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RESEARCH MEMORANDUM

PRELIMINARY RESULTS FROM A LIMITED INVESTIGATION OF THE USE OF CONTROLS DURING SERVICE OPERATIONAL TRAINING WITH FIGHTER AIRPLANES

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SUMMARY

Preliminary results from a limited investigation of the use of controls during service operational training with four fighter airplanes are presented. These preliminary data indicate that in these tests the service pilots in performing their operational training missions utilized the positive V-n envelope but rarely approached the negative V-n envelope. The maneuvers performed in service operational training which are critical as far as horizontal-tail loads are concerned appear to be less severe than any present design requirements. The maneuvers that are critical for the vertical tail also appear to be mild compared to present design requirements.

INTRODUCTION

The present methods for determining airplane design loads require, among other things, a knowledge of the motion of the control surfaces. In the usual methods the maximum design loads are obtained by specifying what are believed to be the critical motions of the controls, or by specifying the critical airplane response; however, the actual control motion and airplane response obtained in regular operational flying may differ appreciably from the specified variations.

In order to obtain some preliminary information on the airplane response and the actual amounts and rates of control motion used by service pilots in the performance of their regular training missions, the National Advisory Committee for Aeronautics with the cooperation of the Air Force and Bureau of Aeronautics, Department of the Navy, has been conducting a flight program with several jet-propelled fighter airplanes. In addition to the data on airplane control motions, this information was needed to determine the most important quantities and ranges of measurements to be used in the design of an instrument for statistical loads measurements. No attempt has been made, at this time, to make a statistical analysis of the data obtained in these preliminary studies; however, the data obtained are believed to be of general interest and are presented at this time as envelopes of maximum values.

SYMBOLS

n_V normal load factor

n_T transverse or lateral load factor

q dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft

V true airspeed, ft/sec

V_i indicated airspeed, knots

β sideslip angle, deg

δ_a right aileron angle, deg

ρ mass density of air, slugs/cu ft

$\dot{\delta}_e$ elevator rate, radians/sec

$\dot{\phi}$ rolling velocity, radians/sec

$\ddot{\theta}$ pitching angular acceleration, radians/sec^2

AIRPLANES AND TESTS

Four fighter airplanes have been tested: the F-86A, F2H-2, F-84G, and F-94B airplanes. (Refs. 1 to 5 present preliminary data on these airplanes.) Two views of the test airplanes with information on the use of boost and tip tanks during the tests are shown in figure 1. The airplanes were flown by regular service pilots and were instrumented and the data evaluated by NACA personnel. Approximately 20 flights were obtained with each airplane and about 10 different pilots flew each airplane. In these flights, about 500 maneuvers were performed with each airplane. These flights were made in conjunction with the normal squadron operational training; however, data were recorded only on those flights which involved mostly acrobatics, ground gunnery, aerial gunnery, and dive bombing. The pilots were aware of the instrumentation in the airplane; however, they were informed that the data obtained would not be associated with them in any way. Although only a relatively few hours were obtained on each airplane (about 20 hours), the data are believed to be representative of many more hours of normal flying since data were not recorded in cross-country flying or other operational uses where few maneuvers were made. At this time, it must be emphasized that the data to be presented are not an indication of what the airplane or pilot can do but what they did do in the performance of their normal operational missions. In addition, with the exception of the F-86A, the airplanes of this investigation were not the type to experience pitch-up. Pitch-up was experienced on the F-86A airplane in several maneuvers but, in general, the pilots avoided the pitch-up region.

