UTILIZATION OF THE PILOT DURING BOOST PHASE OF THE STEP I MISSION

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SUMMARY

Some of the capabilities of the human pilot for controlling the Step I Dyna-Soar launch have been assessed by requiring the pilot to control the simulated launch. The piloting task was well within the capability of the human pilot. With only rudimentary presentation, the pilot could control the launch to within acceptable limits of the desired velocity and altitude. As the primary controller of the launch, it is believed that the pilot can add materially to the reliability and flexibility of the launch.

INTRODUCTION

The role of the pilot in the launch of a multistaged vehicle with orbital capability has been examined extensively during the past year (for example, ref. 1). Generally, these studies used launch simulations in which the pilot, presentation, controller, and analog computer formed a closed-loop system. In one study the effects of the launch-acceleration environment on the performance of the pilot was investigated, and the human centrifuge was used to close the launch-acceleration loops in normal and longitudinal acceleration. The results of these studies were generally encouraging and showed that the use of the pilot as the primary controller of the launch of multistaged vehicles holds promise.

It is the purpose of this paper to indicate some of the capabilities of the pilot for controlling the Step I Dyna-Soar launch based on a fixed-base simulation program and on the results of previous investigations at the Flight Research Center.

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SYMBOLS

a_x	longitudinal acceleration, g units
g	acceleration due to gravity, ft/sec^2
h	altitude, ft
Δh	altitude error, ft
I_Y	vehicle moment of inertia in pitch, slug-ft^2
q	dynamic pressure, lb/sq ft
R	range, nautical miles
S	reference area, sq ft
V	relative velocity, ft/sec
ΔV	velocity error, ft/sec
α	angle of attack, deg
γ	flight-path angle, deg
$\Delta\gamma$	flight-path error, deg
δ_h	stabilizer position (X-15), deg
δ_n	nozzle position (Dyna-Soar), deg
ζ	damping ratio
ω_n	vehicle undamped natural frequency, radians/sec

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LAUNCH SIMULATIONS

In figure 1 is shown the nominal Step I Dyna-Soar mission. The two-stage launch to a velocity of 19,000 ft/sec with a range capability for the lifting glider of 3,000 to 4,000 miles is shown. This study investigated primarily the boost phase of the mission but did consider briefly the effects that piloting errors at burnout would have on the range capability of the glider.

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Control, presentation, and guidance similar to that which proved satisfactory during previous launch programs was used to enable the pilot to control the desired boost trajectory. For pilot's control, the Flight Research Center's three-axis controller was used by virtue of its generally satisfactory performance during previous fixed-base and centrifuge investigations. The previous paper by Brent Y. Creer, Harald A. Smedal, and Rodney C. Wingrove showed that more conventional controllers, for instance, a two-axis controller with toe pedals, would have been satisfactory at the level of acceleration (about 5g) expected for this vehicle. It was determined during the Flight Research Center's centrifuge boost program that longitudinal staging accelerations up to 9g had very little effect on the ability of the pilot to perform the boost control task. In fact, at this level of acceleration the pilots estimated that only 30 to 40 percent of their physical effort was required for the control task. There was some loss in peripheral vision due to the normal component of the acceleration environment, but actual data show no deterioration in performance at this acceleration level. Since the Dyna-Soar launch is not expected to require an acceleration higher than 6g, little effect of the acceleration environment on the pilot's performance would be expected. However, a good support system, such as the molded seat used during the centrifuge program (ref. 1), is vital for the pilot's comfort and for fixing the pilot-controller position during acceleration.

For the present study, no new presentation concepts were developed. Rather, known required quantities were presented to the pilot on conventional instruments as is shown in figure 2. Primary control quantities were angle of attack, angle of sideslip, angle of bank, altitude, and velocity. No vernier rockets were used for control of final velocity, but a sensitive presentation of the final thousand feet per second proved useful for indicating when to cut off thrust. Other useful quantities were pitch attitude, pitch and yaw program errors, and remaining burning time. A stage warning light was useful, especially for controlling vehicles with unstable aerodynamics. A card of the desired attitude-altitude provided alternate guidance.

