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Report 2266

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A METHOD OF ANALYZING PROPELLER-EXCITED VIBRATORY FORCES ON A MODEL

by

Chengi Kuo

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HYDROMECHANICS LABORATORY
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DAVID TAYLOR MODEL BASIN
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NOTATION

V	Vertical force
H	Horizontal force
Q	Torsional moment
F_s, F_p	Starboard and port forces produced by the respective eccentricities
e_s, e_p	Starboard and port eccentricities
ω	Angular velocity
β	Relative angular displacement between the weight eccentricities
S	Half distance between the centerlines of the rotating weight
H	Distance of propeller shaft axis below the axes of rotating weights
V_{AS}, H_{AS}, Q_{AS} V_{BS}, M_{BS}, Q_{BS}	Vertical and horizontal forces and torsional moment for Components A and B rotating in phase
V_{AO}, H_{AO}, Q_{AO} V_{BO}, H_{BO}, Q_{BO}	Vertical and horizontal forces and torsional moment for Components A and B rotating out of phase
V_{VA}, V_{VB1}... etc H_{VA}, ... etc Q_{VA}, ... etc	Influence coefficients; see Equation [10]
R_{VA1}, R_{VB1}... etc R_{MA1}, ... etc R_{QA1}, ... etc	Response coefficients; see Equation [11]
V_{A1}, V_{B1}, etc H_{A1}, ... etc Q_{A1}, ... etc	Force coefficients; see Equation [12]
$[F]$	Force matrix

[C]	Influence coefficient matrix
[R]	Response matrix
[D]	Adjusted influence coefficient matrix
[P]	Propeller force vector
[S]	Propeller response vector
K_{FV}	Vertical force coefficient
K_{FH}	Horizontal force coefficient
K_{FQ}	Torque coefficient
ρ	Density of the fluid
N_S	Shaft revolutions per second
D	Propeller diameter

ABSTRACT

A very brief description is given of a technique which involves the use of elastical isolation of the model stern to evaluate propeller-excited vibratory forces on models. The method of analyzing the results obtained in the experiments is given in detail and its application is illustrated by an example.

ADMINISTRATIVE INFORMATION

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INTRODUCTION

The interest in and the need for examining the vibratory forces excited by propellers have long been recognized. In recent years, they have become more important as the speed and power of ships continue to increase. The pioneering investigation on propeller-excited hull vibration was done by Lewis[1,2] more than 30 years ago. Subsequently, attempts to correlate the forces of the model and full-scale ship have been made at the Massachusetts Institute of Technology[3] and the National Physical Laboratory[4] while theoretical studies have been considered at the Davidson Laboratory[5] and experimental work conducted in Japan[6] and at the Netherlands Ship Model Basin.[7] At the David Taylor Model Basin work in this area has been aimed at finding some experimental techniques to measure the model vibratory forces and methods to analyze the results obtained. This report briefly describes the background leading up to the present experimental setup, the basic principles involved, and the instrumentation. A method of analyzing the results is examined in detail and data obtained from experiments carried out in October 1965 are used to illustrate its application. The digital computer program is also discussed.

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[1] References are listed on page 65.

BACKGROUND ON THE MEASUREMENTS OF VIBRATORY FORCES ON A SELF-PROPELLED MODEL

The earlier work carried out in the field of propeller-excited vibratory force measurements with models was done by Lewis and published in 1935 and 1936.[1,2] Further experiments were later carried out by Lewis and Tachmindji.[3] A brief outline of the method used in the latter work is given here to illustrate some of the problems involved.

In view of the complexity of the propeller-excited forces acting on the hull, Lewis and Tachmindji have replaced the actual system by an equivalent system made up of a vertical force V, a transverse force H, and a couple Q about the longitudinal axis. Force V was taken as that which would produce the same vertical motion at a particular point in the model as the combination of the vertical and longitudinal forces plus the pitching couple. Force H and couple Q were taken as those which would produce the same transverse and torsional (heeling) motion about the longitudinal axis at the same point due to the combination of the horizontal force and the heeling and yawing couples. Forces V and H were arbitrarily assumed to act in the plane of the propeller and to pass through the centerline of the shaft. The measuring technique adopted for the force system was the "null-balance" method which used forces produced by a vibration generator to balance the forces produced by the propeller. The vibration generator had a pair of rotating weights and was mounted in line with the plane of the propeller. It was designed in such a way that proper phasing of the rotating weights enabled producing a pure resultant vertical force or a pure couple or a combination of forces and couple. In addition, the eccentricities of the rotating weights could be varied to give different magnitudes of force. The vibration generator was geared to the same synchronous motor that drove the propeller and operated at the blade frequencies while the magnitude of the generated forces and its phase with respect to a reference position of the propeller blade could be adjusted remotely. To use this approach, a vibration pickup capable of selecting and detecting any of the three motions produced by the propeller was mounted on the bow.

As an example of the application of the null-balance technique, consider the case of vertical motion. The pickup was set to respond to vertical motion, and the vibration generator was set to produce a pure vertical force by rotating the weights in opposite direction and in phase. With the model self-propelled, the phase and magnitude of the generated vertical force were adjusted until no vertical motion could be detected. It will be noted, however, that this balance of vertical motion does not necessarily imply that propeller vertical force is equal and opposite to that produced by the vibration generator since, in practice, the propeller produces vibratory forces and moments in other degrees of freedom which would also contribute to some extent to the response of the pickup. Similar techniques were used to balance the other motions.

To solve for the forces and the couple, it was necessary to determine a set of "influence coefficients" which indicate the magnitude and phase of the vertical, transverse, and torsional motion produced by a unit force in each degree of freedom at zero phase (i.e., with a positive peak at zero phase reference). The final required results would be obtained by solving a set of simultaneous equations involving the vibration-generator forces and the influence coefficients.

When similar experiments were carried out at the Taylor Model Basin after Lewis and Tachmindji completed their work, some difficulties were encountered regarding the variation of the influence coefficients with time, i.e., responses of the model with known vibration generator forces changed from each set of experiments with time. In addition, there was the problem of determining the "no-load" forces which are defined here as the forces other than those produced by the propeller or by the eccentricities of the vibration generator weights. A portion of this "no-load" force was produced by the rotating shafts and gears of the vibration generator due to imperfections in the manufacturing and subsequent wear, and the remainder of the no load was produced by other rotating parts. At a given angular speed, the external no-load maintains a constant phase with respect to the propeller shaft while the phase of the vibration generator internal no-load varies with the phase setting of the vibration generator. To determine the no-loads, the propeller was removed and the vibration generator amplitude and phase adjusted to achieve a balance. However, when the balance was reached in propelled condition, the phase setting of the generator would generally be different from the no-load balanced condition, and thus the no-load contribution from the generator would be at a different phase. Because of this, accurate no-load would be difficult to achieve.

The measuring technique had to be modified to overcome some of the deficiencies mentioned above and to reduce the coupled motions to tolerable limits or to eliminate them completely. To reduce the coupled motions significantly necessitated a substantial increase in the rigidity of the model. The model used by Lewis and Tachmindji was constructed of wood and reinforced by metal framework; further stiffening would be impractical. On the other hand, if a uniform beam is cut in equal halves, the natural frequency of each half would be four times that of the original beam. Using this approach, the model was cut at a position of about two diameters forward of the propeller plane. The reason for the separate stern was to achieve an essentially rigid body with natural frequencies considerably above the blade frequencies to be considered; it was hoped that suspending the stern from the remainder of the model with soft mounts would yield natural frequencies for relative motion between the two parts significantly below the lower range of the blade frequencies. Such an arrangement minimized transmission of the stern motion to the forward part of the model and the reflection of the distorted motions from the model to the stern. This separated-stern technique for making the propeller-excited vibratory forces was adopted at the Model Basin in 1956; its earlier applications have been reported by Stuntz, Pien, Hinterthan, and Ficken.[8] The original "null balance" technique was dropped in favor of calibrating the response of the stern to known input forces and using the calibrated measurements to determine the response of the stern to the unknown propeller-excited forces. In their approach, the turned pickup was replaced by four velocity pickups mounted on the stern, and the outputs were amplified and filtered before being fed into the vibration analyzing system.

The present work used basically the same techniques as outlined in Reference 8. However, the instrumentation has been modified and improved since the publication of that work and a different analytical approach was used for the 1965 experiments.

EXPERIMENTAL SETUP FOR THE 1965 EXPERIMENTS

DESCRIPTION OF THE MODEL AND STERN ATTACHMENTS

The lines of the wood model were derived from the Series 60 forms.[9] The basic data are:

Model No.	4287
Length BP	20 ft
Beam	2.66 ft
Draft fore	1.066 ft
Draft aft	1.066 ft
Displacement	2127 lb
Block coefficient	0.60
Type of stern	open water type
Propeller diameter	0.83 ft
No. of blades	4

Figures 1a and 1b are sketches of the side and plan views of the stern arrangement attachments.

The stern was separated from the main portion of the model at about Station 18 (the model length between the perpendiculars was divided into 20 equally spaced stations) and suspended from a frame structure. This frame structure consisted basically of two I-beams along the fore-and-aft direction joined by two channels along the transverse direction to form a rectangular frame. This frame was mounted on the main hull of the model like a cantilever, and the stiffness of the connection was such that it could be regarded as having a "fixed" end condition. The stern was attached to the main hull by two cables located on the centerline of the frame structure; the actual attachment was made through rubber shear mounts both on the frame and on the stern.

These rubber mounts were selected to achieve a low natural frequency and so minimize the transmission of motion between the stern and the hull through the frame structure; at the same time, they had to be sufficiently strong to support the stern. The estimated natural frequency for vertical motion was about 11 cps, a value below the lower range of the blade

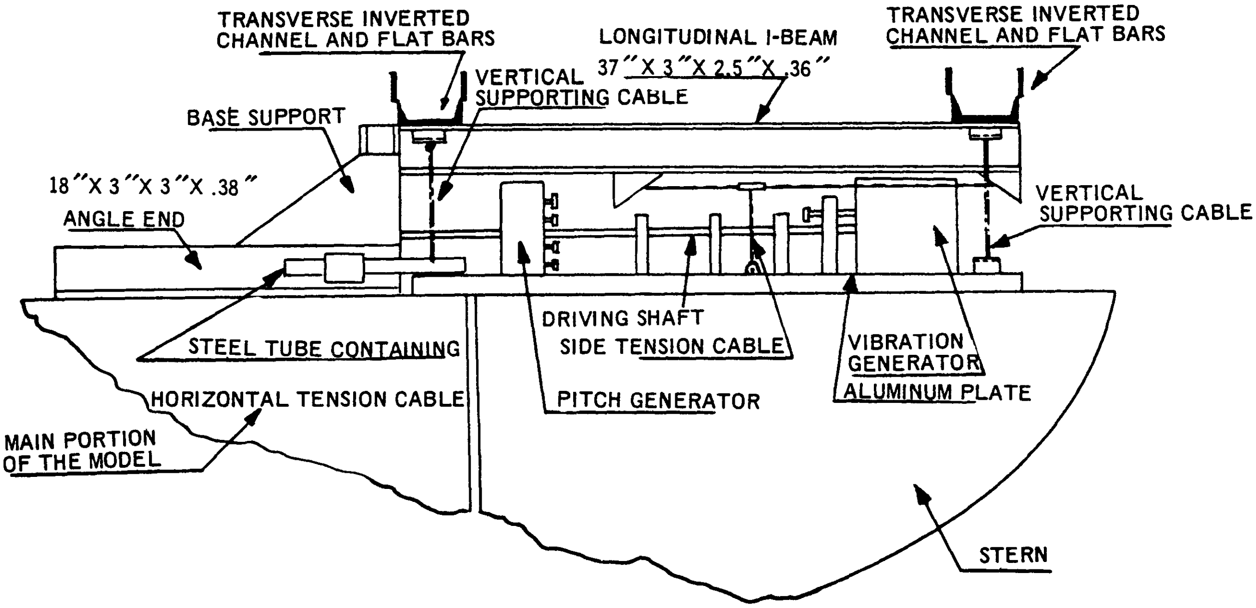

Figure 1a - Sketch of the Side View of the Stern Arrangements

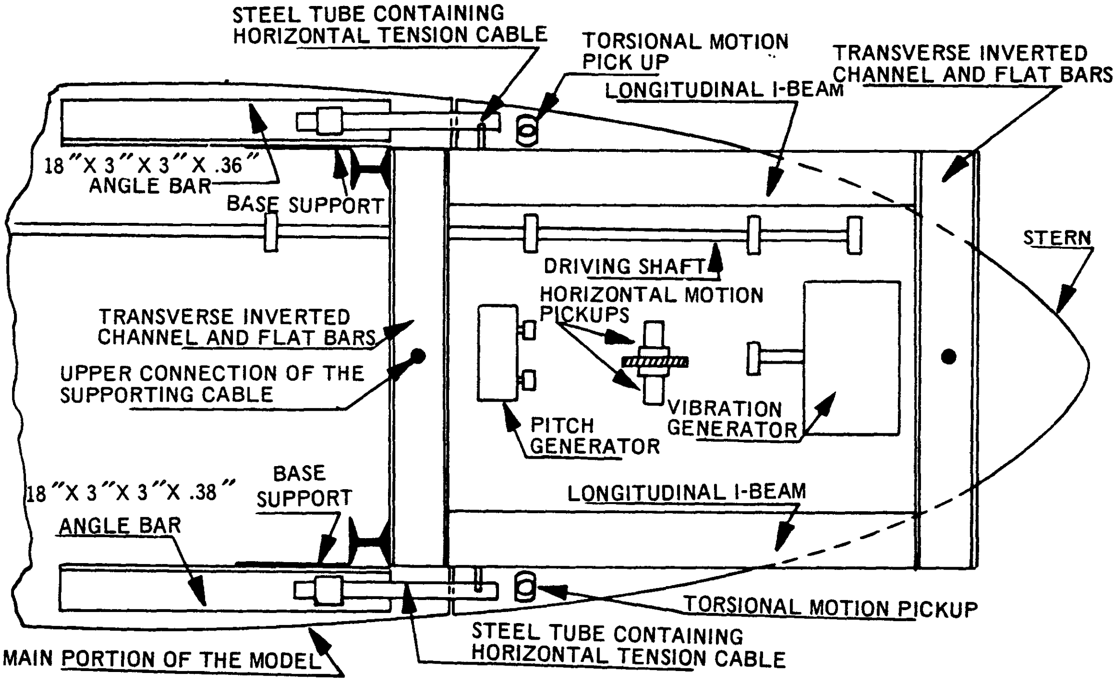

Figure 1b - Sketch of the Plan View of the Stern Arrangements

Figure 1 - Stern Arrangements

frequency encountered in the experiments. To compensate for relative listing and rolling motion between the stern and the main hull, two adjustable connectors were placed between two tension cables below the I-beams and the stern. Estimated natural frequency of the stern suspended on cables was found to be 12.1 cps.

In addition to the vertical supporting cables, the stern was also connected to the main hull of the model by two horizontal cables parallel to the sides of the model. These cables were used in an attempt to restrain any surging and yawing motion of the stern with respect to the main hull while allowing complete freedom for vertical, horizontal, and torsional motions. The pitching motion of the stern with respect to the main hull could not be restricted by the mounting nor could it be eliminated or restrained simply; thus in order to overcome the undesired pitching motion, it was decided to locate the vertical pickups with the aid of a pitching generator in such a way so as to minimize the effects of this motion.

In order to accommodate vibration generator, pitch generator, pickups, driving shaft etc., a 36- by 24-in. aluminum baseplate 1 in. thick was fixed to the stern and holes were made in the plate so that the pickups could be mounted at various heights below the deck level. A number of additional connections were used to support the stern when it was out of the water so as to avoid over straining the supporting cables.

