# *EXCITATION BY ROCKETS*

*C. E. Tammadge — Canadair Limited, Montreal, Canada*

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Abstract

Standard methods of excitation are not always practical when a single mode of known frequency requires investigation. This form of investigation is often required on a modified aircraft. The simplest method of excitation is by "Stick Jerks", but this may not be successful owing to: power controls; high frequency modes; or inability to force at the required points on the structure.

A new method of excitation has been developed and proved in flight, which consists of firing small rocket charges attached to the aircraft structure. Damping values at gradually increasing airspeeds are obtained, as in "Stick Jerk" tests, and flutter speeds predicted.

## INTRODUCTION

When a full flight flutter program is planned on a new aircraft to investigate several modes, fairly elaborate excitation and recording equipment is required and can be justified. However when unexpected flutter occurs during the flying stage of a prototype, or modifications are made to a standard aircraft which may result in reduced flutter speed, tests are required with a minimum of installation and grounding time of the aircraft, and yet give the required prediction of flutter.

The methods by which aircraft can be excited can be divided broadly into two techniques: First continuous excitation, in which a sinusoidal force, capable of frequency variation is applied to the aircraft and flutter prediction is determined from the amplitude response of the structure; and second the impulse technique, in which an impulse is applied to the aircraft and the damping of the structure is determined.

The most usual form of continuous excitation is by using inertia weights and it is preferable to use multipoint phased excitation. This of course if a major installation which would necessitate grounding the aircraft for a considerable time. Any form of inertia excitation would however have a low frequency limitation of approximately 3 c/s caused by the impracticable large size of weight required to excite these low frequency modes.

For impulse excitation stick jerk tests have been made and some very good results have been obtained. This system is very attractive as it is simple, but the force applied at each impulse is not constant, overtone modes are difficult to excite, and on an aircraft with fully powered controls it is difficult to excite modes above about 10 c/s.

A requirement therefore existed for a method of excitation which was simple to install and would excite a mode of either high or low frequency by applying a repeatable force to the aircraft stucture. To meet this requirement, rocket units have been developed.

## THE IDEAL IMPULSE

When considering the ideal impulse required to excite a structure in a given mode three things should be considered:

(1) The point of application of the impulse to obtain the maximum response in the mode of interest,

(2) The maximum safe load that the selected point of application on the structure can withstand without damage; and,

(3) The shape and duration of the impulse in relation to the period of the mode of interest, to obtain the maximum amplitude reponse.

To find the effect of the point of application, consider the response of a cantilever beam in its first three normal modes, to a unit impulse applied at various points along its length as shown in Figure 1. It will be seen that the maximum response occurs in all modes when the impulse is applied at the free end, that in the second and third mode a node occurs at approximately 0.80 length, and that when the impulse is applied at this 0.80 length position there is little or no response in these two modes. Also it will be seen that at no matter what position along its length the beam is exicted, the maximum response is always in the fundamental mode. Therefore we may say that:

(1) A mode will not be excited if an impulse is applied at its node, and,

(2) If the second of third modes are of interest, positioning alone of a single unit will not make them predominate.

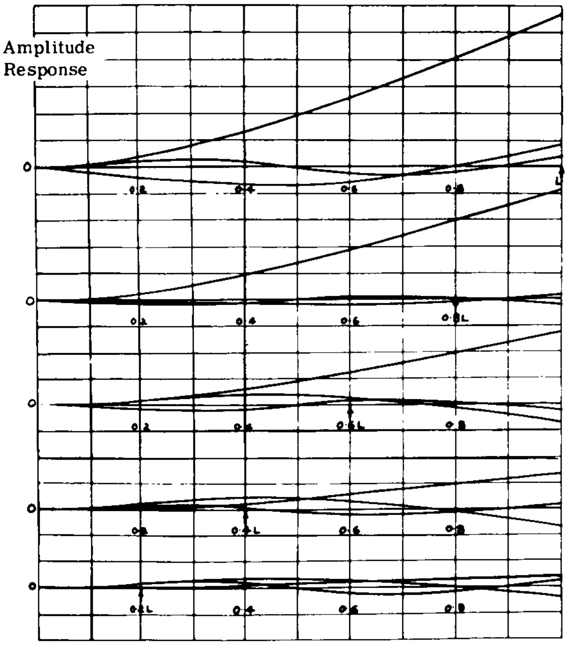

Figure 1. Response of Cantilever Beam in First Three Normal Modes to a Unit Impulse Applies at the Points Indicated

