

NACA - Langley

1949 INSPECTION

Pilotless Airc Res Div

## PILOTLESS AIRCRAFT RESEARCH DIVISION

## Introduction

You are now in the model assembly shop of the Pilotless Aircraft Research Division. This division of the Langley laboratory conducts research applicable to both airplanes and missiles using rocket-propelled models in free flight. The purpose of these flights is to obtain aerodynamic data, structural data and data on autopilot mechanisms. During your visit here today some of the techniques developed to obtain these data will be described and a few of the results will be presented.

Rocket-propelled models are used to obtain continuous data from subsonic speeds, through the transonic range and far into the supersonic region at nearly full-scale Reynolds numbers. Although the models are small relative to airplanes, they are flown at low altitudes. Thus the Reynolds number corresponds to full-scale airplanes at higher altitudes. Another factor which allows us to closely simulate the viscous effects is that the models are tested under conditions of free air turbulence and stagnation temperature. Because these data are obtained in free flight, no limitations are imposed by model support interference, jet boundary corrections, or free-stream Mach number gradients. Flight structural testing to destruction presents no undue problems because the models carry no human pilots and are expendable. The success of these rocket techniques is dependent on the ability to obtain measurements from the model while in flight. This is done by means of telemeters and radar equipment devised by the Langley Instrument Research Division.

The rocket models, of course, cannot be flown in a thickly

populated area. They are fired at Wallops Island, a test station located on the Atlantic Ocean near the Maryland-Virginia state line. This is an aerial photograph of the test station. (Point to it) It is an island with ocean on this side and marsh on this side. This is the launching area from which the models are fired (point to second photograph). Here is a photograph of a typical model immediately after firing.

The first chart shows some of the types of investigations that can be conducted using rocket models in free flight. The particular type of model and testing technique used depends on the type of information desired. For example, the first seven items listed (point to them) can all be obtained over a complete Mach number range from one flight of a model such as this one which contains telemeter and mechanism for pulsing the controls (point to XF-92 model). If however, only lift, drag, and trim change are of interest we use a simpler model such as this one (point to RM-7s) which is flown with fixed controls. If only the drag at zero lift is desired, a model such as this (point to RM-2T) containing no instrumentation at all is used. The data are obtained solely from ground radar and radiosonde measurements. The damping in roll can be measured using a relatively simple model such as this one (point to RM-13) or from a more complex model such as this (point to RM-8) which is arranged to also provide data on the dynamic stability, control effectiveness and hinge moments. By building models of known stiffness and strength aeroelastic effects and air loads such as aileron reversal, flutter, and wing divergence are investigated. Pressure distributions are used to determine local air loads and inlet performance (point to words).

Automatic stabilization (point to words) is studied by first

measuring the various aerodynamic derivatives of the missile using a model such as this one (point to RM-8) and then matching to them the response characteristics of the autopilot as measured from laboratory tests. The overall performance of the autopilot and missile is then evaluated using an autostabilized model such as this one (point to RM-4).

Techniques have been devised for studying special dynamic problems (point to words) such as means for pilot escape from airplanes and ways of stabilizing booster-rocket systems.

The techniques and procedures (point to words) used in this research work also have tactical value for missiles and are useful to other ranges engaged in test and evaluation work. Typical of these are reliable angle-of-attack indicators, zero-length launchers, booster separation, and Doppler radar equipment for measuring velocity and acceleration.

This chart has given you an overall picture of the work of this Division. The rest of the discussion here today will be devoted to giving you a more detailed picture of some of the techniques mentioned.

