# *THE APPLICATION OF MEASUREMENT TECHNIQUES TO TRACK FLUTTER TESTING*

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Abstract

This paper discusses the application of measurement techniques to captive flight flutter tests at the Supersonic Naval Ordnance Research Track (SNORT), U. S. Naval Ordnance Test Station, China Lake, California.

The high-speed track, by its ability to prove the validity of design and to accurately determine the actual margin of safety, offers a unique method of flutter testing for the aircraft design engineer.

## INTRODUCTION

In the few years that high-speed tracks have been in existence, their usefulness has been demonstrated as a vital laboratory instrument in expanding knowledge in many scientific fields. Capable of providing high linear accelerations of relatively long duration with dependable recovery of the test item for examination and retesting, the supersonic track offers nearly all the advantages of laboratory testing, combined with the advantages of free flight.

The versatility and control of the test environment offered by the high-speed track provide an optimum medium for experimental studies in the best of analytical procedures. Tracks have been successfully used for the captive flight testing of rockets, guided missiles, model or full-scale airplanes, or their components, under conditions approximating free flight into the supersonic range, including measurement of thrust, acceleration, velocity, lift, drag, vibration, shockwave effects, flutter, and aerodynamic heating. They have been used also for aeroballistic tests of high-velocity launching of rockets or projectiles, as well as tests of fire-control systems, fuze function, aircraft damage, ejectable components, and for the development and calibration of inertial guidance systems and components. On the high-speed track, large test items can be brought up to supersonic velocities and sustained at these velocities long enough to make the observations and measurements required and stopped intact. One of the paramount virtues of the supersonic track lies in the relative ease with which instrumentation, both photographic and electronic, can be precisely applied to the point of action to insure optimum coverage.

The problem of flutter has, in recent years, been given primary consideration in the design of high-speed aircraft and missiles. The application of the supersonic track to flutter testing has been the result of efforts to find more adequate means of evaluating and testing new designs in their progress to the flight test stage.

## SLED DESIGN

In supersonic track flutter tests, the test item is mounted on a track vehicle properly designed to realize the required degree of simulation, and a series of runs are made, each at discrete increments of velocity until either flutter of the test item occurs or an adequate margin of safety has been demonstrated. A general-purpose sled is used where the flutter characteristics of these surfaces are not unduly influenced by the aerodynamic effects of the vehicle itself.

Figure 1 is a view of a general-purpose track sled used for vertical stabilizer flutter tests. Figure 2 is a view of the same sled adapted for flutter tests of a horizontal stabilizer. It may be necessary

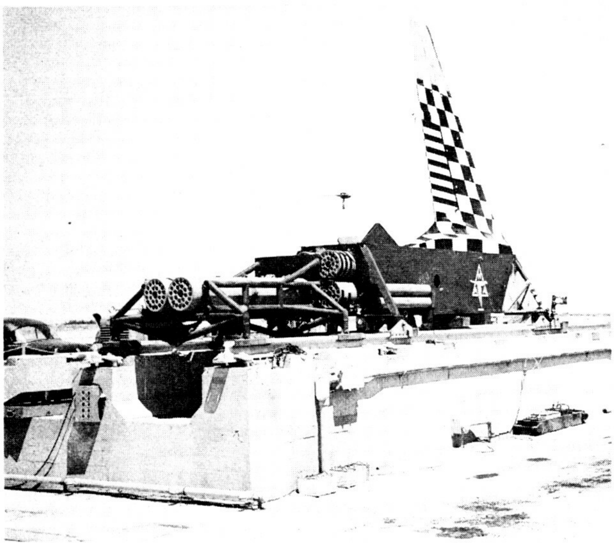

Figure 1. General Purpose Flutter Test Vehicle with Vertical Stabilizer

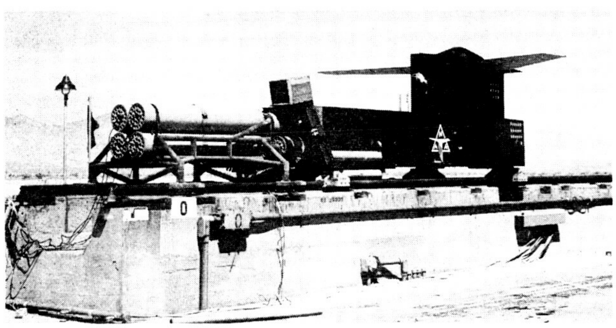

Figure 2. General Purpose Flutter Test Vehicle Adapted for Horizontal Stabilizer Tests

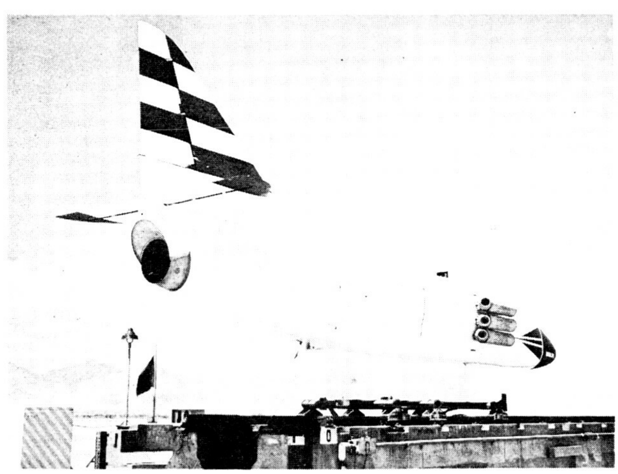

Figure 3. Track Flutter Test Vehicle Incorporating Entire Fuselage in Sled Design

to incorporate an entire fuselage into the sled design to preserve the aerodynamic and structural effects on the stability of the tail structure, as shown in Figures 3 and 4. It is, of course, necessary that the complete control systems associated with the tail structures be incorporated into the design of the sled structure.