RESULTS AND DISCUSSION

The operational V-n diagram for the F-86A airplane is shown in figure 2. The solid symbols are those for the test airplane of this program. The open symbols are from 1,150 hours of operational training in many F-86A airplanes in this country (ref. 6). With the exception of the 4 square symbols, the points shown define the envelope of all the points obtained in the tests. The square symbols represent all the points obtained above the structural limit load factor. The service limit load factor for the F-86A airplane is 6. The structural limit load factor is 7.33 and the ultimate load factor is 11. It may be seen that the pilots reach the positive service limit load factor over almost the entire speed range; however, the negative load-factor range was rarely entered. In the Air Force data the service limit load factor was exceeded 28 times and the structural limit load factor was exceeded 5 times. The ultimate load factor was exceeded twice, once at a speed of 438 knots and once at an unknown airspeed. For the test airplane, the service limit load factor was reached but not exceeded by any appreciable amount (shown by the solid symbols). In the negative load-factor region, there are very few points in both sets of data. In the Air Force data a load factor of -1.0 was reached once; whereas in the present test program with the F-86A the maximum negative load factor was about -0.3. It is interesting to note that, below the service limit load factor, the two sets of data are very similar.

The V-n diagrams for the other test airplanes were quite similar to that for the F-86A. In general, the positive maximum load factor was reached throughout most of the speed range; however, none of the airplanes approached the negative maximum load factor at any speed. The highest negative load factor measured was -1.1 for the F-84G airplane.

One contributing factor to the lack of negative load factors may be in the limitations of jet-engine operation at negative accelerations.

Envelopes of the maximum pitching angular accelerations for the test airplanes are shown in figure 3. If the normal load factor and pitching angular acceleration are known, the maneuvering horizontal-tail load may be determined. The maximum maneuvering horizontal-tail load will occur when maximum load factors are combined with maximum pitching accelerations. The curves shown represent the envelope of hundreds of test points for each airplane. The maximum positive and negative pitching accelerations increase with airspeed until a point corresponding approximately to the upper left-hand corner of the V-n diagram is reached and then decrease with further increases in airspeed. The difference between the accelerations reached with all the airplanes is not great. The maximum positive pitching acceleration was about 1.7 radians per second per second and the maximum negative pitching acceleration reached was about -2.0 radians per second per second. It may also be noted that the maximum positive and negative pitching accelerations are about equal, although there was a slight tendency in these tests toward higher negative pitching accelerations. The relatively high pitching accelerations shown at the lowest speeds were obtained in stalls and spins. A comparison of the test data with several design requirements or methods is shown in figure 4. The test boundary represents the boundary of the maximum pitching accelerations reached on all the test airplanes. The boundary indicated as A is based on the airplane reaching its limit load factor with an elevator deflection in which the maximum elevator angle is reached in 0.2 second (ref. 7). The boundary labeled B is based on a semiempirical method (ref. 8) and was calculated for a maximum elevator rate of 3.5 radians per second. The line labeled C is the design requirement of 6 radians per second per second at the upper left-hand corner of the V-n diagram. There are several other design requirements or methods not shown here; however, they are somewhat similar and reach about the same value of maximum pitching acceleration.

The design curves shown apply only to the F-86A airplane but the curves for the other airplanes are quite similar. It can be seen that the flight values of pitching acceleration are less than one-half of the calculated or design values. It should be emphasized that these design curves represent the maximum values that could be obtained, and a pitching acceleration of about 5 radians per second per second is within the maximum capabilities of the pilot and the airplane for most of these airplanes; however, the test points represent what the service pilots actually used in the performance of their missions. In other results which are not shown here, it is also indicated that the maximum pitching accelerations may occur at maximum load factor.

The maximum elevator rates associated with these maximum pitching accelerations are shown in figure 5. Also shown are two design curves which are similar to those of figure 4. The elevator rates for the test airplanes decrease with speed throughout the speed range, and the positive and negative rates are approximately equal. Of these airplanes only the F-86A was equipped with elevator boost; however, all the airplanes were equipped with power-driven trim tabs. It is not known what use, if any, the pilots made of the trim tab in maneuvering the airplanes. In addition, the F-86A airplanes are equipped with an elevator rate restrictor which restricts the maximum elevator rate to about 0.8 radian per second. The high rates shown at the lowest speeds were obtained in stalls and landing approaches and did not affect the airplane motion. It may be seen that the elevator rates used in these operational tests were below the maximum possible rates. In regard to the other control-surface rates, the maximum rudder rates for unstalled maneuvers were about 1.3 radians per second and decreased rapidly with airspeed. Rudder rates as high as 2.8 radians per second were measured on the F-94B airplane in stalls.