INSTRUMENTATION

Mechanical

Located near midship of the model, a 1/2 hp motor drove the propeller, or the vibration generator, or the pitch generator as desired via belts and pillow blocks. To allow for some relative movements between the main portion of the model and the stern, a short length of resin-like shaft (trade name a DAPRENE) was inserted near the junction of the two parts. It also served as a "flexible shaft" to prevent the transmission of loads across the two portions. The length of the shaft which actually contained the propeller or dummy hub was supported inside a hollow tube on several soft rubber O-rings; it could be adjusted in the longitudinal direction to situate the propeller at any required position away from the hull. When the vibration generator was in use, the belt engaged the pulley of the shaft which lined along the deck and the stern plate; the pitch generator or the vibration generator could be put into operation by proper choice of the connecting belts. The vibration generator used two out-of-balance weights; these could be rotated through tooth gears and locked to achieve angular displacement between the two weights. All the rotating components in the generator were carefully balanced dynamically, and given the actual weights of the rotating masses and eccentricities, the output forces could be readily evaluated. A sketch of the vibration generator is shown in Figure 2.

It has been found that when the model has been in the basin for a period, water tended to leak into it through the thin rubber strip which joined the main hull and the stern along the girth. Accordingly, a pump was installed inside the model, and it operated automatically whenever a given level of immersion was reached.

Electronics

Three pairs of velocity pickups were mounted on the stern to measure the vertical, horizontal, and torsional motions. Manufactured by Consolidated Electrodynamics Corporation, these transducers had a 2.0-in. diameter at the base, were 2.8 in. high and weighed 0.82 lb. The natural frequency of the pickups was 6 cps, and the frequency responses were flat ±5 percent ranging from 8 to 700 cps at 75 F.

The vertical pickups were mounted in the plane of the centerline of the model and below the aluminum baseplate which was flush with the deck of the stern; the exact locations of these pickups along the longitudinal axis were determined experimentally with the aid of the pitch generator and in such a way as to minimize their responses to the pitching motion. The horizontal pickups were mounted on a rigid bar situated near the centerplane; their positions were adjusted to minimize response to torsional motion. The torsional pickups were mounted parallel to each other on the deck and near the edges of the baseplate. The outputs from each of the pickups were arranged to achieve the aims stated above. The

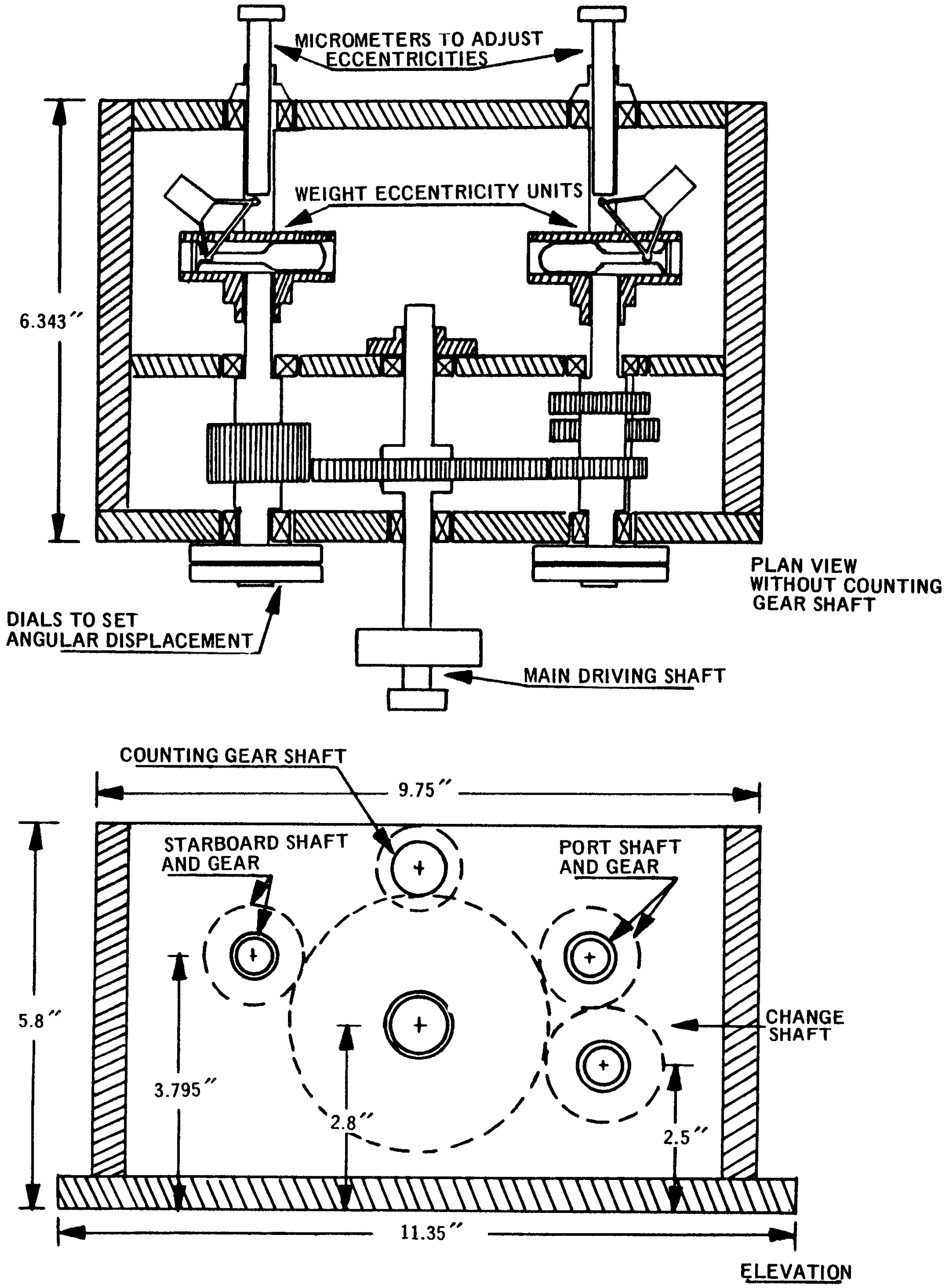

Figure 2 - Vibration Generator

torsional pickups were connected in such a way that in the vertical motion (both pickups moving in the same direction) the outputs opposed each other while for torsional motion (pickups moving in opposite direction), the outputs reinforced each other.

The block diagram in Figure 3 illustrates how the outputs from the vibration pickups were analyzed and recorded. The voltage signal from a pair of the pickups was first amplified and filtered (to remove odd harmonics of blade frequency) and simultaneously fed into two vibration analyzers. At the same time, a carrier and harmonic generator supplied two carriers to the analyzers and a tuning frequency signal to the filter.

The following notations were used for identification. One carrier, denoted as the 0-deg carrier, was fed to the analyzer designated as "A," and the other which lags the former by 90 deg was connected to analyzer "B." The inputs to the carrier and harmonic generator came from a synchronizing pulse generator which supplied one pulse per cycle and from a pulse generator which gave 128 pulses per cycle. The net effect of the setup was that each analyzer produced a d-c voltage proportional to the part of the blade frequency content of the signal that happened to be in phase with the carrier wave supplied to that particular analyzer, and the outputs were recorded on charts by two pens. The relationship between the vector (amplitude-phase) representation of the signal (force or sensitivity or reading) and Component A-B were:

$$A = \text{amp} \times \cos (\text{phase})$$

$$B = \text{amp} \times \sin (\text{phase})$$

$$\text{amp} = (A^2 + B^2)^{1/2}$$

$$\text{phase} = \tan^{-1} (B/A)$$

METHOD FOR EVALUATING THE PROPELLER FORCES

INFLUENCE COEFFICIENTS

To facilitate the evaluation of the propeller forces, the influence coefficients or the responses due to known input force are first determined. It is then possible to evaluate the magnitudes and phases of

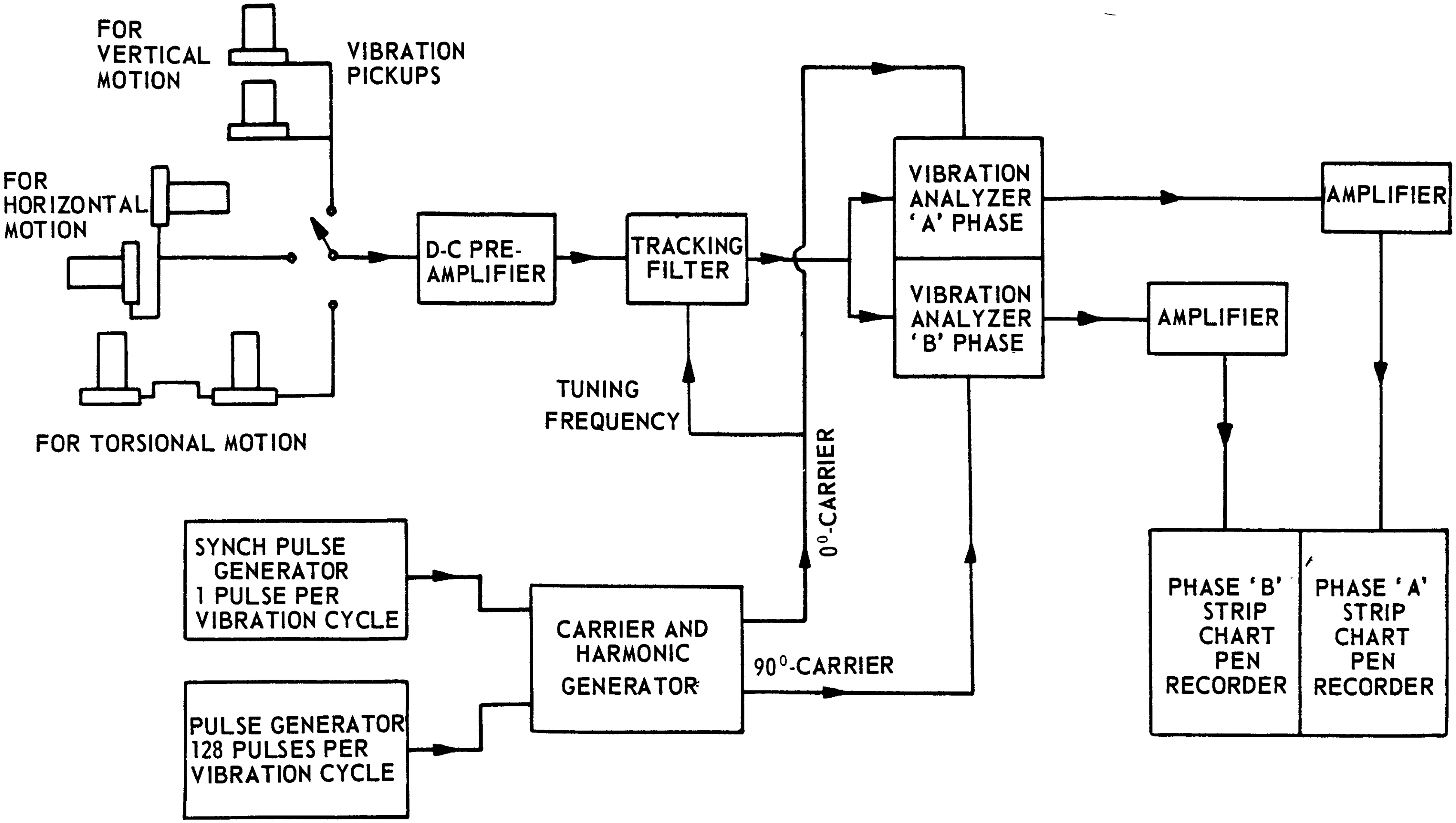

Figure 3 - Electronic Instrumentation

the propeller-excited vibratory forces from the recordings made when the model was self-propelled. To achieve this, the stern was excited by means of a vibration generator mounted on the stern and the responses were recorded.

The equations for evaluating the influence coefficients and the forces and phases may be derived by a number of methods; that selected here is just one of several possible approaches.

Let F_s and F_p represent the input forces produced by the starboard and port weights rotating at a given frequency. The magnitude of each will be proportional to the weight, eccentricity, and frequency squared, i.e.,

$$\begin{aligned} F_s &= W_s \rho_s \omega^2 \\ F_p &= W_p \rho_p \omega^2 \end{aligned} \tag{1}$$

where W_s, W_p are rotating weights,

ρ_s, ρ_p are eccentricities, and

ω is angular velocity.

As an example of how equations may be derived for the forces generated, take the case where the weights are rotating at 0 deg out of phase but in the same direction (see Figure 4a). The following components of forces are obtained by resolving the forces and taking moments about the axis of the propeller shaft:

$$\text{Vertical direction } V = F_s \cos\theta + F_p \cos(\theta + \beta) \tag{2}$$

$$\text{Horizontal direction } H = F_s \sin\theta + F_p \sin(\theta + \beta) \tag{3}$$

$$\begin{aligned} \text{Torsional about center of shaft axis} \quad Q = {} & F_s \sin\theta \quad H - F_s \cos\theta \cdot S \\ & + F_p \sin(\theta + \beta) \cdot H + F_p \cos(\theta + \beta) \cdot S \end{aligned} \tag{4}$$

where S is half the distance between the centerlines of the rotating weights and H is the distance of propeller shaft axis below the axes of the rotating weights.

As stated earlier in the section on Instrumentation, the output from the analyzers produced voltages in phase with the 0- and 90-deg carriers. Substituting into Equations [2], [3], and [4] for θ equal to zero and 90 deg yields:

$$\begin{aligned}
V_{AS} &= F_s + F_p \cos\beta \\
V_{BS} &= \quad - F_p \sin\beta \\
H_{AS} &= \qquad F_p \sin\beta \\
H_{BS} &= F_s + F_p \cos\beta \\
Q_{AS} &= - F_s \cdot S + F_p\,(H \sin\beta + S \cos\beta) \\
Q_{BS} &= F_s \sin\theta + F_p\,(H \cos\beta \;\; S \sin\beta)
\end{aligned} \tag*{[5]}$$

Likewise for opposite rotation (see Figure 4b), the relevant equations are:

$$\text{Vertical direction } V = F_s \cos\theta + F_p \cos(\theta - \beta) \tag*{[6]}$$

$$\text{Horizontal direction } H = F_s \sin\theta - F_p \sin(\theta - \beta) \tag*{[7]}$$

$$\begin{aligned}
\text{Torsional direction } Q = {} & F_s \sin\theta\, H - F_s \cos\theta \cdot S \\
& - F_p \sin(\theta - \beta)\, H + F_s \cos(\theta - \beta) \cdot S
\end{aligned} \tag*{[8]}$$

Again by substituting into Equations [6], [7], and [8] with θ equal to 0 and 90 deg, the equations governing opposite rotation are derived as:

$$\begin{aligned}
V_{AO} &= F_s + F_p \cos\beta \\
V_{BO} &= \qquad F_p \sin\beta \\
H_{AO} &= \qquad F_p \sin\beta \\
H_{BO} &= F_s - F_p \cos\beta \\
Q_{AO} &= - F_s \cdot S + F_p\,(H \cdot \sin\beta + S \cdot \cos\beta) \\
Q_{BO} &= F_s\, H - F_p\,(H \cdot \cos\beta - S \cdot \sin\beta)
\end{aligned} \tag*{[9]}$$

Equations [5] and [9] are the basic equations to be used to calculate the forces excited by the generator; the angle β may be selected to suit the particular forces generated.