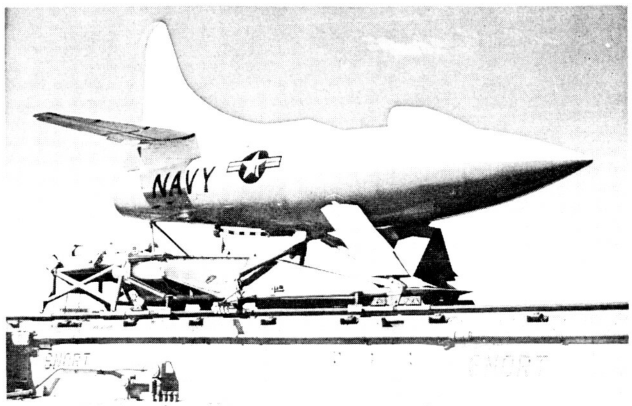


Figure 4. Navy Flutter Test Sled Utilizing Entire Fuselage of Plane

## CONTROL OF SLED VELOCITY

The design of the sled vehicle and the propulsion system to be used is mainly a problem in attaining the required velocities. It is convenient to consider the progress of the sled down the track as being in four distinct phases: the acceleration phase, the low-acceleration phase (or in other types of track tests, the sustain phase), the coast phase, and the braking phase.

The acceleration phase is achieved by several rocket motors firing together or in sequence, or by the use of one or more detachable booster sleds accelerating the main vehicle. When the thrust of the rocket motors is equal to the aerodynamic drag of the sled, a condition of zero acceleration is achieved, and the sled is sustained at a constant velocity. In certain flutter tests, it is required that the test item be accelerated to a velocity well below the expected critical velocity, and then accelerated more slowly to the critical velocity. For such tests, additional thrust is staged as required to bring about the low acceleration desired.

In the coast phase, the test sled is decelerated by the action of aerodynamic drag and track sliding friction. The braking phase adds the water-braking forces.

Accurate evaluation of all the acceleration and deceleration forces is necessary in designing the test vehicle to meet the test requirements. It is desirable, of course, to accelerate the sled as rapidly as possible to the required velocity so as to conserve range distance and to permit adequate time for observation and measurement of the behavior of the test item before the braking phase must be started.

The structural strength of the vehicle places limits on the acceleration that can be applied. Strengthening the carriage to withstand more acceleration increases its weight. The loads imposed on the sled structure for any specified maximum velocity are in almost direct proportion to the total weight of the test vehicle. It is mandatory, therefore, that weight be conserved not only to reduce these loads but also to reduce the amount of thrust required to achieve the desired velocity. It is perfectly possible that the addition of more thrust can result in a lower maximum velocity due to the weight of the additional rocket motors.

Figure 5 shows a typical velocity-distance profile of a flutter test in which a single staging of the propulsion rockets was used. Figure 6 shows a typical three-stage velocity-distance profile of a flutter test requiring a low-acceleration phase near the critical velocity of the test item.

In this test, an additional coast phase was programmed between the first and second stages to allow the final velocity to be controlled within very close limits. It can be seen, therefore, that by the careful selection of available rocket motors and by the use of such techniques as coast periods, sled velocity can be regulated in controlled increments for flutter tests.

## INSTRUMENTATION FOR FLUTTER TESTS

Photographic and electronic instrumentation is used to observe and measure the motions of the test item throughout the entire high-velocity portions of a flutter test. Measurements on these records are made to determine the velocity at which flutter occurred, the frequency of the flutter, and the shape of the flutter mode.

### Electronic Instrumentaton

The flutter frequency and the flutter mode shape can be determined by the use of transducers attached to a sufficient number of points on the test item to measure the deflections of the surface. The use of the accelerometer type of transducer, although offering the advantage of direct measurement, complicates the instrumentation system and the assessment of the data.