The maximum aileron rates measured were about 1.4 radians per second; however, the maximum aileron rates did not decrease with airspeed.

The envelopes of the maximum sideslip angles reached in these operational tests are shown in figure 6. The maximum sideslip angle decreased rapidly with airspeed for all airplanes. The maximum angles for the F-84G and F-94B airplanes were approximately equal at the higher airspeeds. The angles reached with the F2H-2 airplane were somewhat less throughout the speed range. No angles are shown for the F-86A airplane since sideslip angle was measured in only 5 percent of the maneuvers. The maximum angles shown here were reached in rolling pull-outs, rolls with normal acceleration, sideslips, and rudder kicks. The boundaries shown are defined by all these maneuvers; no one maneuver was more critical than another. The highest sideslip angle measured was over 32° on the F-84G airplane and occurred in a spin. One design criterion states that an angle of 5° of sideslip be designed for at the limit diving speed; this is about 5 times the value reached in these tests.

Data on angles of attack are not presented herein; however, angles of attack greater than 40° and -25° were measured on the F-84G airplane in spins.

An indication of the vertical-tail loads reached is shown in figure 7 where the sideslip angle β is multiplied by the dynamic pressure q and plotted against airspeed. This parameter is roughly proportional to the vertical-tail load. The highest vertical-tail loads indicated in these tests were obtained at a speed which corresponds roughly to the upper left-hand corner of the V-n diagram. The two relatively high points shown for the F-94B airplane at higher speeds were obtained in inadvertent airplane lateral oscillations and were not the result of one of the critical maneuvers listed before. It is interesting to note that stability deficiencies, such as uncontrolled lateral oscillations, may produce loads as high as those in controlled maneuvers.

Also shown in figure 7 is the value of βq obtained from the requirement that a full aileron roll be made at 0.8 of the limit load factor. (The method of ref. 9 was used to calculated βq.) It can be seen that this requirement results in a value of βq greater than those obtained in these tests. The criterion of 5° of sideslip at limit speed will result in a value of βq of about 5,000, which is approximately twice the maximum value obtained in these tests.

In figure 8 the envelopes of the maximum transverse load factors measured in these tests are shown. In general, they increase with airspeed up to some airspeed between 250 and 300 knots and then decrease at the highest airspeeds. The points shown outside the boundaries are isolated points which fell above the mass of data. The maximum transverse load factor measured was about 0.54 on the F-94B airplane. One design requirement states that the airplane shall be designed to withstand a side load factor of 2. This value is in considerable excess of any load factors measured in these tests.

One of the critical maneuvers for design of the vertical tail is the rolling pull-out type of maneuver which consists of high normal load factors combined with rolling velocities. The envelopes of the transverse load factors plotted against normal load factor are shown in figure 9. The several points which are located above the curves are isolated values of the transverse load factor obtained in the tests. The data indicate that relatively high values of transverse load factor can be obtained at high normal load factors as well as at low normal load factors. All the isolated high points were obtained in the rolling pull-out type of maneuvers and at altitudes of less than 8,000 feet.

The rolling velocities associated with the normal load factors for the four test airplanes are shown in figure 10. The rolling velocity increases with load factor at low load factors, reaches a peak at a load factor of about 2 to 3, and then decreases with further increase in normal load factor. The maximum rolling velocity reached was about 3.5 radians per second at a load factor of 3 with the F-84G airplane.

The envelopes of the aileron angles used are shown in figure 11 as a function of airspeed. The full-throw maximum aileron angles for the test airplanes are about 20° for the F-94B and F2H-2 airplanes, 18° for the F-84G airplane, and 15° for the F-86A airplane. At the lower speeds, almost full aileron is used for the F-84G airplane but, as the speed increases, the maximum aileron angle used decreases rapidly. All these airplanes have aileron boost systems. It is interesting to note that the maximum curves for all airplanes are similar at higher airspeeds.

In regard to the other control-surface angles, the maximum elevator angles ranged from 30° up to 11° down. The maximum rudder angles were about 10° except in stalls and landings where angles up to 24° were used.

