# Air Superiority with Control Configured Fighters

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**Potential benefits that accrue to air superiority fighters by integrating automatic feedback control system technology into the design have been studied using the F-4 as the baseline configuration. Configuration changes and reduced static stability margins were investigated along with the use of unconventional control surfaces. Results indicate that reductions in trim drag from reduced tail-off static stability are significant at maneuvering load factors. Maneuverability improvements are achieved by reduction in drag and structural loads, and by improved controllability. These concepts enhance air superiority, and by application throughout the design can result in a smaller, lighter, and more economical fighter.**

## Introduction

THE purpose of fighter aircraft is to achieve and maintain air superiority. This is realized and maintained by having the best pilots flying the best aircraft and by having the best support organization. Best means simply that each element is better than that of all the possible adversaries. The fighter aircraft must be superior to the threat in those areas of performance and handling qualities which are pertinent to combat. These areas have been quantified in the theory of energy maneuverability which identifies certain parameters, such as specific excess power, as the measure of combat performance. When the capabilities of the threat in these same areas are known, they can be used to specify the requirements and define the parameter values to be designed into a new superiority fighter.

Whatever the required level, however, achieving superiority in competitive design, just as achieving superiority in the area of combat, requires total dedication. Full advantage must be taken of all potential sources for attaining air superiority. One such potential source is the development of a configuration design which exploits total capabilities of control system technology, popularly termed Control Configured Vehicle (CCV), or in the case of the fighter, Control Configured Fighter (CCF). The basic control system is, of course, an integral part of an aircraft, and when all the characteristics and potential of a feedback primary control system are considered during the configuration definition, additional performance advantage, in particular, combat performance advantage, may be realized. If the fighter is designed such that the control system can provide performance augmentation, or more specifically, combat performance augmentation, then air superiority will accrue to the Control Configured Fighter over the conventionally designed fighter.

The question then is, how can control system technology maximize the total design efficiency and thereby enhance the combat performance of the air superiority fighter? What can the control system augment beyond stability augmentation? Studies to provide answers to these queries have been performed at McDonnell Aircraft Company (MCAIR) for the past year, using the data base of the F-4 as the base point for the investigations. Some interesting conclusions have been reached to date. One conclusion is that skillful application of CCV principles can provide a drag reduction. The possible drag reduction is most significant at high load factors (high values of lift coefficient) and is therefore of benefit to specific excess power in air-to-air combat maneuvers. Another significant result is that CCV can enhance the maximum attainable load factor (the maximum useable lift coefficient) at both subsonic and supersonic Mach numbers. Benefits have been found to exist in areas of the flight envelope where the maneuverability is limited by control effectiveness or by stability and control characteristics.

To derive the most from these benefits, CCV has to be designed-in, rather than added-on. It is really a matter of accounting for and exploiting the capabilities of control system technology applied to the control augmentation primary flight control system as the design decisions are made.

If the capabilities of the automatic flight control system can be anticipated in the preliminary design phase, the drag and maneuverability benefits can be traded-off for smaller engines and smaller wings resulting in a smaller, lighter and more economical fighter. Stated simply, integration of the control system in the conceptual design stages of aircraft configuration will assure that the minimum sized vehicle is achieved with maximum performance benefits. Throughout this CCV design process, the active control system must be relied upon to the same extent, and with the same confidence as a primary structural component. Even though this CCV design concept is new, it is still conventional in approach and within the state-of-the-art, in that it is based on proven techniques already in use in the design of high performance fighter aircraft, spacecraft, and missiles.

## CCV Concepts

There are several CCV concepts, four of which have been identified as applicable to the air superiority fighter. They are the concepts of reduced static margin, maneuver load control, control augmentation with blended controls, and active flutter control. Reduced static margin is simply the use of the automatic flight control system to substitute for static longitudinal stability, $Cm_\alpha$. Maneuver load control is the use of automatically controlled aerodynamic devices on the wing to modify the spanwise loading on the wing in a maneuver, in order to relieve limits on the maneuvering load factor or angle of attack and thus augment the maneuverability. Control augmentation with blended controls is the use of the automatic flight control system to improve the response of the airplane to cockpit control motion, about all axes, particularly at high angles of attack, in order to relieve limits on maneuverability based on control response characteristics. Active Flutter Control is the use of feedback control of aerodynamic surfaces to suppress flutter and reduce the weight required for passive flutter control.

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The concept of reduced static margin is concerned directly with the performance and maneuverability compromises associated with airplane balance and static longitudinal stability. There are always design compromises forcing the c.g. to move aft, and aft limits must be observed to maintain acceptable handling qualities. These aft limits have always accounted for the control system characteristics; witness the concern with stick-free stability, and the frequent use of downsprings, bobweights, and all the bag-of-tricks in feel system arrangements. If now the automatic flight control system becomes a full-time function, it will allow a further aft balance limit. The control surface fixed limit will be relieved, and the aft limit will be based on controllability with a moving control surface. This, then, can be explored for possible benefits to the airplane's performance.