To simplify the evaluation of the influence coefficients, three sets of coefficients would now be defined as follows:

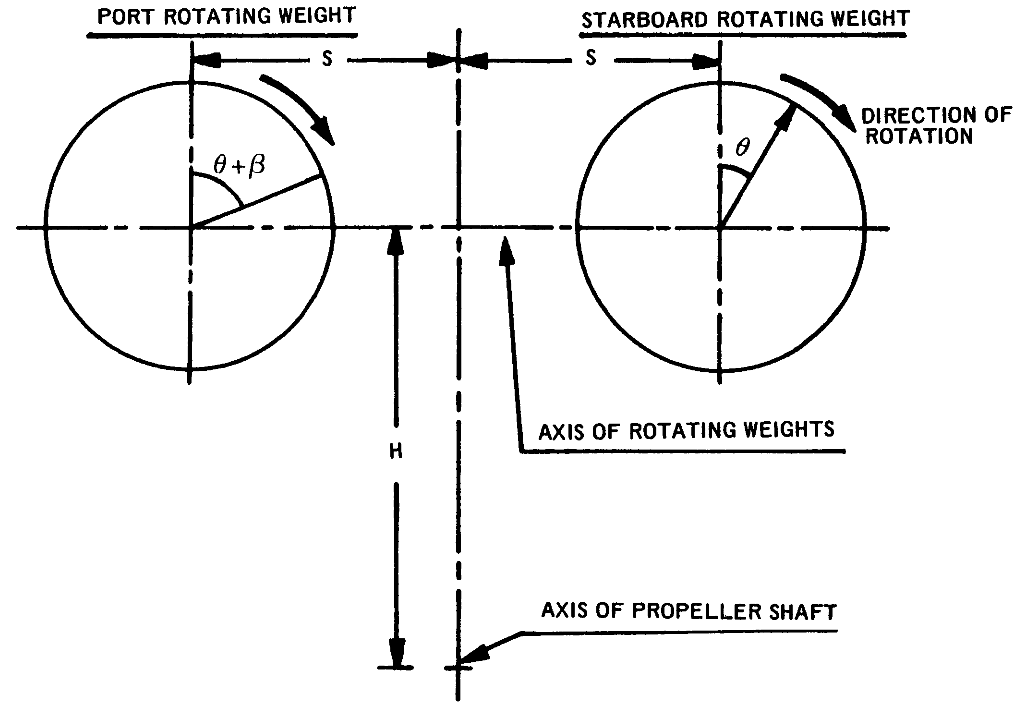

Figure 4a – Same Direction of Rotation

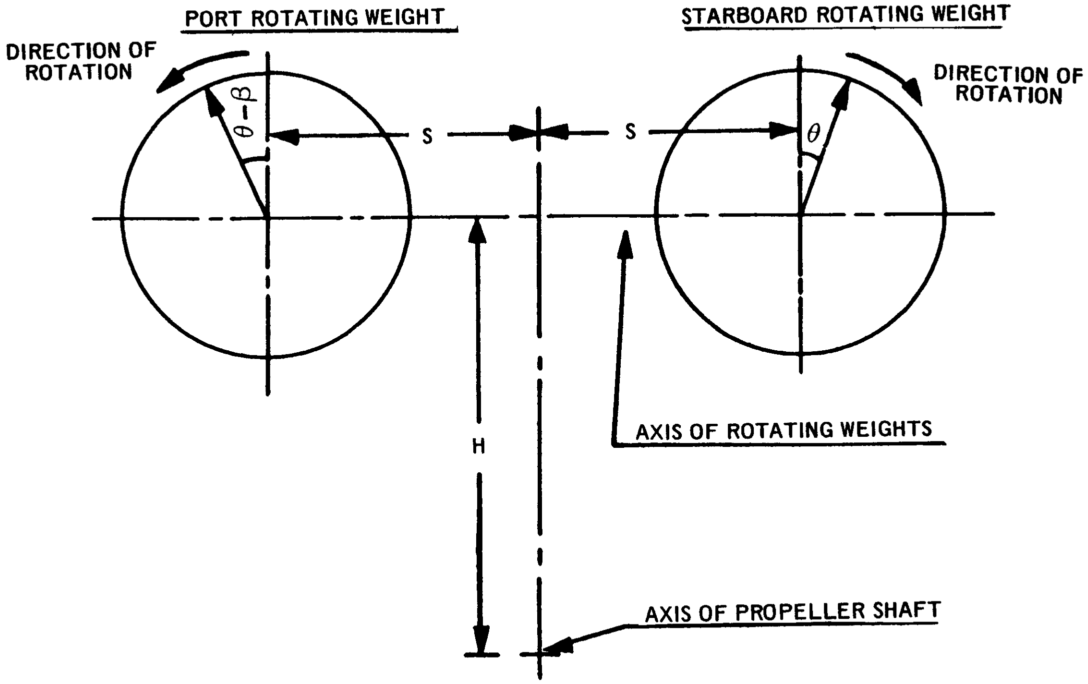

Figure 4b – Opposite Direction of Rotation

Figure 4 - Treatment of the Forces

1. Influence Coefficients

$$V_{VA},\ V_{VB},\ V_{HA},\ V_{HB},\ V_{QA},\ V_{QB}$$
$$H_{VA},\ H_{VB},\ H_{HA},\ H_{HB},\ H_{QA},\ H_{QB} \qquad [10]$$
$$Q_{VA},\ Q_{VB},\ Q_{HA},\ Q_{HB},\ Q_{QA},\ Q_{QB}$$

The first letter in all the coefficients represents the response (V for vertical, H for horizontal, and Q for torsional), the second letter denotes the source of excitation, and designations A and B represent the carriers. Thus, for example, Q_{HA} is the torsional response due to a horizontal force and analyzed by A.

2. Response Coefficients

$$RV_{A1},\ RV_{B1},\ RV_{A2},\ RV_{B2},\ RV_{A3},\ RV_{B3}$$
$$RH_{A1},\ RH_{B1},\ RH_{A2},\ RH_{B2},\ RH_{A3},\ RH_{B3} \qquad [11]$$
$$RQ_{A1},\ RQ_{B1},\ RQ_{A2},\ RQ_{B2},\ RQ_{A3},\ RQ_{B3}$$

The letter R denotes responses, i.e., the reading on the pen recorder, and A and B have their usual meanings. The second letter represents the source of the excitation, and the last number denotes a particular calibration index aimed at producing required forces or couples, e.g., 2 may be the case with the weights 90 deg out of phase and rotating in the same direction.

3. Force Coefficients

$$V_{A1},\ V_{B1},\ V_{A2},\ V_{B2},\ V_{A3},\ V_{B3}$$
$$H_{A1},\ H_{B1},\ H_{A2},\ H_{B2},\ H_{A3},\ H_{B3} \qquad [12]$$
$$Q_{A1},\ Q_{B1},\ Q_{A2},\ Q_{B2},\ Q_{A3},\ Q_{B3}$$

The first letter of each coefficient stands for the direction of the forces (e.g., H for horizontal) and A and B have the usual meanings. The numbers correspond to those mentioned in the second set, and for any case to be used, these coefficients may be readily evaluated by replacing the "S" and "O" in Equations [5] and [9] with the required condition number. As an example, consider the case where the weights are rotating, are in opposite direction, and are in phase. Let this case be designated as "1";

then the force coefficients are derived by substituting "1" in place of "0" in Equation [9] giving

$$\begin{aligned} V_{A1} &= F_s + F_p \cos\beta \\ V_{B1} &= F_p \sin\beta \\ H_{A1} &= F_p \sin\beta \\ H_{B1} &= F_s + F_s \cos\beta \\ Q_{A1} &= -F_s + F_p (H \sin\beta + S \cos\beta) \\ Q_{B1} &= F_s H - F_p (H \cdot \cos\beta - S \sin\beta) \end{aligned} \qquad [13]$$

It can be seen from the above three sets of coefficients that the response coefficients are obtained from the recorder readings when the vibration is excited by the vibration generator whereas the force coefficients are readily evaluated from Equations [5] and [9]. Thus the influence coefficients may be evaluated by solving a set of simultaneous equations. As an example, typical equations are outlined below for the case used in Equation [13]:

$$(V_{A1} V_{VA} - V_{B1} V_{VB}) + (H_{A1} V_{HA} - H_{B1} V_{HB}) + (Q_{A1} V_{QA} - Q_{B1} V_{QB}) = RV_{A1}$$

$$(V_{B1} V_{VA} + V_{A1} V_{VB}) + (H_{B1} V_{HA} + H_{A1} V_{HB}) + (Q_{B1} V_{QA} + Q_{A1} V_{QB}) = RV_{B1}$$

$$(V_{A1} H_{VA} - V_{B1} H_{VB}) + (H_{A1} H_{HA} - H_{B1} H_{HB}) + (Q_{Q1} H_{QA} - Q_{B1} H_{QB}) = RH_{A1}$$

- - - - etc - - - - etc - - - - - - - - - -

Consider three cases where the vertical forces are dominant in one instance, torsional forces are dominant in another, and the third yields a combination of horizontal and vertical forces. When these cases are used to solve for the influence coefficients, they lead to the following matrix equation:

$$[F] \cdot [C] = [R] \qquad [15]$$

where $[F] = \begin{bmatrix} V_{A1} & -V_{B1} & H_{A1} & -H_{B1} & Q_{A1} & -Q_{B1} \\ V_{B1} & V_{A1} & H_{B1} & H_{A1} & Q_{B1} & Q_{A1} \\ V_{A2} & -V_{B2} & H_{A2} & -H_{B2} & Q_{A2} & -Q_{B2} \\ V_{B2} & V_{A2} & H_{B2} & H_{A2} & Q_{B2} & Q_{A2} \\ V_{A3} & -V_{B3} & H_{A3} & -H_{B3} & Q_{A3} & -Q_{B3} \\ V_{B3} & V_{A3} & H_{B3} & H_{A3} & Q_{B3} & Q_{A3} \end{bmatrix}$

$$[C] = \begin{bmatrix} V_{VA} & H_{VA} & Q_{VA} \\ V_{VB} & H_{VB} & Q_{VB} \\ V_{HA} & H_{HA} & Q_{HA} \\ V_{HB} & H_{HB} & Q_{HB} \\ V_{QA} & H_{QA} & Q_{QA} \\ V_{QB} & H_{QB} & Q_{QB} \end{bmatrix}$$

$$[R] = \begin{bmatrix} RV_{A1} & RH_{A1} & RQ_{A1} \\ RV_{B1} & RH_{B1} & RQ_{B1} \\ RV_{A2} & RH_{A2} & RQ_{A2} \\ RV_{B2} & RH_{B2} & RQ_{B2} \\ RV_{A3} & RH_{A3} & RQ_{A3} \\ RV_{B3} & RH_{B3} & RQ_{B3} \end{bmatrix}$$

The coefficients can be evaluated by matrix inversion, i.e.,

$$[C] = [R]\ [F^{-1}] \qquad [16]$$

PROPELLER FORCES

Now with the coefficients available from Equation [16], the forces excited by the propeller during a self-propelled test run can be evaluated from the responses experienced by the pickups. Thus the equation between propeller forces, responses, and influence coefficients may be expressed as follows

$$[D]\ [P] = [S] \qquad [17]$$

where

$$[D] = \begin{bmatrix} V_{VA} & -V_{VB} & V_{HA} & -V_{HB} & V_{QA} & -V_{QB} \\ V_{VB} & V_{VA} & V_{HB} & V_{HA} & V_{QB} & V_{QA} \\ H_{VA} & -H_{VB} & H_{HA} & -H_{HB} & H_{QA} & -H_{QB} \\ H_{VB} & H_{VA} & H_{HB} & H_{HA} & H_{QB} & H_{QA} \\ Q_{VA} & -Q_{VB} & Q_{VA} & -Q_{HB} & Q_{QA} & -Q_{QB} \\ Q_{VB} & Q_{VA} & Q_{HB} & Q_{HA} & Q_{QB} & Q_{QA} \end{bmatrix}$$

$$[P] = \begin{matrix}\text{Propeller force}\\ \text{vector}\end{matrix} = \begin{bmatrix} V_{APT} \\ V_{BPT} \\ H_{APT} \\ H_{BDT} \\ Q_{APT} \\ Q_{BPT} \end{bmatrix}$$

$$[S] = \begin{matrix}\text{Propeller response}\\ \text{vector}\end{matrix} = \begin{bmatrix} RV_{APT} \\ RV_{BPT} \\ RH_{ADT} \\ RH_{BPT} \\ RQ_{APT} \\ RQ_{BPT} \end{bmatrix}$$

In the elements of propeller force vector, the first and second letters have the usual meanings, the third letter indicates source of excitation i.e., propeller force, and the fourth indicates a particular test run. The elements of response vector have similar meanings. Thus the solution to Equation [17] is obtained by inverting Matrix D, giving

$$[P] = [S]\ [D^{-1}] \qquad [18]$$

Although the setting up of the equations and method of solution appear to be complex, the actual inversion and handling of the coefficients can be readily done by a digital computer. Computer programs for IBM 7090 have been written to evaluate the forces and phase and are available in FORTRAN IV language.

The method of solution allows any phase relationships between the rotating weights and the selection of the three cases for evaluating the influence coefficients to be done quite arbitrarily. However, from the point of view of the numerical solution, certain combinations are better than the others. The reasons for the choices will be discussed later.

DESCRIPTION OF THE CALIBRATION AND TEST RUNS

The calibrations were performed to determine the response of the stern to the known input forces so that the unknown propeller-excited forces could be determined from a knowledge of the known responses. A brief description on how the forces and moments are generated is given below to clarify some terminology to be used later in the analysis.

Basically, the calibration forces and couples were produced by proper phasing of the two weights rotating with eccentricities. To simplify the explanation, one uses the starboard weight (looking from aft towards the bow) rotates in clockwise direction as the reference, and refers the port weight to this reference. Five combinations of angles and directions of rotation were considered:

1. 0-0 Opposite. In this case, both port and starboard weights are in phase (see Figure 5a) and rotating in opposite directions. The resultant force produced is in the vertical direction with no horizontal force or couples.

2. 0-95 Same. The port weight leads the starboard weight by 95 deg (see Figure 5b) and the weights are rotating in the same direction. In this case, both vertical and horizontal forces as well as couples are generated.

3. 0-96 Opposite. The port weight leads the starboard weight by 95 deg (see Figure 5a) and the weights are rotating in opposite directions. Vertical and horizontal forces plus couple are generated.

4. 0-180 Same. The port and starboard weights are 180 deg apart (see Figure 5d) and rotating in the same direction. The forces are cancelled, leaving only a couple.

5. 0-180 Opposite. The port and starboard weights are 180 deg apart (see Figure 5e) and rotating in the opposite direction. Horizontal forces and couple are generated.