Recently, it has been suggested that a more realistic rolling requirement than those presently used would be that the airplane roll 90° in 1 second (ref. 10). The envelopes of the minimum times for the test airplanes to roll 90° are shown in figure 12. It may be seen that the minimum time to roll 90° for all the test airplanes is about 1 second except at the lowest and highest speeds.

CONCLUDING REMARKS

On the basis of the approximately 2,000 maneuvers performed in these tests during operational training, no definite conclusions may be made at this time; however, it is indicated that the service pilots utilized the positive V-n envelope but rarely approached the negative V-n envelope. The maneuvers performed which are critical as far as horizontal-tail loads are concerned appear to be less severe than any present design requirements. The maneuvers that are critical for the vertical tail also appear to be mild compared to present design requirements. This does not mean that the present design requirements are overly conservative since these airplanes could reach the design limits if the pilots controlled the airplane in the manner specified by the requirements. The data presented do indicate, however, that, in these tests, the service pilots in performing their normal operational training missions did not approach the design limits of the airplane.

There may be a question as to whether higher rates and accelerations might be obtained in combat than in training. That question has not been answered as yet; however, in World War II it was found that the airplanes reached higher normal load factors in training than in combat, and at this time there is no reason to believe that the present trend is much different.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., April 17, 1953.

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AIRPLANES INVESTIGATED

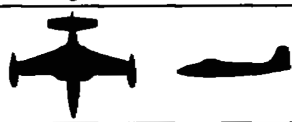
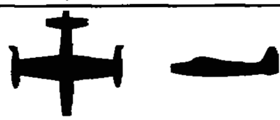
AIRPLANE		BOOST		TIP TANKS	
		ELEV.	AIL.	ON	OFF
F-86A		YES	YES	NO	YES
F2H-2		NO	YES	YES	NO
F-84G		NO	YES	YES	YES
F-94B		NO	YES	YES	YES

Figure 1.

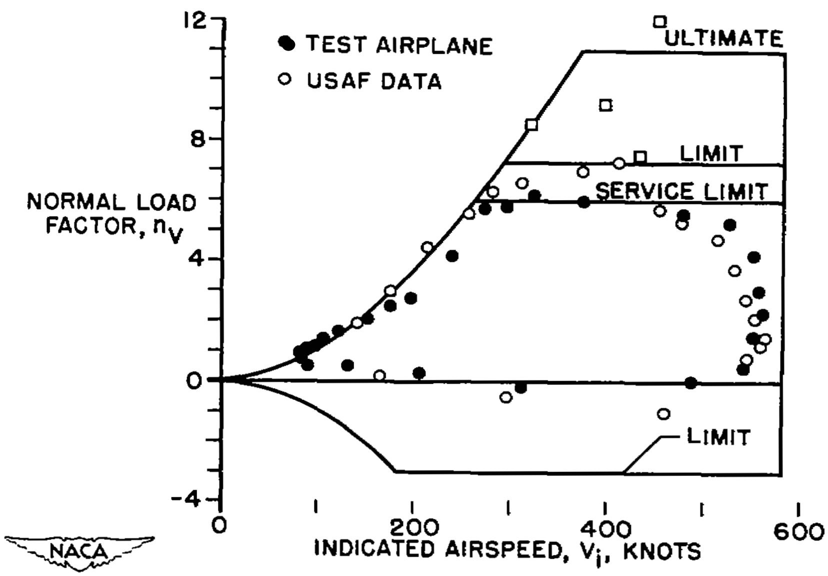


Figure 2.