A maneuver load control system is one which employs control surfaces and an automatic control system to modulate the loads on the wing in maneuvers involving acceleration normal to the flight path. For the fighter, the candidate loads for modulation are buffet and drag due to lift. The concept defined for providing maneuver load control in the large aircraft is aimed at minimizing wing bending moments during maneuvers. For these aircraft, modulation of structural loads can result in weight savings and fatigue life improvement at the expense of increased drag in maneuvers. On the other hand development of the fighter wing design is predicated on reducing the drag penalty during maneuvers. Devices producing weight savings at the expense of increased drag are seldom incorporated in fighter designs. Weight savings can be achieved by applying maneuver load control techniques to permit attainment of performance objectives with a smaller and lighter wing or a smaller and lighter engine. If the maneuver load control techniques were applied to existing aircraft, enhanced performance and maneuverability growth potential would result.

Use of control augmentation techniques for primary flight controls can provide improved maneuverability in those flight regimes where maneuverability is inhibited or limited by undesirable handling characteristics at high angles of attack. This type of control can also provide a responsive, well-damped platform to control the aircraft for precise weapon delivery in air-to-air gunnery, air-to-ground gunnery, and air-to-ground bombing. Precision control and highly acceptable handling qualities are achievable with a Control Augmentation System (CAS) through skillful blending of both conventional and unconventional aerodynamic controls to satisfy commanded control laws for mission segment optimization. This concept of CCV wherein the CAS utilizes the best combination of control surface moment producers to optimize a particular mission segment will greatly improve the effectiveness of the weapon system for advanced fighters.

Active feedback control of flutter is a design concept which offers the potential of weight and performance benefits in advanced aircraft. Design requirements for some of these future aircraft include high speed at low altitude with thin wings. These configurations tend toward flutter critical designs which require significant additional weight to prevent flutter passively, even with the optimum use of advanced structural materials. An expansion of the flight envelope is also promised for both contemporary and future aircraft when these vehicles are carrying externally mounted stores. Studies to assess the practicality of achieving these promised benefits are being conducted at MCAIR. The effort, to date, has emphasized the development of general theoretical approaches and design concepts for integrated control dynamics and structural dynamic analyses of active flutter control. Computer programs have been developed to aid in this integrated study of dynamic stability. These programs, which evaluate a general aeroelastic system considered as an integral part of a multiloop feedback control system, have been used to study the feasibility of active flutter control of a particular F-4 wing/store configuration.[1]

## Performance and Static Margin

In attempting to exploit modern automatic control techniques for improving aircraft designs and to explore the effects and particularly the benefits of the automatic control system, the first and obvious application is the area of static longitudinal stability. The effect of c.g. position on trimmed drag coefficient is illustrated in Figs. 1, 2, and 3 for three significant Mach numbers using F-4 data. It will be noted