The maximum safe load that can be applied to any part of the structure is fairly readily determined from static considerations, but it is desirable to work with standard units and a thrust of 200 lb. is considered to be a reasonable standard.

The shape of the impulse capable of maximum energy transfer to the structure will be of a rectangular form with the force equal to the maximum safe load and the time equal to the ideal duration. To determine the ideal duration, consider the response of an undamped single degree of freedom system subjected to a rectangular impulse, the response curves obtained will be as shown in Figure 2. It will be seen that the maximum response will occur when the duration of the impulse equals half the period of the mode of interest. An impulse of less time than this will result in less amplitude and of greater time than this, while resulting in the same initial amplitude, the response immediately after the initial peak will be distorted and the subsequent amplitude will be reduced. The effect of damping will be to reduce the peak amplitude, this reduction will be approximately 5% for the damping factors applicable to aircraft near a flutter condition.

To return to the problem of exciting overtone modes. It was shown that on a cantilever beam, positioning of the impulse would not make the overtone modes predominate. Therefore, an impulse applied for half the period of the first overtone would also excite the fundamental mode which would predominate. If however a second impulse is applied in the opposite direction to the first, and after a specified time interval the overtone mode can be made to predominate, the time interval between such impulses to obtain maximum response can be shown to be half the period of the required mode. This double impulse technique is also advantageous when trying to excite at a point on the structure at which the load is limited, and also when the amplitudes excited by a single impulse are too small for analysis.

## ROCKET CONSTRUCTION AND PERFORMANCE

To obtain a suitable impulse to meet the ideal requirements stated, rockets have been developed.

The first rockets used at the Royal Aircraft Establishment to produce an impulse on an aircraft structure was in 1953. The case of each rocket shown in Figure 3 consisted of a steel tube, threaded internally at each end, the ends of the tubes being closed by end caps. One end cap was a solid disc while the other was a disc machined with a venturi at its centre. This case was filled with a number of hollow sticks of cordite in the centre of which was located an electrically fired gunpowder igniter. The electrical leads for firing the igniter were brought out through the venturi, and an internal grill was located between the cordite and the end cap to prevent large pieces of cordite blocking the venturi. The