MAXIMUM PITCHING ACCELERATIONS

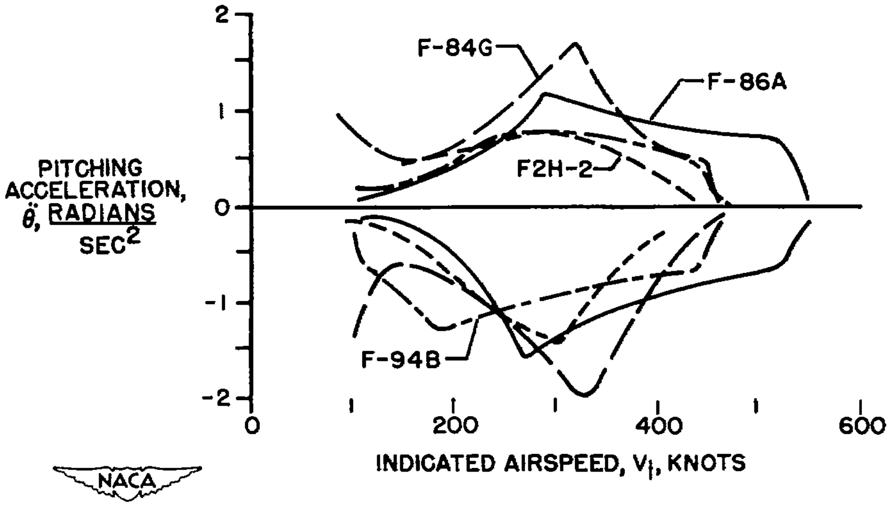


Figure 3.

COMPARISON OF DESIGN METHODS AND FLIGHT TESTS

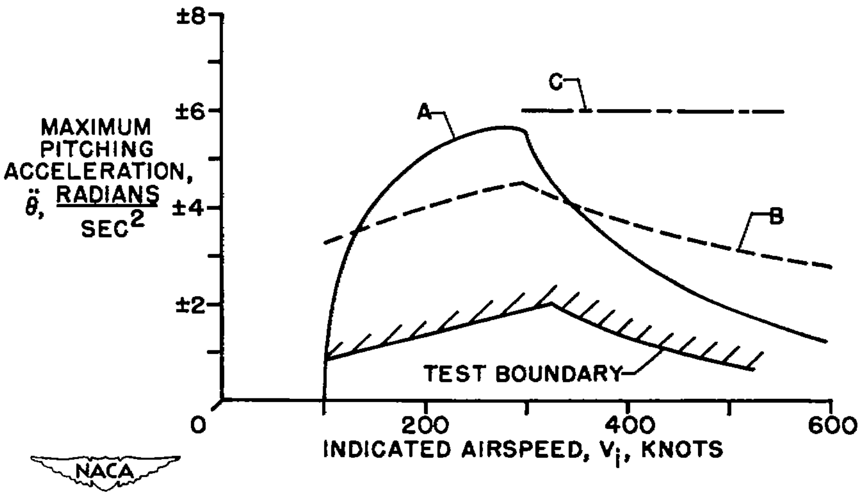


Figure 4.

[redacted]

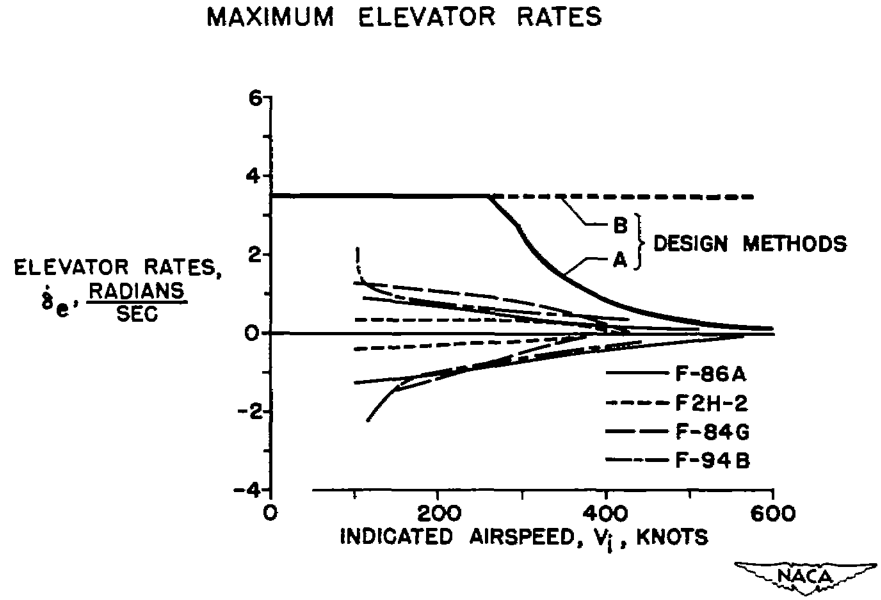


Figure 5.