It will be noted here that it was not always possible to set the weight at 0 or 90 or 180 deg apart because of the gearing, but the calculation is based on an arbitrary angle between port and starboard weight settings so that the extra forces or couples generated are taken into consideration. In the actual analysis, various combinations of the three

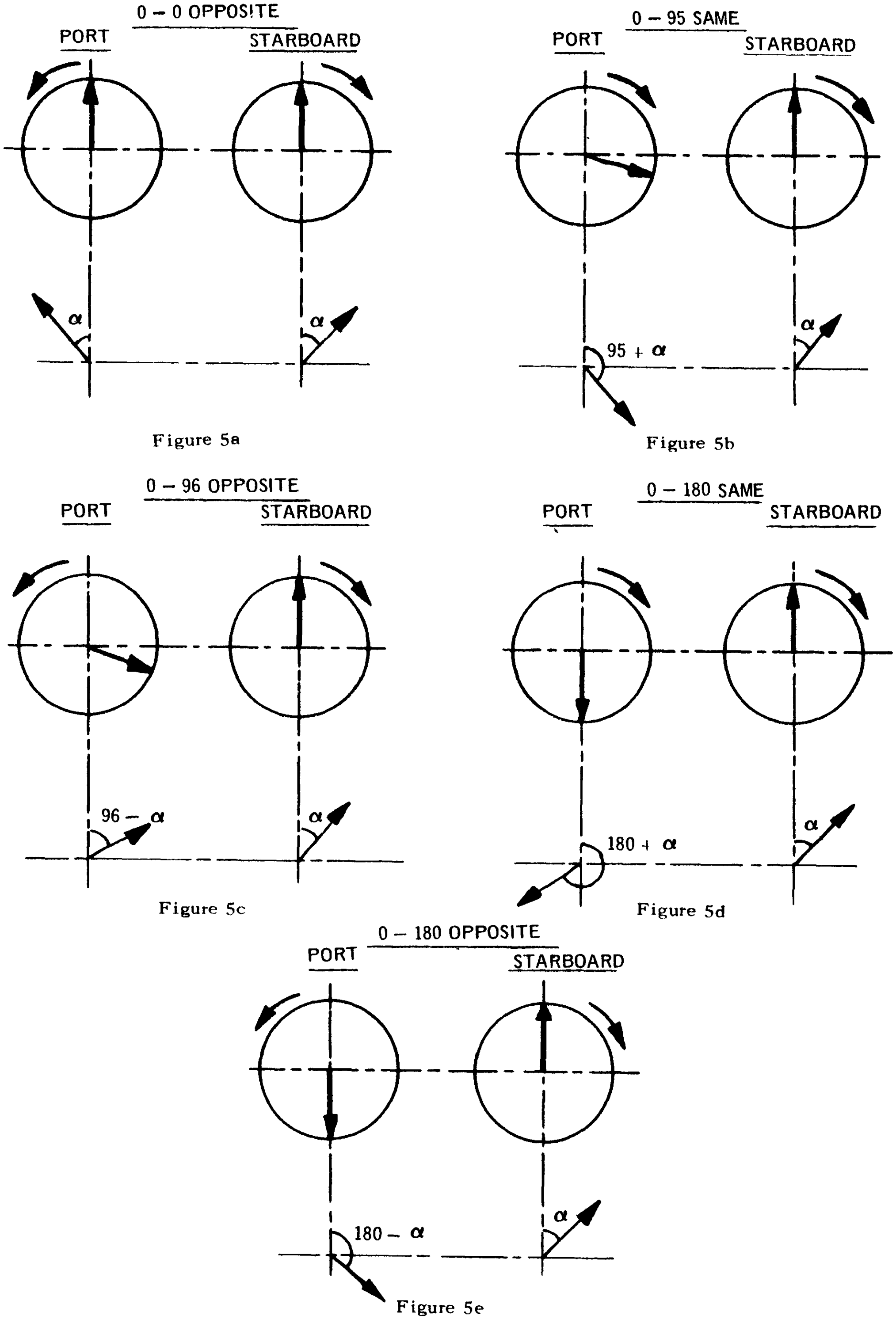

Figure 5a

Figure 5b

Figure 5c

Figure 5d

Figure 5e

Figure 5 - Phasing the Rotating Weights of the Vibration Generator

angular settings were used in the calculation. Six pickups were used in operation to record their responses to the known vertical and horizontal forces and the couples.

In the self-propelled experiments, the forward section of the model was attached to the towing carriage and no-load conditions (i.e., shaft revolving without the propeller over a speed range) were first performed at the same speeds as those for the no-load case. At the end of each set of test runs, the no-load condition was repeated to check that no variation existed between the two measurements.

METHODS FOR ANALYSIS OF THE EXPERIMENTAL RESULTS

Two methods were available for the analysis of the results and it is useful to examine their merits and disadvantages in detail.

The first method was used in the analysis of the tests before 1965, and a number of digital computer programs have been written to perform the actual computation. This method required the calibration data to be made at the blade frequencies of the actual test runs and at approximately the same magnitude for both the generator forces and propeller-excited forces. For example, for a four-bladed propeller operating at 8 cps the generator was operated at 32 cps and at some eccentricities of the out-of-balance weights so that comparable magnitudes of forces could be evaluated graphically. The main advantage of this approach is that the calibration and the test are carried out at comparable frequencies and a direct comparison can be made to minimize errors in the instrumentation responses. But there are a large number of disadvantages:

1. This approach is too rigid because it requires the corresponding calibration data to be available before the test results can be examined.
2. Because of the need for direct correspondence, the solutions for the evaluations of the propeller-excited forces are too sensitive to isolated errors at a particular frequency, and these errors are rather difficult to detect.
3. The need to match each calibration data with the corresponding test data involves storing large amounts of data on the computer and then

searching for the particular case involved. Not only is this inefficient from the computing point of view, but when there are no calibration data, then the test data are wasted and vice versa.

4. Since the phases of the forces are derived from examination of the magnitude and direction of the components, the phase angle is much too sensitive when dealing with the case where one component is very small and varies between small positive and negative values at different frequencies.
5. The frequencies tend to vary even during the recordings, and this approach would be hard put to take this variation into account.
6. The use of comparable magnitudes of calibration forces and excited forces involves some knowledge of the magnitudes to be expected. This requires drawing graphs--an undesirable step in the process of analysis.

The second method is really an attempt to overcome some of the difficulties encountered in the first approach. This method requires that the calibration recording be made at a number of eccentricities for the out-of-balance weights at each frequency in the range of blade frequencies considered. The results obtained are fed into the IBM 7090 Computer and curve-fitting techniques are employed to represent each component of response as a function of frequency and eccentricity. The advantages of this approach are:

1. Since the response components are expressed as functions of the frequency and eccentricity, it is possible to evaluate any frequency and magnitude of the calibration data for the calculation of the propeller-excited forces. More important, this two-dimensional surface fitting correctly represents the responses behavior with eccentricity and frequency, and the effects of errors are greatly minimized.
2. Because the response components are mathematical functions, the phase angle would also be a mathematical function, and some control over its behavior is achieved.
3. Computer program can be used to take into account the minor fluctuation of the frequencies during the recordings (e.g., record the actual frequency indicated by the counter), and the program will adjust the values to a common basis before the fitting is done.

4. With mathematical equations to define the responses, it is now possible to store only the coefficients of the equations, and this allows a greater flexibility in evaluating the calibration data and in selecting which set are to be used in the analysis.
5. The actual handling of the results is done by the computer, with minimum "interference" by humans.

The main difficulty of this method may be in selecting the orders of fit to be applied to the responses. Thus the assumption had to be made here that the response components varied linearly with eccentricity but as the square of the frequency. This was adopted for all components. As a safeguard against feeding incorrect calibration data into the computer, the input data and fitted values are tabulated or they may be plotted on the same graph for visual examination before they are used to evaluate the propeller-excited forces. Ways to handle the data will be compared in the next section. Appendix A gives the details of computer program ZC92 for preparing the calibration data; it contains an option to prepare for the test data before making the matrix inversion operations to evaluate the propeller-excited forces.

THE RESULTS AS DETERMINED BY VARIOUS ANALYSES

A series of test runs was performed with the propeller located at distances of 5, 15, 25, and 35 percent of the propeller diameter away from the stern frame and at blade frequencies varying from 29 to 45 cps. These results were then used to evaluate the forces and moments excited by the propeller with various combinations of calibration data in an attempt to find the most suitable way to carry out the analyses. Some of the analyses carried out are examined in the following sections.

USE OF RESPONSE DATA DIRECTLY IN THE ANALYSIS

The calibration data used were derived from the following angular setting and phasing:

1. 0-0 Opposite - vertical forces only.
2. 0-95 Same - vertical and horizontal forces and moments.
3. 0-180 Same - moments only.

The eccentricities selected were 0.10, 0.20, 0.30, and 0.40 in. The data used in the calculations were those obtained directly from the calibration, without any fairing or adjustments. The results of forces and phases obtained at 29, 36, and 45 cps for propeller located at 5 and 25 percent of propeller diameter away from the stern frame are given in Tables 1 and 2.

It will be noted that with the exception of amplitude and phase of the vertical force, the variation due to the choice of various eccentricities did not seem to have a great effect on the results. The possible explanation for the differences in the vertical directions are (1) that the measurements for the test runs were small when compared with the calibration data and (2) that the phase angle was too sensitive to small changes in the amplitude of the components.

The relatively good agreement in horizontal and torsional amplitudes and phases suggests (1) that the scatters in the response curve for these items were quite consistant with one another and (2) that unless the amplitude of test runs are very small, there is no need to try to find comparable calibration amplitude.

USE OF RESPONSE DATA DIRECTLY WITH MINOR ADJUSTMENTS

In this case, two of the eccentricity positions used above were repeated, but the small values of response data were replaced by zeros. The results of the comparison are given in Table 3. The comparison of results obtained in the two analyses indicated that the final answer is not seriously affected by such a step.

USE OF MANUALLY-FAIRED CALIBRATION DATA

The calibration data selected for the investigation had the following angular settings and phasing:

1. 0-95 Same - vertical and horizontal forces and moments.
2. 0-180 Opposite - horizontal forces and moments.
3. 0-96 Opposite - vertical and horizontal forces and moments.

The eccentricities selected were 0.10, 0.20, and 0.30 in. For each eccentricity, the responses were plotted against frequency in the range of

TABLE 1

Analysis with Direct Use of Data with Propeller at 5 Percent Diameter away from the Stern

Eccentricity in.	Vertical		Horizontal		Torsional	
	Ampl.	Phase	Ampl.	Phase	Ampl.	Phase
(Frequency 29 cps)						
0.10	0.20	1.1	1.93	26.9	35.10	-18.2
0.20	0.33	-11.8	1.82	25.6	33.82	-18.2
0.30	0.12	21.9	1.80	24.9	35.10	-19.1
0.40	0.18	26.9	1.75	24.9	34.15	-18.3
(Frequency 36 cps)						
0.10	0.24	- 6.0	3.29	23.7	63.67	-20.6
0.20	0.46	8.7	3.17	22.1	63.75	-21.3
0.30	0.46	10.7	3.22	22.6	67.59	-21.1
0.40	0.75	14.8	3.14	21.5	66.61	-20.2
(Frequency 45 cps)						
0.10	0.76	4.6	4.83	27.2	94.95	-18.2
0.20	1.27	9.0	4.82	27.3	97.77	-17.7
0.30	2.50	6.3	4.81	27.2	98.17	-19.2
0.40	1.14	23.0	5.04	27.0	99.78	-16.1

TABLE 2

Analysis with Direct Use of Data with Propeller at 25 Percent of Diameter away from the Stern

Eccentricity	Vertical		Horizontal		Torsional	
in.	Ampl.	Phase	Ampl.	Phase	Ampl.	Phase
(Frequency 29 cps)						
0.10	0.13	-35.9	0.49	17.3	7.95	-25.1
0.20	0.19	-35.1	0.47	16.3	7.62	-24.9
0.30	0.15	-42.0	0.47	15.5	7.86	-25.8
0.40	0.15	-42.5	0.46	15.4	7.64	-25.1
(Frequency 36 cps)						
0.10	0.09	- 7.1	0.80	12.1	14.85	-31.2
0.20	0.16	- 0.2	0.77	10.5	14.85	-31.8
0.30	0.16	1.3	0.79	11.0	15.75	-31.5
0.40	0.24	4.0	0.77	10.0	15.50	-30.7
(Frequency 45 cps)						
0.10	0.47	-16.8	0.84	11.9	14.81	-28.5
0.20	0.53	-14.2	0.84	11.9	15.21	-27.9
0.30	0.84	-15.0	0.84	11.6	15.33	-27.5
0.40	0.37	-10.2	0.87	11.3	15.54	-26.6

TABLE 3

Analysis with Direct Use of the Data after Minor Adjustments

(Propeller located at 5 percent of propeller diameter away from stern)

Case	Eccentricity	Vertical		Horizontal		Torsional Moment	
	in.	Ampl.	Phase	Ampl.	Phase	Ampl.	Phase
Original	0.20	0.33	-11.8	1.82	25.6	33.82	-18.2
Modified	0.20	0.38	-13.1	1.89	25.5	35.41	-18.4
Original	0.20	0.46	8.7	3.17	22.1	63.75	-21.3
Modified	0.20	0.40	7.4	3.32	22.4	65.03	-21.1
Original	0.20	1.27	9.0	4.82	27.3	97.77	-17.7
Modified	0.20	0.73	6.8	4.63	27.9	93.32	-17.5

TABLE 4

Analysis with Manually Faired Calibration Data

(Propeller located at 5 percent of propeller diameter away from stern)

Eccentricity in.	Vertical		Horizontal		Torsional	
	Ampl.	Phase	Ampl.	Phase	Ampl.	Phase
(Frequency 29 cps)						
0.10	1.44	- 5.7	1.68	40.9	30.58	-12.5
0.20	0.43	5.8	1.60	26.8	17.83	-10.6
0.30	0.96	-22.2	1.43	28.0	28.13	-15.0
(Frequency 36 cps)						
0.10	1.87	-42.9	2.76	28.1	55.50	-17.5
0.20	0.53	-19.4	3.31	25.8	36.90	-12.7
0.30	0.34	-24.5	3.54	21.8	62.22	-12.6
(Frequency 45 cps)						
0.10	7.19	-43.8	5.19	26.1	81.87	-17.9
0.20	0.71	33.1	5.10	31.1	47.30	- 9.6
0.30	2.48	26.7	6.90	24.4	103.47	-12.3

TABLE 5

Analysis with Computer-Faired Calibration Data, Combination 1[*]

(Propeller located at 5 percent propeller diameter away from stern)

Eccentricity in.	Vertical		Horizontal		Torsional	
	Ampl.	Phase	Ampl.	Phase	Ampl.	Phase
(Frequency 29 cps)						
0.10	0.22	- 3.0	1.83	26.0	35.83	-18.6
0.20	0.17	1.6	1.83	25.4	35.94	-18.8
0.30	0.31	- 2.3	1.74	25.3	35.95	-19.2
(Frequency 36 cps)						
0.10	0.36	7.1	3.24	22.7	64.41	-20.8
0.20	0.44	11.5	3.28	22.6	66.43	-20.7
0.30	0.22	1.1	3.14	22.7	63.93	-21.2
(Frequency 45 cps)						
0.10	1.29	7.0	4.67	26.9	95.63	-17.8
0.20	1.67	7.6	4.72	26.9	97.04	-17.4
0.30	0.81	5.7	4.83	27.0	100.66	-18.4

[*] Relations between the rotating masses:
0-0 opposite
0-95 same
0-180 same

29 to 45 cps, and the "best" manual fit of straight lines was drawn on the graphs. These manual-fitted values were then used in the analysis; the results are presented in Table 4. As expected, the results were not consistent with different settings of eccentricity; in fact, the agreement was considerably worse than that found in the two previous analyses. The main reason for such large variation is attributed to attempts at fitting a two-dimensional varying function with one-dimensional solution manually, i.e., the responses are both functions of the eccentricity and frequency, and cross fairing is essential if any fairing must be done at all. In addition, this also indicated that manual fairing cannot take the interrelated responses into account. Consequently some improvements may be achieved, but the alterations may make the results considerably worse than if the calibration data were used in their original form.