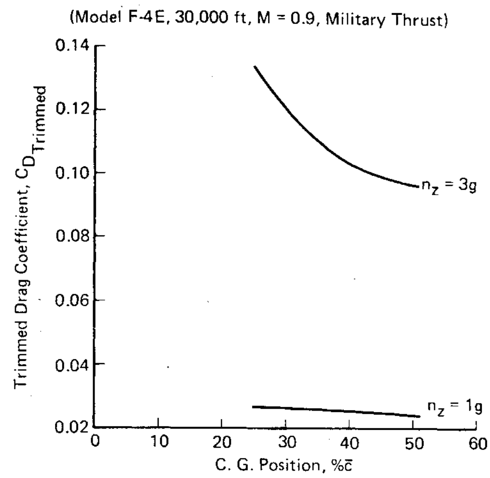


**Fig. 1 Effect of center of gravity position on trimmed drag.**

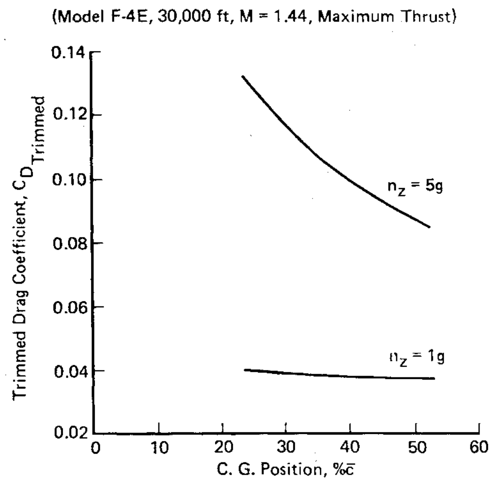


**Fig. 2 Effect of center of gravity position on trimmed drag.**

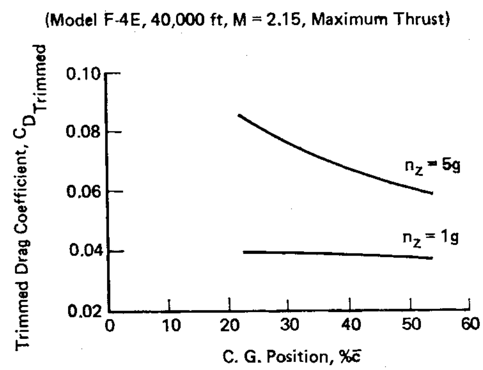


**Fig. 3 Effect of center of gravity position on trimmed drag.**

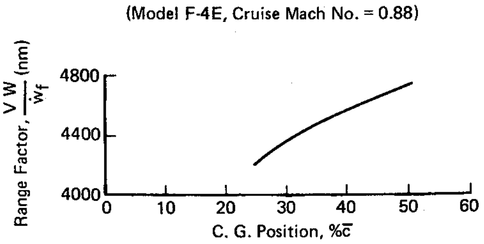


**Fig. 4 Effect of center of gravity position on range factor.**

that there is a significant reduction in drag at the aft c.g. particularly at the higher load factor. This effect is the trim drag, and includes both the tail drag and the incremental wing drag due to lift arising from the incremental wing lift needed to balance the down tail load. The latter component tends to be more parabolic than linear with load factor and results in an increase in the total effect at higher load factors. Still, the effect at one $g$ is measurable, and is illustrated for the cruise condition in Fig. 4. It will be noted that allowing the airplane balance to move from 36% to 46% mean aerodynamic chord (m.a.c.) would increase the range 4%. The beneficial effects of an aft balance on combat performance, or specific excess power, are illustrated in Figs. 5, 6, and 7. The increase in specific excess power attributable to an aft shift of the c.g. of 10% m.a.c. is quite significant, is greater at supersonic Mach numbers than at subsonic Mach numbers, and seems to increase with increasing speed. At the subsonic point shown, the increase in $P_s$ is 6.7% of the true speed. At 1.6 Mach number, it is 14.8%, and at 2.15 Mach number it is 15.4%.

These quoted potential performance benefits are for a reduction in static margin by an aft shift in c.g. with no change in external geometry. Depending on the capability of the system to provide acceptable handling qualities with this level of static instability implies a reliance on the automatic flight control system at a level equivalent to the basic

