTOMER SUPPLY DIVISION . . . J. D. Campbell, Manager

Commercial Projects Dept. . . . . W. C. Russell
Navy Projects Dept. . . . . . M. Foster
USAF and F-104 Projects Dept. . . W. W. Peirce
Technical Supply Dept. . . . . W. C. Bowden
Stores and Shipping Dept. . . . . W. M. Lowe
Supply Control Dept. . . . . . J. T. Nibley
Supply Administration Dept. . . . E. Scott
Contract Logistics Dept. . . . . F. E. Stockman

CUSTOMER SERVICE DIVISION N. M. Harrison, Manager
T. E. Mason, Asst Mgr.

Transport Projects Dept. . . . . . R. G. Richards
Patrol Projects Dept. . . . . . . C. R. Pittman
F-104 Projects Dept. . . . . . . G. E. Bentley
Maintenance Training Dept. . . . . J. P. Bartz
Service Administration Dept. . . . . H. R. Keatley

SERVICE REPRESENTATIVES, P-3 ORION

LOCATION	NAME	MAILING ADDRESS	TELEPHONE
Patuxent River NATC, Maryland	D. H. Horadam, Regional Rep.	P.O. Box 218, NATC Patuxent River, Maryland 20670	Volunteer 3-3111 Ext. 645 or 251
Patuxent River NATC Maryland	F. Hampton, Resident Rep.	P.O. Box 218, NATC Patuxent River, Maryland 20670	Volunteer 3-3111 Ext. 645 or 251
Norfolk NAS, Virginia	A. Barber, Resident Rep.	P.O. Box 8127, Ocean View Station Norfolk, Virginia 23503	622-8211 Ext. 2685
Jacksonville NAS, Florida	J. Gipson, Resident Rep.	P.O. Box 1300, Yukon, Florida	389-7711, Ext. 8731 NAS Jacksonville
Key West NAS, Florida	S. Brown, Resident Rep.	P.O. Box 1087, Key West, Florida 33040	294-4417, Key West
Moffett Field NAS, Calif.	F. Hays, Resident Rep.	Lockheed P-3A Office Unit One P.O., General Delivery Moffett Field, Calif.	967-6961 Mountain View, California
North Island NAS, San Diego	R. B. Hedin, Resident Rep.	P.O. Box 525 Coronado, California 92118	435-6611, Ext. 1272 Coronado, Calif.
Honolulu, Hawaii	R. C. Spooner, Regional Rep.	Navy 14, P.O. Box 409 FPO San Francisco, Calif.	430-66126
Honolulu, Hawaii	T. Snelling, Resident Rep.	Navy 14, P.O. Box 409, FPO San Francisco, Calif.	430-64257
Burbank, California	R. E. Kananen, Supervisor P-3 Project, Customer Service	Lockheed-California Company P.O. Box 551, Burbank, California 91503	Thornwall 2-9151 or Triangle 7-2711 Ext. 4628 or 4307

ERRATA

It has come to our attention that Pg. 19 of Orion Service Digest Issue 9 contained an error under the heading "CLEARING ARTIFICIALLY INDUCED ASYMMETRY TRIPS." The eighth line of type under that heading, *"close (push in) L & R BK FLAP circuit breaker,"* should be moved to the 14th line (which begins "outer shaft. — —") and the paragraph should conclude:

> outer shaft. Close L & R BK FLAP circuit breaker. (If the brakes trip again at this point in the procedure, there is a malfunction in the flap drive or the asymmetry system. Reset the system as outlined under "Clearing Fault Induced Asymmetry Trips.")

Those readers who maintain a file of Digests are urged to paste the above clipping over the latter part of this paragraph in their copy of Issue 9, and to obliterate the 8th line.

LOCKHEED CALIFORNIA COMPANY · A DIVISION OF LOCKHEED AIRCRAFT CORPORATION