RESULTS AND DISCUSSION

Figure 3 shows a typical piloted launch from the fixed-base Step I simulation. The performance quantities are shown in the upper half of the figure, and the control quantities are shown in the lower half. The control task was initiated 20 seconds after ground launch with the vehicle at an initial angle of 87°. In order to accelerate the 9,000-pound glider to the desired end conditions of about $h = 250{,}000$ feet and $V = 19{,}000$ ft/sec, two stages of about 5g each were required.

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Typical mass and aerodynamic characteristics for the finned vehicle were assumed. For this launch the vehicle longitudinal stability was statically stable for the first stage and unstable for the second stage; however, several levels of stability - both stable and unstable - were investigated. Representative characteristics for the lateral and directional modes were assumed, but primary emphasis was placed on the longitudinal modes of motion. Titan (Lot J) missile weight and inertia characteristics were used (table I), as were the Titan nozzle-deflection and rate limitations.

For primary guidance, flight-path error was presented to the pilot. This error was controlled by controlling angle of attack through nozzle angle. Shown also in figure 3 is the vehicle first-stage structural limit of $\alpha q = 3,750$ considered during the study. Only small values of α were required to correct flight-path error during the first stage, but considerably higher values were required during the second stage where aerodynamic lift was small. Of interest also was the absence of disturbances during staging where a limit of $\alpha q = 350$ was used. L1124

Reference 1 has also shown that a control problem could exist at staging for vehicles of this type. Figure 4 orients the assumed Dyna-Soar vehicle aerodynamic characteristics in pitch relative to previous investigations. The crosshatched region shows the scope of previous investigations of static stability and damping. Included is the piloted controllability limit for zero-time thrust delay between stages. Indicated are points investigated in considerable detail under the acceleration environment during the Flight Research Center's centrifuge program and the two levels of damping at which the piloting controllability limits were verified during closed-loop centrifuge operation. Shown also in figure 4 are the first- and second-stage Dyna-Soar longitudinal aerodynamic characteristics representing the basic unaugmented configuration. The Dyna-Soar vehicle appears to be easily controllable, but lightly damped. With reference to figure 3, which illustrates the control task with the basic configuration, it can be seen that the control motions are characterized by small precisely timed inputs. The pilots commented that even stable static stability is not appreciated without damping.

For staging, the "fire-in-the-hole" technique (or firing of the second stage before separation of the first stage) proposed for the Dyna-Soar vehicle proved very beneficial during thrust delays, but second-stage unstable aerodynamics can result in a control problem if staging occurs at an angle of attack.

Figure 5 shows the results of an investigation of the control of the second stage of the Dyna-Soar vehicle. Shown is the ratio of angle-of-attack excursions to the staging angle of attack for various levels of second-stage instability. These data indicated that for the basic level of instability ($\omega_n^2 = -2.5$ radians^2/sec^2), an excursion in α of

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approximately 2.5° can be expected for each degree of staging angle of attack. Staging up to about 1.5° could be tolerated to restrict the α excursions to the assumed αq limit. However, it was relatively easy to control staging angle of attack to low values.

In order to determine the effect of vehicle aerodynamic characteristics on the pilot's performance, launches were made at several levels of vehicle stability and damping. The performance of one pilot is summarized in figure 6, which shows a typical launch as a function of velocity and altitude. Also indicated in this figure is the spread in altitude and velocity at first staging and also at the final cutoff velocity of 19,000 ft/sec. Shown in the left inset is a typical set of second-stage end velocities and altitudes for the basic vehicle and two other levels of vehicle stability and damping. No variation in performance with stability or damping was indicated. However, it was indicated that the pilot can control the final velocity and altitude for this mission with the simple presentation used to within about 20 to 30 ft/sec in velocity and 3,000 to 4,000 feet in altitude.

The ability of the pilot to adjust to more demanding control tasks during the launch was investigated by unexpectedly failing augmentation loops and guidance during the launch. The results of these simulated emergencies are shown in the other insets as final incremental altitude and velocity about the desired quantity. It can be seen in figure 6 that the pilot has the capability of performing this launch control task even with limited presentation.

A heading change has been proposed during the Dyna-Soar launch to avoid dropping the first-stage booster in a restricted area. To determine the effect that this more complex piloting task might have on the pilot's performance, heading changes of 10° and 20° were made during the second stage.

