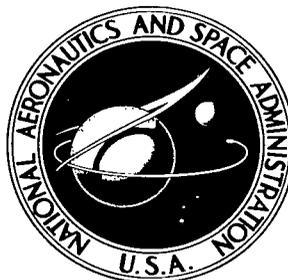


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A SUMMARY OF THE X-15 LANDING LOADS

by James M. McKay and Richard B. Noll

*Flight Research Center
Edwards, Calif.*

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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A SUMMARY OF THE X-15 LANDING LOADS*

By James M. McKay and Richard B. Noll
NASA Flight Research Center

SUMMARY

The dynamic response of the X-15 airplane at touchdown is reviewed briefly to show the unusual landing characteristics resulting from the airplane configuration. The effect of sinking speed is discussed, as well as the influence of the horizontal-stabilizer load, wing lift, and increased landing weight on the landing characteristics. Consideration is given to some factors providing solutions to these problems, such as cutout of the stability augmentation damper at gear contact, pilot manipulation of the stabilizer, the use of a stick pusher at touchdown, and a proposed third skid installed in the unjettisoned portion of the lower ventral fin. Studies to determine the effect on the main-landing-gear loads of relocating the X-15 nose gear are discussed.

INTRODUCTION

A short summary of the X-15 landing-gear-loads results was presented in reference 1, in which the landing gear was indicated to be a source of concern. Because of the marked departure of the X-15 landing-gear system from conventional aircraft landing gear, the unexpectedly high loads that occurred did not correlate with the normally used design parameters of angle of attack, sinking speed, and weight. These high loads and the parameters affecting them can be explained only by means of an overall dynamic analysis. With the dynamic analysis and the experience gained in 151 landings, a better understanding was obtained of the landing-gear loads and the dynamics that affect them. Throughout the program, typical modifications were made to increase the energy-absorption capacity of the gear. However, these changes were restricted by practical hardware considerations, with the result that some problems were unresolved. These problems have been overcome by modifying the landing procedure.

The purpose of this paper is to review the status of the X-15 landing-gear loads, to discuss the parameters that affect these loads, and to show additional modifications that might be made to improve the landing-gear system.

*This paper was included in a classified report entitled "Fourth Conference on Progress of the X-15 Research Airplane Program," Flight Research Center, Oct. 7, 1965. NASA SP-90, 1965.

SYMBOLS

F_T	horizontal-stabilizer aerodynamic load, pounds
L	lifting force, pounds
W	airplane landing weight, pounds
α	angle of attack, degrees
δ_h	horizontal-stabilizer deflection, degrees

GENERAL DESCRIPTION

The locations of the landing gear are shown in figure 1, which also includes a diagram to indicate the nature of the main-gear operation. The main landing gear, located well aft on the fuselage and directly beneath the horizontal tail, consists of steel skids and Inconel X struts attached through bellcrank arms to shock struts inside the fuselage. Drag braces are attached to the fuselage ahead of the trunnion and to the skid at the strut-attachment pin. During flight, the skids and landing-gear legs are folded forward against the outside of the fuselage. The nose gear, located far forward on the fuselage, is of conventional design, nonsteerable, with dual co-rotating wheels for the prevention of shimmy.

DISCUSSION

Main-Gear Response

Many of the features of an X-15 landing are unusual; these characteristics are illustrated in figure 2. The main-gear shock-strut force, measured with respect to time from main-gear touchdown, is shown, and sketches are included to identify the landing sequence. The airplane weight, wing lift, and tail loads are indicated by the arrows in each sketch. The sketch at the left shows that a nose-high attitude is established just prior to touchdown. The first peak on the force curve occurs as the vertical velocity at the main gear is arrested, as indicated by the second sketch. Up to this time, the reactions are similar to those for a conventional airplane because the force in the gear depends upon the weight and the vertical velocity of the airplane. Here the similarity ends. Since the center of gravity of the airplane is well ahead of the main gear, a rapid nose-down rotation occurs, and the airplane impacts hard on the nose gear, as illustrated in the third sketch. The high pitch rate cannot be controlled by the pilot because the stabilizer is directly above the main gear. The nose-gear touchdown for the landing illustrated occurred about 0.8 second after the initial main-gear touchdown and usually occurs within 1.0 second for all X-15 landings. As the airplane rotates downward, the wing

lift is rapidly decreased and a pronounced down load occurs on the stabilizer. The result is an increased force on the main gear, shown as the second peak in the last sketch. Note that the force at the second peak is much greater than at the first peak.

