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Vibration and Flutter of Aircraft Aerials

By

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ADDENDUM

Since writing this report the author has carried cut brief wind tunnel tests on a blade aerial to establish the change in its lift direction resulting from ice accretion on its leading edge.

The tests on the unmodified aerial showed that with the aerial stationary positive-lift is present for all angles of incidence up to a value well in excess of the stalling angle, angles of up to 20° being checked. With simulated ice on the leading edge however, a similar test showed that negative lift occurs at angles of incidence in excess of 2°. The cross-sectional shape tested in the latter case was that given in Fig.5(a) and the negative lift continued to occur up to an angle of 10°, which was the maximum angle tested in this case. At an angle of incidence of less than 2° the lift force in the "iced up" case was so small that its direction could not be determinedwith the crude apparatus used.

It is considered that these tests confirm the original hypothesis that the oscillatory instability of the blade aerials when "iced up" is in fact stalling flutter of the type described in paras.6.

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ROYAL AIRCRAFT ESTABLISHMENT

Vibration and Flutter of Aircraft Aerials

by

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SUMMARY

Fatigue failures of blade end whip aircraft aerials have been investigated and it is shown that stalling flutter and mechanically excited vibration have both contributed in large measure to the failures. All the aerial types involved possess considerable flexibility and very low internal damping. It is shown that the introduction of damping into the mounting of the aerials has a very beneficial effect on their behaviour as regards both flutter and mechanically excited vibration. Methods are described for preventing failure from either cause.

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1 Introduction

Numerous failures of aircraft aerials have occurred on various types of service aircraft during flight. Several aerial types were involved, including blade aerials and. whip aerials in use with identification, direct ion finding and communications equipments. Loss of any one of the aerials associated with a given equipment usually resulted in complete unserviceability of that equipment, thoreby bringing about a potentially dangerous situation. The development of suppressed aerials to replace external aerials is still a long term project, and it is therefore necessary to establish the cause of the failures and to find a practicable cure.

It has been ascertained that the cause of most of the failures on both whip and blade aerials is stalling flutter brought about by the change of cross section of the aerials through ice accretion at their leading edges. The few other failures occurred on blade aerials only and were caused by mechanically excited vibration.

All the aerial types involved possess considerable flexibility and very low internal damping. It has been found that introduction of damping in the mounting of the aerials has a very beneficial effect on their behaviour from both flutter and mechanical vibration points of view. Successful mountings have been developed which prevent stalling flutter of blade aerials and whip aerials and also reduce the amplitude of mechanically excited vibration of blade aerials to a negligible value.

In the case of blade aerials with a streamlined section the simple expedient of mounting the aerial with its trailing edge facing forwards has been found to prevent stalling flutter. This expedient, however, does not influence the mechanical vibration characteristics of the aerial and is therefore not a complete cure in itself.

Although failures occurred on many different aerial types, as far as mechanical vibration and flutter are concerned they can broadly be classed as either blade aerials or whip aerials. It has therefore been convenient to divide this note into two parts, Part I dealing with blade aerials and Part II dealing with whip aerials. In each case an explanation of the causes of failure is given together with a description of the curative measures which can be adopted.

PART I - Blade Aerial Failures

2 General Description of the Blade Aerials

These are, with one exception, tapered streamlined section aerials forged from high quality light alloy. The exception is the Type 90 aerial which is a parallel streamlined section steel aerial. The mot chord of these aerials is 1.2 ins and the thickness/chord ratio is approximately 1:4. The blade aerials are cut off from the same basic forging and are used in lengths of from 10 ins to 18 ins. The attachment to the aircraft is accomplished in some cases by moulding into a plastic bollard and in others by screwing and pinning to a circular mounting plate. Examples of these aerials are shown in Fig.1. The lateral fundamental flexural natural frequencies of the blade aerials varies from 70 cycles per second for the 11 inch long Type 347 Aerial, to 37 cycles per second for the 17.5 inch long Type 346 Aerial. The damping coefficient of the aerials in their fundamental flexural modes is about 0.003 times the value for critical damping. The blade serials are used with I.F.F. Identification and Rebecca direction finding equipments, for which whip aerials are unsuitable because of their greater flexibility and smaller surface area.

3 Information obtained from Blade Aerial Failures

These failures took the form of either breakage of the aerial blade close to the root, or breakage across the mounting plate along a fore and aft line with consequent damage to the aircraft skin. Examples of typical failures are show in Fig.3.

Metallurgical examination of' the fractures indicated that they were due to rapid fatigue of the material brought about by lateral bending of the aerial. The number of stress reversals was estimated from the fractures to be of the order of 100,000, which implied high peak stresses resulting from considerable aerial lateral bending. The fact that failure invariably occurred close to the aerial root suggested that the oscillation involved the fundamental lateral flexural mode.

Service Defect Reports showed that most of the failures occurred during icing conditions and in some cases the pilots observed the aerials oscillating with large amplitude for some minutes before breaking off.

4 Possible Sources of Excitation of Blade Aerials

Severe continuous oscillation or' external aerials can, in general, be excited from two possible sources. These we:-

(i) Mechanical vibration of the airframe transmitted direct through the aerial mot.

(ii) Some form of aerodynamic excitation, e.g. flutter, compressibility effects, or buffeting arising from airflow turbulence.