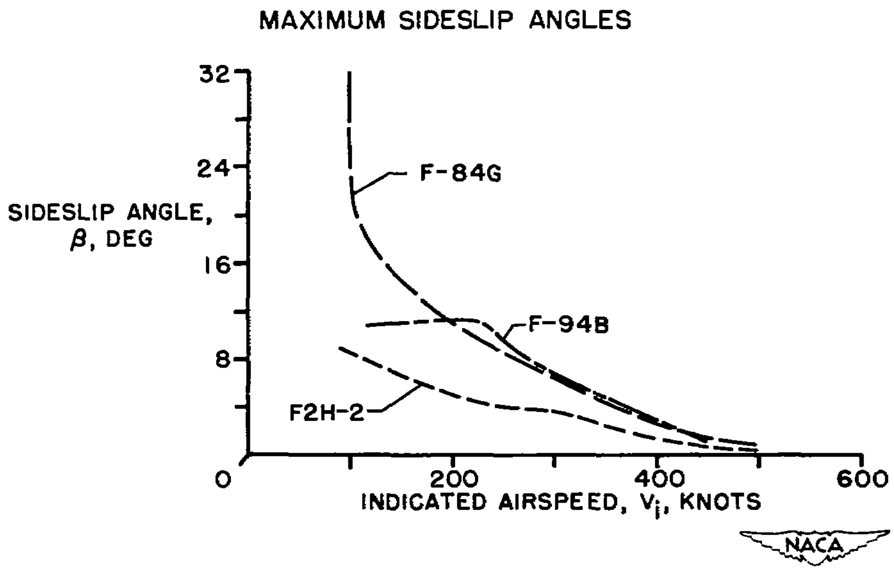


Figure 6.

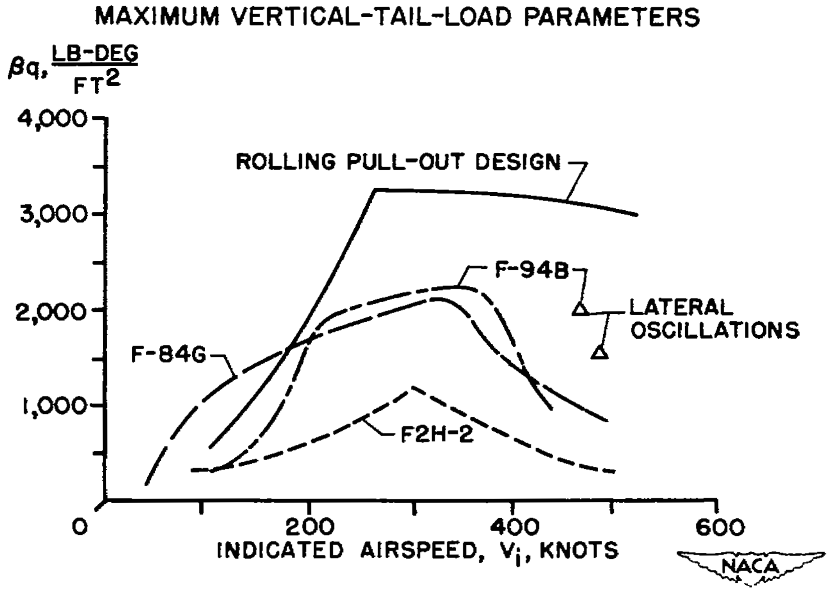


Figure 7.