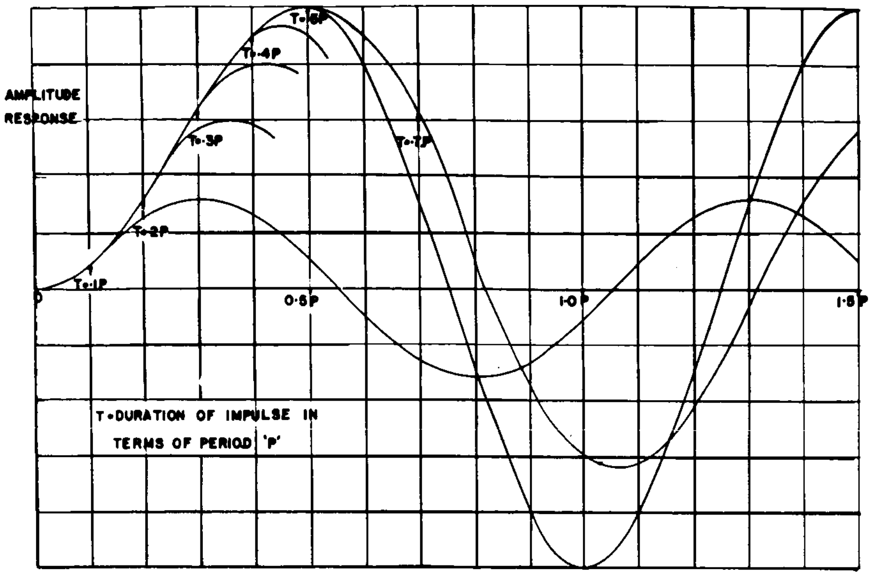

Figure 2. Response of Simple Undamped System to a Rectangular Impulse

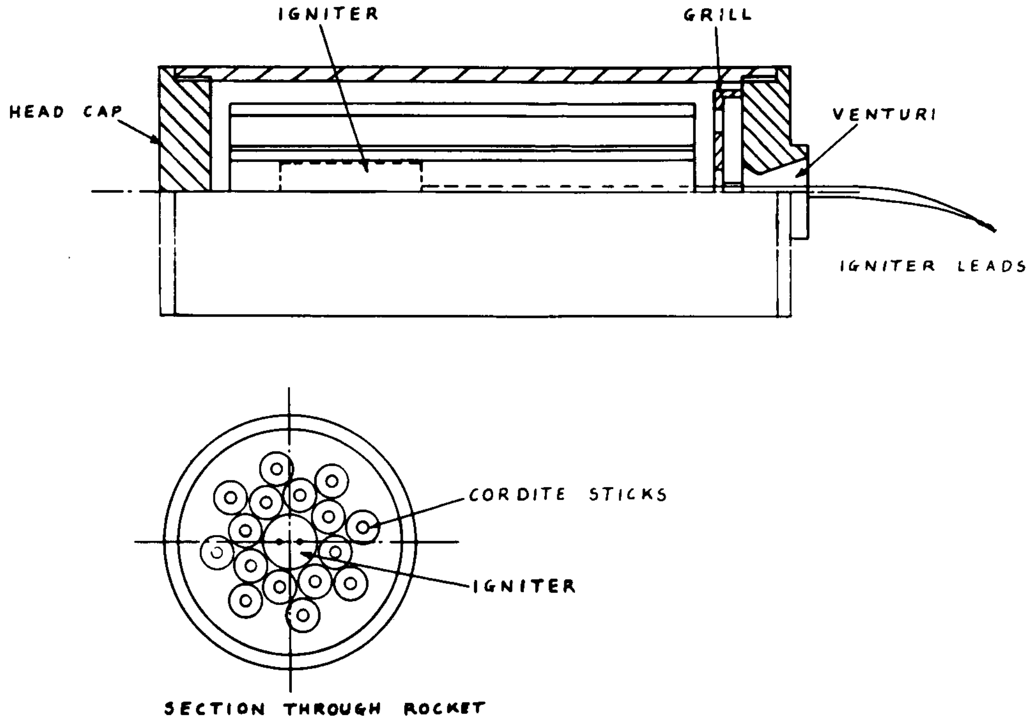

Figure 3. Construction of Rocket Using Cordite Sticks

overall dimensions of this unit were approximately 4-1/2" long and 1-3/4" diameter.

The impulse of this first unit was measured by using a balistic pendulum. This pendulum consisted of a length of 4" diameter steel rod weighing approximately 40 lb. suspended on wires such that it hung with its axis horizontal. A hole was drilled in one end of the rod to accommodate the rocket, and an accelerometer was mounted on the opposite end. The impulse of the unit as measured on this balistic pendulum was approximately 200 lb. for 50 milliseconds, as shown in Figure 4. The build up of force was fast and a small initial peak occurred, there was a slight