For blade aerials many of the failures took place on low speed aircraft. High Mach number airflow occurring in the vicinity of the aerials was therefore unlikely. Turbulent airflow round the aerials was also improbable, as in many cases the aerials were well out on the aircraft wing fairly close to the leading edge.

Two possibilities therefore remained to be investigated, mechanically exoited vibration and flutter.

5 Mechanical Vibration of Blade Aerials

To investigate the likelihood of severe mechanically excited vibration of blade aerials, a Type 93 I.F.F. aerial was fixed rigidly to a vibration exciter. Fig.4 shows this aerial being subjected to a lateral root amplitude of ± 0.010 ins at its natural frequency (41.5 cycles per second). The resulting tip amplitude was ± 1.75 ins and fatigue failure at the aerial root ooourrod after less than 200,000 cycles. It is significant to observe that an amplitude of ± 0.010 ins at 41.5 cycles per second is within the acceptable limits of airframe vibration as laid down in A.P.970, Vol.I, Chap.701.

Within the range of natural frequencies of the blade aerials several engine and propeller order frequencies are normally found on any reciprocating engined aircraft. It is probable therefore, that a blade aerial mounted on such an aircraft would be excited on resonance to fairly large amplitudes at one or more particular engine speeds within the normal running range. This fact is illustrated by the interference diagram inFig.8. The engine and propeller order frequencies in this diagram are those which would be produced by a Bristol Centaurus engine driving a four-bladed propeller. The constant frequency lines are the fundamental flexural froquencies of four representative blade aerial types.

6 Stalling Flutter of Blade Aerials

Much of the obtainable evidence on blade aerial failure suggested that ice formation on the aerials was an important factor. One of the effects of icing on a blade aerial is to increase its mass and thus bring about a small reduction in its natural frequencies. Such small changes are not likely to produce a large increase in the number of mechanical vibration failures, and the aerodynamic effect of ice accretion was therefore investigated.

The leading edge of a Type 93 I.F.F. aerial was coated with plastioine to simulate ioe formation. The section of the coating is shown in Fig.5A. This aerial was mounted on an aircraft in the normal manner and was observed to oscillate in its fundamental lateral bending mode at all airspeeds above 130 knots I.A.S. with an estimated tip amplitude of ± 4 ins. The amplitude of oscillation remained fairly constant with variation of airspeed from 130 knots up to 310 knots (the maximum speed obtainable on the testing air craft). Yawing the aircraft to either side produced a marked increase in amplitude. Variation of engine speeds did not alter the amplitude appreciably.

The fundamental torsional frequency of the Type 93 aerial was measured and found to be 1600 cycles per second. The considerable difference between this frequency and the fundamental lateral bending frequency of 41.5 cycles per second indicated that flexure-torsion flutter at current flying speeds was not possible, even when allowance is made for the frequency changes resulting from considerable icing on the leading edge of the aerial. It seemed most likely that the phenomenon was a type of stalling flutter in the lateral bending mode.* Under lateral motion of the aerial the relative airflow (see Fig.7a) is at an angle to the blade and produces a sideways force, which with a normal aerofoil section would oppose the motion. With the type of section resulting from ice accretion on the leading edge, however, a sufficiently high velocity of lateral

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* The type of flutter envisaged here is different from the type usually referred to as stalling flutter, in which an aerofoil of conventional section oscillates in a twisting motion about a mean position of high (stalling) incidence to the airflow.

motion could produce the necessary incidence to cause stalling, which would create a sideways force in the reverse direction (negative lift) to assist the motion (see Fig.7b). Under these conditions a sustained oscillation becomes possible due to the existence of the negative lift, representing negative aerodynamic damping, over part of the cycle.

7 The Prevention of Mechanical Vibration and Stalling Flutter Failures

The simplest methods of preventing large mechanically forced amplitudes are either to introduce sufficient damping into the system to reduce the amplitudes to a low level, or to design a flexible mounting which would give the system a natural fundamental flexural frequency below the lowest engine or propeller order frequency present, in an attempt to avoid resonance. The latter scheme would require a natural frequency below 10 cycles per second. A linear system with such a low natural frequency would inevitably be very "soft" and the aerial would therefore be subject to large lateral deflections due to normal aerodynamic side loads. In the case of the directional equipments such lateral deflections could not be permitted and the use of a normal flexible mounting was therefore precluded. It was also necessary to avoid reducing the torsional stiffness of the system as this would increase the possibility of flexure-torsion flutter.

A mounting was devised which was successful in preventing both stalling flutter and excessive mechanical vibration of the blade aerials. This mounting is shown diagrammatically in Fig.6. The aerial is hinged at its root about an axis AB parallel to the longitudinal axis of the aircraft and two spring loaded friction damping pads supplying a total sliding friction torque of 7 lbs ins are applied to the front and back of the aerial bollard at points below the axis of rotation. Rotation of the aerial about the axis is limited to ± 3 degrees by rigid stops.