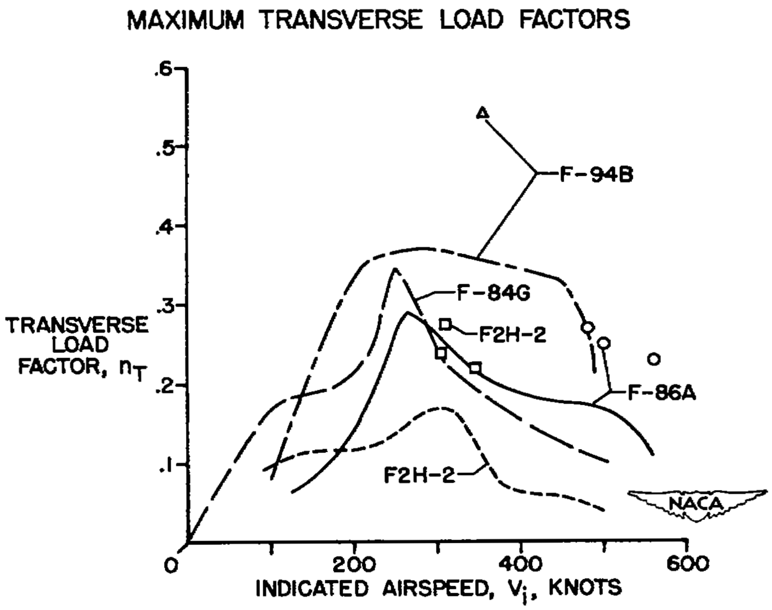


Figure 8.

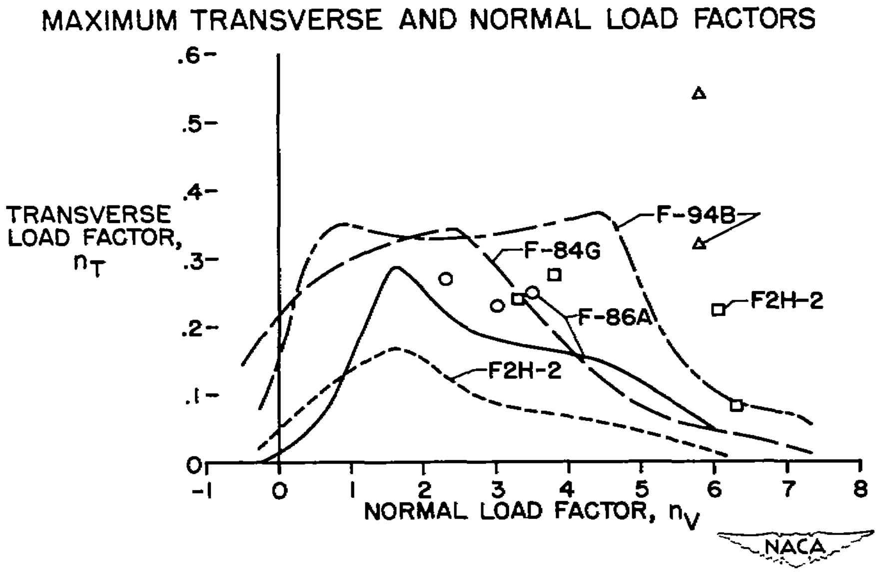


Figure 9.

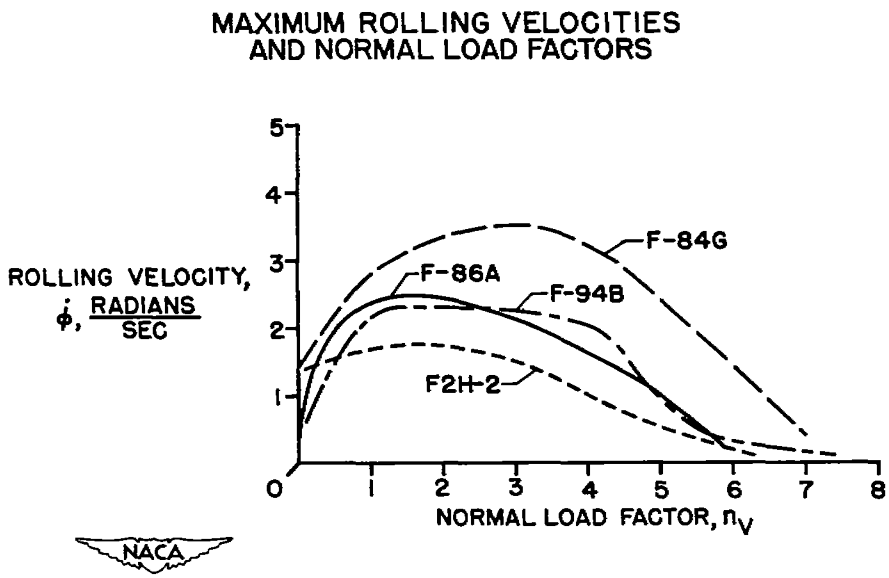


Figure 10.