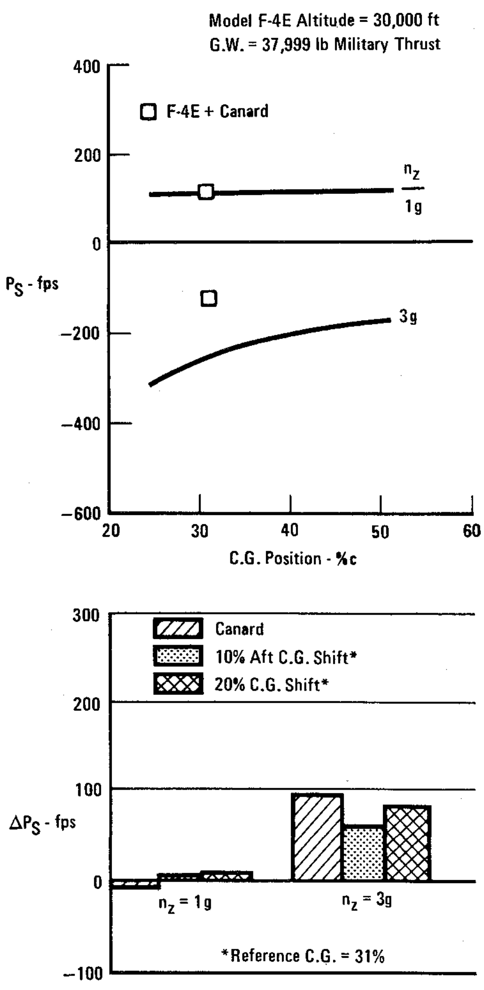


**Fig. 5 Specific excess power, $M = 0.9$.**

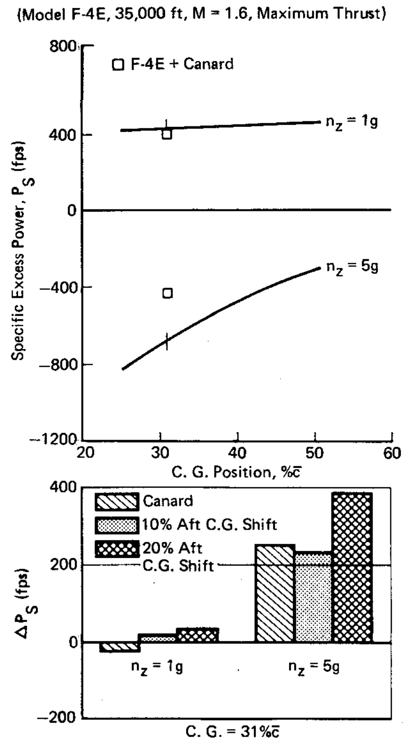


**Fig. 6 Specific excess power.**

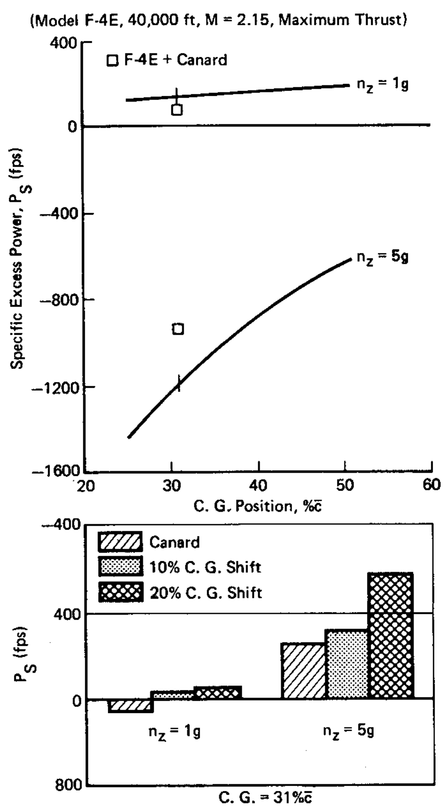


**Fig. 7 Specific excess power.**

airframe. It can be inferred from these data that performance improves as the c.g. is moved aft, and, therefore, the best performance is achieved with the most aft balance possible. However, static stability is reduced as the balance move aft, and other things being equal for conventionally controlled aircraft, the handling qualities are degraded. The most aft c.g. location acceptable is the most aft location where the handling qualities comply with all criteria. For the conventional airplane, the critical criterion is usually the static longitudinal stability, and the aft limit center of gravity is referred to the neutral point, or balance point for neutral static stability.

For the concept of the Control Configured Fighter, the criteria for the most aft balance point acceptable are predicated on the capabilities of the active feedback flight control system. The stick-fixed neutral point criterion is bypassed, but at the most aft c.g. behind the neutral point, the flight control system must be capable of providing static and dynamic stability and control response which are acceptable to the pilot, and at least as good as those required of a conventional stable design. This requires a control augmentation system capable of producing the required control surface deflections and rates in the dynamic flight situation, and a control surface capable of producing the required pitching moments. This latter requirement relates horizontal tail size to aft c.g. location for airplanes where the horizontal tail is the pitch control surface. This requirement becomes the criterion for the CCF and is analagous to the stick-fixed neutral point criterion for the traditionally designed configuration. More concisely, the criterion requires that it shall be possible at any attainable angle of attack to produce either a positive or negative pitching acceleration. At the critical aft balance point and angle of attack, it must be possible to produce a recovery moment by a control deflection in the recovery direction. Checking for this capability in the wind tunnel requires testing through the critical angle of attack with maximum recovery control deflection. This is just opposite to the control deflection normally investigated in conventional wind-tunnel testing. Figure 8 illustrates some test data measured on the F-4 wind-tunnel model with positive stabilator deflections. These show that the F-4 meets this CCF aft balance criterion aft to 44% m.a.c. with an available positive deflection of 12°.

It would seem that moving the aerodynamic center forward relative to the c.g. should be equivalent to moving the center of gravity aft. A configuration change that moves the aerodynamic center forward should produce drag reductions similar to those for aft c.g. A forward destabilizing surface, a canard, is such a device and has been investigated on a wind tunnel model of the F-4. The configuration studied is a close coupled canard which moves the aerodynamic center forward 11% m.a.c. The results of the drag analysis are shown in Figs. 5, 6, and 7, and it can be seen that for maneuvering flight, the expected benefits are achieved. However, at 1g there is a slight increase in drag reflecting the added wetted area or the profile drag of the added surface. These results are for a simple fixed canard, added with no other changes. Wind tunnel data indicate some favorable interference between the canard and the wing at high angles of attack which increases the useable lift coefficient. Exploitation of these effects, plus the possibility of using the canard for additional control surface area, would allow compensating reductions in the wing and tail area.

The aerodynamic center can also be moved forward by simply reducing the tail size. This, however, does not produce the drag reductions at high lift produced by the aft center of gravity or by the canard. Those drag reductions are trim drag reductions achieved by reducing tail-off static stability. Trim drag, however, is not directly sensitive to tail area. Tail size reduction must, however, satisfy the controllability criterion. Once again using the F-4 data base, we find that the critical condition for tail size is the takeoff and landing configuration as illustrated in Fig. 9. The forward and aft balance limits are shown as functions of the tail size. The CCF concept allows an aft shift of the permissible balance range, here considered to be 6% m.a.c., with a small reduction in tail size. The performance benefits of the CCF concept accrue primarily from the aft balance and from the reduction in tail-off static stability.

The inter-relationships between the conventional aircraft and CCF aft balance limits and the aerodynamic centers as they vary with Mach number are illustrated in Fig. 10. Both aft balance limits are critical at subsonic Mach numbers. It will be noted that the CCF balance point is still stable at supersonic Mach numbers. In fact, it is stable without the horizontal tail. The conventional stability criteria usually result in a very large static margin and sluggish response of the aircraft at supersonic Mach numbers, which limits the aircraft's maneuverability. The maximum maneuvering load factor achievable on the F-4 for instance, with full control deflection at high altitude and supersonic Mach number, is significantly lower than the structural limit. With CCF balance limits this excess stability is reduced and maneuverability is improved, as illustrated in Fig. 11. Aft balance limits are seen to provide a greater maneuvering load factor. The effects at subsonic Mach numbers are at a predetermined angle of attack, namely the F-4 maximum useable angle of

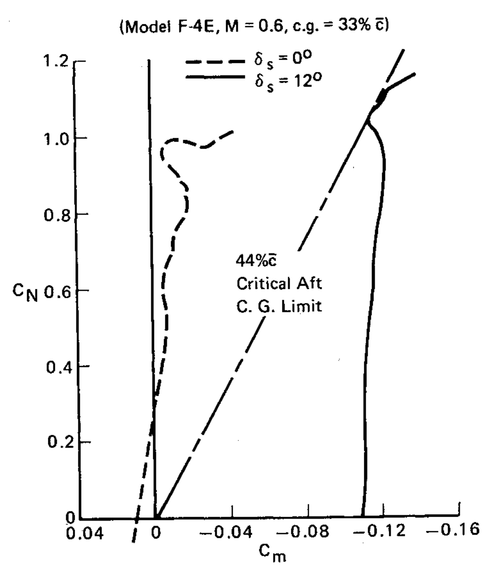


Fig. 8 Longitudinal control.