### Longitudinal Stability

One of the stability and control difficulties encountered with aircraft flying through the transonic speed range has been a serious trim change sometimes resulting in uncontrollable attitudes being reached. A measure of the trim change can be obtained from the normal acceleration developed in flight when the controls are held fixed. We make use of this fact to study the trim changes and also the drag of different airplane configurations through the transonic speed range. Here are two models typical of those flown in this investigation. The

controls are locked at different deflections, and in flight the normal and longitudinal accelerations are telemetered to ground stations. Some data of this type are shown on the first chart. (Expose chart 1) On this chart is plotted normal-force coefficient,  $C_N$  against Mach number for two stabilizer incidences labeled  $i_t$  for the same center-of-gravity location. It will be noted that through the transonic speed range the values of  $C_N$  become more positive, indicative of a pitching-up tendency. The stabilizer is an effective control through this speed range as indicated by the change in  $C_N$  resulting from changing the tail setting. On this side of the chart are plotted the drag coefficients,  $C_D$  against Mach number for the same flights. The drag rises abruptly in the transonic region. Some indication of the effect of lift on drag can be obtained from the difference between the drag curves for the two tail settings.

Some indication of whether or not the fixed-control models are dynamically stable can be obtained from the measured acceleration. However in order to study the degree of dynamic stability and to measure the variation with angle of attack of the various aerodynamic parameters, a technique utilizing pulsed controls is used. The success of this technique in addition to being dependent on the high-precision, high-frequency telemeters developed by the Instrument Research Division also depends on this angle-of-attack indicator also developed at this laboratory. A model with pulse controls is set up here with its Deacon booster in much the same way as it is at Wallops Island when ready for launching. With this booster, supersonic Mach numbers are reached without the need for a sustainer rocket inside the model itself. Of course after the booster has stopped thrusting it is rejected and the characteristics of the model alone are determined.

The model equipped with a power unit to pulse the control up and down in a square-wave pattern. I will now demonstrate this. Observe the elevator motion. A sample of the telemeter records from such a model is shown on the next chart (expose chart 2). The pulsing of the elevator in this up-and-down fashion at a rate of about 1 cycle per second produces corresponding changes in angle of attack and normal acceleration. The dynamic stability is indicated by the period and rate of decay of the oscillation while the control is stationary between pulses. The other values determined were hinge moment, Mach number, longitudinal acceleration and transverse acceleration.

Typical of the flying-quality items that can be determined from records such as these are shown on the next two charts. (Expose chart 3) The elevator required for level flight,  $1g$ , and for a  $3g$  maneuver for the airplane at sea level and 40,000 feet altitude are shown on this chart plotted against Mach number. Data like these present trim changes, stability, control, and maneuverability in a form understandable to pilots.

The characteristics of the short-period longitudinal oscillation as determined from the model converted to full scale are shown on this chart. (Expose chart 4) Here the period of the oscillation is plotted against Mach number for zero and 40,000 feet altitude and here the cycles to damp to one-tenth amplitude are given. It can be seen that cycles to damp increased with increasing Mach number and altitude.

The curves for the damping are drawn conservatively through the points of least damping. The reason for the scatter of points is not known but since we know it is not in the instruments, it may be characteristics of the speed range. Because these data are obtained in free flight all the aerodynamic factors that affect the damping are properly integrated into the motion of the model. Similarly all the degrees of freedom, cross-coupling and non-linearity are properly represented.

In addition to the flying qualities, the recorded data can be analyzed to yield various basic design factors, some of which are shown on this chart. (Expose chart 5) The three different symbols represent flights of three different models of the same configuration at different weights and center-of-gravity locations. The items shown are the aerodynamic-center position, the lift-curve slope,  $C_{L\alpha}$ , the rate of change of lift coefficient with flap deflection,  $C_{L\alpha}$ , the effectiveness of the elevator in changing the pitching moment,  $C_{m\delta}$ , and the damping-in-pitch parameter,  $C_{mq}$ . The data for none of these parameters except the damping show an inordinate amount of scatter. The variations of all the factors in the transonic range are expected to be influenced by the Reynolds number because of separation from shock-wave - boundary-layer interaction. However, it will be noted that the Reynolds number of these tests is about 14 million, which is full scale for many airplanes at altitudes of 40,000 feet and for missiles at lower altitudes. Even though the model is expended, the cost is small considering the amount of data that are obtained continuously over a complete Mach number range including the transonic at full-scale Reynolds numbers.