A comparison of the pilot's performance with and without the heading-change task is shown in figure 7. Also shown is the variation in altitude and velocity for the two tasks. It is apparent that the addition of heading-change task had little effect on the ability of the pilot to control the vehicle burnout altitude and velocity. Figure 8 shows the effect of piloting errors in velocity and heading at burnout on the range capability of the lifting glider. The crosshatched region shows the range resulting from errors in velocity of 50 ft/sec and in heading of 2°. It can be seen that the expected piloting errors are insignificant compared to the maneuvering envelope of the vehicle for the 19,000 ft/sec mission.

Since the North American X-15 is a rocket-powered vehicle and is designed to be piloted to 250,000 feet, a brief comparison will be drawn between the piloting requirements for the X-15 design altitude mission and the piloted Dyna-Soar launch. Typical launches are compared in figure 9. Shown in this figure are the longitudinal acceleration, velocity, altitude, angle of attack, and pilot's control position.

The launch accelerations during boost are quite similar and the piloting tasks are similar once the X-15 is rotated to the proper attitude angle of 31°. The X-15 launch requires constant pitch attitude to burnout, whereas the Dyna-Soar ideally requires constant angle of attack (zero).

Piloting the X-15 during the launch would serve to delineate the L
piloting problems of the Dyna-Soar vehicle. Based on simulator investi- 1
gations of the control task and of the effects of acceleration environ- 1
ments, both control tasks appear to be well within the capability of the 2
human pilot. 4

CONCLUDING REMARKS

In summary, it appears that the human pilot is capable of controlling the launch of the unaugmented Dyna-Soar vehicle. The launch acceleration environment anticipated will have a negligible effect on the performance of the pilot. With augmented damping, some negative stability could be controlled by the pilot. With only rudimentary presentation, the pilot can control the vehicle to within acceptable limits of the desired velocity and altitude. The inclusion of the turn task had little effect on the pilot's control of final altitude and velocity. As the primary controller of the launch, it is believed that the pilot can add materially to the reliability and flexibility of the launch maneuver.

REFERENCE

1. Holleman, Euclid C., Armstrong, Neil A., and Andrews, William H.: Utilization of the Pilot in the Launch and Injection of a Multistage Orbital Vehicle. Paper No. 60-16, Inst. Aero. Sci., Jan. 25-27, 1960.

TABLE I.- TITAN MISSILE CHARACTERISTICS

Stage I (at launch):	
Weight, lb	232,400
Thrust at sea level, lb	300,000
I_Y, slug-ft^2	3,310,000
Control arm, ft	42
Burning time, sec	138.5
Stage II:	
Weight, lb	54,500
Thrust, lb	80,000
I_Y, slug-ft^2	221,000
Control arm, ft	21
Burning time, sec	157.5
Glider:	
Weight, lb	9,000
Wing area, sq ft	330