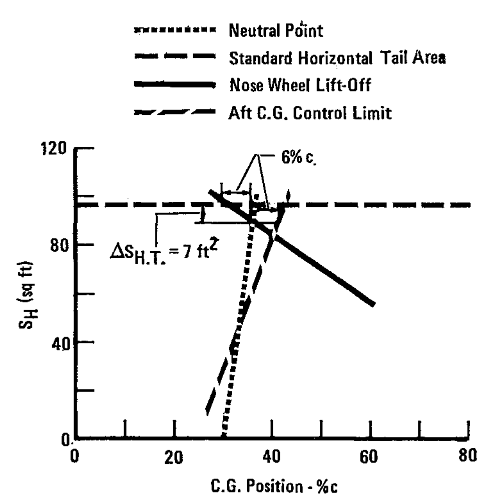


Fig. 9 Horizontal tail sizing F-4E (CCF).

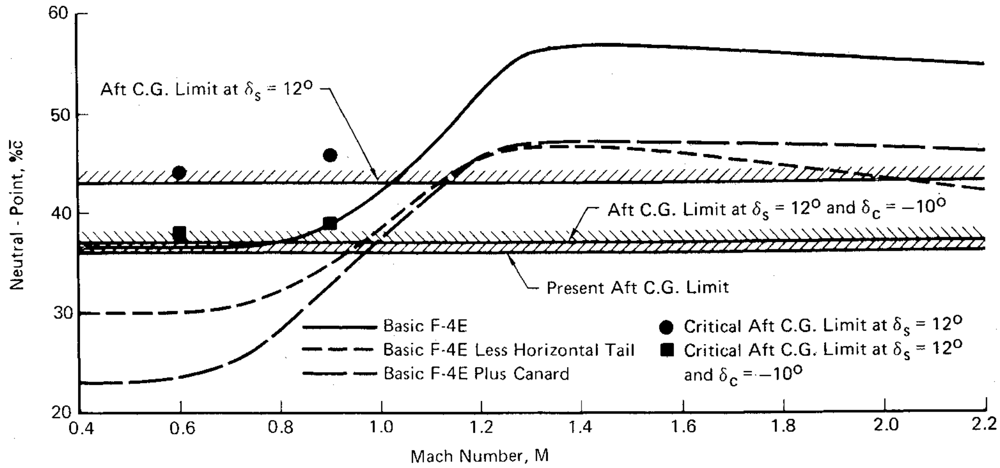


**Fig. 10 Stick fixed neutral point.**

attack, which is based on lateral stability and control, unaugmented. The apparent benefit of aft balance is the result of lift redistribution between wing and tail. Actually, this lateral-directional limit can also be raised by the direct application of the CCF concepts to the lateral control system. The large gains in supersonic maneuvering with aft balance result from the reduction in the excessive static longitudinal stability in this region.

## Control and Maneuverability Augmentation

The limits on subsonic maneuverability resulting from lateral-directional stability and control can be raised by application of CCV principles. These subsonic maneuverability limits shown in Fig. 11 are maximum useable angle-of-attack limits based on handling qualities consideration. At higher angles of attack, the airplane experiences wing rocking which at a high enough angle of attack becomes quite severe and may result in loss of control. Wind-tunnel test data indicate a deterioration in static lateral-directional stability in this angle-of-attack region. Artificial static lateral-directional stability can be provided through the automatic flight control system. Figure 12 illustrates a computer simulation closely representative of this phenomenon at a Mach number of 0.7 at 32,000 ft. Shown is the F-4 with its normal control system at angle of attack just above the maximum useable boundary. The sideslip divergence and the resultant roll divergence against full corrective aileron deflection are apparent. The other trace shows the behavior with augmented sideslip stability. The sideslip and bank angles are well controlled. This is achieved by increased servo rudder authority using a blended feedback of sensed lateral acceleration from an accelerometer located ahead of the center of gravity, and yaw rate from a yaw rate gyro.

Figure 13 is a similar comparison at a Mach number of 0.9 at 32,800 ft altitude. Here again the sideslip divergence is suppressed and control is retained. These illustrate the improvement in maneuvering load factor which accrues to the CCF concept when the maneuver limit is the result of lateral static or dynamic stability characteristics.