These methods are used to provide data on the longitudinal, lateral, or directional stability and control of complete airplane or missile configurations. The factors influencing the design of the control surfaces themselves have been studied by other rocket techniques. Mr. \_\_\_\_\_ will now tell you about some of this work.

#### Lateral Controls and Damping in Roll

The problem of obtaining effective controls through transonic and supersonic speeds is of great importance to both airplane and missile designers. By means of a rocket-model technique, we have been able to study various control arrangements through this speed range. The

actual controls studied were arranged as ailerons and their rolling power measured, but the general trends also apply to rudders and elevators.

A typical test vehicle, which you see here on exhibit (point to RM-5 model on chart stand), consists of a pointed cylindrical fuselage to which the particular wing-aileron configuration under investigation is attached in a three-panel arrangement. The wings are set at zero incidence and the control is set at the desired deflection. The rolling velocity produced by the control is obtained by means of this small radio transmitter (point). These data, in conjunction with Doppler radar, flight-path velocity measurements, and radiosonde observations, permit the evaluation of the wing-aileron rolling effectiveness as a function of Mach number.

Some idea of the scope of this investigation can be obtained from these charts (uncover charts 6A and 6B). We have studied the effects of airfoil section (point to list), aileron span (point to partial-span ailerons), spoilers (point), aileron contour (point), leading-edge ailerons (point), and wing plan form. Both the wing-aileron rolling effectiveness and the drag of these configurations have been determined continuously over the Mach number range from 0.7 to 9.8 at large Reynolds number.

The experimental technique which we have just discussed permits only the evaluation of the rolling effectiveness parameter,  $\frac{pb}{2V}$ , for a control surface. This quantity is a combined function of the rolling moment produced by the ailerons and the damping moment produced by the wing in roll. In order to allow an evaluation of the rolling moment due to the ailerons from such results, techniques have been developed for determining the damping in roll.

Here is one of the models used in the damping-in-roll investigation. The configuration is similar to the control investigation model except that the ailerons are set at neutral and a torque is applied by a special nozzle of the type shown here which forces the model to roll as it is propelled through the air. The nozzle consists of four small units which are offset from the center of the model and set at an angle to provide the desired torque. In flight the measurements are the same as those discussed for the control-effectiveness technique. (Expose chart 9) Here (point) is a plot of measured rolling velocity against Mach number for this straight-wing configuration. Knowing the torque produced by the nozzle, the damping-in-roll factor,  $C_{\ell_p}$ , is readily determined giving due consideration to inertia and any incidental asymmetry that exists.

Values of  $C_{\ell_p}$  are plotted here (point) against Mach number. Zero damping is here. Calculated values at high subsonic speeds and at supersonic speeds are also shown for comparison. It can be seen that the experimental results indicate that damping is maintained through the transonic region (point) and is somewhat less than theory at supersonic speeds (point). The fact that damping in roll is maintained through the transonic speeds indicates that the rolling effectiveness obtained on this model (RM-5 point) is a direct measure of the ability of the control to provide a rolling moment in this speed range.

The values of  $C_{\ell_p}$  obtained are also of direct value in the calculations of dynamic stability and in the design of autopilots. Mr. \_\_\_\_\_ will now discuss some of the work on autopilots.

#### Automatic Stabilization

In the automatic stabilization of a missile, the high speeds and



normally small sizes make it particularly necessary to know the aerodynamic parameters, (point to  $C_{\ell_p}$  chart), such as  $C_{\ell_p}$  as well as the characteristics of the automatic control system. At subsonic speeds adequate roll stabilization has been obtained by this Laboratory with several different autopilot systems. (Expose chart)

The flight records from rocket-powered model for two systems are shown on this chart. The first of these (point) is a flicker-type or bang-bang system which is sensitive to roll displacement and rate of roll. In such a system residual oscillations are inherent and, for this reason, such a system may not be satisfactory where fine control is necessary. However, the system is mechanically simple and has been used where small steady-state oscillations are not objectionable.