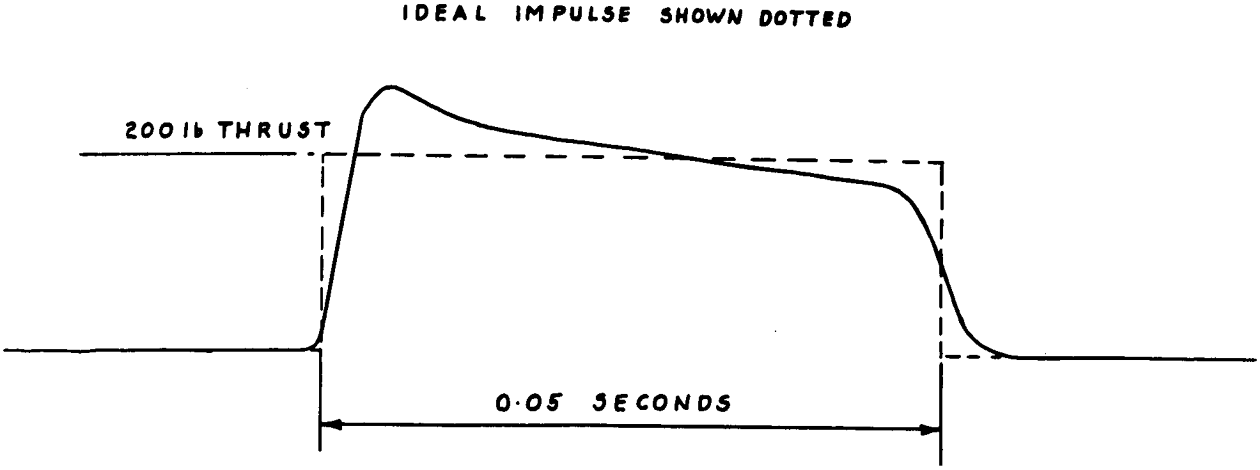

Figure 4. Impulse from Cordite Rocket

fall-off of force over the burning period, at the end of which the reduction of force was reasonably rapid. The current required to fire these units was approximately 5 amps.

Although this rocket was not specifically designed for flight flutter excitation the response was very close to that required ideally to excite a 10 C.P.S. mode, but it contained two basic faults. First the cordite used in this rocket was temperature sensitive and would lose 40% of its thrust at -50°C or 40,000 feet. This loss in thrust can only be overcome by using a platenised propellant. Secondly, the overall size of the unit is large compared with the space available inside the extremities of the main surfaces of a large number of modern aircraft. This space limitation was overcome in part by turning the jet of gasses through 90° such that the thrust was produced at right angles to the longitudinal axis of the unit. This permitted mounting of the rocket parallel to the outer skin surface of the aircraft. The change in direction of the thrust was produced by welding a right angled tube over the venturi. This may not be the most efficient way of producing the desired effect, but tests showed that only about 5% of the thrust was lost. However, this still left a tube of nearly 2" diameter to be mounted between the outer skin surfaces.

New rocket units were therefore developed at the R.A.E. specifically to meet the requirements of aircraft excitation. These units, shown in Figure 5, consisted of a tube with a platenised propellent deposited on the walls of the tube, the overall dimensions were 7/8" diameter by 4" long. Three rockets were designed to give thrusts of 200 lb. for 50,25 and 12-1/2 milliseconds in order to excite modes of 10, 20 and 40 C.P.S. respectively. The actual thrusts produced by these units as measured on a balistic pendulum were very similar in shape to that obtained from the first unit.

A new problem did however reveal itself which affects sequential firing of these units. It was found that the variation in the time from closing the electric switch which fired the igniter, to the commencement of thrust was large compared with the overall burning time. This could be as high as 6 milliseconds or approximately ±50% of burning time in the case of the 12-1/2 millisecond units. Therefore if two units were fired either together or half a period apart to excite a mode, it was possible, if the firing time delay tolerance on each unit was a maximum and in the opposite direction, for the impulses to completely cancel each other. This problem requires further investigation.