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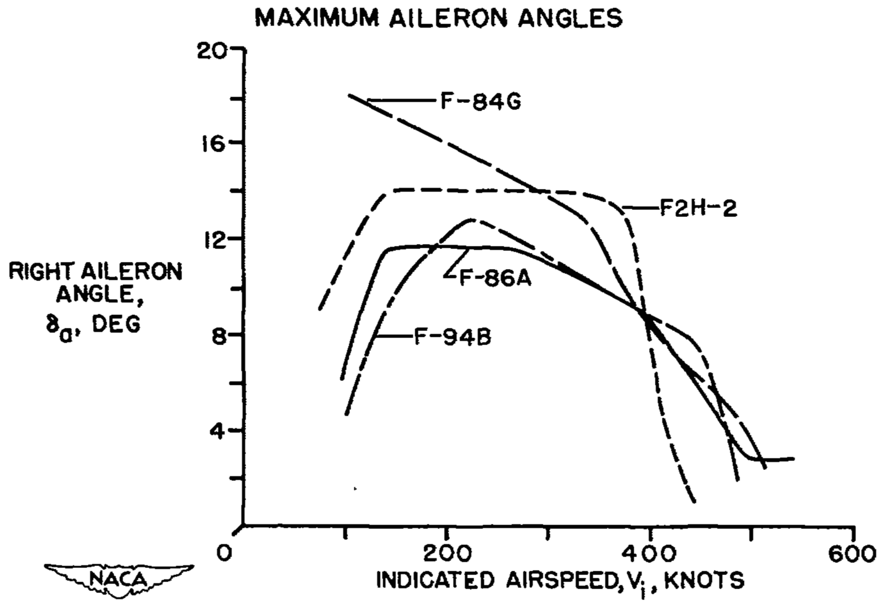

Figure 11.

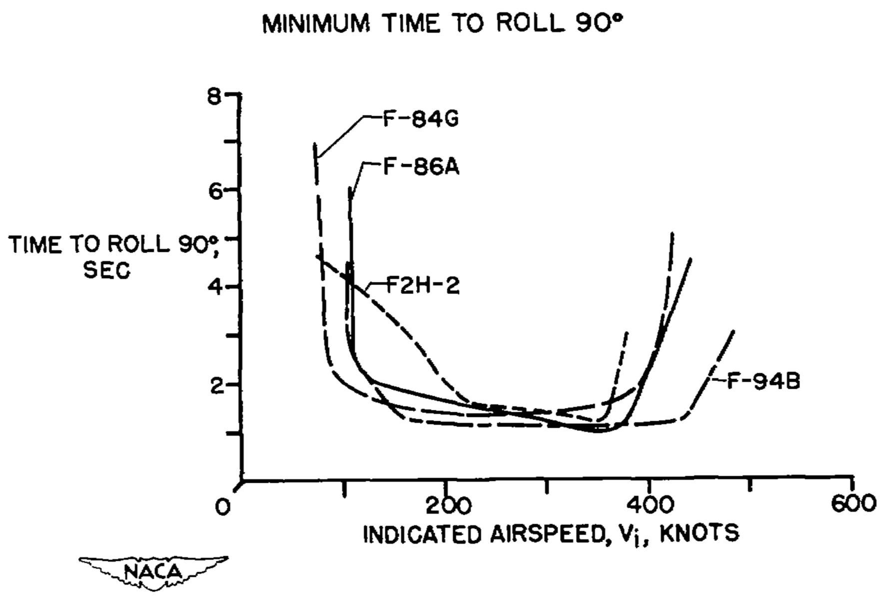

Figure 12.

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SECURITY INFORMATION

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