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TYPICAL DYNA SOAR-LAUNCHES

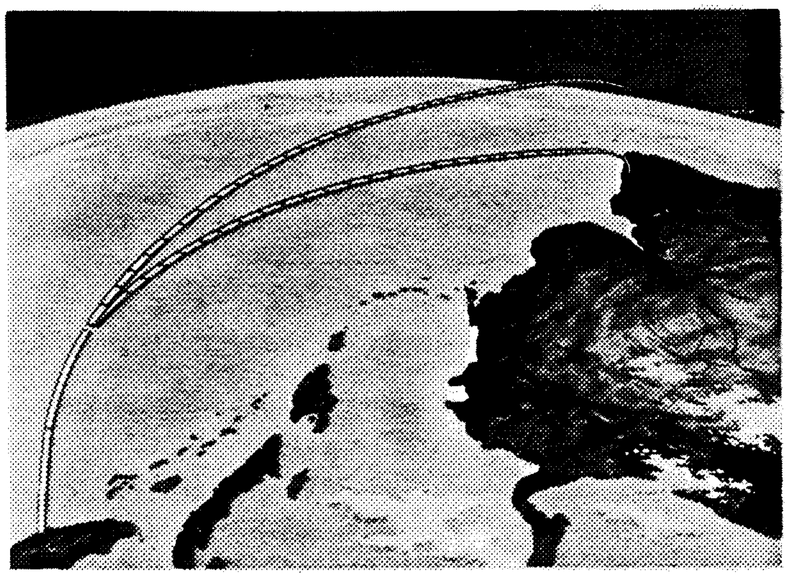

Figure 1

PILOT'S PANEL

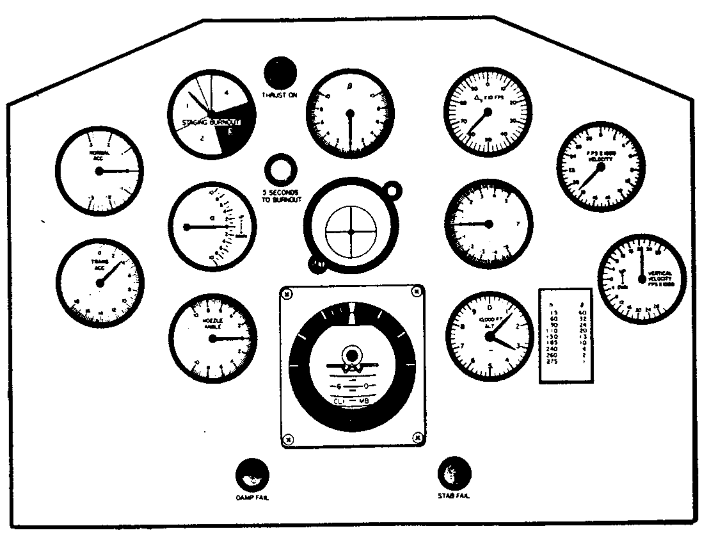

Figure 2

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TYPICAL PILOTED LAUNCH