The only elasticity in the system is therefore that of the aerial itself and for small amplitudes of vibration (i.e. those producing torques of less than 7 lbs ins at the aerial root) the aerial will behave as though it were fixed. However, for larger amplitudes the aerial will rotate about the axis AB against the friction damping, The system thus possess non-linear characteristics and for large amplitudes the damping i,s in excess of the critical. value. The possibility of severe vibration on resonance due to mechanical excitation is thus removed. For small values of friction torque, stalling flutter involving a motion of rebounding on the limiting stops still occurred with the plasticine coated aerial, end it was found by experiment that the friction torque of 7 lbs ins was necessary to prevent the flutter completely. The action of the mounting in preventing the stalling flutter is that it restricts the lateral motion of the aerial and thus prevents the occurrence of stall conditions sufficient to maintain an oscillation.

It has been found in practice that the expedient of mounting the blade aerials back to front (i.e. trailing edge facing forwards) has eliminated most of the failures. The effect of this reversal is to alter considerably the shape of the ice formed on the aerial under icing conditions. The consequent change in the overall cross sectional. shape of ice and aerial appears to have a profound influence on the stalling flutter characteristics. Brief icing wind tunnel tests indicated that ice forms on the reversed aerial in a manner similar to that shown in Fig.5B. An aerial coated with plasticine with this cross section showed no tendency to flutter over the 0 - 310 knots indicated airspeed range. Reversal of blade aerials has been carried cut on service aircraft on account of its simplicity. The mechanical vibration characteristics of the aerials are not altered by reversal and it is probable therefore that mechanically excited vibration will still occur on these aerials.

PART II - Whip Aerial Failures

8 General Description of the Whip Aerials

Whip aerials are manufactured basically from circular section drawn steel. The diameter decreases in several steps from the root along the length of the aerial. The root is 0.25 ins diameter and is threaded to screw into a plastic bollard which is fitted to the aircraft. Whip aerials of various lengths up to 60 ins are used, but most of the failures occurred on the 27 ins V.H.F. communications and the 36 ins Standard Beam Approach aerials shown in Fig.2. The fundamental flexural natural frequencies of the 27 ins V.H.F. and the 36 ins S.B.A. aerials are 11 cycles per second and 6 cycles per second respectively. The damping coefficient of the whip aerials in their fundamental bending modes is about 0.004 times the value for critical damping.

9 Whip Aerial Failures

whip aerial failures are mentioned in this report for the sake of completeness although the cause of failures has previously been ascertained and a cure established in wind tunnel tests at the R.A.E.

The failures were identified by metallurgical examination to be due to rapid fatigue of the material resulting from a relatively small number of high stress reversals. Failure occurred almost invariably close to the aerial root in a lateral direction, indicating lateral bending of the aerial in its fundamental mode. Fatigue of the material was usually accelerated by stress concentrations occurring across the aerial root threads and at sudden changes in aerial diameter, many failures occurring at both places.

The fundamental flexural natural frequencies of the 27 ins V.H.F. and the 36 ins S.B.A. aerials are below the lowest engine and propeller order frequencies found on piston engined aircraft in the normal engine speed ranges.

Failure of these aerials, therefore, was unlikely to be caused by mechanical excitation on resonance in the fundamental flexural mode. Furthermore, many of the failures had been seen to occur in icing conditions, preceded by continuous lateral oscillation to angles in excess of ± 30 degrees.

The wind tunnel tests showed that the cause of the failure was stalling flutter which occurred during the early stages of icing when the original circular section of the aerial had become elliptical due to ice formation on its leading edge. The ellipse behaves as an aerofoil and the flutter is caused in the same way as that of the blade aerials. The flutter frequency is again the fundamental natural flexural frequency of the iced aerial.

The principle of the prevention of this flutter is the same as that of the blade aerials. The damping required is however very much less in the case of the whip aerials. The successful flexible mounting developed during the wind tunnel tests allows the aerial a range of rotation of ± 5 degrees about an axis through its root and parallel to the longitudinal axis of the aircraft. Over this range damping and stiffness are supplied by a sponge rubber pad in compression.

10 Conclusions reached in the Investigation of Blade Aerial and Whip Aerial Failures

Vibration and stalling flutter occurring in the fundamental lateral flexural mode have been responsible for large numbers of fatigue failures of blade aerials and whip aerials, In many cases fatigue of the material has been accelerated by some form of stress concentration.

A very important contributory cause of severe vibration and flutter of both blade and whip aerials is the extremely low internal damping of the materials from which they are manufactured. As a result of this absence of damping very little energy input is required to maintain an oscillation of large amplitude and consequent high peak stress.

It has been found possible to prevent vibration and stalling flutter of blade aerials and whip aerials by installing a suitable form of flexible mounting in each case. The principle of both types of mounting is that of providing a limited range of lateral motion over which the stiffness is low and damping very high.