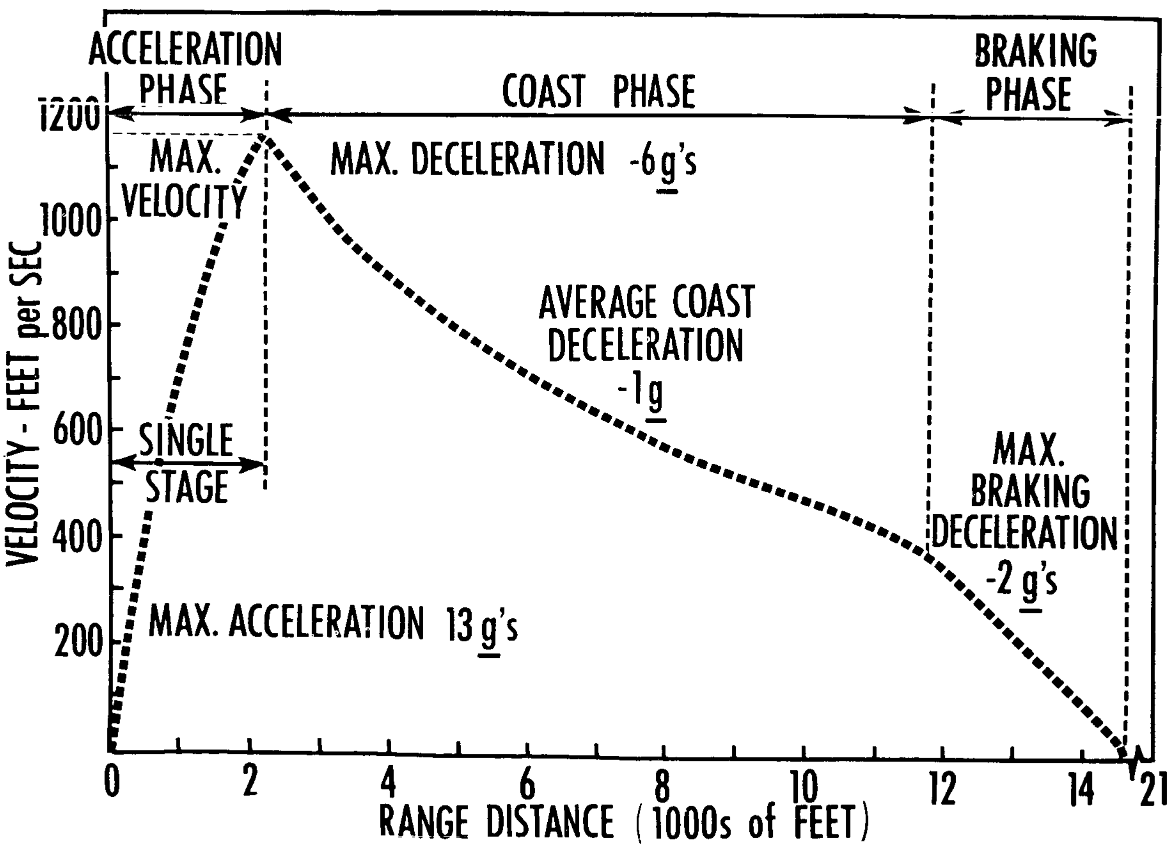


Figure 5. Typical Single-Stage Flutter Test Velocity-Distance Profile

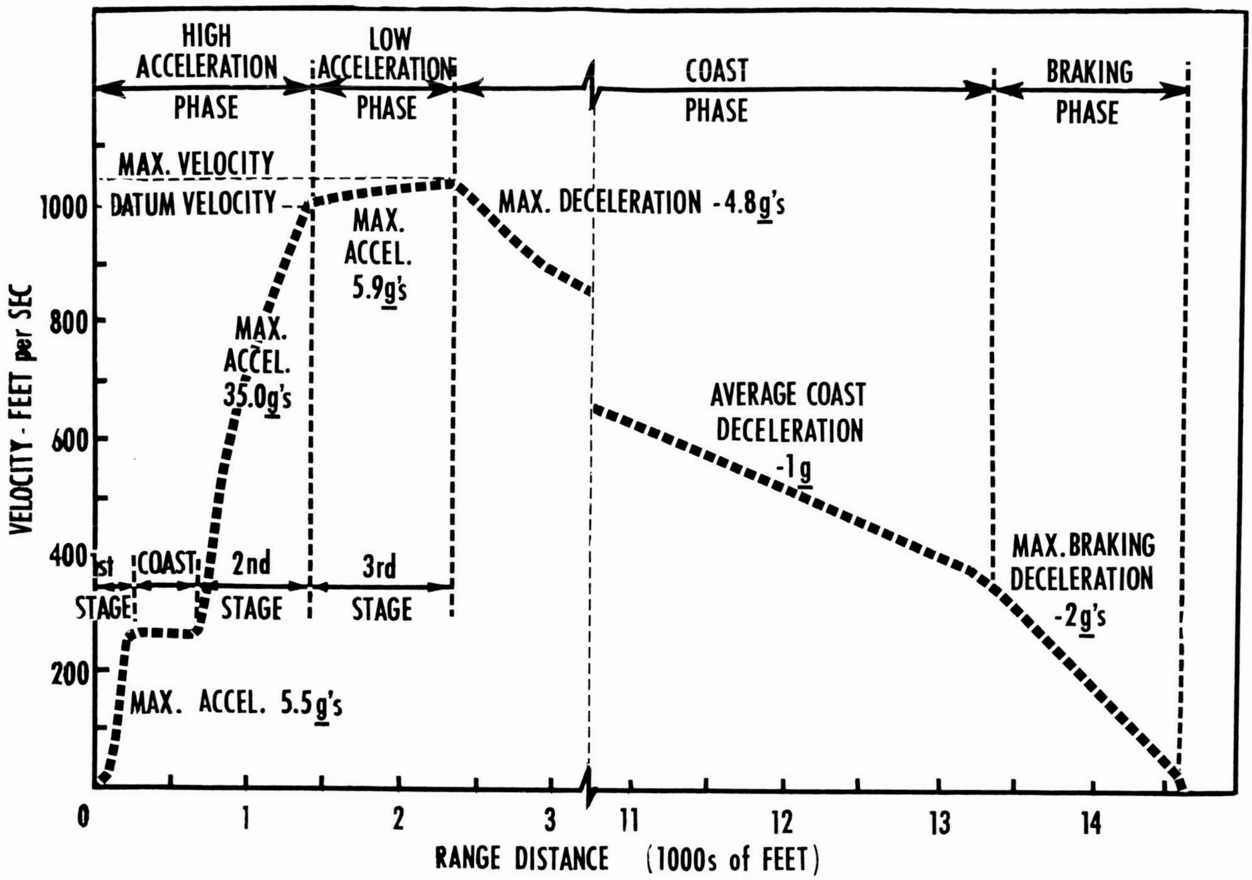


Figure 6. Flutter Test Velocity-Distance Profile Achieved by Three Stages of Propulsion

Since the output of the accelerometer is proportional to the absolute acceleration, the acceleration of the sled is added to the output as "noise" and must be subtracted to determine the primary data. Accelerometers sense, in addition, the random vertical, longitudinal, and transverse motions of the sled during its run. These motions must be measured by additional transducers and instrumentation in order to obtain the relative deflections of the test item itself.

Accelerometers are expensive and must be mounted internally, and are lost if the test item is destroyed during the test. Strain gages, on the other hand, are inexpensive, can be mounted either internally or externally, and, by proper calibration, will indicate the direct structural deformation of the stabilizer assembly. Conventional static load-deflection tests are made to convert strain gage readings to structural deflections in the calibration process.

FM/FM telemetry systems are normally used to transmit the transducer outputs to the ground-based recorders. In the FM/FM system, the outputs of the transducers modulate sub-carrier oscillators whose outputs are multiplexed into a composite signal. This signal is then used to modulate a carrier frequency. The carrier is transmitted from the sled

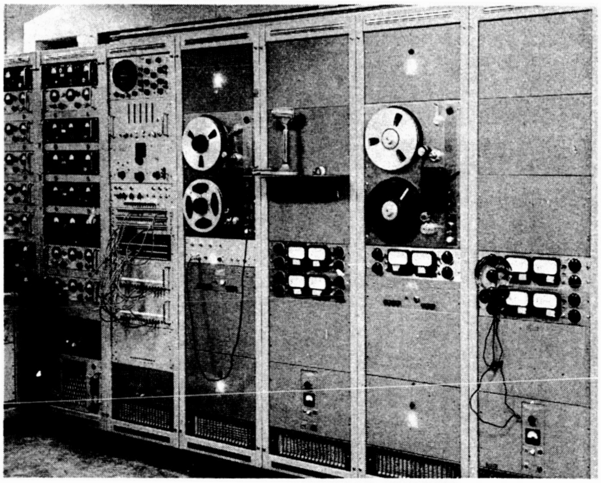

Figure 7. Section of Telemetry Receiving-Recording Station at SNORT

and received at the ground station (Figure 7), where it is demodulated and the multiplexed signal recorded on magnetic tape. The magnetic tape or "master" is played back through bandpass filters, which separate the frequency-modulated sub-carrier frequencies, to the various discriminators. One discriminator is used for each sub-carrier used in the sled-borne system. The output of each discriminator, which is a replica of the respective sled-borne transducer output, is then recorded, along with other discriminator outputs, on a recording oscillograph for evaluation and assessment.

Figure 8 illustrates a typical sled-borne FM/FM telemetry system for flutter tests. Figure 9 is a typical FM/FM telemetric record obtained on a track flutter test. This record shows the initiation of flutter with build-up to destruction of the test item. The timing trace permits correlation with other recorded data while the track coil record indicates range distance.

Instead of a telemetry system, sled-borne recorders, either the magnetic tape or recording oscillograph type, can also be used to record transducer outputs. However the rather rugged environment of the sled or the need for many channels of information may preclude their use. There is also a problem of time-correlation of data if sled recorders are used. Means must be provided to correlate the sled-recorded information, either by sled-borne oscillator or by a sled-borne timing receiver, to the range master timing system. If a timing oscillator is used it must be very stable, or its output must be telemetered for comparison with the master system.