The second curve (point) on the chart shows a record obtained from a flight of the same rocket-powered model stabilized with a proportional-type control system. As can be seen, somewhat finer control is obtained in that the model damped to a constant angle of bank following a disturbance.

Early attempts to obtain roll stabilization with these systems in the supersonic regime failed due to inherent aerodynamic limitations. Therefore the emphasis was placed on work leading to aerodynamic improvements in stability and control. This model (point to RM-4) is a supersonic research missile configuration which incorporates some of these aerodynamic improvements (point) in combination with the proportional roll stabilization system used previously on the subsonic missile. Note that as I roll the model the ailerons move immediately in a direction to restore the model to its initial attitude.

The work on automatic stabilization will be extended to cover longitudinal and directional stabilization. This is complicated by

the nonlinear characteristics of some of the aerodynamic factors and by cross coupling between some of them. By measuring the aerodynamic factors by means of missile models such as this one (point to RM-8) which is equipped with programmed controls and then matching these characteristics with the autopilot system, it will be possible to place autostabilization of supersonic missiles on a firmer footing.

To return to piloted aircraft (expose chart) another problem connected with supersonic flight is that of pilot escape from an airplane. The NACA has continued research on the nose-ejection method. In the full-scale airplane the pilot is within the ejected nose. (point at chart) Research at low speed in the Langley spin tunnel and  $7 \times 10$  foot tunnel has indicated that the jettisonable nose should be stabilized by the addition of fins in order to avoid excessive accelerations due to tumbling. Also, an investigation in the Langley Physical Research Division free-flight apparatus at a Mach number of 1.2 has verified the need and adequacy of the fins determined at low speeds. At the Pilotless Aircraft Research Division, we have successfully jettisoned the nose of a rocket-propelled model in flight at a Mach number of 0.9 (a region of current interest) to determine the separation characteristics. In the flight test, the drag of the nose and the remaining body were determined and are plotted here against separation distance in diameters. It can be seen that the nose shielded the body for an appreciable distance, thereby lowering its drag.

Another important factor for separation is the relative weights of the nose and aft body as can be seen on this chart of drag-weight ratio or deceleration. It can be noted for the actual model case, the deceleration of the nose is less than the body; therefore, separation occurred. For a more normal case where the nose would be lighter, its

deceleration would be greater than the body and separation would not occur unless the nose were forced to one side or the drag of the aft body increased by some means.

We will now show you by means of a motion picture some actual firings of models of different types at our Wallops Island Station.

This motion picture will be in slow motion - actual flight motion was approximately 3 times as fast. Several views of each actual launching will be shown, followed by tracking motion pictures.

The first scene is of the 100-watt continuous-wave Doppler radar unit by which the velocity and the acceleration of the research models are measured in flight. Note trackers operating equipment.

Next is the launching of a typical two-stage research vehicle. The model is now flying under the power of its booster rocket. A puff of smoke will indicate the burning out and rejection of the booster rocket. After this, a puff of smoke will be seen which will indicate the starting of the sustaining rocket propelling the model to its maximum speed.

The next scene is the launching of a fixed-control longitudinal stability research model as described previously. It also utilizes a booster stage in addition to the sustainer rocket.

No roll stabilization is incorporated in the longitudinal stability models since it is not necessary to stabilize them in roll.

This is a launching of one of the pulsed-control longitudinal stability-and-control models as previously described. There is the model-booster combination in flight. Note response of the combination to the controls. Rejection of booster. Model responding to control motion.

This is a flight of another model utilizing pulsed-control technique.

A similar booster arrangement was used but in this case the model was not equipped with a sustaining rocket motor. Drag separation rejection of the booster.