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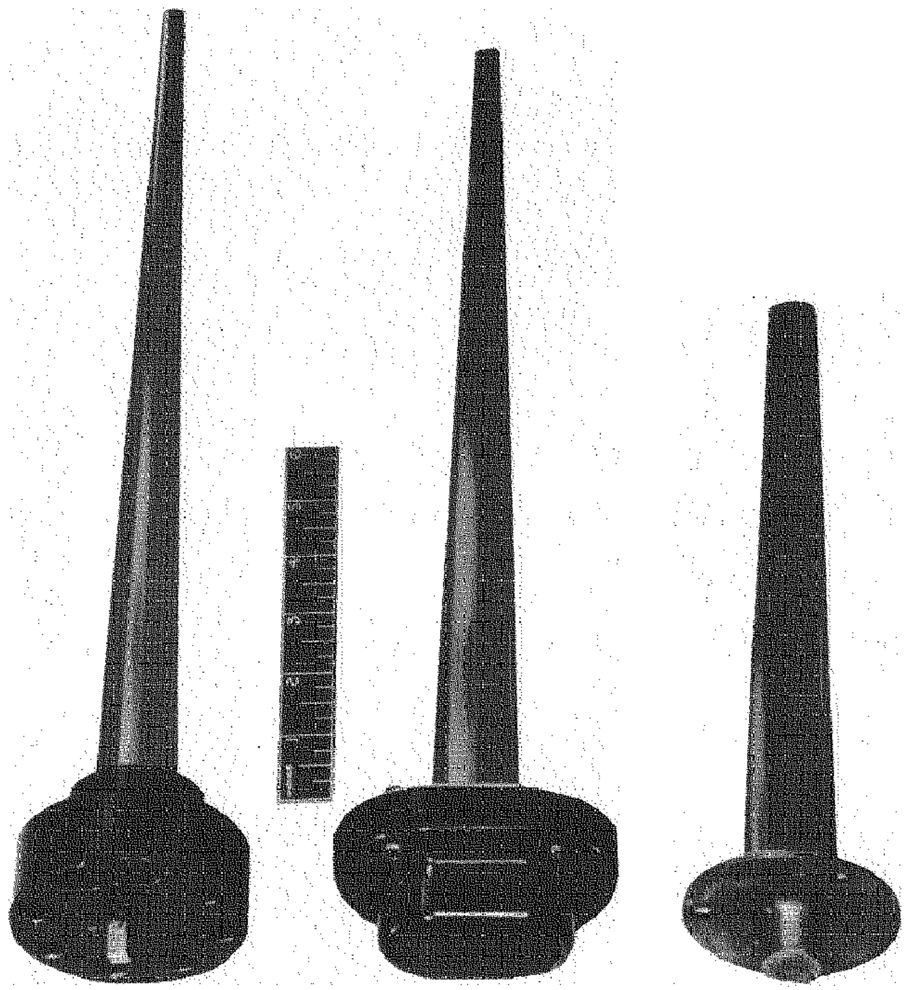