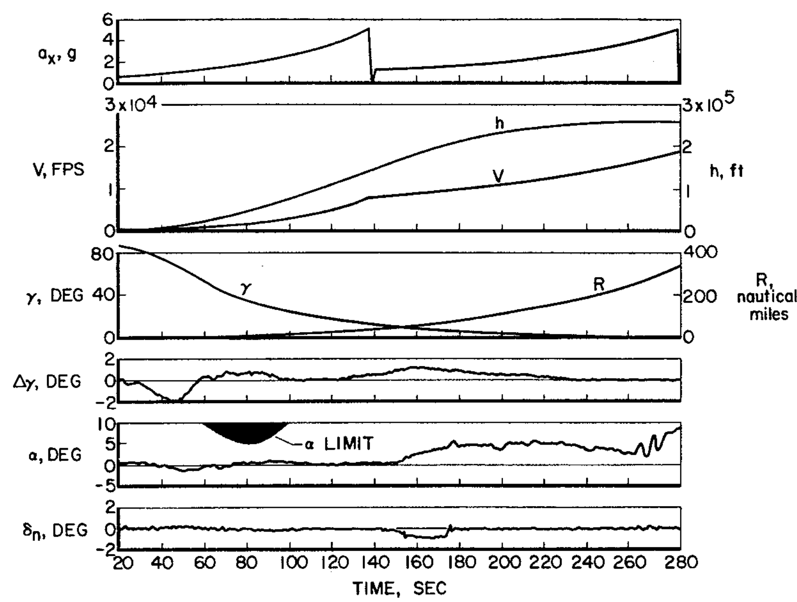

Figure 3

VEHICLE CONTROLLABILITY

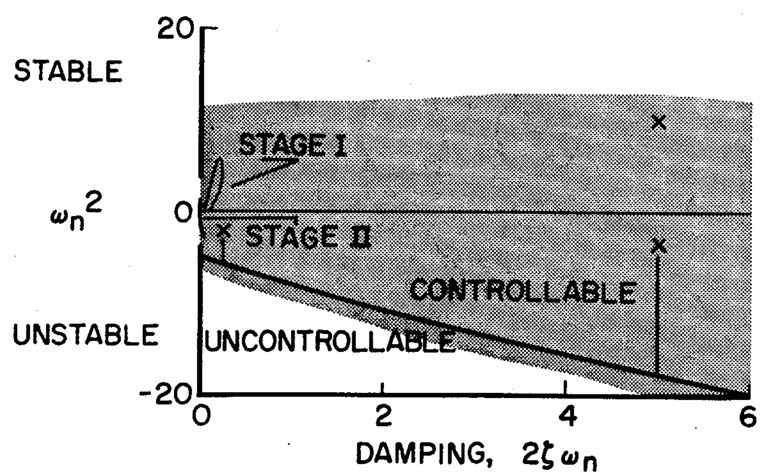

Figure 4

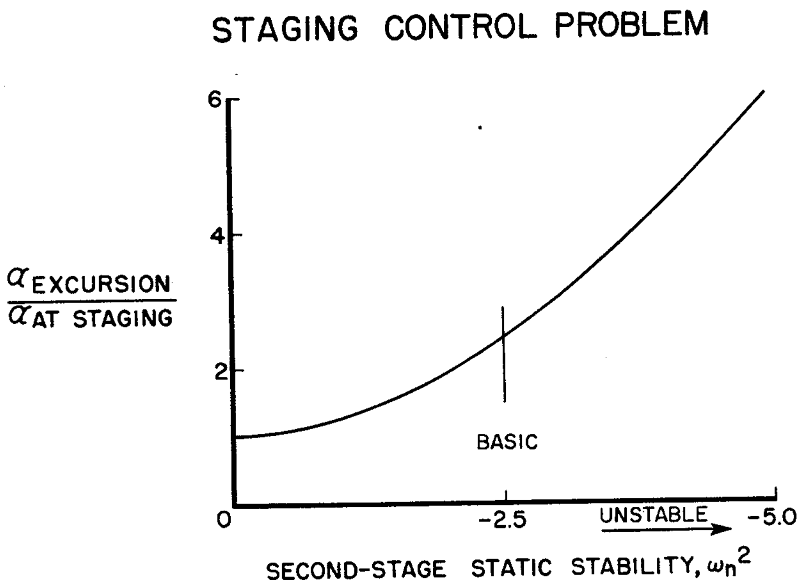

Figure 5

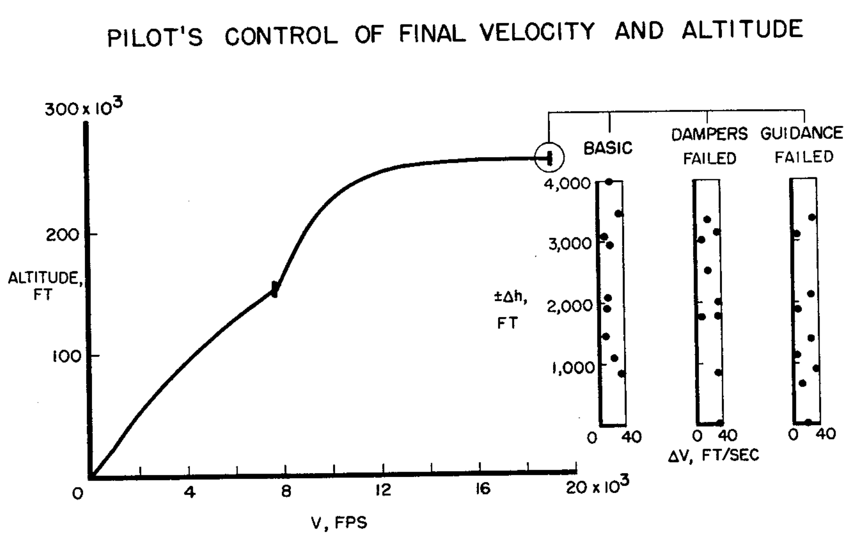

Figure 6

EFFECT OF HEADING-CHANGE TASK

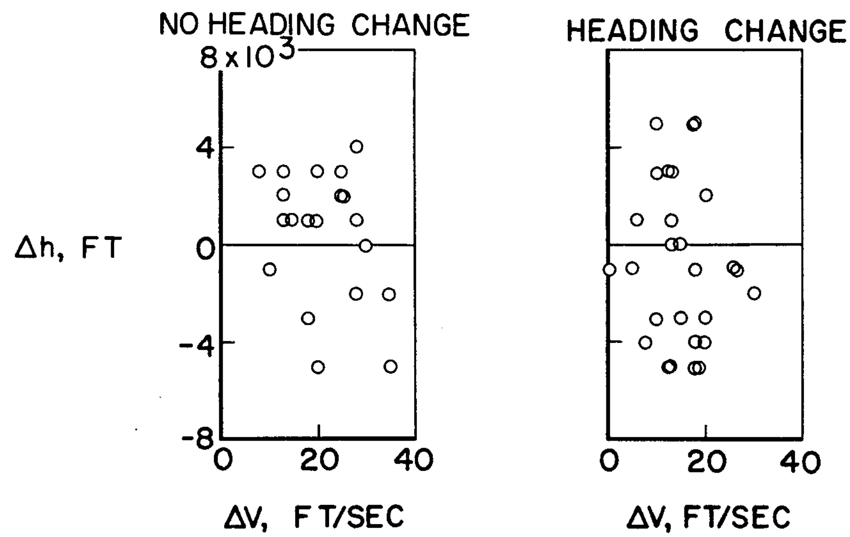