Similar improvements in longitudinal maneuverability can be achieved by control augmentation techniques. The longitudinal control characteristic peculiar to the CCF concept is the exploitation of an unstable location of the center of gravity relative to the aerodynamic center. This requires that the feedback control system automatically provide the static angle-of-attack stability. Figure 14 illustrates a simulated, typical longitudinal response to a step force control input, comparing the conventional F-4 with the CCF F-4. The CCF F-4 has a static margin for this simulation run of negative 8.5% m.a.c., with the CAS incorporating feedbacks of normal load factor and pitch rate and with gains optimized for controlling this negative static stability. The criterion used is the C* control law parameter which combines load factor sensed at the cockpit and pitch rate. The CCF curve shows better damping with nearly the same aircraft response

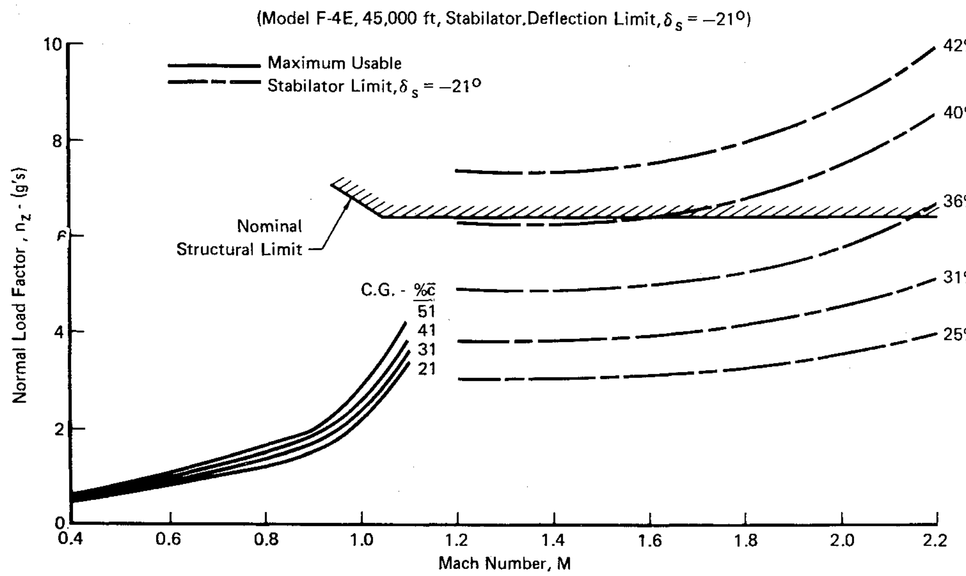


**Fig. 11 Load factor variation with center of gravity location.**

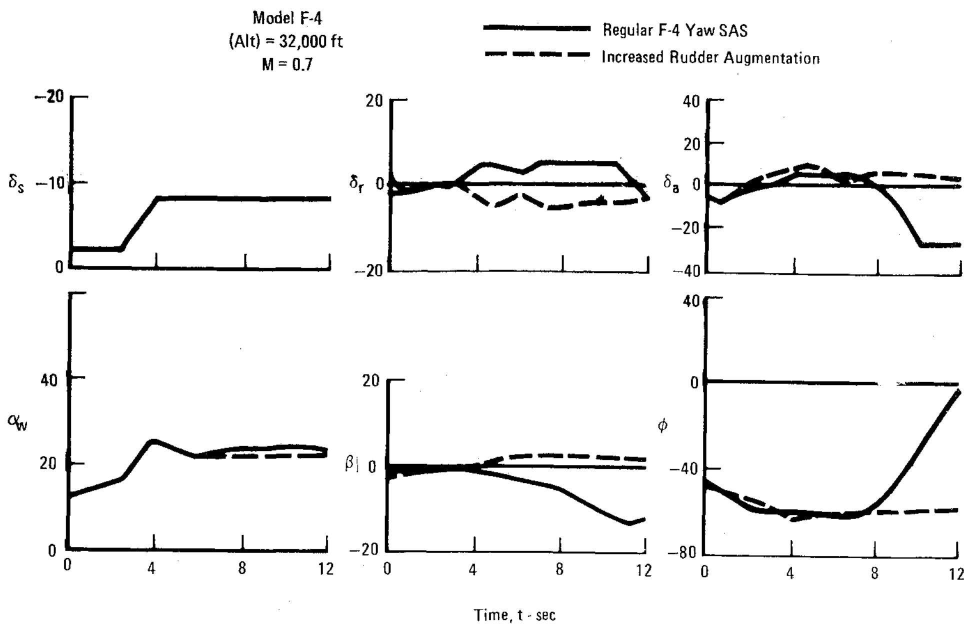


**Fig. 12 Lateral-directional stability augmentation at high angles of attack (alt = 32,000 ft).**

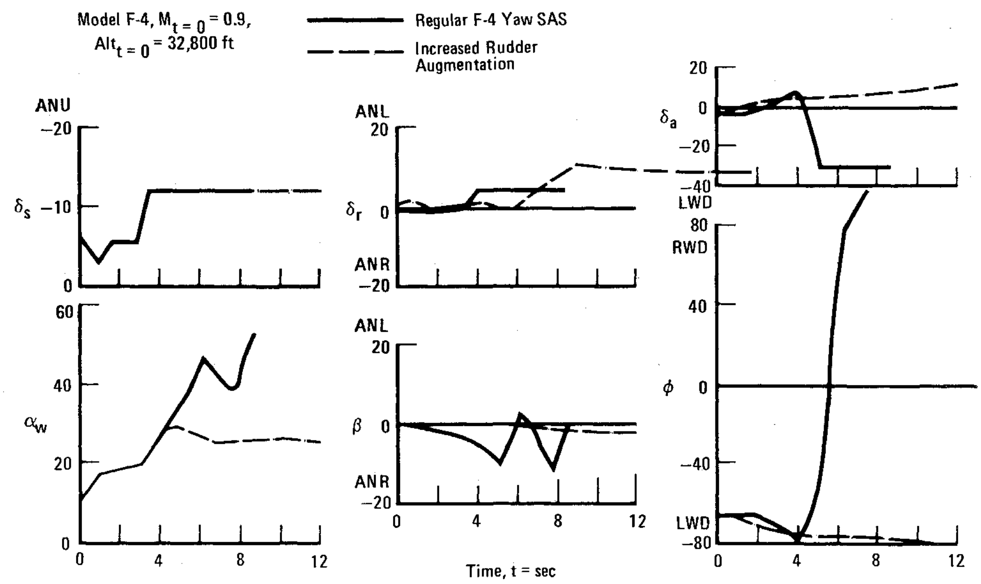


**Fig. 13 Lateral-directional stability augmentation at high angles of attack (alt = 32,800 ft).**

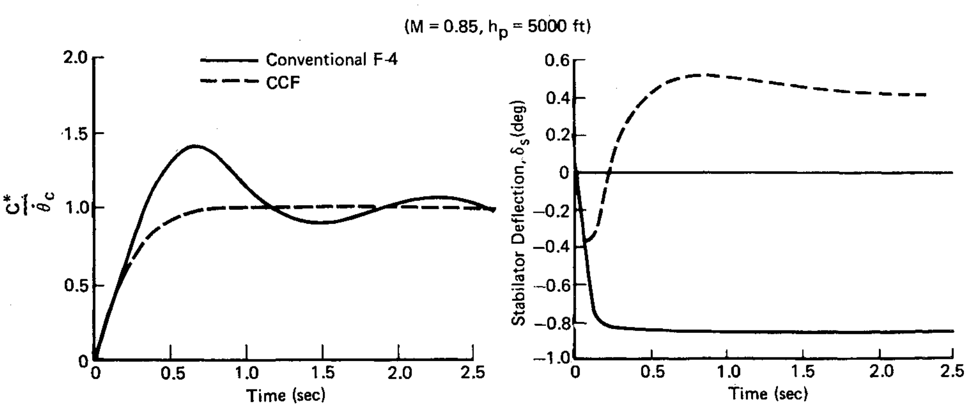


**Fig. 14 Response to step input longitudinal.**

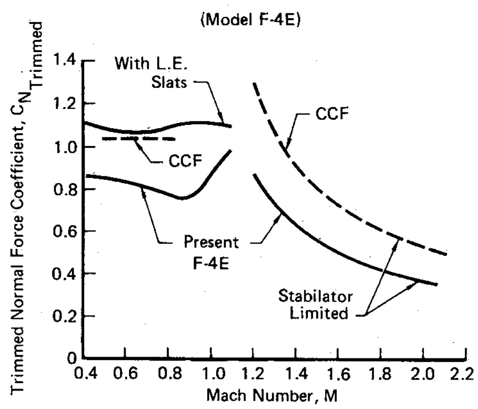