FIG.1. TYPICAL EXAMPLES OF BLADE AERIALS

FIG.2. THE 27" V.H.F. AND THE 36" S.B.A. WHIP AERIALS

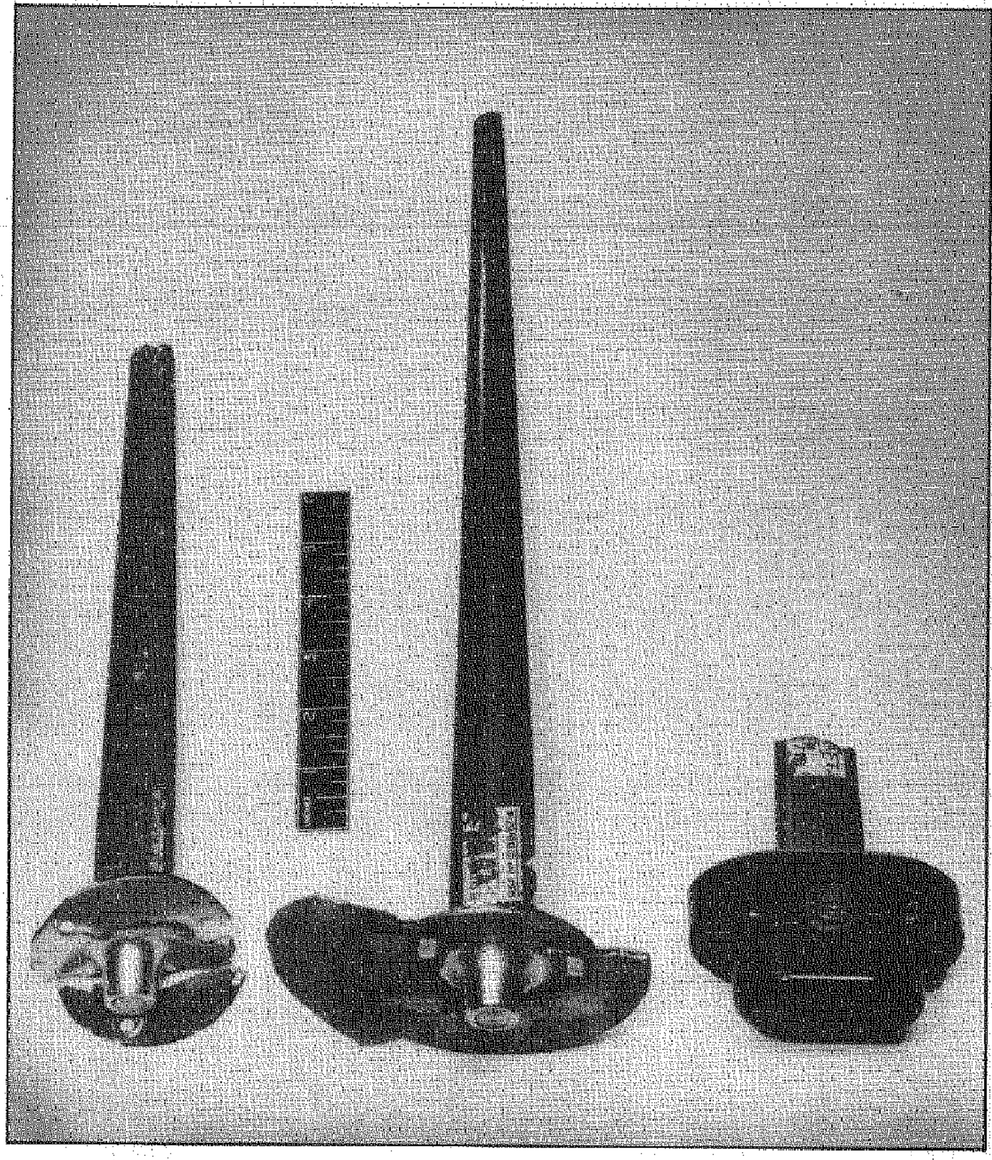


FIG.3. TYPICAL EXAMPLES OF BLADE AERIAL FAILURES

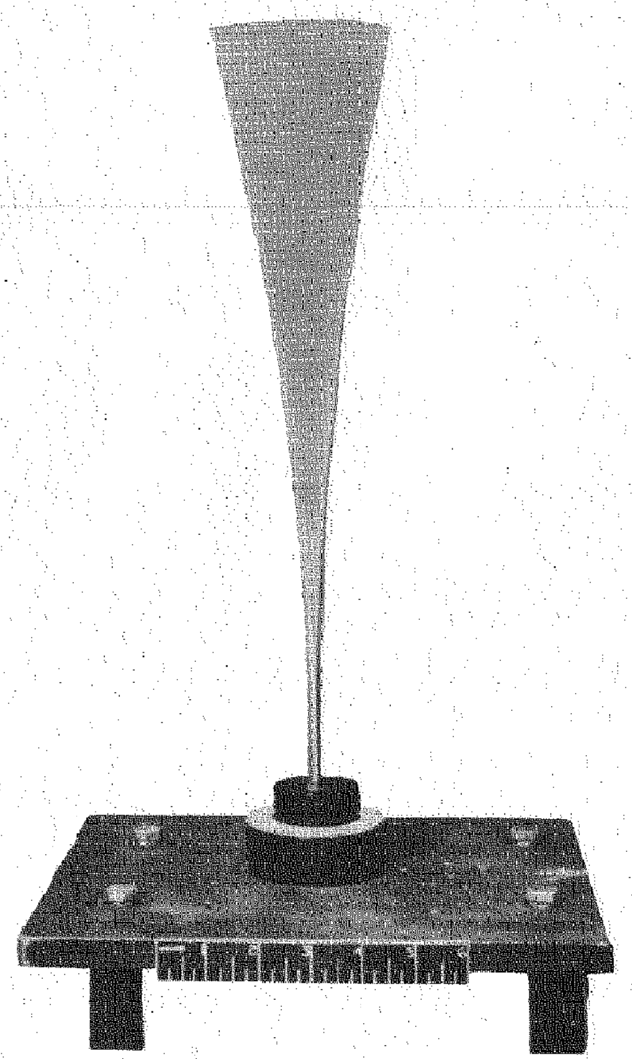


FIG.4. MECHANICAL EXCITATION OF A BLADE AERIAL ON A VIBRATION TABLE (ROOT AMPLITUDE = ±0·010 in.)