This is a flight of a flutter research vehicle. This model was used to study a new aeroelastic problem involving coupling between wing bending and body pitching. The wings are expected to fail during power-on flight and all the useful data are obtained before and during wing failure. There! Note the corkscrew path after failure of the test wings. A systematic investigation of flutter for various wing plan forms is being carried on through the use of this and a similar vehicle.

This is the launching of an autopilot servomechanism model described previously. Watch the disengagement of its booster unit. The model is flying successfully under the stabilization of its autopilot system.

This completes the program at the Langley Pilotless Aircraft Research Division.

(mpm, 5/26/49)





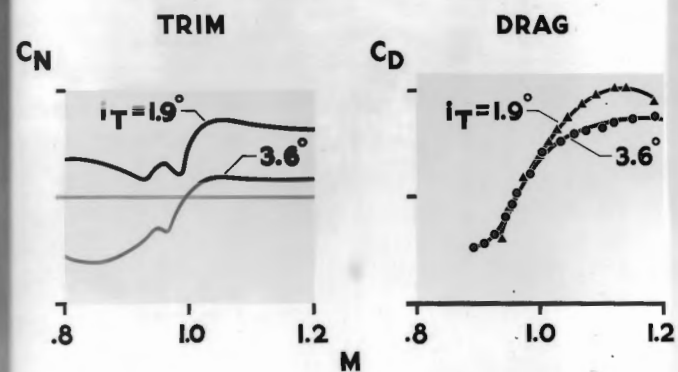
  
LAL 61132

## ROCKET MODELS

### TYPES OF INVESTIGATIONS

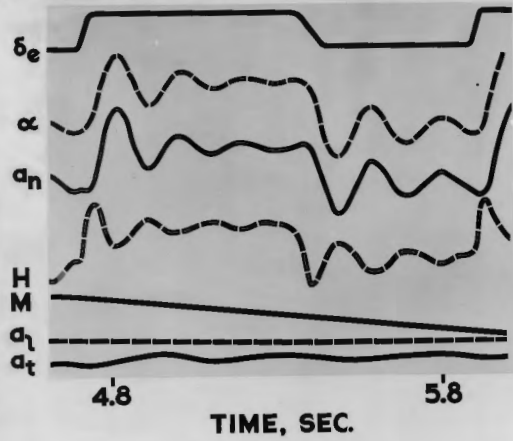
LIFT  
DRAG  
DYNAMIC STABILITY  
STATIC STABILITY  
TRIM CHANGES  
CONTROL EFFECTIVENESS  
HINGE MOMENTS  
DAMPING IN ROLL  
AEROELASTIC EFFECTS  
AIR LOADS  
PRESSURE DISTRIBUTION  
INLET PERFORMANCE  
AUTOMATIC STABILIZATION  
SPECIAL DYNAMIC TECHNIQUES  
TECHNIQUES AND PROCEDURES

