CHAPTER III - VIBRATION

To insure the utmost in safety and passenger comfort, it is desirable, that the Aircraft Manufacturer make a study of the vibration response in the airplane which is produced by the exciting forces that are inherent in the power plant group. It is only within the scope of this Manual to discuss this phase of the airplane vibration problem.

The principal sources of vibration originating in the power plant group are as follows:

(1) Half order harmonic of the engine torque reaction, usually due to faulty ignition or distribution.

(2) First order primary engine unbalance or shaking force produced by the reciprocating portion of the master rod shank which is usually much heavier than the link rods, and the first order harmonic of engine torque reaction, usually due to faulty ignition or distribution.

(3) Second order engine unbalance which results from shifting of the center of gravity of the master rod and piston system from the crank center twice each revolution, due to the geometry of the knuckle pin and link rod combination.

(4) Four and one-half order engine unbalance due to firing frequency. With a four-cycle nine-cylinder engine there will be four and a half firing impulses per revolution. With a fourteen cylinder engine this would be a seventh order engine unbalance.

(5) First order propeller unbalance, occurring at propeller speed, due to errors in center of gravity to the propeller axis, errors in blade track and aerodynamic pitch setting.

(6) N order propeller excitation, where N is the number of blades, which occurs at N times propeller speed and is due to the propeller blades passing a wing, fuselage, or part of the airplane structure.

In studying vibration arising from the power plant group, a means is first needed for exciting vibration while the airplane is at rest on the ground. Considerable information may be obtained on the resonant response of the various modes of free vibration of an aircraft structure by this means. Figure 106 is a photograph of such an exciter, together with propeller shaft, attaching nuts, and certain instruments useful in observing vibration. The propeller shaft attaching nuts shown are necessary for the installation of the unbalanced weight on the engine crankshaft, which installation duplicates the effect of first and second order engine unbalance and propeller unbalance. With the use of a special rocker box cover (not shown in the photograph), it is possible to duplicate engine half and first order unbalance or torsional excitation.

Briefly, this exciter consists of an eccentric mass supported by ball bearings on a shaft which may be either the special propeller hub nut or rocker box cover. In either case, the eccentric mass is mounted with all other equipment in place, and is driven by a variable speed motor covering a speed range at least up to twice maximum engine speed, or N times propeller speed, where N is the number of propeller blades. The minimum speed should be as low as possible, at least to idling RPM. At least one horsepower will be required to drive one inch pound unbalance at the higher speeds.

Several types of devices are available for both indicating and recording frequency and amplitude. The first requisite of such a device is that it be flyable, and second, applicable to the range of frequencies and amplitudes under investigation. Obviously, there is little need in using electrical or magnetic pickups and cathode analyzers in investigating visual vibration; on the other hand, a kymograph is of little value in registrating vibration arising from any source higher than third order propeller speed. The most universally applicable device for measuring vibration and amplitude is a wave analyzer which responds to one frequency at a time and measures the amplitude of the tuned frequency. The results as found from this device are immediately available; all that is necessary is to plot the data. Pick-ups can be either the magnetic type or piezo-electrical crystals.

One of the most useful instruments for use in vibration studies is a type frequency meter known as a Frahm Tachometer, consisting of a group of tuned reeds of predetermined frequency enclosed in a light metal box. Each reed has a slightly higher frequency than the one preceding it, so that any range of frequency can be covered. For aircraft work, the most useful range is from 800 to 5000 CPM; the spacing between reeds vary from 20 CPM at the lower range to 200 CPM at the higher range. It will be found in operation that several reeds will respond to impressed vibration. By dampening the box with the hand or a piece of felt, all can be damped out except the predominant frequency. The reeds adjacent to the ones responding might also respond slightly, but this will not detract from the usefulness of the device.

The procedure to be followed in determining the natural response frequency of an engine mount and airplane structure is as follows: Refer to Figure 107. Provide about 2 inch pounds of unbalance of the rotating weight. The actual magnitude of unbalance is unimportant as it is only necessary to supply sufficient excitation to obtain a definite response. If on trial, this is found to be unsatisfactory, the magnitude can be varied to suit the demand. Attach the exciter to the crankshaft by means of a suitable nut and run through a speed range from the lowest propeller speed to twice engine speed, or a speed equal to propeller speed times the number of blades, whichever is higher. Record the responsive frequencies and amplitude of the power plant group both in pitch and yaw, and also any critical vibration in the airplane. Then with the same unbalance, set up on a rocker box for torsional excitation, run through a range of speeds duplicating the engine operation, noting frequency and amplitude as before.