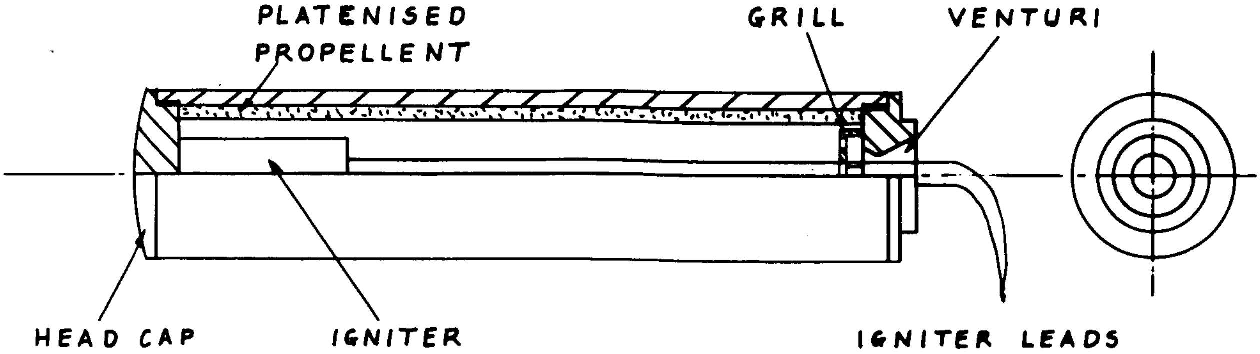

Figure 5. Construction of Rocket Using Platenised Propellent

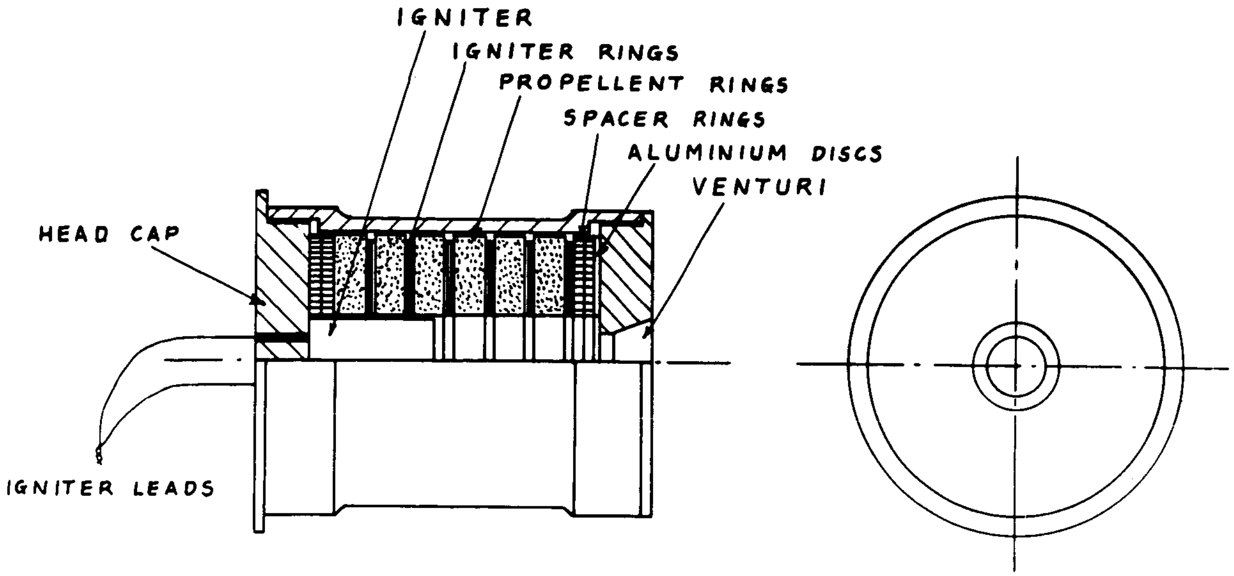

Figure 6. Construction of Rocket Using Propellent & Igniter Rings

A third type of rocket construction is shown in Figure 6. This again is a 10 lb. sec. impulse unit producing 100 lb. thrust for 100 milliseconds, it is about half the length of the original unit used at the R.A.E. This rocket was designed by the Canadian Armament Research and Development Establishment, and consists of rings of propellent interspaced with rings of igniter with a central igniter similar to that used in the other two units. In this unit the igniter leads are brought out through holes in the head cap of the unit, and a thin aluminum disc covers the venturi. Tests with this unit have given very little scatter in the time delay which may be the result of the aluminum discs, but further testing is required to confirm this.