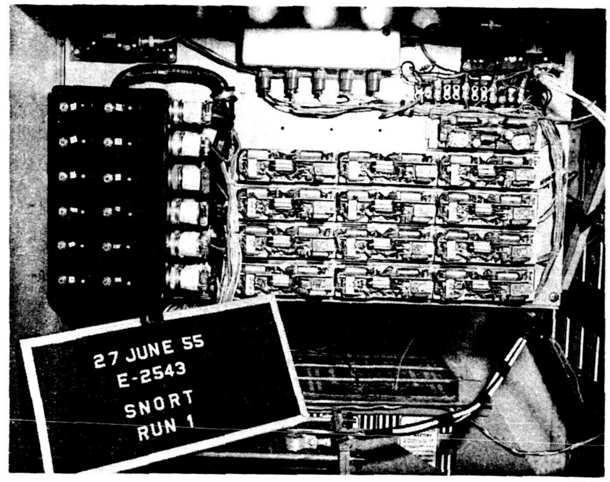


Figure 8. Typical Sled-Borne Telemetering System for Flutter Tests

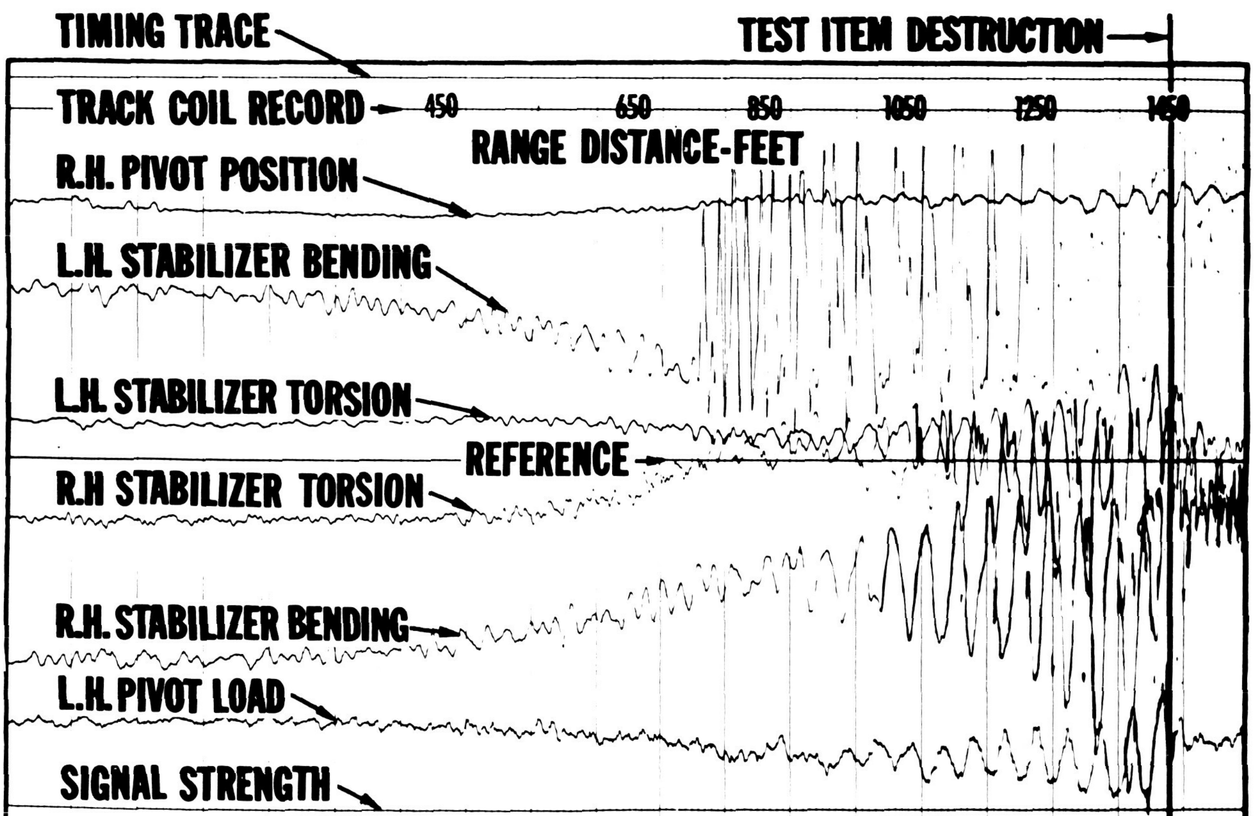


Figure 9. Typical FM/FM Telemetric Record of a Flutter Test

In flutter testing high-speed photography is invaluable in determining the nature of the lifting surface motions. Photographic coverage can be either by sled-borne cameras to view the test surface in its own frame of reference, or by ground-based equipment, either fixed in place so as to cover the significant portions of the test run or installed on tracking mounts.

Sled-Borne Cameras

Due to the rather extreme physical environment of the test sled, special photographic recorders are used. Some instruments normally used for ground installations, such as the Fastax, have been modified to withstand this environment. The newer prism-type cameras, such as the Wollensak Fastair and the Fairchild HS100, have been used very successfully for on-board recording, and offer sampling rates up to 5,000 per second. Various lenses are available for use with these cameras, the choice depending upon the configuration of the sled and the test item. These cameras offer certain weight and power advantages over the Fastax camera, although the Fastax is still used for on-board recording. In addition to these cameras, two pin-registered cameras for sled use have been developed; one has a 35mm half-frame format, the other a 16mm full-frame, offering frame rates at 200 and 300, respectively. These cameras will operate at better than 50 g's in any axis.

Ground-Based Cameras

Ground-based photographic instruments are located either off the track or on track overheads. Their down-range location and field of view are preset on the basis of the best available prediction of the position of the test vehicle during flutter of the test item. Several cameras can be set up at different locations to provide over-lapping coverage if required. The Eastman High Speed camera, offering 16mm black and white or color recording at frame rates up to 3,000 per second, and the 16mm and 35mm Fastax, for black and white recording at up to 5,000 frames per second, are used for high-speed recording from ground locations. Various lenses, up to 48" in focal length, are available for these cameras. The 16mm and the 35mm Mitchell cameras are used for medium speed recording (up to 120 frames per second) with lenses to 96" in focal length available.