## FIXED CONTROL MODEL



LAL 61133

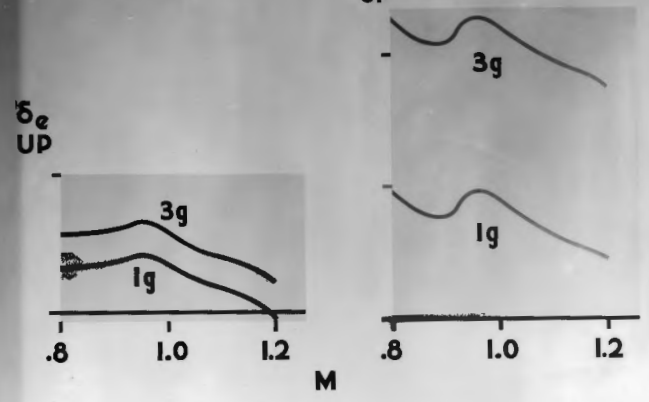
### PROGRAMMED ELEVATOR



### ELEVATOR REQUIRED

SEA LEVEL

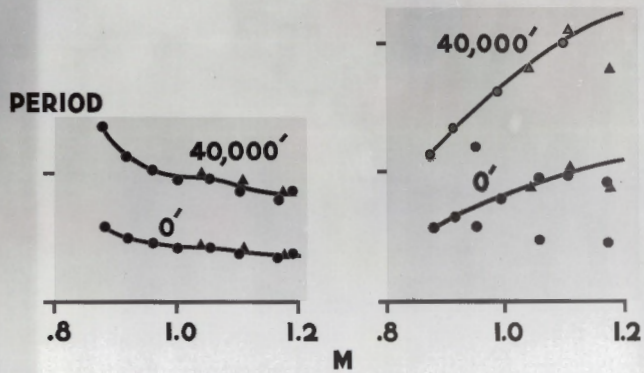
$\delta_e$  UP 40,000 FT.





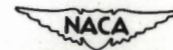
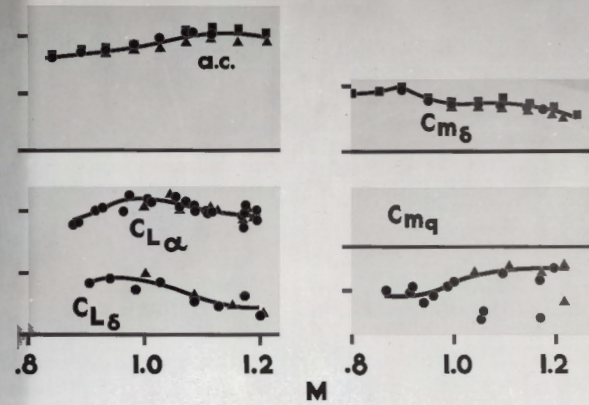
## DYNAMIC STABILITY

CYCLES  
TO DAMP



## BASIC DESIGN DATA

R=14 MILLION



LAL 61135

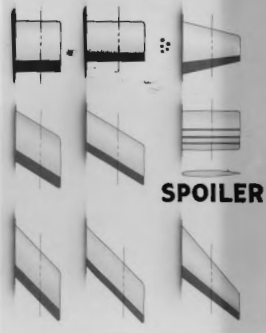
## LATERAL



65-006  
65-009  
65A009  
16-009  
6% CIR. ARC  
9% CIR. ARC  
9% DBL.WDG.

ALSO 65A003  
ALSO 65-012

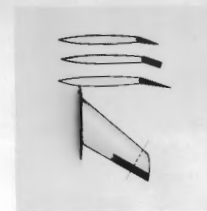
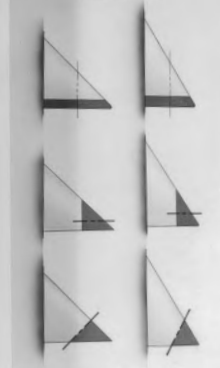
### 65A009