These data are best recorded on a curve as in Figure 108. This is a plot of the response frequency vs. engine RPM for a Cyclone engine fitted with a 16:11 reduction gear and a three-blade propeller. At each period of response mark the engine RPM which produced this response. The amplitude can be jotted down adjacent to the point.

In flight no artificial excitation is needed, and all that is necessary is to observe objectionable vibration, noting its frequency and amplitude. By varying engine RPM, airplane speed and trim, it will be easy to identify the exciting force, and steps can be taken for correcting it.

Having determined the frequencies of all modes of vibration, and identifying all the exciting forces, and having done all that is possible to correct the condition, it remains to establish limits in operation. (It is often found that objectionable vibration is present in an operating range most advantageous to the airplane-engine combination from an operation standpoint). In such cases, it is often possible to vary the engine mount characteristics and shift this point out of the desired operating range.

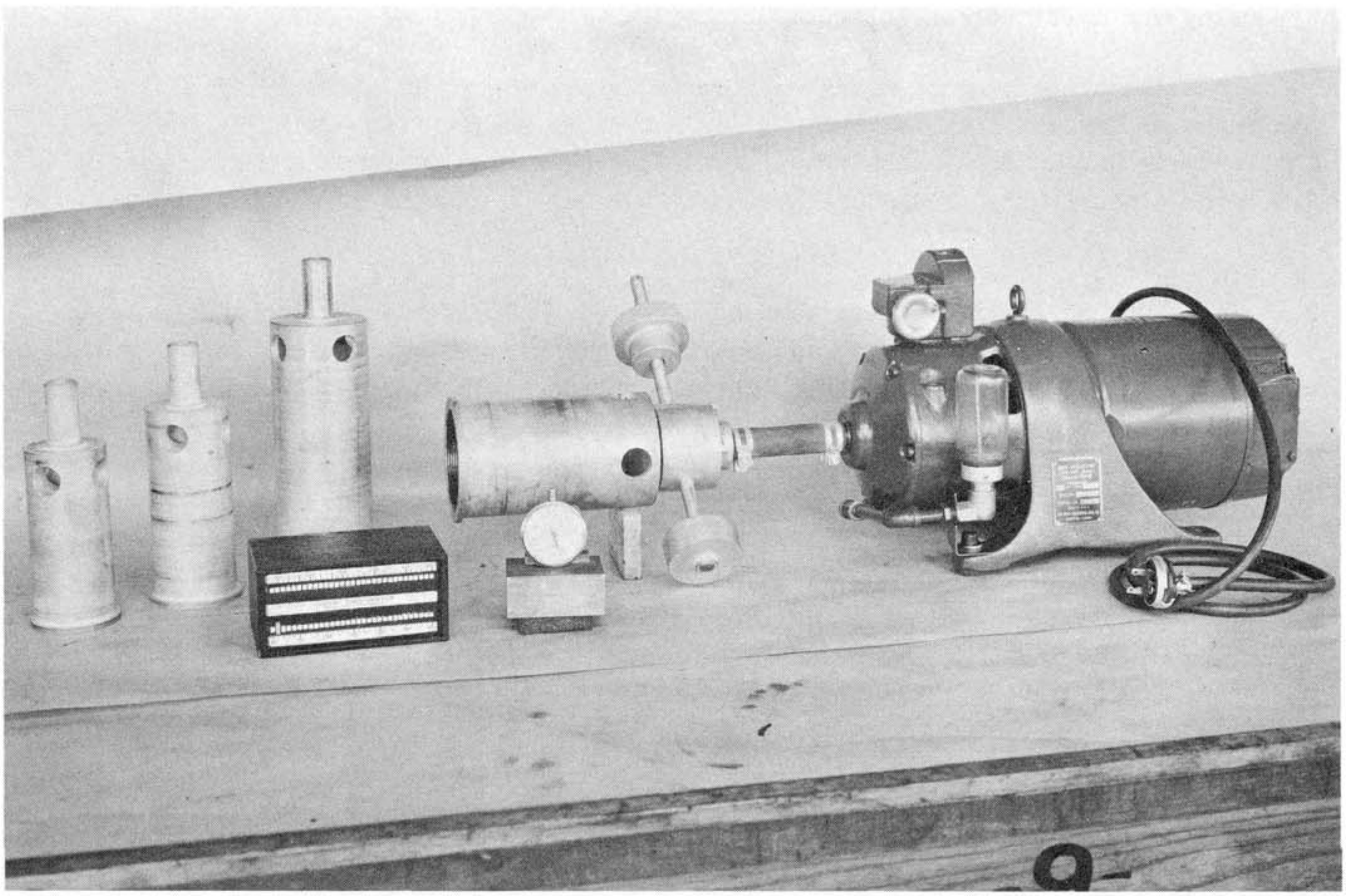
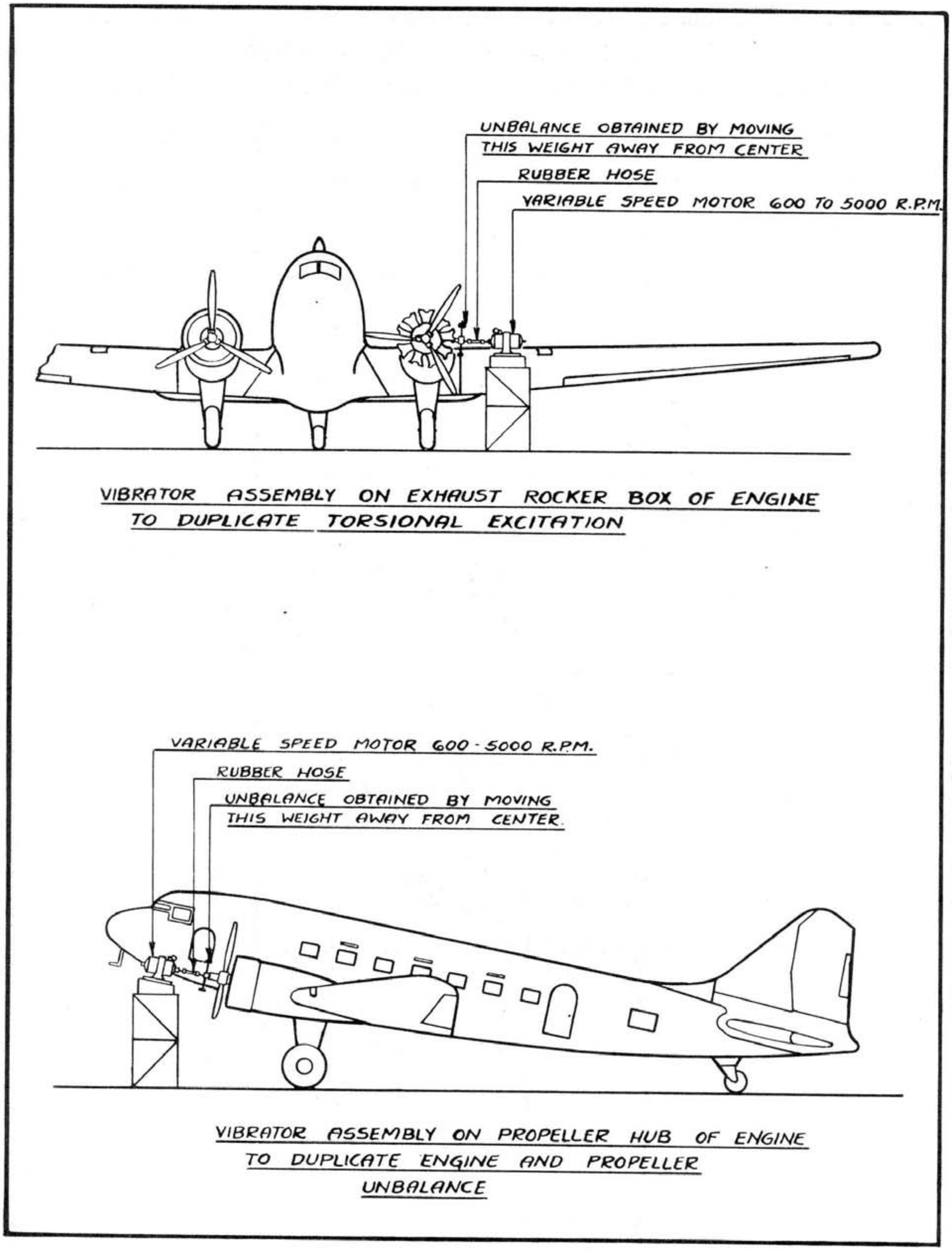