USE OF COMPUTER-FAIRED CALIBRATION DATA

As explained earlier, each component of the response readings was fitted in the least square sense against eccentricity and frequency. The orders of fit were one between the response and the eccentricity and square for coefficients against frequency. Four combinations of directions of rotation and angular displacements were considered:

1.
   a. 0-0 Opposite
   b. 0-95 Same
   c. 0-180 Same
2.
   a. 0-0 Opposite
   b. 0-180 Opposite
   c. 0-180 Same
3.
   a. 0-0 Opposite
   b. 0-95 Same
   c. 0-180 Opposite
4.
   a. 0-180 Opposite
   b. 0-180 Same
   c. 0-95 Same

The results of the vibratory force analysis are presented in Tables 5 through 8 for three frequencies, with the propeller located at 5 percent of propeller diameter away from the stern of the model. A careful examination of the results yields the following points of interest:

1. The results showed basically the same tendencies as the use of the calibration data directly from measurement, with the exception that the variations at different frequencies were less than using calibration data directly.
2. The results for the vertical components were still not good, but, again, fitting data of small magnitudes cannot be expected to be good.
3. Because the fitted calibration data offer a better choice for different directions of rotation and angular displacements than when the response is small for one type of motion, e.g. vertical, the predominant calibration data related to it may be dropped in favor of two other types of motion. In this case, the 0 - 0 deg opposite rotations which produced pure vertical forces may be dropped as in Case 4 and in Table 8 the results indicate better agreements in the vertical components than those involving calibration data for vertical motion as illustrated in Tables 5 to 7.
4. As already mentioned above, because the vertical components are very small, the numerical solutions of the equations are also affected, but when the 0 - 0 deg opposite rotation is dropped, there is an overall improvement of all components. Table 8 shows the least variation in the magnitude and the phases of all the components.
5. With a choice of calibration data, it is both possible and desirable to select the most suitable calibration data to use with a set of test results.
6. Use of different combinations of calibration data provided a check on the method of analysis. The consistency of results obtained inspires confidence in this approach.

PRELIMINARY EXAMINATION OF THE EFFECTS OF PROPELLER LOCATION ON THE VIBRATORY FORCES

As a test to verify the experimental techniques, instrumentation, and method of analysis, experiments were performed for the propeller located at 5, 15, 25, and 35 percent of the propeller diameter aft of the stern and without the rudder. These experiments were first carried out with a dummy hub on the shaft over a range of blade frequencies and then

TABLE 6

Analysis with Computer-Faired Calibration Data, Combination 2*

(Propeller located at 5 percent of propeller diameter away from stern)

Eccentricity in.	Vertical		Horizontal		Torsional	
	Ampl.	Phase	Ampl.	Phase	Ampl.	Phase
(Frequency 29 cps)						
0.10	0.30	-2.1	1.76	25.4	36.05	-19.1
0.20	0.29	-0.2	1.81	25.3	36.58	-19.3
0.30	0.29	0.5	1.79	25.1	36.32	-19.4
(Frequency 36 cps)						
0.10	0.23	1.5	3.14	22.7	64.00	-21.2
0.20	0.25	2.4	3.21	22.7	65.00	-21.3
0.30	0.27	4.2	3.20	22.8	66.26	-21.3
(Frequency 45 cps)						
0.10	0.88	5.9	4.81	27.0	99.98	-18.3
0.20	0.96	7.6	4.87	27.2	102.12	-18.1
0.30	0.89	8.2	4.82	27.2	102.08	-18.1

*Relations between the rotating masses:
0-0 opposite
0-180 opposite
0-180 same

TABLE 7

Analysis with Computer-Faired Calibration Data, Combination 3*

(Propeller located at 5 percent of propeller diameter away from stern)

Eccentricity in.	Vertical		Horizontal		Torsional	
	Ampl.	Phase	Ampl.	Phase	Ampl.	Phase
(Frequency 29 cps)						
0.10	0.26	-19.7	1.82	29.1	31.86	-17.4
0.20	0.30	-26.3	1.82	27.5	31.25	-17.4
0.30	0.31	-28.3	1.84	26.8	31.19	-17.6
(Frequency 36 cps)						
0.10	0.80	21.0	3.46	23.9	61.02	-19.7
0.20	0.92	25.6	3.54	23.6	60.16	-19.4
0.30	1.00	26.8	3.58	23.3	59.95	-19.3
(Frequency 45 cps)						
0.10	2.38	13.5	4.40	25.7	78.79	-18.1
0.20	3.39	13.7	4.70	25.7	76.71	-17.4
0.30	3.79	13.7	4.75	25.6	75.79	-17.3

*Relations between the two rotating masses:
0-0 opposite
0-95 same
0-180 opposite

TABLE 8

Analysis with Computer-Faired Calibration Data, Combination 4[*]

(Propeller located at 5 percent of propeller diameter away from stern)

Eccentricity in.	Vertical		Horizontal		Torsional	
	Ampl.	Phase	Ampl.	Phase	Ampl.	Phase
(Frequency 29 cps)						
0.10	0.31	-2.3	1.74	25.3	35.95	-19.2
0.20	0.31	-0.6	1.80	25.2	36.53	-19.4
0.30	0.31	0.0	1.78	25.1	36.28	-19.5
(Frequency 36 cps)						
0.10	0.22	1.1	3.14	22.7	63.93	-21.2
0.20	0.24	1.6	3.20	22.7	65.92	-21.3
0.30	0.26	3.4	3.19	22.8	66.20	-21.3
(Frequency 45 cps)						
0.10	0.81	5.7	4.83	27.0	100.66	-18.4
0.20	0.84	7.7	4.89	27.2	102.98	-18.2
0.30	0.76	8.3	4.83	27.3	102.90	-18.2

[*] Relations between the rotating masses:
0-180 opposite
0-180 same
0-95 same

repeated with the dummy hub replaced by a propeller. The results of the experiments were presented in graphical form with the vertical force coefficient (K_{FV}), horizontal force coefficient (K_{FH}), and torque coefficient (K_{FQ}), and their phases versus the locations of the propeller at three frequencies; see Figures 6, 7, and 8. Those coefficients are defined as follows:

$$K_{FV} = \text{vertical force coefficient} = \frac{V_F}{\rho \; N_s^{\,2} \; D^4}$$

$$K_{FH} = \text{horizontal force coefficient} = \frac{R_F}{\rho \; N_s^{\,2} \; D^4}$$

$$K_{FQ} = \text{torque coefficient} = \frac{Q_F}{\rho \; N_s^{\,2} \; D^5}$$

where ρ is density of the fluid,
N_s is shaft revolutions per second, and
D is propeller diameter.

It will be noted that these coefficients were the ones used by Lewis[10] when he examined the propeller-excited forces. These coefficients are adopted here because they were found to be the most suitable for presenting the data.

Figure 6 gives the vertical force coefficients and their phases for various locations of the propeller. The results for blade frequencies of 29 and 45 cps showed the same trend but at 36 cps both the force coefficient and its phase were somewhat different from the other two frequencies. A possible reason for this deviation may be found from an examination of the recordings for the vertical components which were small compared to the other components. A glance at the smaller outputs of the force response shows that the small variations are difficult to record accurately from a pen recorder and that any large amplification of the recording units tended to distort and misrepresent the readings.

The results of the horizontal force coefficients against the propeller locations (see Figure 7) indicated that the forces reduce steeply where the propeller is moved away from the stern; they appear to approach a minimum value around a distance of 35 percent of the propeller diameter aft of the stern. The phase curves at these frequencies are very similar to each other.

Figure 8 gives the torque coefficient and their phases versus propeller locations. The appearance of the curves are very similar to those indicated for the horizontal force coefficients in Figure 7.

The results show the general variations to be found in the recordings. It would therefore be advisable to smooth the test recordings in the least square sense before performing the calculations to evaluate the propeller-excited forces and moments. This provision is available as an option on computer program ZC92. The results obtained in the present experiments seem encouraging, but further experiments are required to find the location of the propeller for the minimum forces and torques.

EXAMINATION OF THE EXPERIMENTAL TECHNIQUES

GENERAL PROCEDURE

To obtain the influence coefficients necessary for evaluating the responses, it has been necessary to carry out calibration runs before and after each series of experiments in the towing tank. This procedure was required because the model is constructed of wood and its behavior is known to alter with time. To overcome this difficulty, the above procedure is very desirable. Ideally, all the test runs should be completed in one continuous period. However, it is not always possible to carry out the tests in a short time because it takes about 20 min to complete the recordings for each speed, and if the tests must be spread over a given period, then all the calibration results should be considered in the analysis. It is thus suggested that each response coefficient, as defined by Equation [11], should be expressed not only as functions of eccentricity and frequency when they are being fitted with mathematical equations, but also of time, e.g.,