Tracking Mount

The "M-45" tracking-camera mount (Figure 10) is a basic tracking unit capable of supporting both Mitchell and high-speed cameras with long focal length lenses, for tracking studies of high-speed test vehicles. These units are mobile, self-powered, and provide tracking rates up to 60° per second. These mounts are normally used on 25-foot high dirt mounds located 3,000 feet off-track at various distances down range. Placing the mounts above the desert terrain tends to minimize image degradation due to heat waves while their 3,000-foot off-track position not only protects the operator but gives him some advantage in tracking fast-moving sleds.

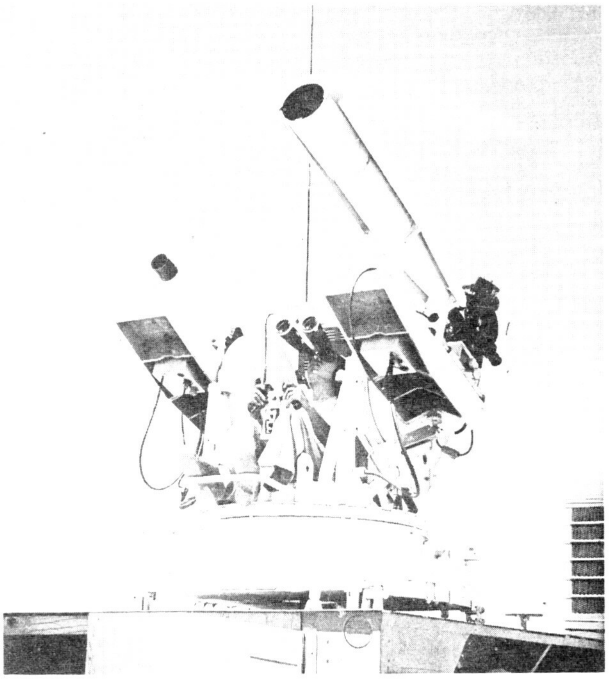

Figure 10. M-45 Tracking Camera Mount used for Tracking Studies of Sleds

INSTRUMENTATION CONTROL

Photographic ground instrumentation is usually controlled on a time-basis by an automatic sequencer. Figure 11 is a view of the SNORT programmer which supplies control signals at the proper time and duration to start and stop instrumentation equipment. It also provides the pulse at "zero" time which actuates the firing contactors in the blockhouse. At each instrument location down range, a control box receives the signal and in turn controls power to the camera.

The control of ground-based cameras operating at high-frame rates becomes critical since such cameras may provide only fractions of a second recording time. Since it is necessary that such cameras be properly sequenced with the event, carbon rods or micro switches, which are broken or actuated by the passage of the sled, are used to effect camera control

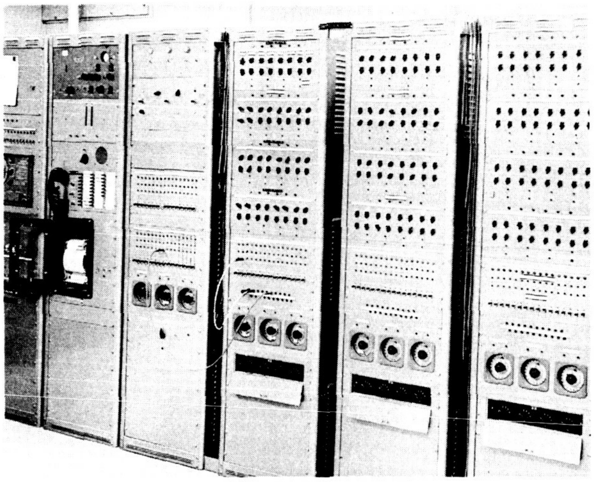

Figure 11. SNORT Programmer for Control of Instrumentation During Test Firings

on a sled-position basis instead of the time-basis control afforded by the programmer.

Control of sled-borne photographic and electronic equipment is accomplished by either the range programmer (with pull-away plugs) or by the use of a sled-borne pistol switch actuated when knife blades on the sled cut charged screens mounted on the track beam. Squibs in the switch are fired in this manner to either open or close contacts for the control of the on-board equipment. Knife blades are also used to effect rocket staging.

Figure 12 shows a typical instrumentation control panel mounted in the sled. The battery pack for photographic cameras is located on the left, and the pistol switch assembly is shown on the lower right of

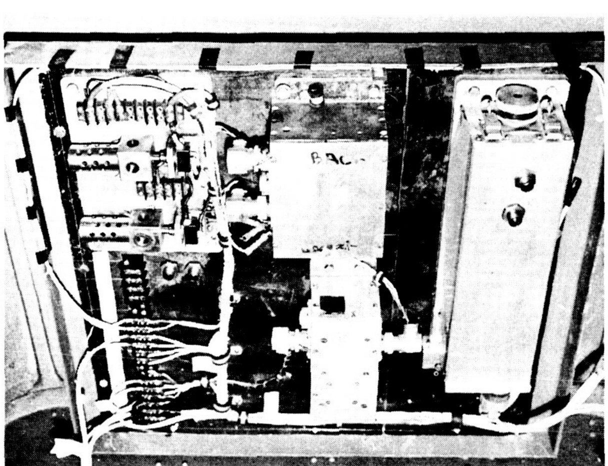

Figure 12. Typical Sled-Borne Instrumentation Control Equipment

the photograph. Figure 13 is a rear view of a general purpose flutter test sled showing the knife blades used for control of rocket staging and for instrumentation equipment. This view also illustrates the water-brake probe extending below the sled.