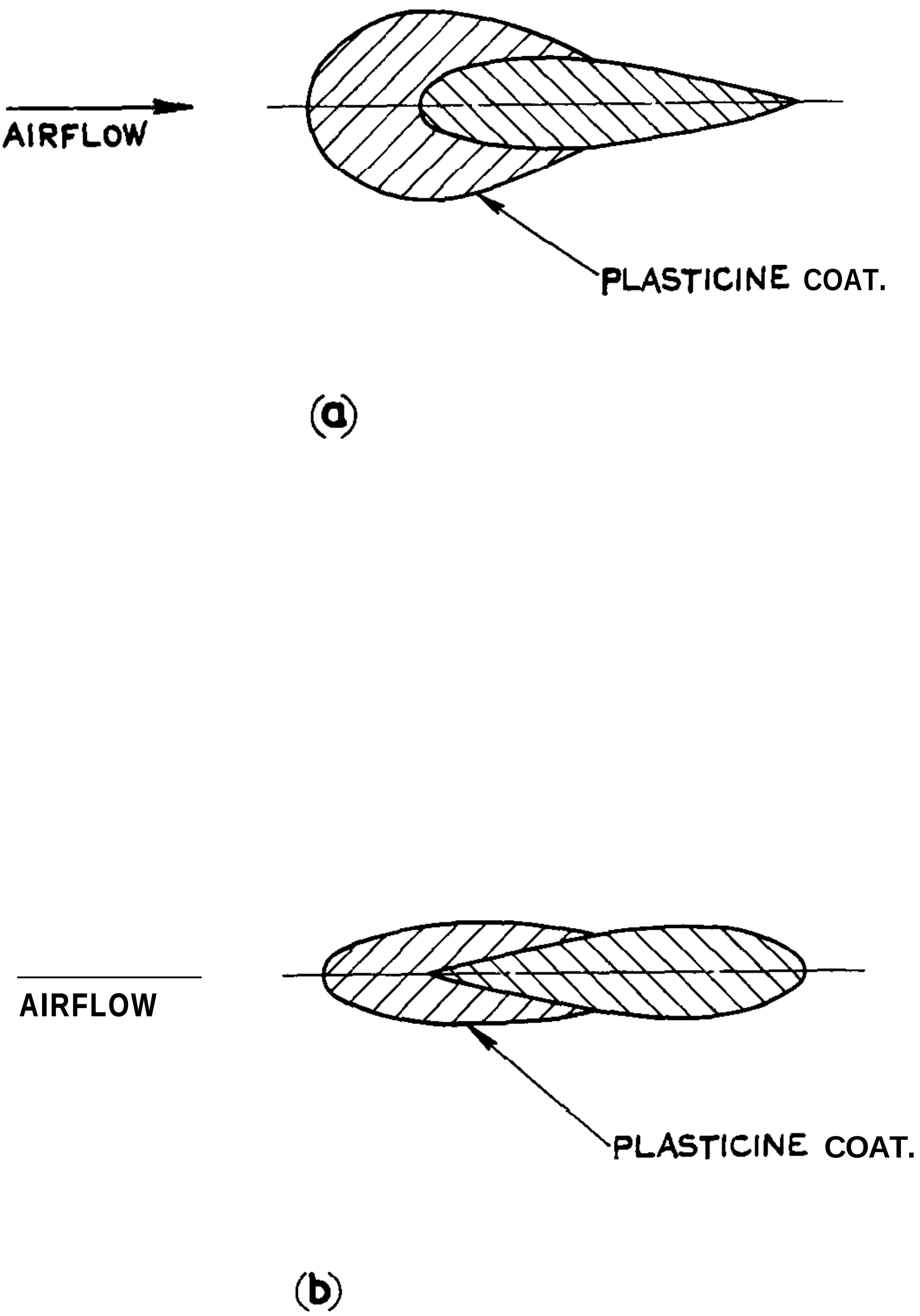


FIG. 5 (a & b) CROSS SECTIONS OF PLASTICINE COATED BLADE AERIALS TESTED FOR FLUTTER.

FIG. 6.