The design of the X-15 landing gear, based on weight and sinking speed, as for conventional systems, does not consider all factors that contribute to the gear loads. This is emphasized in figure 3, which shows shock-strut force plotted against sinking speed at touchdown for many landings. The first peak, indicated by the circular symbols, has a definite relationship to the sinking speed, but the second peak, which is the critical one, identified in the plot by the square symbols, is essentially independent of sinking speed. Note that the values for the second peak closely approach the design limit and some exceed this limit.

Effect of Horizontal-Stabilizer Angle

An analytical study of the landing dynamics showed that several important parameters affecting the second reaction involved aerodynamic factors. At this point in the X-15 program, the problem was no longer one of understanding the nature of the loads but rather how best to reduce them. It was realized that the stabilizer down loads were caused by efforts of both the pilot and the stabilizer augmentation system to prevent the rapid rotation onto the nose gear (ref. 2). The effect of stabilizer angle on the gear loads is shown in figure 4, in which the maximum shock-strut load is plotted as a function of the stabilizer setting that occurred at nose-gear touchdown. Immediately prior to touchdown, the stabilizer trim position is between 4° and 5° leading edge down. If the pilot pulls back on the stick and puts the leading edge farther down, the loads increase. If he pushes the stick forward and moves the leading edge up, the loads decrease, as shown in the figure. It is evident that the gear loads can be significantly reduced if the stabilizer angle is prevented from moving in the leading-edge-down direction during the landing itself. It is important to note that this parameter was the first with which the landing data appeared to be correlated.

Effect of Wing Lift

The second factor affecting the landing-gear loads is the wing lift. Again, the inability to prevent rapid rotation onto the nose gear results in higher gear loads because of the sudden decrease in wing lift (ref. 2). Figure 5 shows the effect of wing lift on the main-gear loads as a function of touchdown velocity. Note that increasing wing lift on the ordinate scale designates a decreasing gear load. Data at nose-gear touchdown fall between the calculated curves for angles of attack of 0° and -4° . The overall trend, as expected, is an alleviation of the main-gear load with increasing angle of attack. These results also indicate that, as long as a positive wing lift can be maintained during the nose-gear touchdown, any increase in landing velocity is also an alleviating factor.

In the data obtained for the only flaps-up landing made to date, shown by the solid symbol, the wing lift decreased to a down load, which added to the load on the main gear. The rapid loss of wing lift is minimized in conventional aircraft by locating the main gear so that the stabilizer is effective in controlling the rotation. This location for the landing gear, however, is impractical for the X-15 configuration.

Effect of Landing Weight

The third factor of major concern is weight. The X-15 landing weight has increased steadily from the initial landing weight of 13,230 pounds and now ranges between 15,000 pounds and 15,500 pounds. Although weight alone is not the most significant factor in determining the maximum gear load, it is still true that, other things being equal, the greater the weight, the higher the load. The effect of weight is shown in figure 6, where data are presented for which all parameters except weight are constant, or at least tightly bounded. Two sets of points are shown, representing maximum shock-strut load as a function of landing weight. The circles are from landings with stabilizer settings at nose-gear touchdown of -16° to -24° . The squares are from landings at lower stabilizer settings of -4° to 4° . A line has been faired through each set of points. For the landings made with the higher stabilizer settings, the limit load would be reached at a landing weight of 15,700 pounds. In an emergency, the landing weight with residual fuel aboard could be as high as 17,000 pounds. Only by the pilot making a push maneuver to obtain low stabilizer settings can this type of landing be accomplished successfully. Although the design limit would be exceeded, the loads could be held below the yield limit as indicated.

The extreme values of the stabilizer setting, wing lift, and increased landing weight occurred simultaneously during an emergency landing of the X-15-2 airplane in Nevada. The pilot routinely pulled back on the control stick, driving the stabilizer leading edge down to its maximum value. In addition, the flap mechanism failed at the same time, which resulted in a down load on the wing and, therefore, on the gear. And, finally, residual fuel increased the landing weight by about 1000 pounds. The combined result was an overstressed gear, which, of course, failed.