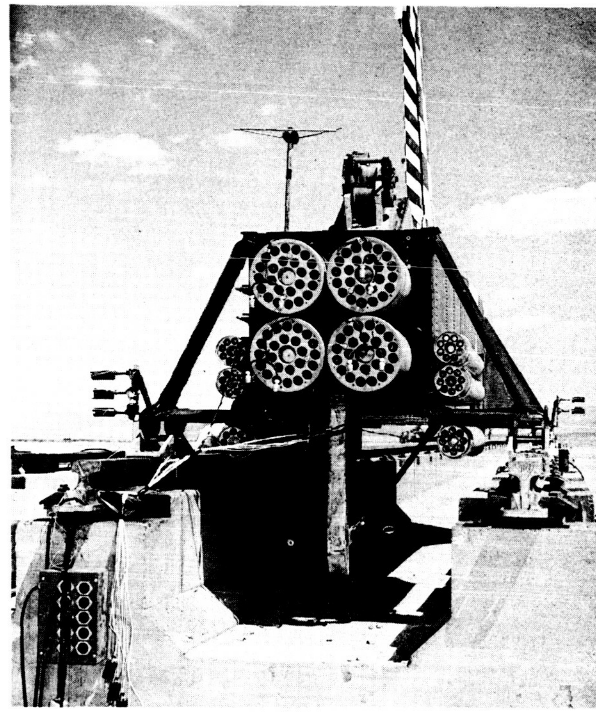

Figure 13. Rear View of General Purpose Flutter Test Sled Showing Knife Blades and Water Brake Probe

The frame rate of the high-speed cameras used in flutter tests must be sufficiently high to permit detailed examination of the test item motion on an extended time basis. At least 20 frames of recording is required per cycle of flutter motion, and so the minimum frame rate must be at least 20 times the expected flutter frequency. The film capacity of the particular camera and the required recording time set limits on the maximum frame rate that can be used.

Sled-borne cameras are usually started before the sled rockets are fired to eliminate their starting under high linear accelerations. In determining the maximum frame rate of these cameras, adequate consideration must be given to the times involved in the acceleration, and high-velocity phases of the test as well as the required coverage during the coast phase.

Timing Systems

Time correlation of photographic and other recorded data is obtained by the use of master range timing systems. Timing pulses at various rates are transmitted by radio links to the instruments down range requiring time-correlation. Timing signals are provided to sled-borne instrumentation by either a sled-borne fixed-frequency oscillator, or by a sled-borne receiver for reception of the range time signals. When required, the fixed-frequency oscillator signals can be telemetered and recorded for comparison with the range master system. The rocket-firing pulse is used as a reference or staring point in time, which is usually considered as "zero time". At SNORT, two radio links are used: (1) a nine-channel pulse coded modulated carrier of 505mc, and (2) a single channel pulse amplitude modulated carrier of 360mc. The single channel equipment is used to carry the 100BCT signals. The 9-channel PCM equipment transmits the 100BCT, and 8 other signals as required between d.c. and 10KC.

Acceleration-Velocity Data Systems

Sled position as a function of time is the primary data requirement of every flutter test conducted on the supersonic tracks since it yields, by calculation, information on velocity and acceleration. The position-time measuring system at SNORT is a track coil or magnetic-pickup system.

It consists of a permanent magnet, either of the "U" or "E" configuration, mounted on the test vehicle, pickup coils mounted every 100 feet for the entire 21,500-foot length of track, and transmission lines connecting the coils to the terminal equipment in the Test Control Building. When the magnet passes over the coils, pulses are generated which are recorded by the terminal equipment. The time between successive pulses determines the average velocity and average acceleration of the test vehicle between coils.

Instantaneous velocity determinations can be made by the use of two magnets mounted a known distance apart on the test sled or by the use of track-mounted current-conducting glass rods connected to the track coil system. Measurement of the time interval between the magnet pulses or pulses generated by the breaking of the rods, yields velocity determinations at specific points down range. Figure 14 is a section of a sample record of the track coil system using two sled-mounted "U" magnets and the glass-rod break system.

More precise velocity data can be obtained at SNORT by means of a precision velocity measurement system, more commonly known as "VMS". The instrumentation of this system consists of two data sources: sled-position vs. time is measured with the magnetic track coil system, and sled-acceleration vs. time is measured by a sled-borne accelerometer and a PDM telemeter system. The tape recorded data is converted to digital form and entered into the IBM 701 computer by automatic assessment equipment. The two different sets of data are combined by a near-optimum digital-filtering technique to provide a set of hybrid wide-bandwidth data.

This system is capable of measuring the velocity of a test vehicle over a range of 200 feet per second to 2,000 feet per second, to an accuracy of 0.1 feet per second or better, and with a bandwidth of 50 cycles. Figure 15 is a section of a typical track coil record using a sled-mounted "E" magnet. The VMS precision pulse, shown on the record, accurately indicates the cross-over or "zero" point of the magnet pulse.