Figure 7

PILOTING ACCURACY

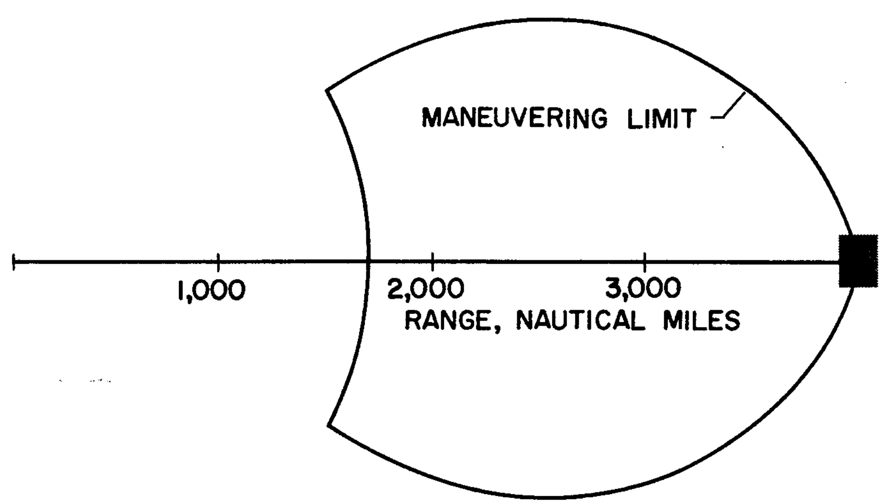

Figure 8

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COMPARISON OF X-15 AND DYNA-SOAR LAUNCHES

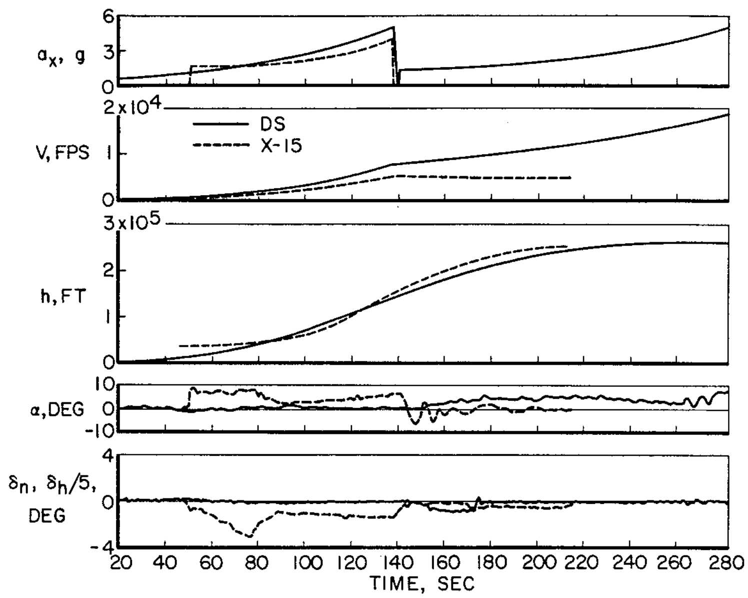

Figure 9

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