Figure 106



VIBRATOR ASSEMBLY ON EXHAUST ROCKER BOX OF ENGINE TO DUPLICATE TORSIONAL EXCITATION

VIBRATOR ASSEMBLY ON PROPELLER HUB OF ENGINE TO DUPLICATE ENGINE AND PROPELLER UNBALANCE

Figure 107

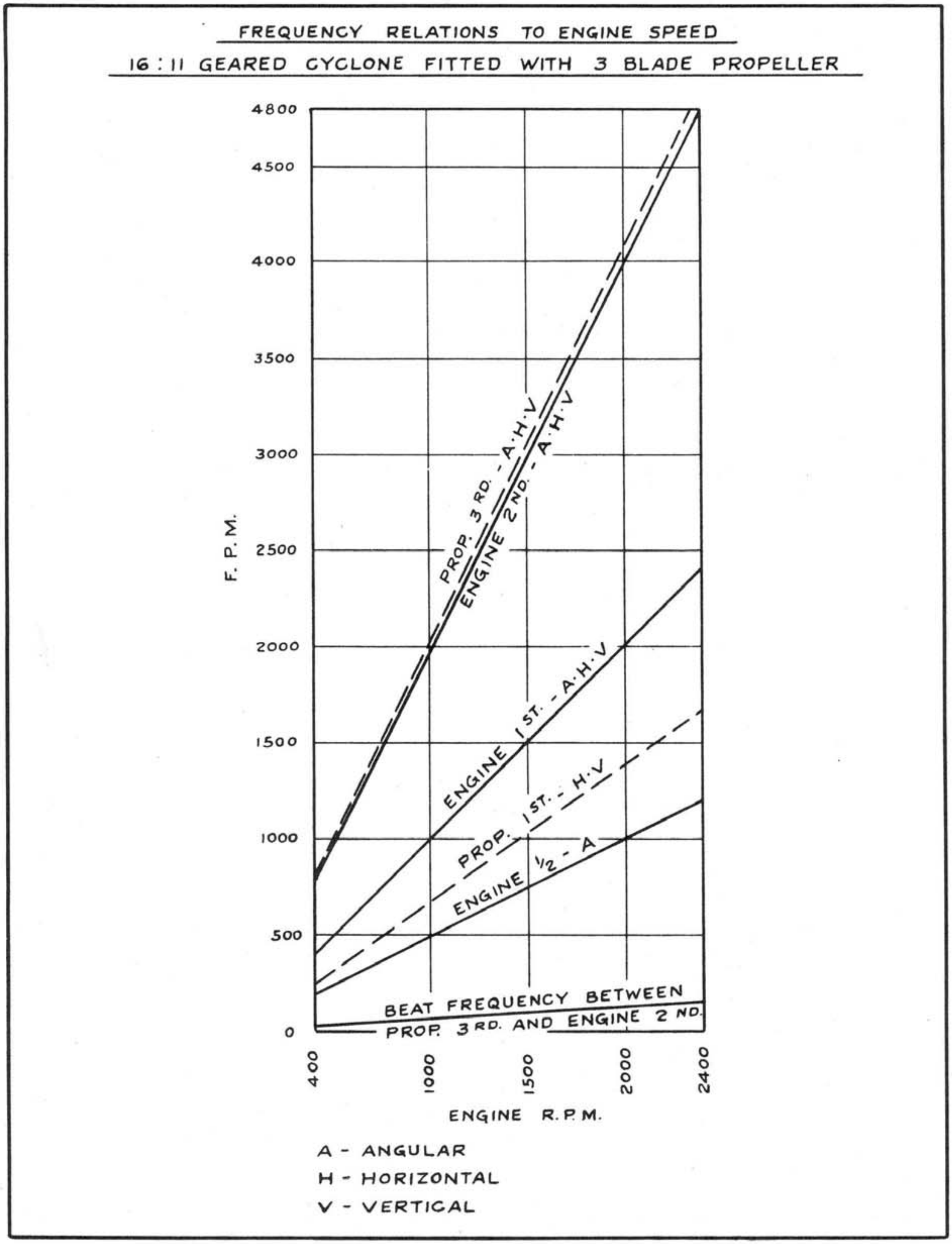

FREQUENCY RELATIONS TO ENGINE SPEED
16 : 11 GEARED CYCLONE FITTED WITH 3 BLADE PROPELLER
F. P. M.
4800
4500
4000
3500
3000
2500
2000
1500
1000
500
0
PROP. 3 RD. - A·H·V
ENGINE 2 ND. - A·H·V
ENGINE 1 ST. - A·H·V
PROP. 1 ST. - H·V
ENGINE 1/2 - A
BEAT FREQUENCY BETWEEN
PROP. 3 RD. AND ENGINE 2 ND.
400
1000
1500
2000
2400
ENGINE R.P.M.
A - ANGULAR
H - HORIZONTAL
V - VERTICAL

Figure 108