Of all the factors affecting the gear loads, the most difficult to control, without restricting the research role of the aircraft, is weight. The contribution of the stabilizer setting is more easily controlled by the pilot push maneuver. In addition, a switch has been installed to disengage the stability-augmentation system at main-gear touchdown to prevent the control system from forcing the stabilizer leading edge down. Experience has shown that the pilot can be depended upon to push the stick during normal landings, even though the push maneuver must occur within 0.4 second after main-gear touchdown to be effective in reducing the gear loads. However, this maneuver is unnatural for the pilot and, in an emergency, he is apt to revert to habits formed through experience and pull back on the stick. For these reasons, an automatic stick pusher has been developed, which, similar to the disengage switch, will be activated at touchdown. This device is being installed on the aircraft and will be evaluated in flight.

Another approach under consideration is to alleviate the main-gear loads by use of a third skid. This concept is shown in figure 7, in which a photograph has been retouched to show a third skid located in the unjettisoned portion of the lower vertical stabilizer between the two present skids. The skid would be effective in redistributing the load and in relieving the critically stressed gear components, particularly if either the stick pusher or the landing flaps failed to operate. The third-skid concept is undergoing design evaluation.

After the emergency landing with the X-15-2 airplane, noted previously, consideration was given to a design for a new landing gear which would apply the experience gained with the basic X-15 gear system. However, constraints on the program, which dictated minimum modifications, resulted in a gear system that was changed very little from the original. The present gear locations were used, and a dynamic analysis was utilized to aid the designers in rebuilding the gear system on the basis of the second reaction. Figure 8 shows the basic changes that were made. The gear was lengthened, the shock-strut stroke was increased, and the strut hydraulic and air-spring characteristics were altered to provide additional energy dissipation. However, the landing dynamics of the new gear were not appreciably changed and most of the deficiencies of the basic system were inherited. It was necessary, therefore, to incorporate the disengage switch for the stability augmentation system and the use of the pilot push maneuver in the gear design to permit operation of the X-15-2 airplane in all of its planned configurations.

Some changes were made also in the nose gear. The shock-strut stroke was increased to accommodate the increased weight of the vehicle. The trunnion was lowered 9 inches to allow a greater attitude at nose-gear touchdown.

Further modifications of the X-15-2 main gear will be required for use with the proposed ramjet package. The landing-gear legs must be lengthened to provide ground clearance for the ramjet. This increase in length will reduce the attitude at nose-gear touchdown, but the length of the new nose gear is sufficient to maintain an attitude similar to that of the basic X-15. An emergency landing with the ramjet on board could be at a weight of almost 20,000 pounds, which is far beyond the capability of the present gear. However, dynamic analysis of a lengthened gear with modified shock-strut characteristics shows that, by use of the disengage switch and an automatic stick pusher, the emergency condition can be tolerated. The third-skid concept is also being considered to provide an additional margin of safety for the ramjet project.

Effect of Nose-Gear Location

If future modifications are to be made to the X-15 landing-gear system because of increased airplane weight or length, structural modifications will be required. Relocation of the main gear will still be impractical, but relocation of the nose gear is possible. The results of analytical studies on relocation of the nose gear on the basic X-15 are presented in figure 9, in which maximum main-gear shock-strut load is shown as a function of nose-gear

distance ahead of the center of gravity. The present location of the nose gear on the basic X-15 is approximately 23 feet ahead of the center of gravity, as indicated in the figure. The main-gear loads can be significantly reduced by moving the gear farther back. The X-15 nose gear can be relocated behind the cockpit between 12 feet and 14 feet ahead of the center of gravity. Liquid-oxygen-tank structure prevents a location farther rearward. Fortunately, the center of percussion (the optimum position) is 12 feet ahead of the center of gravity.

CONCLUSIONS

The X-15 landing-gear system is representative of a compromise between a gear of conventional design and location and a gear that possesses qualities of simplicity, ease of stowage, clearance for the lower vertical stabilizer, and slideout stability. Subsequent experience with the airplane has proved that the gear location caused much higher landing loads than were expected. These experiences, coupled with the increasing weight of the X-15 airplane, have required periodic modifications to the landing-gear system to provide an acceptable factor of safety. Most important, however, has been the success of the X-15 landing loads program in providing an understanding of the nature of the loads and establishing the requirement for the use of a dynamic analysis for predicting the loads.