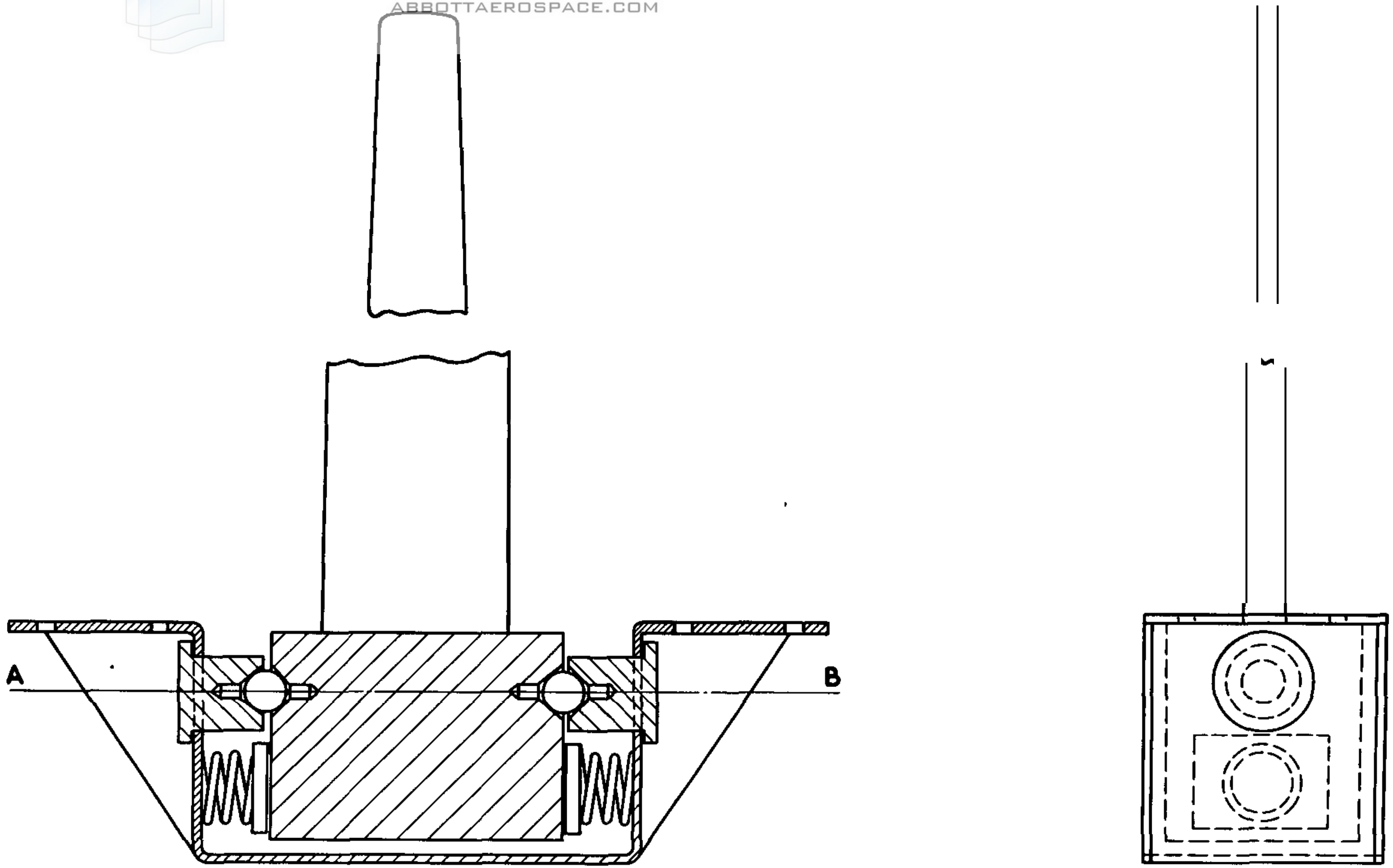
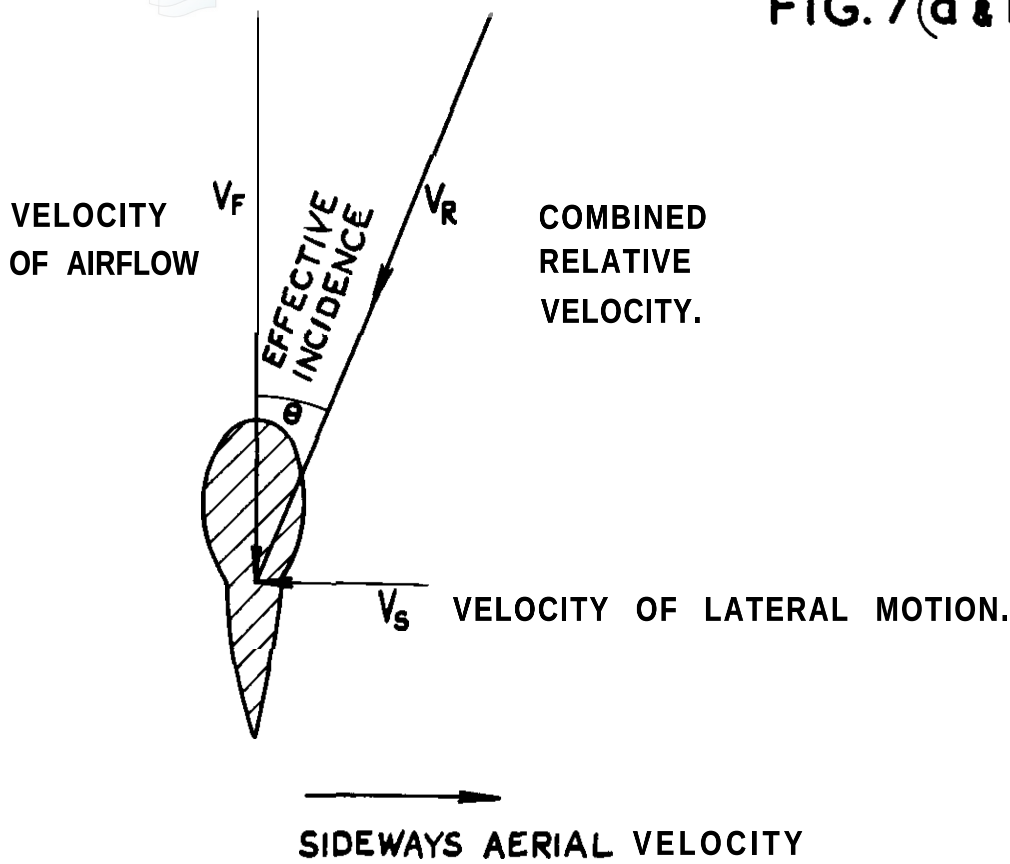


FIG. 6. DIAGRAM OF EXPERIMENTAL FLEXIBLE MOUNTING USED TO PREVENT MECHANICAL VIBRATION AND STALLING FLUTTER OF BLADE AERIALS.

FIG.7(a & b)

(a)



(b)