$$RV_{B1} = f(e, w, t)$$

where t may be hours or days or weeks. It is felt that this approach

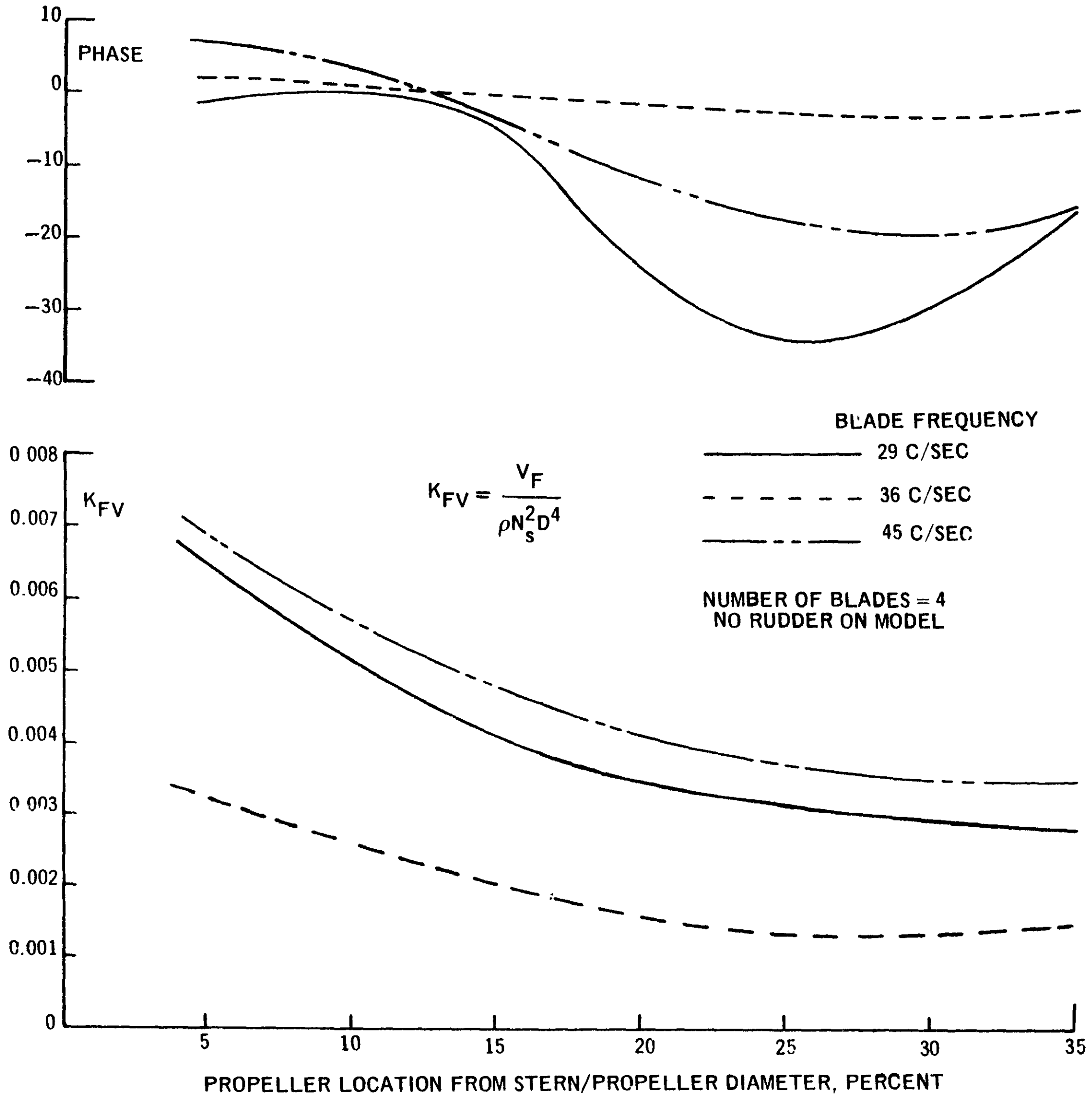

Figure 6 - Vertical Force Coefficient K_{FV} versus Propeller Location

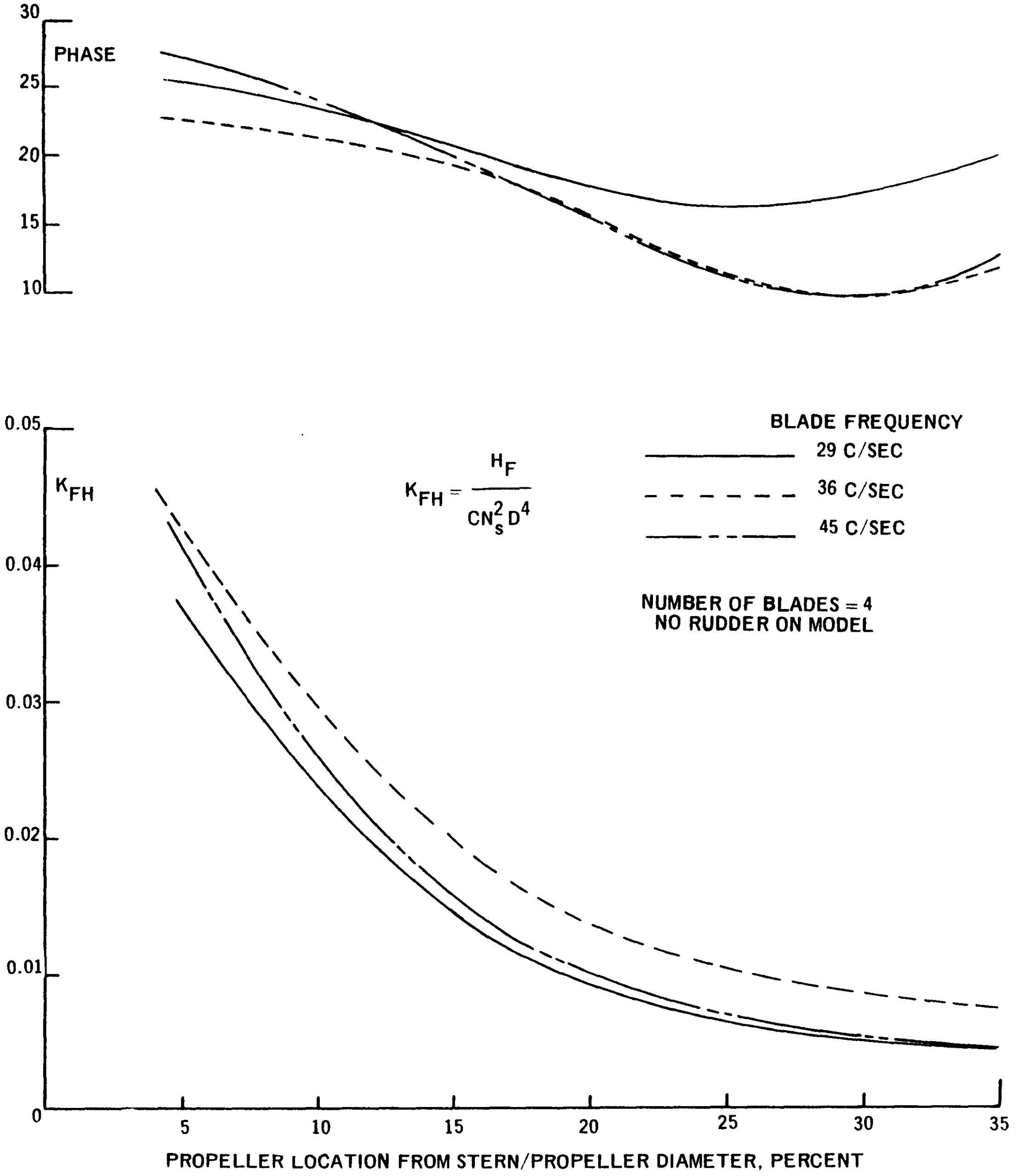

Figure 7 - Horizontal Force Coefficient K_{FH} versus Propeller Location

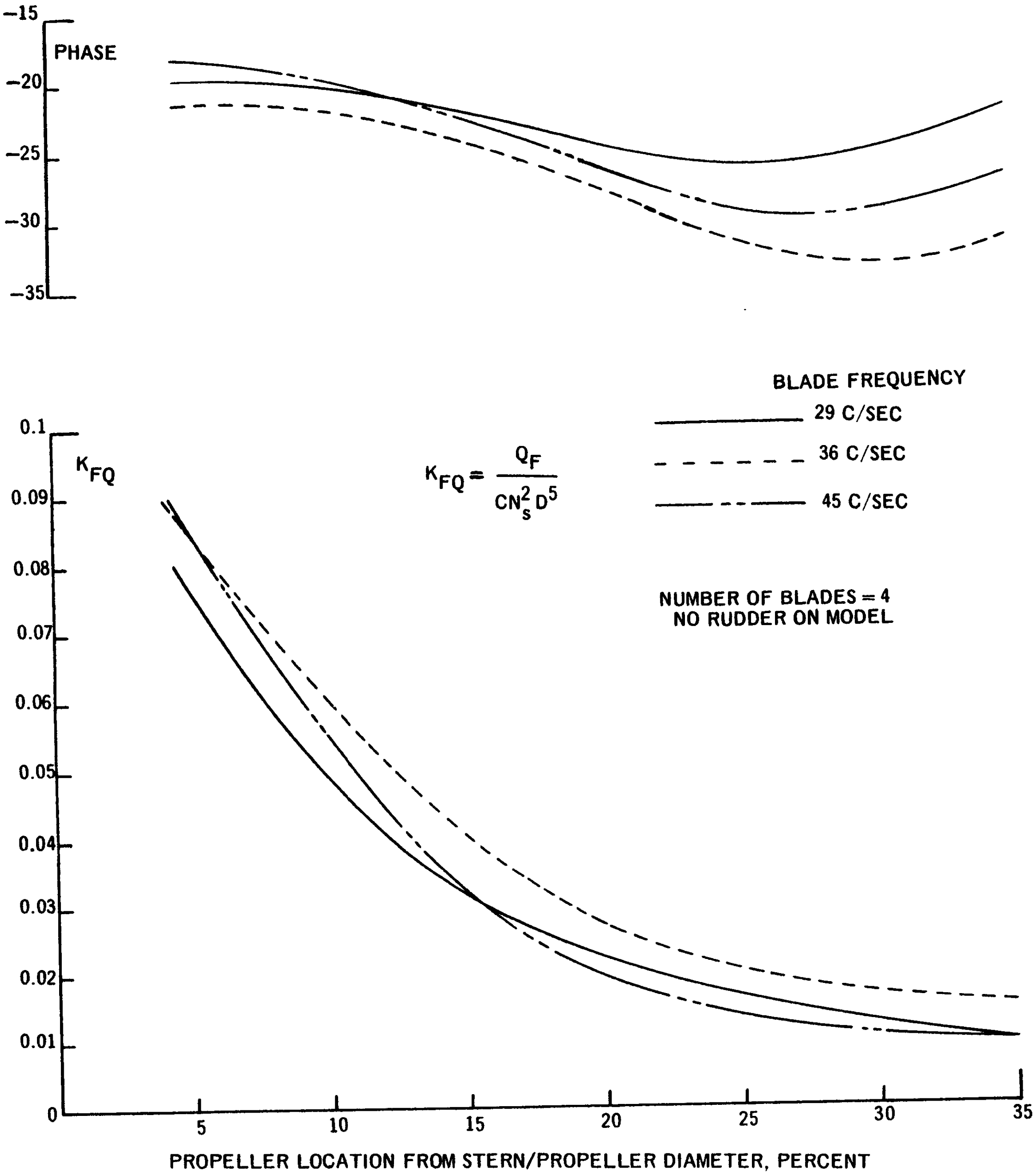

Figure 8 - Torque Coefficient K_{FQ} versus Propeller Location

would give a fairer representation of the model behavior; otherwise one may be in doubt as to which set of calibration data should be selected for use.

As a check on the analytical procedure, five sets of calibration tests were performed during the experiments although only three sets are required for the evaluation of the influence coefficients. The purpose of having five sets was to allow a choice in selecting a combination of the calibration data to use in evaluating the propeller forces. The results indicated that the values of propeller forces were basically the same and independent of the combination of the calibration data used. This served as a reliable check on the whole procedure.

Additional checks can also be applied to test the procedure:

1. Perform a calibration test with an arbitrarily selected micrometer setting which is in the range of the eccentricity under consideration and allow the analysis of the responses to determine the actual eccentricity used.
2. If four sets of calibration data are available, then use the responses of one set as the data in the analysis and check the determined values against calibration input data.

If it proves necessary to extend experiments over a long period, one of these two methods may be adopted to check the response variation with time instead of repeating the whole calibration process; any variation between the initial and repreated evaluations may be used to correctly determine the propeller forces. For example, if the initial and repeated results for the same eccentricity setting differed by 3 percent, then the same percentage correction would be applied to the propeller forces obtained in the latest experiments.

MECHANICAL OPERATIONS

No dynamic calibration was carried out on the vibration generator to ensure that the correct forces were obtained. However, accurate measurements of the weight of rotating masses and a static comparison of micrometer position against eccentricity would give very accurate measurements of the force since all other rotating points have been carefully balanced dynamically.

Resin appears to be the best available material for the flexible portion of the shaft between the main hull and the stern shafts because it is molded into cylindrical shape yet is soft enough to allow flexure to take place.

The engaging and disengaging of the belts to drive the propeller shaft and vibration generator may affect the tension of the belts, but changing tension in the belts did not appear to have altered the experimental results.

It was not possible to prevent water leaking into the model since a soft connection was desirable. However, the automatic pumping device over came much of the problem and its operation affected only the electronic instruments slightly.

ELECTRONIC INSTRUMENTATION

By far the most difficult problem has been to achieve a consistent performance by the electronic instrumentation, in particular the tracking filter. Because of the sensitivities involved, the filter tended to drift with temperature and power supply variations. At present, the filter is allowed a long period for "warming up" to the stable state, but there is a need for some stabilizing unit to eliminate the drawback.

There was also a tendency for the frequency to vary by a maximum of ±0.2 cps during the recordings of the pen recorder, and because the digital counter could give a reading containing one decimal point only every 10 sec, it was possible to obtain only a mean value. In addition, only two components could be recorded at any instant so that the frequency variations may exist between components. Ideally, all six components plus the frequency should be recorded on magnetic tape to obtain simultaneous values. This approach would not only save the task of handling recordings manually before computer analysis but it would also eliminate the need to switch to different ranges of the recorders. When such an arrangement can be made, the pen recorder could serve as a check during the test runs and would speed up the actual experiments.

EXAMINATION OF THE COMPUTER PROGRAM

A computer program (XF5C) was written before 1965 to analyze and evaluate propeller-excited forces from experimental data. This program performs the matrix inversions described earlier, but in order to cover a large frequency range of calibration data and test runs, a large amount of storage spaces on the computer was required. Program ZC92 was written to overcome this difficulty.

Program ZC92 represents the response coefficients for the six components by polynomial equations in the range considered, and it can produce the input calibration data as required by XFSC or coefficients of these polynomials so that generation at any required frequency and eccentricity may be readily obtained. Thus the latter approach would be more desirable if the programs had to be run on a smaller computer. At present the results of the test runs are not smoothed before being used in the calculation, and in order to allow for frequency variations between the components, it is highly desirable for the data to be adjusted before read into the computer. Program ZC92 has an option at the end to do just this process if required.

Careful application of the two computer programs enables an accurate evaluation of propeller-excited vibratory forces from a knowledge of the influence coefficients.

CONCLUSIONS

This report has briefly outlined the technique used in measuring propeller-excited vibratory forces on a model and has given the details of a method for analyzing the results. The following comments can be made:

1. A technique for measuring the propeller vibratory forces on a model is now available. In this approach, the generated forces consist of three components - a vertical force, a horizontal force, and a torsional couple.

2. Cutting the model at a station about one diameter of the propeller forward of the stern proved a suitable arrangement for the experiments. This approach avoids the resonances of the model involved in the measurements.

3. A computer program is available to handle the results from both calibration and test runs and to so present them that they may be used to evaluate the influence coefficients and the vibratory forces. The use of the computer programs allows greater flexibility and speed in the analysis.

4. The handling of instrumentation is difficult and a long "warming up" period is required to ensure proper function of the instruments. There is therefore a need to attach some stabilization units to the instrumentation to shorten the time required to reach operative condition.

5. The time required for experiments would be reduced and the accuracies increased if the outputs from the vibration analyzers could be recorded on magnetic tape instead of on the paper recorders. Magnetic tape allows for simultaneous recording of all six components as well as the frequency. This is also an advantage in analyzing the data since the data can be read into the computer without manual punching of the cards or transference of data.

6. The availability of the technique and method of analysis will allow future investigations in this field to proceed with greater ease.

7. Preliminary examination of the effects of propeller locations on the forces and torques excited on the model for the case with no rudder indicates that sharp reductions in these forces and torques can be obtained when the propeller is moved from about 5 to 20 percent of the propeller diameter. A limiting value was not reached at 35 percent propeller diameter away from the stern. Further experiments are needed to confirm the results.

8. As part of the experimental procedure, it is recommended that an extra set of calibration data with an arbitrary input be taken and the responses be analyzed. From this, the forces can be determined and a check made to determine the input data. This will serve as a check on the procedure to be used or as corrections on the variations of the responses with time.

ACKNOWLEDGMENTS

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The work was performed under the direction of Mr. J.B. Hadler, Head of the Ship Powering Division, Hydromechanics Laboratory, to whom the author is indebted for guidance, support, and continued encouragement.

APPENDIX A

DETAILS OF PROGRAM ZC92 FOR PREPARING CALIBRATION AND TEST DATA

Program ZC92 was written to prepare input data for use with Program XFSC which does the matrix inversions and for the following additional purposes:

1. To fit the response coefficients by method of least squares so that they are expressed as functions of eccentricity and frequency. This approach enables evaluating calibration data at any desired value of frequency and eccentricity within the proper range.
2. To allow for the incorporation of frequency variations in the calculation.
3. To examine the calibration data for errors before feeding them into the main program.

The inputs for this program are explained in the data sheets of Figures 9 through 12.

The output for each combination of the direction of rotation and the phase from the program are:

1. Printout the input response data at all frequencies.
2. Printout the comparison between input data (after attenuation adjustments) and the fitted values against eccentricities.
3. Print the final fit of response data at input frequencies.
4. Print the coefficients of the polynomials used to represent these response data.
5. Punch out the fitted input data in the form suitable as direct input to Program XF5C.
6. Punch out data at required frequencies and eccentricity. This is again in a form suitable for direct use in the computer.

An option is also available to prepare the input data of the experimental test runs so that frequency variations can be included as well as smoothing of the data. The input to that section is given in the appropriate data sheets.

INPUT DATA SHEET FOR ZC92 (CALIBRATION DATA)

CARD 1

1. Number of sets of forces being generated (NSAN)
2. Number of combinations of forces required (NCOMB)
3. Order of fit of response to micrometer settings (MORET)
4. Number of frequencies recorded in calibration (NFRE)
5. Order of fit of response coefficients to frequency (NFFT)
6. Number of attenuations used (NATT)
7. Reference attenuation of component A (NSDA)
8. Reference attenuation of component B (NSDB)

1 2 3 4 5 6 7 8

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CARD 2

An array of attenuations for component A (STADD)

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CARD 3

An array of attenuations for component B (STBDD)

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CARD 4

1. Number of output frequencies for XF5C (NOTF)
2. Location of eccentricity (SIMIC)

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CARD 5

An array of the selections of responses for XF5C (IELET)

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CARD 6

An array of output frequencies (OUTFQ)

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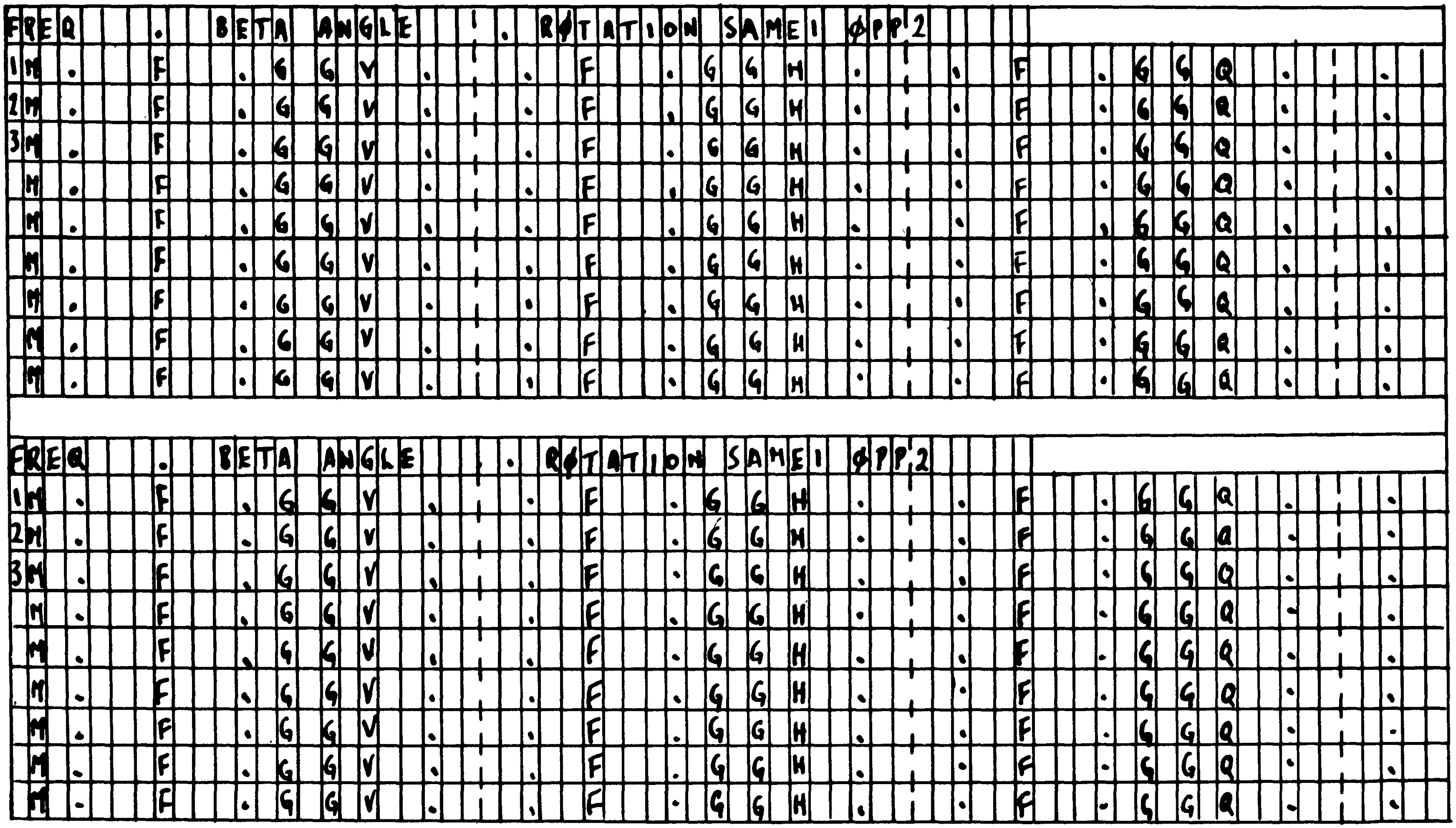
The other data are the measurements from the calibration.. The formats are in the following data sheet. Up to 9 micrometer settings are provided.