Flight Research Center,
National Aeronautics and Space Administration,
Edwards, Calif., October 7, 1965.

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1. McKay, James M.; and Kordes, Eldon E.: Landing Loads and Dynamics of the X-15 Airplane. NASA TM X-639, 1962.
2. Noll, Richard B.; Jarvis, Calvin R.; Pembo, Chris; Lock, Wilton P.; and Scott, Betty J.: Aerodynamic and Control-System Contributions to the X-15 Airplane Landing-Gear Loads. NASA TN D-2090, 1963.

X-15 LANDING-GEAR SYSTEM

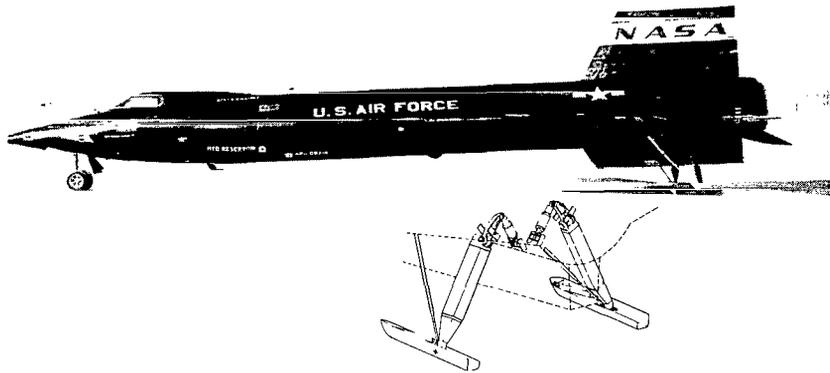


Figure 1

MAIN-GEAR SHOCK-STRUT FORCE

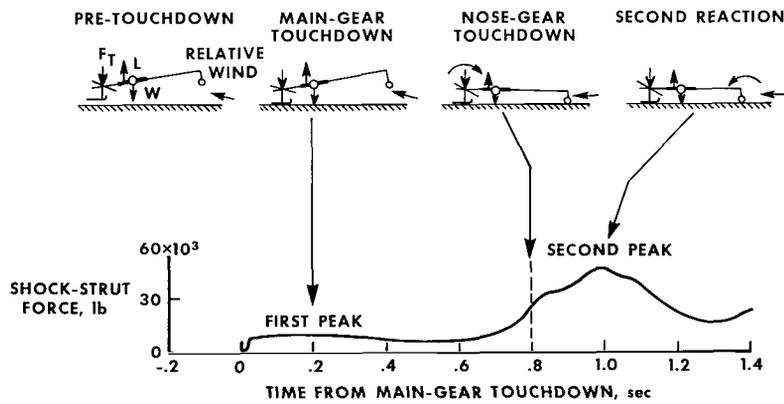


Figure 2

INFLUENCE OF AIRPLANE SINK SPEED ON MAIN-GEAR LOAD

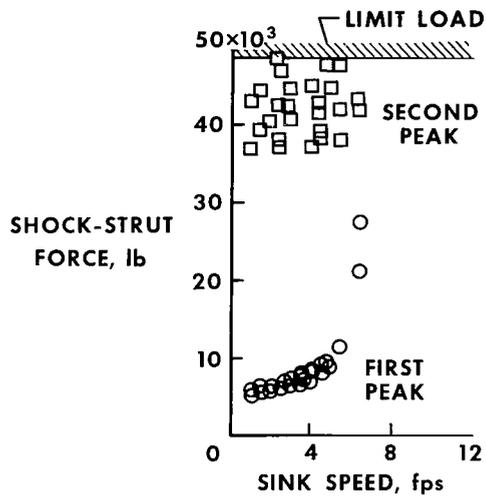


Figure 3

INFLUENCE OF STABILIZER POSITION ON MAXIMUM MAIN-GEAR LOAD

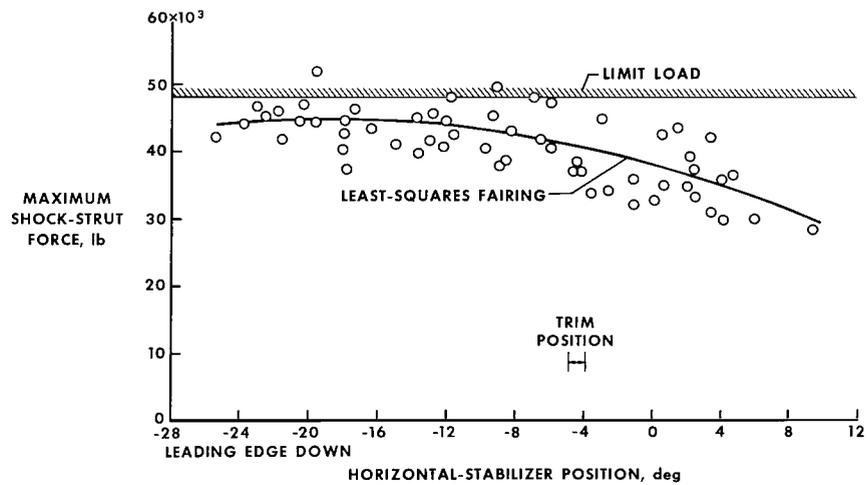


Figure 4

EFFECT OF WING LIFT ON TOTAL MAIN-GEAR LOAD

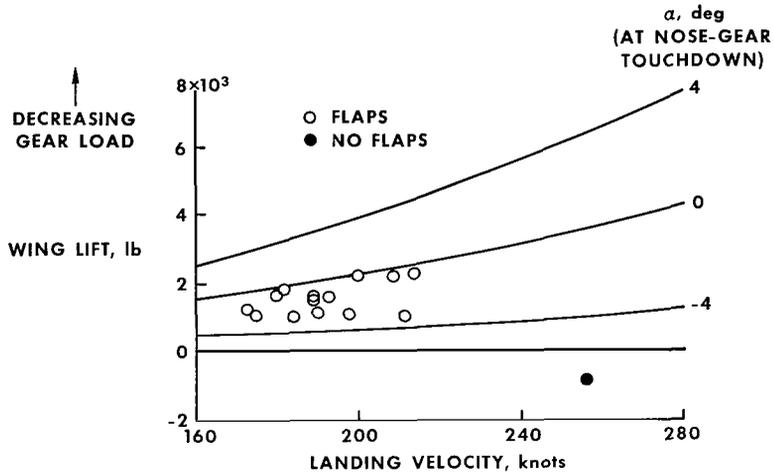


Figure 5