## USE OF ROCKETS ON AIRCRAFT

When using these rocket units in practice it is fairly obvious that safety precautions must play an important part. The cases of these units are of course given a good safety factor but the weak part of the construction is the threads. In the case of the platenised rockets, the threads have been known to fail, but the deposits left by this propellent are very corrosive and the cases should only be used once. By comparison, the cases used with the cordite sticks were used many times without a single failure.

Additional safety precautions against possible failure of the cases should in general not be necessary when these units are mounted on an aircraft, but unavoidable positioning of the units close to a fuel tank or in equally dangerous positions might call for a safety tube around the rocket case. The mounting of these units internally or externally will depend mainly on the type of aircraft. Generally, external mounting is the simpler and this should be possible on low speed aircraft. Internal mounting will be more difficult, but by choosing the best position and shape of rocket this should be possible without external fairings. The rockets should be attached to, or held against a firm thrust plate, this may be done in the case of straight thrust rockets, by welding the head disc to the thrust plate and assembling the rockets on the plate.

The safety precautions required in handling these rockets are few. If the ends of the ignition leads are connected, by twisting the bare ends, no potential can occur across the leads and the igniter is safe, in addition the head caps should be removed during transit.

In Figure 9 a circuit diagram is shown for firing 8 rockets in four pairs with a time interval between each pair. This is the most that would be required to excite a mode and for a lower number of units the circuit can be simplified. The wire runs between the rocket units and intervalometer should be kept as short as possible to avoid possible voltage pickup along the wires. If long runs are unavoidable or the wires pass electrical equipment liable to produce pick-up, some provision should be made in the switch to keep the igniter leads shorted until just prior to firing.

When connecting the rockets to this circuit it is recommended that the aircraft wires are shorted just prior to connecting the rockets. The firing circuit should contain two removable safety links, a supply switch which breaks both leads and a firing button. As the actual recording time required is short it is considered worthwhile to include the operations of