**Fig. 15 Maximum useable normal force.**

time. This study was performed to define the control system parameters for the most desirable system considering the stabilator actuator control deflection and the rate and power requirements to provide handling qualities at least as good as the basic F-4. One of the objectives of this study was the degree to which contemporary control system functions and hydro-mechanical control system components could provide rate and power values required for the static and dynamic stability augmentation levels demanded for controlling aircraft with various amounts of negative stability. The study results clearly show that the present F-4 aerodynamic control surfaces with appropriate automatic feedback control functions are adequate with the negative static margins studied. Thus, the combat performance can be enhanced by increasing the maneuverability and by increasing the useable load factor at all speeds, while maintaining precise control and handling qualities, and therefore tracking accuracy, at least comparable to the conventional F-4.

Figure 15 illustrates the increase in useable normal force coefficient where the limits shown are stability and control limits. Also shown in this figure is the maneuverability attainable with maneuvering slats. These latter data are based on flight test results. Maneuvering slats raise the maximum useable angle of attack by improving the static lateral stability, the $C_{n_\beta}$ and $C_{l_\beta}$, when deflected at high angles of attack. They also have a significant effect on the drag characteristics, as illustrated in Fig. 16. It can be seen that extending the slats results in a significant drag increase at zero lift, but greatly improves the drag due to lift. Clearly, a slat that is retracted at low lift coefficients and extended at high lift coefficients improves the maneuverability of the airplane significantly.