INFLUENCE OF AIRPLANE LANDING WEIGHT ON MAXIMUM MAIN-GEAR LOAD

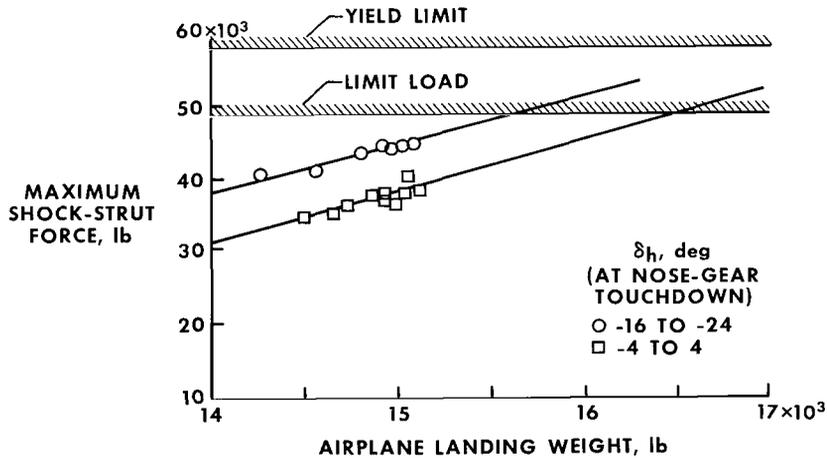


Figure 6

PROPOSED X-15 THIRD MAIN-SKID CONFIGURATION

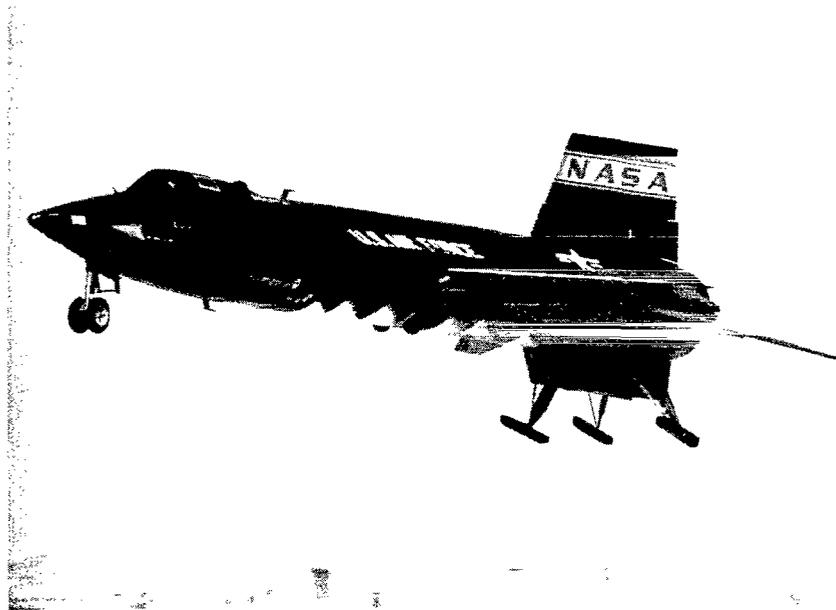


Figure 7

X-15 MAIN-LANDING-GEAR CHARACTERISTICS

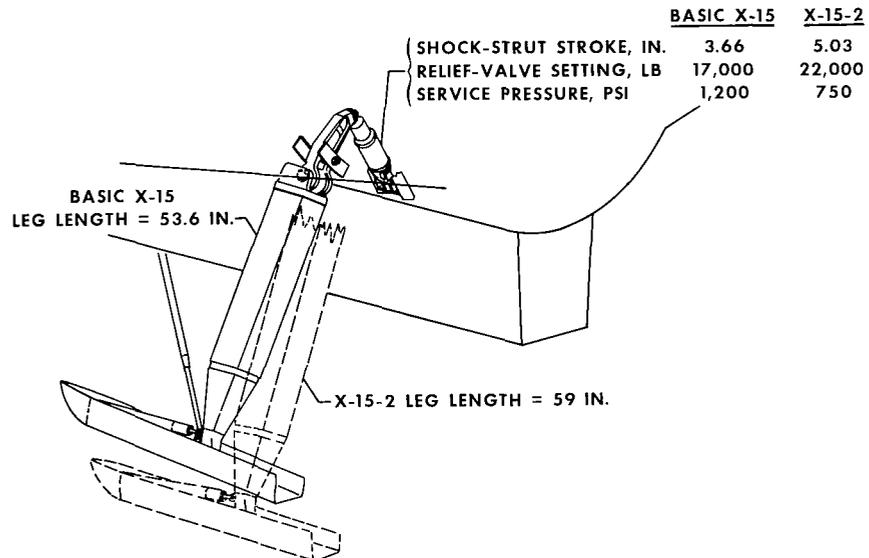


Figure 8

INFLUENCE OF NOSE-GEAR LOCATION ON MAIN-GEAR LOAD

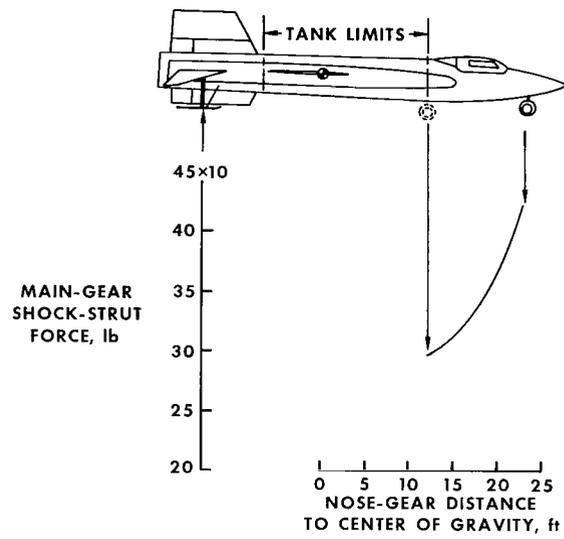


Figure 9

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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