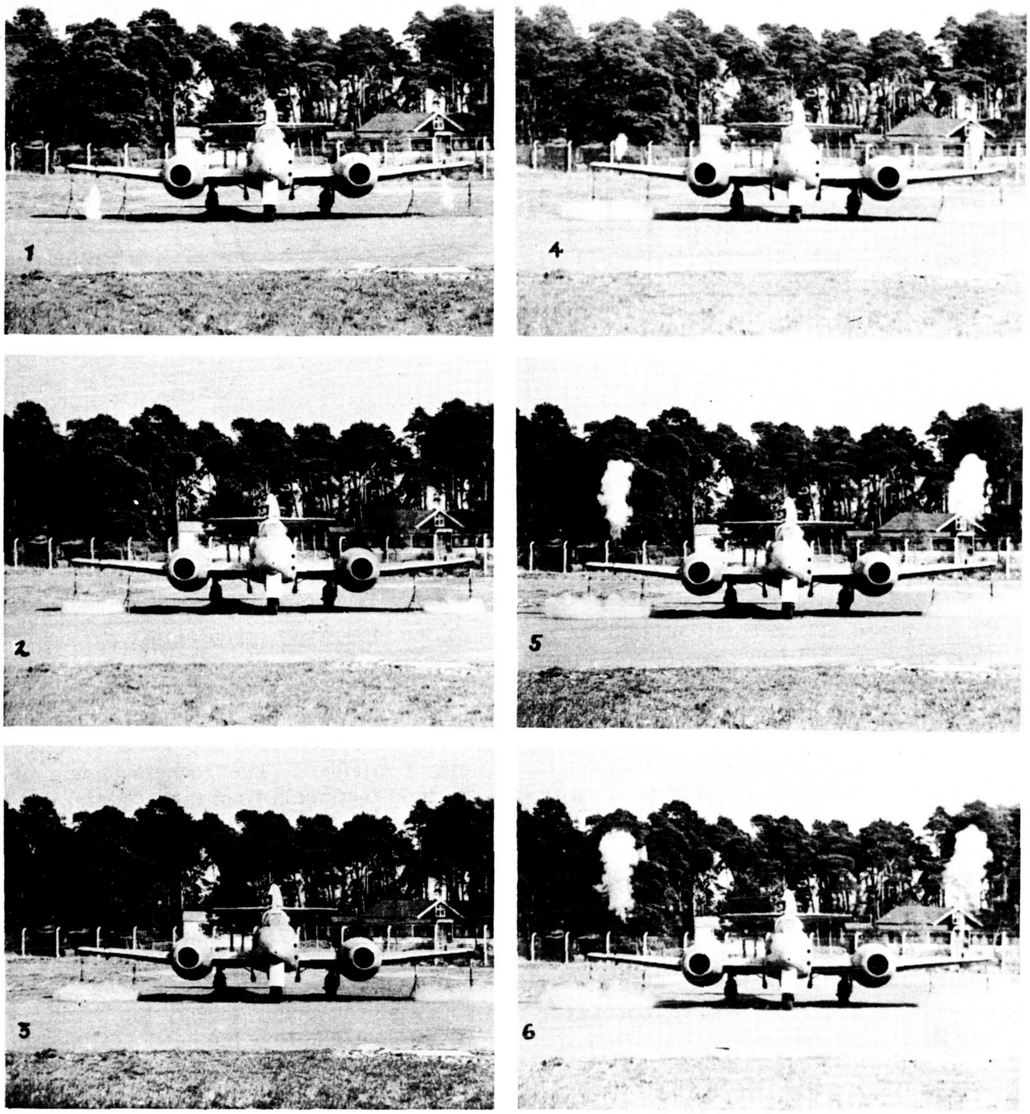

Figure 7. Rockets Being Fired to Excite an 8 C.P.S. Symmetric

switching the recorded in the intervalometer, this also avoids the possibility of forgetting to start the recorder. Most recorders start almost instantaneously and as the first motion of the aircraft structure is usually a little distorted the recorder can be started at about the same time as applying the volts to the first rocket. The switching off of the recorder can be obtained by passing the signal from the intervalometer through a delay switch which will allow a sufficient length of record to enable the decaying waveform to be analyzed.

## APPLICATION OF ROCKETS

This form of excitation has been used successfully on a number of aircraft, with wing tip at fin excitation. Figure 7 shows two pairs of rockets being fired to excite a 8 C.P.S. symmetric mode on a Meteor aircraft at the R.A.E. The rockets used in these tests were the cordite stick type.

As a matter of interest, this type of excitation can be applied to structures having very low natural frequencies. Figure 8 shows 18 rockets, each producing a thrust of 1,000 lb., being fired at the top of a 425 feet chimney stack. The rockets were attached to the architectural lip and fired simultaneously. The response of the stack was measured at the top using accelerometers, the amplitude was approximately 2", the period was approximately 2 seconds, and the structural damping factor $\frac{\text{actual damping}}{\text{critical damping}}$ was 0.01.

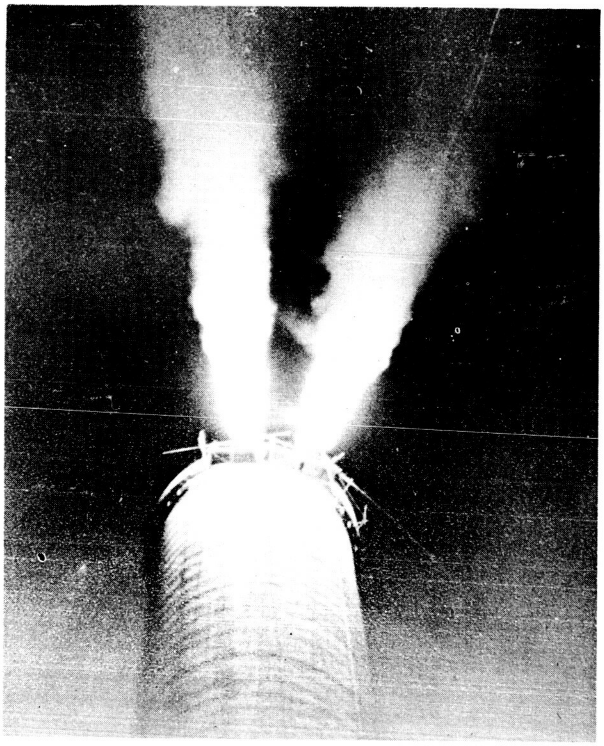

Figure 8. Eighteen 1,000 lb. Rockets Being Fired from Top of a 425 ft. Chimney Stack