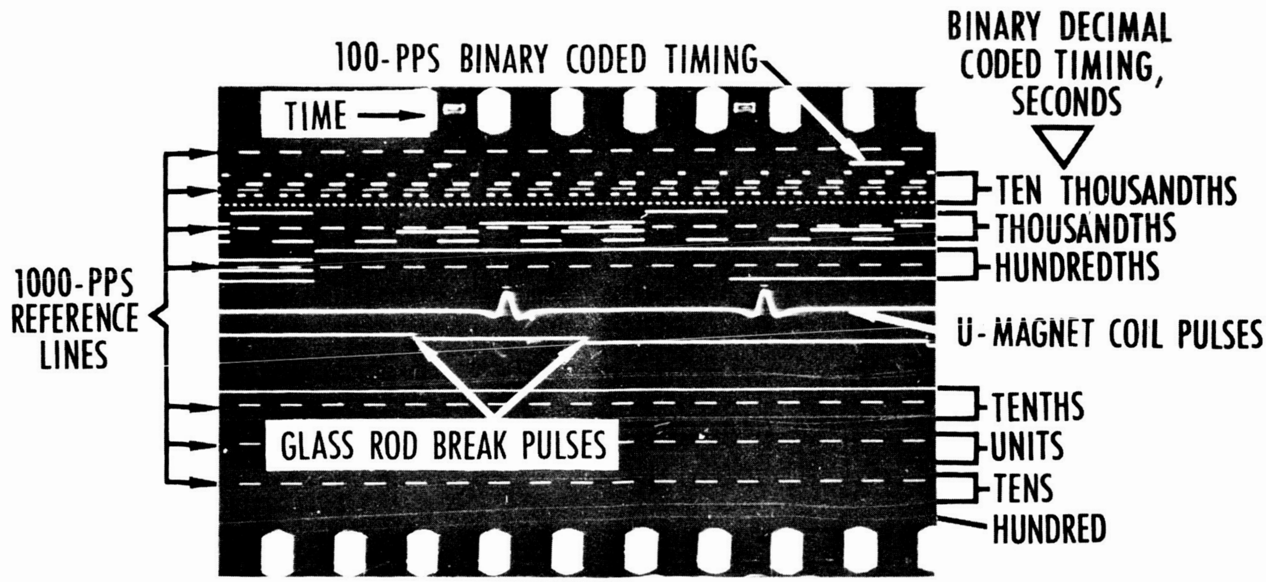


Figure 14. Section of Sample Record of Time-Position Data Using Sled-Mounted "U" Magnets and Glass-Rod Break Circuits

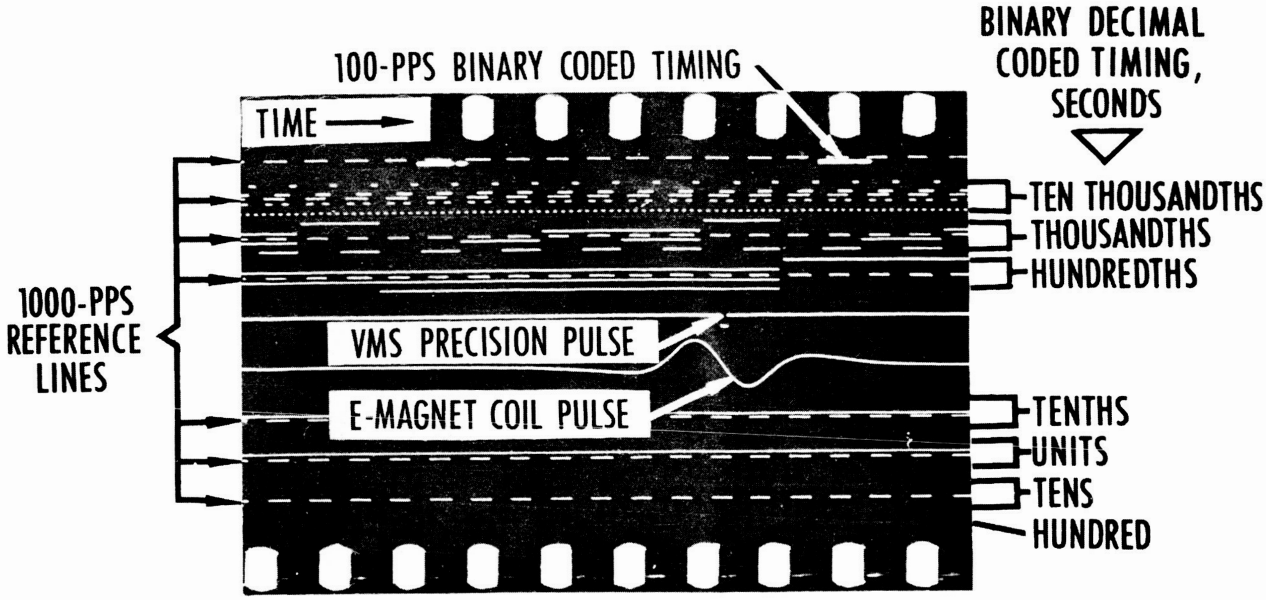


Figure 15. Section of Sample Record of Time-Position Data Using Sled-Mounted "E" Magnet

## CONCLUSIONS

With the development of measurement techniques and testing procedures, coupled with the ability to reproduce realistic free-flight environments at controlled velocities, the high-speed track offers a unique method of flutter testing. By its ability to prove the validity of design and to accurately determine the actual margin of safety, the high-speed track has become a much needed test facility for the aircraft design engineer.