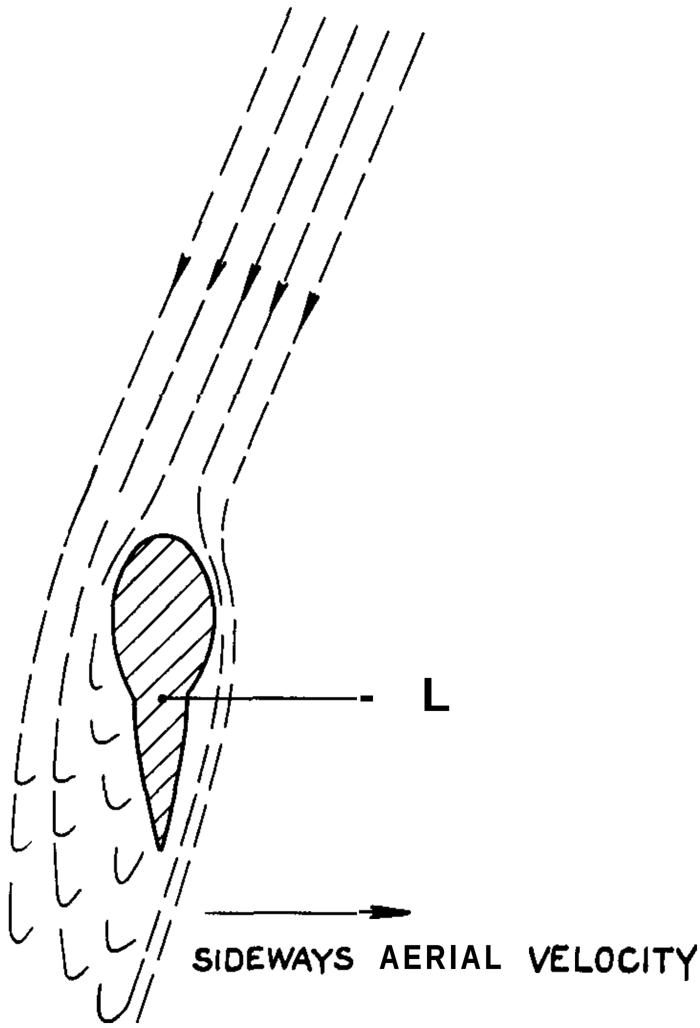


FIG.7 (a & b) DIAGRAMS ILLUSTRATING THE CAUSE OF STALLING FLUTTER.

FIG.8.

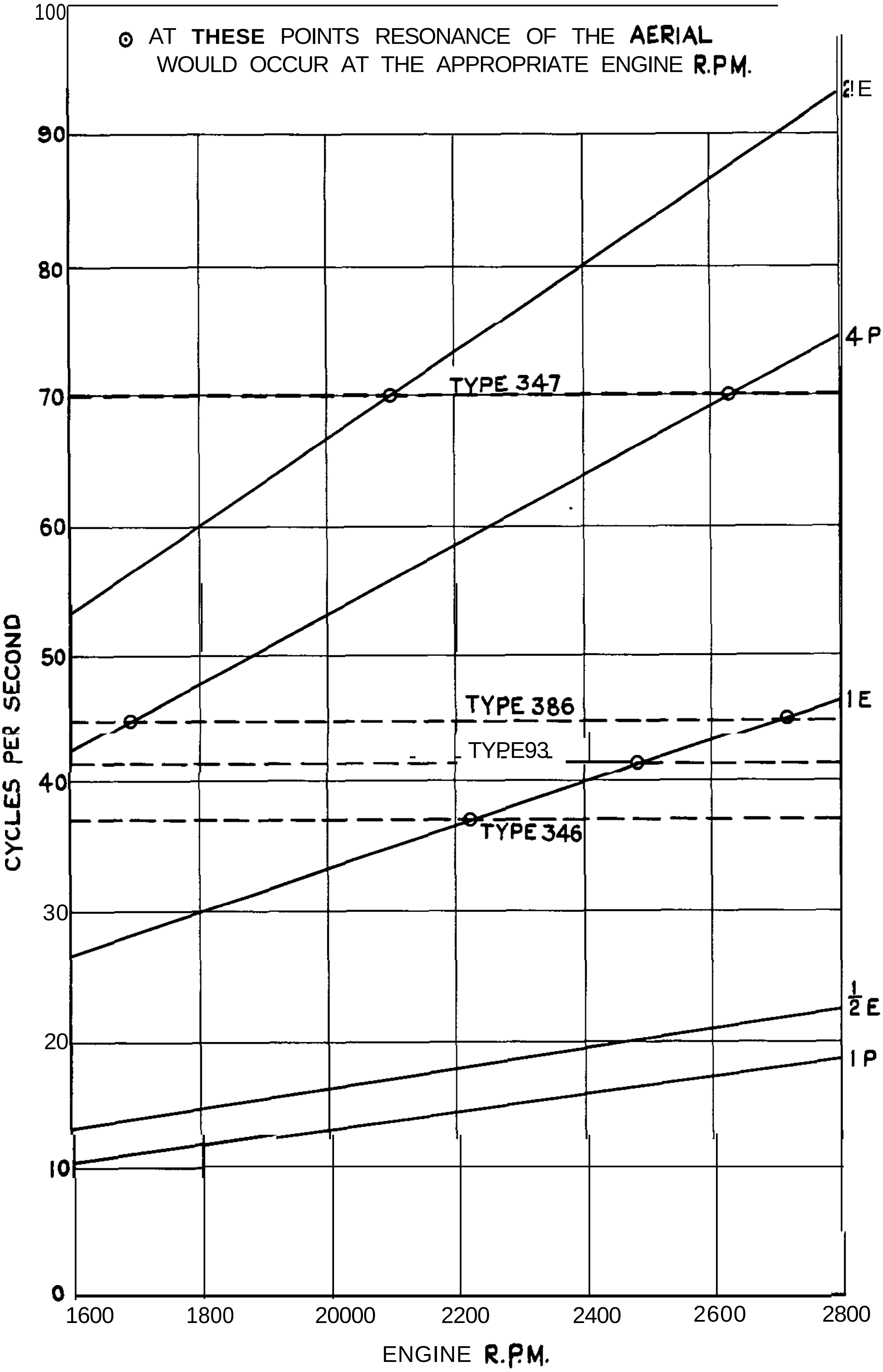


FIG. 8. DIAGRAM ILLUSTRATING COINCIDENCE OF BLADE AERIAL NATURAL FREQUENCES WITH ENGINE/PROPELLER FREQUENCES.

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