## CONCLUSIONS

As with any system, rockets have certain limitations, but they are very suitable when a single mode of known frequency required investigation. The ideal duration of the impulse is half the period of the mode of interest and sequential firing may be employed to isolate a mode, or to obtain a larger amplitude response of the structure. The installation required for rocket excitation is simple and there is virtually no frequency limitation to the use of rockets in the range of flutter frequency experienced on conventional aircraft.

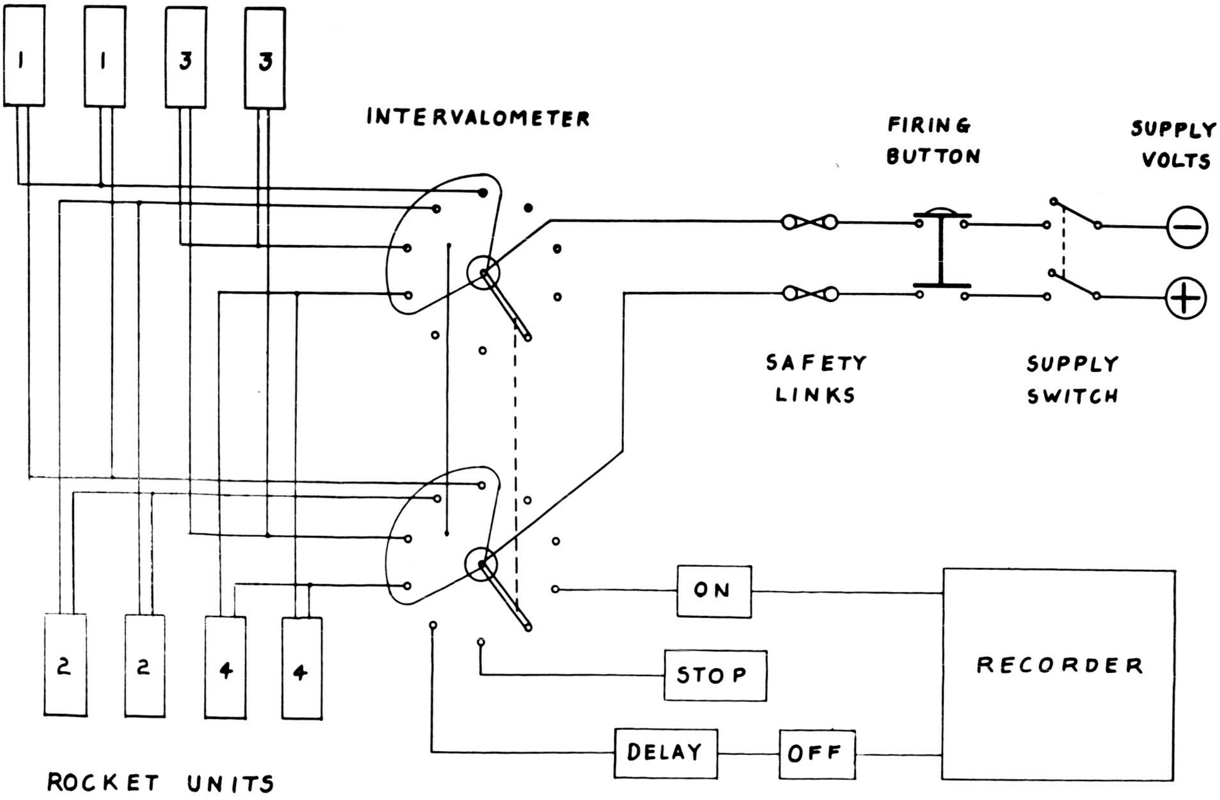

Figure 9. Firing Circuit for Four Pairs of Rockets