## Advanced Design and Sizing

Efficient application of the Control Configured Fighter concepts to advanced design configurations requires that the principles be incorporated early in the life of the design. In

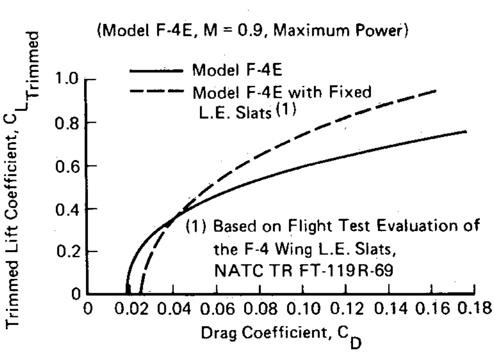


**Fig. 16 Effect of leading edge slats.**

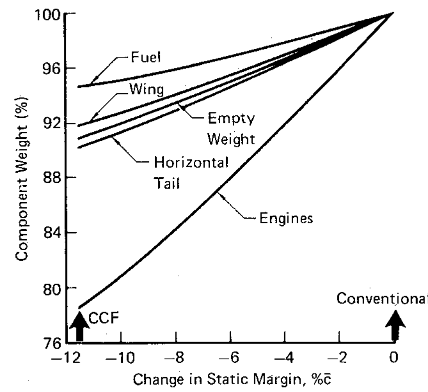


**Fig. 17 Effects of longitudinal stability on some fighter aircraft component weights.**

fact, the basis of the concept is that the characteristics and capabilities of the automatic flight control system be integrated into the design. They can, therefore, have an impact on the configuration by their effects on the balance requirements, and on the size and location of the aircraft configuration components. By considering these capabilities at the early stages of configuration selection, the drag reduction and maneuverability improvement potentialities can be traded for size and weight reductions, and therefore cost reductions. This approach was investigated by applying these techniques to a typical advanced design fighter sizing study. The results are illustrated in Fig. 17. The change in static margin from that for a conventional design is used as the correlating variable. The results of any study are quite dependent on the constraints established for the study. For this one, performance requirements were held constant as was the basic configuration. It can be seen that the size and cost as measured by empty weight are 9% less for the Control Configured Fighter than for the conventional fighter. The wing and tail sizes follow the empty weight quite closely. The slightly steeper slope of the tail size curve is a direct result of the fact that the static margin was varied by moving the wing longitudinally. As a result, the reduced static margin produces an increase in tail length which translates into a smaller required tail area.

The highly significant result, however, is the steepness of the engine size curve. This characteristic results directly from the reduced maneuvering drag of the CCF, which allows a higher thrust loading at the same level of maneuvering performance. For this study, the Control Configured Fighter can use a 21% smaller engine than the conventional fighter and still meet all the maneuverability requirements. This reduced engine requirement is really the key to the size reduction with CCF. Figure 18 presents the variation in

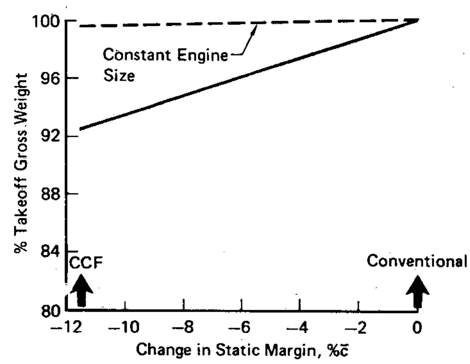


**Fig. 18 Effect of longitudinal stability on fighter takeoff gross weight.**

Takeoff Gross Weight with change in static margin, and for comparison the dashed line illustrates the effect of holding the engine size constant. It is quite apparent that if maximum size and cost reduction benefits are to be realized on the Control Configured Fighter, then the CCF principles must be implemented early in the design. They must be considered before the configuration is sized and before the engine size is established.

## Conclusions

The basic conclusion reached from the studies to date indicates that the CCV principles can result in reduced trim drag in maneuvering and increased maneuvering limits. The aft balance limits, based on F-4 and advanced design configurations, is of the order of 7 to 12% m.a.c. aft of the limit based on static stability. At this point, handling qualities with the automatic control system will be at least as good as the traditional arrangement. Allowable reduction in tail size is not significant. Application of the principles in the advanced design of an air superiority fighter can result in significant savings in size. For the requirements investigated, the weight would be reduced 8 to 10% and the required engine size would be reduced approximately 21%.

Acceptance of the Control Configured Fighter will be largely dependent on the acceptance of a full-time, electrical control system as the primary flight control system for the aircraft. This type of control system will be an integral part of the CCF design and a significant part of the total system reliability. Such a control augmentation system is being engineered for test flight in the F-4 through the Survivable Flight Control System (SFCS) program wherein a full-time fly-by-wire primary flight control system will be developed. The SFCS program goals are compatible with those for incorporating CCF concepts into a flight article, and will contribute to the understanding and reliability of automatic flight controls for use in primary flight control. Establishing the confidence and pilot acceptance base for fly-by-wire primary flight control paves the way for use of such a system for achieving additional significant potential benefits through a CCF design. This development is one more step in the evolution of flight control.

## Reference

[1] Triplett, W. E., "A Feasibility Study of Active Wing/Store Flutter Control," presented at the 1971 Joint Automatic Control Conference, St. Louis, Mo., Aug. 1971.