SPOILER

## CONTROLS

### 65A006



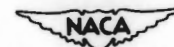
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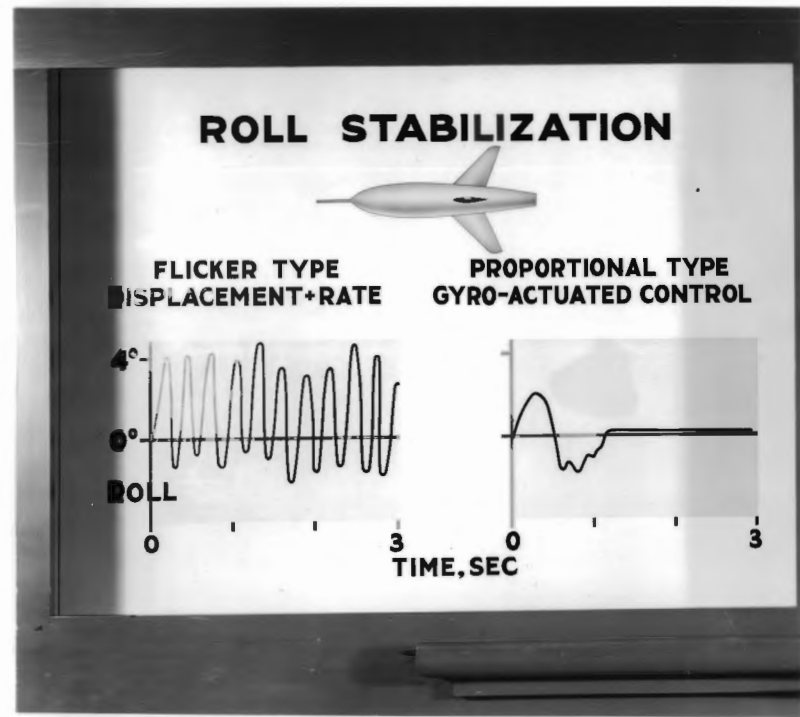
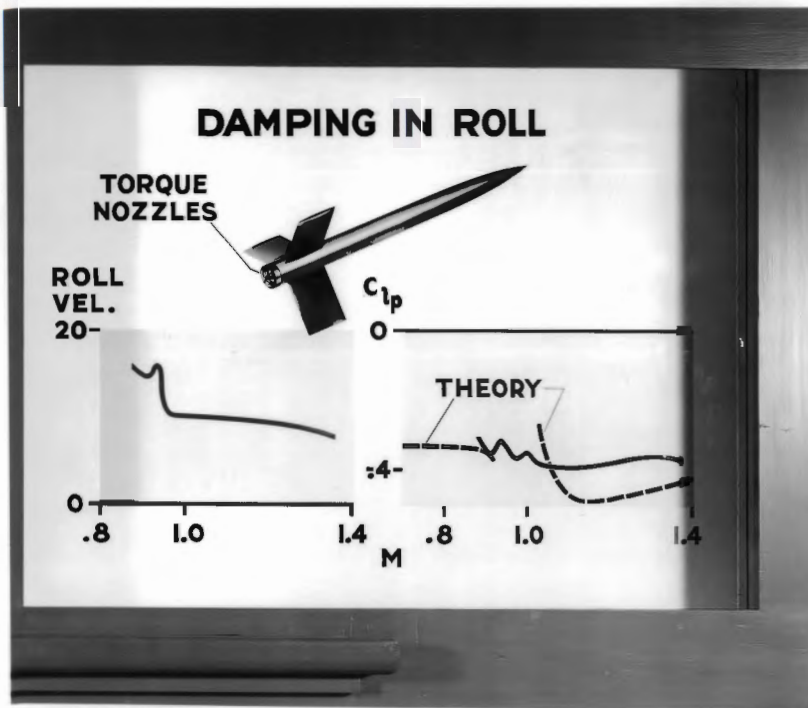
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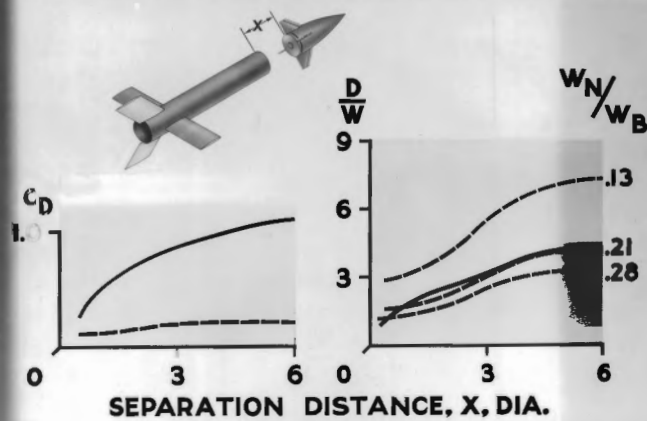
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LAL 61136



# JETTISONABLE NOSE SEPARATION



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