Figure 9 - Input Data Sheet (Calibration Data) for Program ZC92



FREQ . BETA ANGLE . RØTATION SAME1 ØPP2
1M . F . G G V . . F . G G H . . F . G G Q . .
2M . F . G G V . . F . G G H . . F . G G Q . .
3M . F . G G V . . F . G G H . . F . G G Q . .
M . F . G G V . . F . G G H . . F . G G Q . .
M . F . G G V . . F . G G H . . F . G G Q . .
M . F . G G V . . F . G G H . . F . G G Q . .
M . F . G G V . . F . G G H . . F . G G Q . .
M . F . G G V . . F . G G H . . F . G G Q . .
M . F . G G V . . F . G G H . . F . G G Q . .

FREQ . BETA ANGLE . RØTATION SAME1 ØPP2
1M . F . G G V . . F . G G H . . F . G G Q . .
2M . F . G G V . . F . G G H . . F . G G Q . .
3M . F . G G V . . F . G G H . . F . G G Q . .
M . F . G G V . . F . G G H . . F . G G Q . .
M . F . G G V . . F . G G H . . F . G G Q . .
M . F . G G V . . F . G G H . . F . G G Q . .
M . F . G G V . . F . G G H . . F . G G Q . .
M . F . G G V . . F . G G H . . F . G G Q . .
M . F . G G V . . F . G G H . . F . G G Q . .

Figure 10 - Calibration Data Sheet for Program ZC92

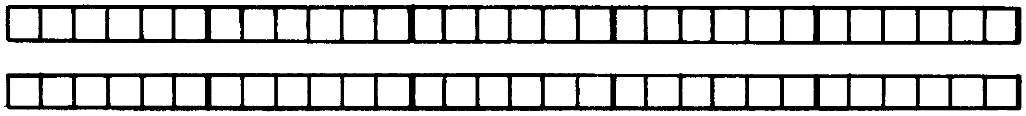
Note: Provisions are made for ⑨ micrometer settings to be recorded at each frequency but the last recording will always have a " 9 " in column 1.

CARD 1

1. Number of sets of test measurements (NSERUN)
2. Number of attenuations used (MATT)
3. Reference attenuation for component A (MDA)
4. Reference attenuation for component B (MDB)

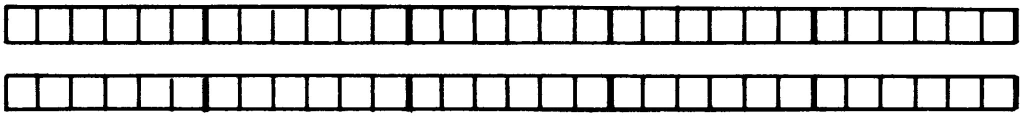
CARD 2

An array of attenuations for component A (TRAD)



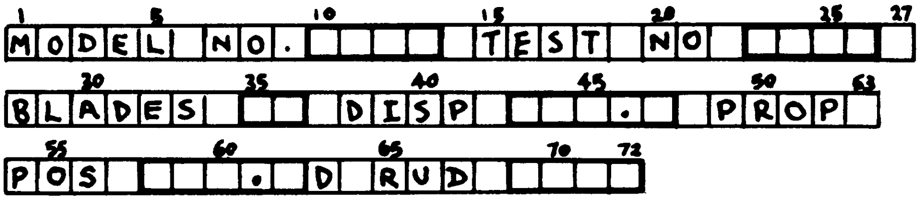
CARD 3

An array of attenuations for component B (TRBD)



CARD 4

Data on the model



CARD 5

There will be ' NSERUN ' number of card 5 and the corresponding test run results in the format on the following data sheet.

1. Number of runs recorded (NORUN)
2. Order of fit to the data (MRUN)
3. Parameter on the data (MLO), e.g. MLO = 1 propeller measurements only, MLO = 2 hub measurements first then propeller measurements.

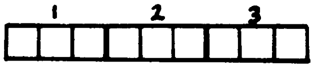


Figure 11 - Input Data Sheet (Test Data) for Program ZC92

RUN No.	SPEED	RPM	FREQ. V	GAIN	V_A	V_B	FREQ. H	GAIN	H_A	H_B	FREQ Q	GAIN	Q_A	Q_B
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.
	.		.	G G	.	.	.	G G	.	.	.	G G	.	.

Figure 12 - Test Data Sheet for Program ZC92

(The data sheet is suitable for dummy hub results or propeller results)

APPENDIX B

A LISTING OF PROGRAM ZC92 AND TYPICAL RESULTS

This appendix contains a listing of Program ZC92, which is in the FORTRAN IV coding, and a printout of a typical set of input data.

CALIBRATION SECTION

The results show how the calibration data are treated for the case where the weights are in phase and rotating in the opposite directions. This consists of:

1. A printout of the input data as read into the computer together with a linear fit of these data against the micrometer eccentricities at blade frequencies of 29, 32, 34, 36, 42, and 45 cps.

2. A printout of the generated responses at input micrometer eccentricities after the data have been smoothed against the blade frequencies.

3. A printout of the coefficients of the polynomial equations representing these responses.

4. A printout of the data in a form suitable for use with the calibration section of Program Xf5C. Note that a similar set of cards is punched so that they may be used directly in the program XF5C.

TEST DATA SECTION

The results show:

1. A typical printout of the input test data as read into the computer.

2. A printout of the data after smoothing the readings against the frequencies so that any variations in the input frequencies may be considered before outputing at required values. A similar set of cards is again punched to enable them to be used directly with Program XF5C.

```
$IBSYS
$RESTORE
$EXECUTE       IBJOB
$IBJOB         MAP
$IBFTC ZC92    NOLIST,NODECK
C      PROGRAM TO OPERATE ON THE PROPELLER VIBRATION CALIBRATION DATA
C      AND TEST MEASUREMNTS BEFORE USING THEM WITH PROGRAM XF5C
C      FOR THE EVALUATION OF THE PROPELLER EXCITED VIBRATORY FORCES
       DIMENSION CYCLE(20),BANG(20), IROT(20),NUM(9),SETT(9),FREV(9),
      1IAB(6,9),VA(9),VB(9),FREH(9),HA(9),HB(9),FREQ(9),QA(9),QB(9),
      2RES(6,20,9),STAD(10),STBD(10),SET(9),YLOC(9),OUT(9),STOR(6,20,9),
      3COEFF(6,20,20),COF(20),EOFF(20),OUTCY(20),SCOF(20),SSTOR (6,20,20)
      4,SURF(6,20,20),BETG(20),SURMU(6,20,20),RESP(6,20,9),OUTFQ(20),
      5STADD(10),STBDD(10),T(6),KROT(20),KR(20),MR(20),OUTVA(20,6,20)
      6,IELET(20,3)
      7     ,TRU(6,20),TFREQ(3,20),NRUN(20),SPEED(20),RPM(20),ICD(6,20),
      8TRAD(10),TRBD(10),SOF(20),SOFP(20),RCOF(6),TFRU(2,6,20),
      9 RPMOT(20),TRCOF(2,6,6),ATRAD(10),BTRBD(10),TR(6,20)
C      ARRAY RES COVERS NO OF GROUPS,I.E.6, NO OF FREQ,NO OF MICROMETER
C      READINGS. MORFT IS ORDER FIT TO MICROMETER READINGS. ARRAY STOR
C      HAS THE FIRST FITTED VALUES FOR EACH SET AND FREQ. COEFF HAS SET,
C      FREQ AND ORDER OF FIT PLUS 1. NFFT = ORDER FIT OF RESPONSE TO
C      FREQ. NFRE IS NO OF FREQ.
   21 FORMAT (12F6.2)
    1 FORMAT( 1H1)
      READ(5,20)NSAN,NCOMB,MORFT,NFRE,NFFT,NATT,NSDA,NSDB
  103 FORMAT(5X,F5.1,F5.4,F5.1,A4,I1,6F6.2)
   20 FORMAT( 24I3)
C      NATT IS NO OF ATTENUATIONS,NSDA IS THE REF. ATT.OF A,NSDB IS REF.
C      OF B,MORFT IS ORDER OF FIT OF MICRO,NFRE IS NO. OF FREQ, NFFT IS
C      ORDER OF FIT OF FREQ AGAINST COEFF OF MICRO-RESPONSE
      READ(5,21)(STADD(JJ),JJ=1,NATT)
      READ(5,21)(STBDD(JJ),JJ=1,NATT)
      DO 22  JJ=1, NATT
      STAD(JJ) = STADD(NSDA)/ STADD(JJ)
   22 STBD(JJ) = STBDD(NSDB)/ STBDD(JJ)
      READ (5,90) NOTF,SLMIC
   90 FORMAT (I3, F6.4)
      READ(5,20) ((IELET(JP,J),J=1,3),JP=1,NCOMB)
      READ (5,21) ( OUTFQ(J), J =1,NOTF)
      MORET=MORFT + 1
      NFRET=NFFT + 1
      DO 5 NS =1,NSAN
      WRITE ( 6,1)
      DO12  I=1,NFRE
      READ(5,10) CYCLE(I),BANG(I),KR(I),IROT(I)
   10 FORMAT(4X,F5.1,11X,F6.1,20X,A4,I1)
      DO 11 J=1,9
      READ(5,13) NUM(J),SETT(J),FREV(J),IAB(1,J),IAB(2,J),VA(J),VB(J),
     1FREH(J),IAB(3,J),IAB(4,J),HA(J),HB(J),FREQ(J),IAB(5,J),IAB(6,J),
     2QA(J),QB(J)
   13 FORMAT(I1,1X,F5.3,1X,F5.1,1X,I1,1X,I1,1X,2F5.2,1X,F5.1,1X,I1,1X,
     1I1,1X,2F5.2,1X,F5.1,1X,I1,1X,I1,1X,2F5.2)
      NCOT= J
      IF(NUM(J) .EQ. 9) GOTO 14
   11 CONTINUE
   14 WRITE (6,15) CYCLE(I),BANG(I),KR(I),IROT(I)
   15 FORMAT(///,2X,4HFREQ,F5.1,11H BETA ANGLE,F6.1,21HROTATION SAME 1 O
     1PP 2, A4,I1)
      WRITE (6,16) (NUM(J),SETT(J),FREV(J),IAB(1,J),IAB(2,J),VA(J),
```

```
     1VB(J),FREH(J),IAB(3,J),IAB(4,J),HA(J),HB(J),FREQ(J),IAB(5,J),
     2IAB(6,J),QA(J),QB(J),J=1,NCOT)
  16 FORMAT(2X,I1,1HM,F5.3,1HF,F5.1,1HG,I1,1HG,I1,1HV,2F5.2,1HF,F5.1,
     11HG,I1,1HG,I1,1HH,2F5.2,1HF,F5.1,1HG,I1,1HG,I1,1HQ,2F5.2)
      WRITE (6,17)
  17 FORMAT(/,5X, 37HTHE ABOVE PRINT OUT IS THE INPUT DATA///)
      DO 18  M=1,NCOT
      IVA=IAB(1,M)
      IVB=IAB(2,M)
      IHA=IAB(3,M)
      IHB=IAB(4,M)
      IQA=IAB(5,M)
      IQB=IAB(6,M)
      C =(FREV(M)/CYCLE(I))**2
      RES(1,I,M) =VA(M)*STAD(IVA)*C
      RES(2,I,M) =VB(M)*STBD(IVB)*C
      D =(FREH(M)/CYCLE(I))**2
      RES(3,I,M) = HA(M)*STAD(IHA)*D
      RES(4,I,M) = HB(M)*STBD(IHB)*D
      E =(FREQ(M)/CYCLE(I))**2
      RES(5,I,M) = QA(M)*STAD(IQA)*E
      RES(6,I,M) = QB(M)*STBD(IQB)*E
      IF( M.GT. 1) GOTO 131
      DO 130 IM = 1,6
 130 T(IM) = RES( IM,I,1)
 131 DO 26  IM=1,6
  26 RES(IM,I,M) = RES(IM,I,M) -T(IM)
      SET(M) = SETT(M)-SETT(1)
  18 CONTINUE
      DO 31 IM=1,6
      DO 110 M =1,NCOT
 110 YLOC(M) = RES(IM,I,M)
      SE=SET(NCOT)
      CALL LFOPY (MORFT,NCOT,NCOT,SET(1),SE,SET,YLOC,SET,OUT,COF)
      DO 27 M=1,NCOT
  27 STOR(IM,I,M) = OUT(M)
      DO 28 M=1,MORFT
  28 COEFF(IM,I,M) = COF(M)
  31 CONTINUE
      WRITE(6,15) CYCLE(I),RANG(I),KR(I),IROT(I)
      WRITE(6,19)
  19 FORMAT (5X,2HVA,11X,2HVB,11X,2HHA,11X,2HHB,11X,2HQA,11X,2HQB/
     16(6H INPUT,2X,3HFIT,2X))
      DO 32  M=1,NCOT
      WRITE(6,23) (RES(J,I,M),STOR(J,I,M),J=1,6)
  23 FORMAT( 6(F6.2,F6.2,1X))
  32 CONTINUE
C     THE INPUT AND FAIRED VALUES ARE PRINTED
  12 CONTINUE
C     THE ABOVE OPERATIONS COMPLETES THE FIRST TIME FITTING OF RESPONSES
C     AGAINST MICROMETER SETTINGS FOR THE RANGE OF FREQUENCIES. THE COEF
C     FICIENTS OF R TO MICRO ARE STORED IN COEFF AS (SET,FREQ,COEFF)
      DO 33 IM = 1,6
      DO 34 M= 1,MORET
      DO 35 I=1, NFRE
  35 EOFF(I) = COEFF ( IM, I, M)
      CALL LFOPY ( NEFT, NFRE, NFRE, CYCLE(1), CYCLE(NFRE), CYCLE, EOFF,
     1CYCLE, OUTCY, SCOF)
C     OUTCY IS THE FITTED COEFF OF MIRCO, SCOF HAS THE SURFACE COEFF
      DO 36 J=1, NFRE
```

```
   36 SSTOR(IM,J,M) = OUTCY (J)
      DO 37 J = 1, NFRET
   37 SURF (IM,J,M) = SCOF(J)
C     SURF ARRAY HAS THE RANGE RESPONSE, ORDER OF FREQ FIT PLUS 1,
C     MICRMETER FIT PLUS 1
   34 CONTINUE
   33 CONTINUE
      DO 76 IM = 1,6
      DO 77 JM = 1, NFRE
      DO 78 ML = 1, NCOT
      P = ( SET(ML)*2.0-(SET(1) + SET(NCOT)))/ (SET(NCOT) -SET(1))
      Q = SSTOR ( IM,JM, 1)
      DO 79 JL= 2, MORET
      MP = JL -1
   79 Q = Q + SSTOR ( IM, JM, JL)* (P**MP)
   78 RESP ( IM, JM, ML) = Q
   77 CONTINUE
   76 CONTINUE
C     GENERATE THE FITTED RESPONSES AT INPUT MICROMETER SETTINGS
      WRITE ( 6,1)
      WRITE (6,2)
    2 FORMAT(5X,65HPRINT OUT OF THE GENERATED RESPONSES AT INPUT MICROME
     1TER SETTINGS)
      WRITE ( 6,80)
   80 FORMAT   (2X, 4HFREQ, 2X, 5HMICRO, 3X, 2HVA, 5X, 2HVB, 6X, 2HHA,
     15X,2HHB, 6X, 2HQA, 5X,2HQB)
      DO 82 JM = 1, NFRE
      DO 81 ML =1,NCOT
      WRITE (6,83)   CYCLE(JM), SET(ML), (RESP(IM,JM,ML),IM=1,6)
   83 FORMAT (1X, F5.1,2X,F5.4, 2(F7.2),1X,2(F7.2),1X, 2(F7.2))
   81 CONTINUE
      WRITE (6,84)
   84 FORMAT (//)
   82 CONTINUE
C     WHEN THE COMBINATION OF THE FORCES ARE GREATER THAN ZERO THEN
C     THERE WILL BE NO PUNCHING OUT OF THE FITS AT EACH ECCENTRICITY
      IF ( NCOMB .GT. 0) GOTO 183
      DO 182 JM= 1,NFRE
      DO 181 ML =2,NCOT
      WRITE( 8,102) CYCLE(JM),SET(ML),BANG(1),KR(1),IROT(1),(RESP(IM,JM,
     1ML),IM=1,6)
  181 CONTINUE
  182 CONTINUE
  183 WRITE ( 6,1)
      DO 231 IJ =1,6
      GOTO (132,133,134,135,136,137), IJ
  132 WRITE( 6,138)
  138 FORMAT( 4X,23H VERTICAL  A  COMPONENT)
      GOTO 145
  133 WRITE( 6,139)
  139 FORMAT( 4X,23H VERTICAL  B  COMPONENT)
      GOTO 145
  134 WRITE( 6,140)
  140 FORMAT( 4X,23HHORIZONTAL A  COMPONENT)
      GOTO 145
  135 WRITE( 6,141)
  141 FORMAT( 4X,23HHORIZONTAL B  COMPONENT)
      GOTO 145
  136 WRITE( 6,142)
  142 FORMAT( 4X,23H TORSIONAL A  COMPONENT)
```

```
      GOTO 145
  137 WRITE( 6,143)
  143 FORMAT( 4X,23H TORSIONAL B  COMPONENT)
  145 WRITE( 6,144)
  144 FORMAT(2X,12HCOEFFICIENTS,  5X,9HPOWERS OF, 3X,9HFREQUENCY,5X,
     112HECCENTRICITY)
      DO 146 JKL =1,NFRET
      JMK = JKL - 1
      DO 147 MKL = 1,MORET
      MMK = MKL - 1
      WRITE( 6,148) SURF(IJ,JKL,MKL),JMK,MMK
  148 FORMAT(2X,F13.7,20X,I2,14X,I2)
  147 CONTINUE
  146 CONTINUE
      WRITE( 6,84)
  231 CONTINUE
      WRITE(6,150) CYCLE(1),CYCLE(NFRE),SET(1),SET(NCOT)
  150 FORMAT(3X,18HFREQUENCY    RANGE,2X,F8.4,3X,2HTO,3X,F8.4/,2X,
     119HECCENTRICITY  RANGE,2X,F8.4,3X,2HTO,3X,F8.4)
  102 FORMAT ( F5.1,F5.4, F5.1, A4,I1,6F6.2)
C     PRINT OUT OF FITTED VALUES
C     SLMIC IS A SELECTED MICROMETER READINNG FOR THE OUTPUT IN
C     CALIBRATION ,NOTF IS NO OF OUTPUT FREQ,OUTFQ IS ARRAY OF OUTPUT FREQ
      SL = (2.0*SLMIC      - (SET(1) +SET(NCOT)))/(SET(NCOT)-SET(1))
      DO 89 IM= 1,6
      DO 91 ML = 1,MORET
      IF ( ML.EQ. 1 ) GOTO 92
      MLES = ML - 1
      DO 94 J= 1, NFRET
   94 SURMU ( IM, J,ML) = SURF ( IM,J,ML)*(SL    **MLES)
      GOTO 91
   92 DO 93 J=1,NFRET
   93 SURMU ( IM,J,ML) = SURF ( IM,J,1)
   91 CONTINUE
   89 CONTINUE
C     THE MICROMETER SETTING IS INCORPORATED IN THE COEFFICIENTS
      DO 100 IM= 1,6
      DO 95 JL = 1,NOTF
      F=(2.0*OUTFQ(JL)-(CYCLE(NFRE)+CYCLE(1)))/(CYCLE(NFRE)-CYCLE(1))
      P = 0.0
      DO 97 ML = 1, MORET
      Q = SURMU ( IM, 1,ML)
      DO 96 J = 2, NFRET
      MLES = J- 1
   96 Q = Q + SURMU ( IM,J,ML)*(F**MLES)
   97 P = P+Q
      OUTVA( NS,IM,JL) = P
   95 CONTINUE
  100 CONTINUE
      BETG(NS)= BANG(1)
      KROT(NS)=IROT(1)
      MR(NS)=KR(1)
      WRITE( 6,106)
  106 FORMAT( 10X, 38HEND OF EVALUATION FOR ONE SET OF ANGLE)
    5 CONTINUE
      SF= 999.9
      DO 206 NT= 1,NCOMB
      WRITE( 6,1)
      WRITE( 6,4)
    4 FORMAT( 5X,62HDATA IN A FORM SUITABLE FOR USE WITH XF5C CALIBRATIO
```

```
     1N SECTION )
      WRITE( 6,3)
    3 FORMAT(5X,3HCPS,3X,3HMIC,2X,4HBETA,1X,3HROT,6H     VA,6H     VA,
     16H     HA,6H     HB, 6H     QA,6H     QB //)
      MA= IFLFT(NT,1)
      MB= IFLFT(NT,2)
      MC= IFLFT(NT,3)
      DO 208 JL=1,NOTF
      WRITE(6,103)OUTFQ(JL),SLMIC,BETG(MA),MR(MA),KROT(MA),(OUTVA(MA,J,
     1JL),J=1,6)
      WRITE(6,103)OUTFQ(JL),SLMIC,BETG(MB),MR(MB),KROT(MB),(OUTVA(MB,J,
     1JL),J=1,6)
      IF( JL .EQ. NOTF) GOTO 209
      WRITE(6,103)OUTFQ(JL),SLMIC,BETG(MC),MR(MC),KROT(MC),(OUTVA(MC,J,
     1JL),J=1,6)
      GOTO 210
  209 WRITE(6,103)           SF,SLMIC,BETG(MC),MR(MC),KROT(MC),(OUTVA(MC,J,
     1JL),J=1,6)
  210 WRITE(6,84)
      WRITE(8,103)OUTFQ(JL),SLMIC,BETG(MA),MR(MA),KROT(MA),(OUTVA(MA,J,
     1JL),J=1,6)
      WRITE(8,103)OUTFQ(JL),SLMIC,BETG(MB),MR(MB),KROT(MB),(OUTVA(MB,J,
     1JL),J=1,6)
      IF( JL .EQ. NOTF) GOTO 286
      WRITE(8,103)OUTFQ(JL),SLMIC,BETG(MC),MR(MC),KROT(MC),(OUTVA(MC,J,
     1JL),J=1,6)
      GOTO 208
  286 WRITE(8,103)           SF,SLMIC,BETG(MC),MR(MC),KROT(MC),(OUTVA(MC,J,
     1JL),J=1,6)
  208 CONTINUE
  206 CONTINUE
C     THE PORTION OF THE PROGRAM TO SMOOTH TEST DATA TO ALLOW FOR THE
C     VARIATIONS IN FREQUENCY
      READ(5,20) NSERUN,MATT,MDA,MDB
      READ(5,21) ( TRAD(J),J=1,MATT)
      READ(5,21) ( TRBD(J), J=1,MATT)
      DO 398 J=1,MATT
      ATRAD(J)= TRAD(MDA)/TRAD(J)
  398 BTRBD(J)= TRBD(MDB)/TRBD(J)
  428 FORMAT(9X,I4,9X,I4,8X,F2.0,6X,F5.1,10X,F5.1,6X,A4)
  424 FORMAT(3X,8HMODEL NO,4X,7HTEST NO,4X,6HBLADES,3X,4HDISP,3X,4HPROP,
     14H LOC,6X,6HRUDDER)
      READ (5, 428) MODEL,NTEST,BLADES,DISP,PROPLO,RUDDER
      WRITE( 6,1)
      WRITE( 6,424)
      WRITE( 6,425) MODEL,NTEST,BLADES,DISP,PROPLO,RUDDER
  425 FORMAT(4X,I4,10X,I4,7X,F2.0,4X,F6.1,3X,F5.2,4H DIA,5X,A6)
      WRITE( 6,84)
      DO 399 JZ=1,NSERUN
      READ(5,20) NORUN,MRUN,MLO
      DO 400 IZ=1,MLO
      READ (5,401)(NRUN(K),SPEED(K),RPM(K),TFREQ(1,K),ICD(1,K),ICD(2,K),
     1TRU(1,K),TRU(2,K),TFREQ(2,K),ICD(3,K),ICD(4,K),TRU(3,K),TRU(4,K),
     2TFREQ(3,K),ICD(5,K),ICD(6,K),TRU(5,K),TRU(6,K),K=1,NORUN)
  401 FORMAT(I3,F6.3,F4.0,F5.1,1X,I1,1X,I1,2F5.2,F5.1,1X,I1,1X,I1,2F5.2,
     1F5.1,1X,I1,1X,I1,2F5.2)
      WRITE(6,423)
  423 FORMAT(10X,32HPRINT OUT OF TEST RUN RECORDINGS)
      WRITE( 6,421)
  421 FORMAT(3X,3HRUN,4X,5HSPEED,4X,3HRPM,4X,4HFREQ,2X,4HGAIN,4X,2HVA,5X
```

```
    1,2HVB,5X,4HFREQ,2X,4HGAIN,4X,2HHA,5X,2HHB,5X,4HFREQ,2X,4HGAIN,5X,
    22HOA,5X,2HOB)
     WRITE(6,422)(NRUN(K),SPEED(K),RPM(K),TFREQ(1,K),ICD(1,K),ICD(2,K),
    1TRU(1,K),TRU(2,K),TFREQ(2,K),ICD(3,K),ICD(4,K),TRU(3,K),TRU(4,K),
    2TFREQ(3,K),ICD(5,K),ICD(6,K),TRU(5,K),TRU(6,K),K=1,NORUN)
422  FORMAT(3X,I3,3X,F6.3,3X,F4.0,3X,F5.1,2X,1HG,I1,1HG,I1, 2F7.2 ,3X,
    1F5.1,2X,1HG,I1,1HG,I1, 2F7.2 ,3X,F5.1,2X,1HG,I1,1HG,I1, 2F7.2 )
     DO 402 K=1,NORUN
     IVA= ICD(1,K)
     IVB= ICD(2,K)
     IHA= ICD(3,K)
     IHB= ICD(4,K)
     IOA= ICD(5,K)
     IOB= ICD(6,K)
     TR(1,K)= TRU(1,K)*TRAD(IVA)
     TR(2,K)=TRU(2,K)*TRBD(IVB)
     TR(3,K)=TRU(3,K)*TRAD(IHA)
     TR(4,K)=TRU(4,K)*TRBD(IHB)
     TR(5,K)=TRU(5,K)*TRAD(IOA)
402  TR(6,K)=TRU(6,K)*TRBD(IOB)
     DO 403 KK=1,6
     DO 409 K=1,NORUN
409  SOF(K)=TR(KK,K)
     IF(KK.LE. 2) GOTO 404
     IF((KK.EQ.3) .OR.(KK.EQ.4)) GOTO 406
     IF( KK .GE. 5) GOTO 407
404  KT=1
     GOTO 410
406  KT= 2
     GOTO 410
407  KT=3
410  DO 405 K=1,NORUN
405  SOFP(K)= TFREQ(KT,K)*60.0/BLADES
     SON = SOFP(1)*0.95
     SUP= SOFP(NORUN)*1.05
     CALL LFOPY(MRUN,NORUN, NORUN,SON,SUP,SOFP,SOF,RPM,RPMOT,RCOF)
     DO 411 K=1,NORUN
411  TFRU(IZ,KK,K)=RPMOT(K)
     DO 412 K=1,MRUN
     KO = K+ 1
412  TRCOF(IZ,KK,KO)= RCOF(KO)
403  CONTINUE
400  CONTINUE
     IF(MLO .EQ. 1) GOTO 415
     DO 416 KK=1,6
     DO 417 K=1,NORUN
417  TFRU(MLO,KK,K)= TFRU(MLO,KK,K) -TFRU(1,KK,K)
416  CONTINUE
415  WRITE( 6,418)
418  FORMAT(3X,3HRUN,4X,5HSPEED,4X,3HRPM,7X,2HVA,5X,2HVB,5X,2HHA,5X,
    12HHB,5X,2HOA,5X,2HOB)
     WRITE(6,419) (NRUN(K),SPEED(K),RPM(K), (TFRU(MLO,KK,K),KK=1,6),
    1K=1,NORUN)
419  FORMAT(3X,I3,3X,F6.3,3X,F4.0,4X, 6F7.2)
     WRITE(8,420)(NRUN(K),SPEED(K),RPM(K),(TFRU(MLO,KK,K),KK=1,1,6),
    1K=1,NORUN)
420  FORMAT(I3,F6.3,F4.0,6F5.2)
399  CONTINUE
     STOP
     END
```

```
$IBFTC ZCLFP   LIST,NODECK
      SUBROUTINE LFOPY (M,NIN, LOUT, XMIN, XMAX, XIN, YIN, XOUT,
     1YOUT, CKOF)
C      THE SUBROUTINE USES FORSYTHE  LEAST SQUARE FIT TO DATA AT
C      ARBITRARY POINTS BETWEEN XMIN AND XMAX. WHILE XIN AND YIN ARE
C      INPUT ABCISSAE AND ORDINATE AND OUT AND YOUT ARE THE CORRESPONDING
C      OUTPUT VALUES,CKOF IS COEFFICIENTS OF THE FIT ORDER M, AND THE
C      NUMBERS OF INPUT AND OUTPUT VALUES ARE N AND LOUT
      DIMENSION XIN(100), YIN(100), YOUT(100), CKOF(20), COEFF(20,20),
     1A(20), P(20,100), ALPHA(20), BETA(20), XNORM(100), YNORM(100),
     2XOUTP (100),XOUT(100)
       N = NIN
      DO 7001 I = 1,N
 7001 XNORM(I) = ( 2.0* XIN(I) - ( XMIN + XMAX))/(XMAX - XMIN)
      DO 7002 I = 1, LOUT
 7002 XOUTP(I) = ( 2.0* XOUT(I) - ( XMAX + XMIN))/( XMAX- XMIN)
      AA = ABS( YIN(1))
      DO 7003 I = 2,N
      BB = ABS ( YIN(I))
 7003 IF ( BB. GT. AA) AA = BB
      DO 7004 I = 1,N
 7004 YNORM(I) = YIN (I)/AA
      CC = 0.0
      DD = 0.0
      DO 7016 I= 1,N
      CC = CC + YNORM(I)
 7016 DD = DD + XNORM(I)
      C = CC
      D = DD
      FIN = FLOAT(N)
      A(1) = C/ FIN
      ALPHA (2) = D/FIN
      DO 7005 J = 1,N
      P(1,J) = 1.0
 7005 P(2,J) = XNORM(J) - ALPHA(2)
      LM = M + 1
      IF ( LM. EQ. 1) GOTO 7006
      JF = 1
      H = FIN
      DO 7007 L = 2,LM
      EE = 0.0
      FF = 0.0
      DO 7017 I = 1,N
      EE = EE + YNORM(I)*P(L,I)
 7017 FF= FF + P(L,I)**2
      E = EE
      F= FF
      A(L) = E/F
      IF ( JF .EQ. M) GOTO 7007
      GG = 0.0
      DO 7018 I = 1,N
 7018 GG = GG + XNORM(I)* ( P(L,I)**2)
      G= GG
      ALPHA ( L+1) = G/F
      BETA(L) = F/H
      H = F
      LPO = L +1
      LMO = L - 1
      DO 7008 LL = 1,N
      P(LPO,LL) = XNORM(LL)*P(L,LL) - ALPHA(LPO) *P(L,LL) - BETA(L)
```

```
     1*P(LMO,LL)
7008 CONTINUE
     JF = JF + 1
7007 CONTINUE
     DO 7009 I = 1,LM
     DO 7010 J = 1,LM
7010 COEFF( I,J) = 0.0
7009 CONTINUE
     COEFF (1,1) = 1.0
     COEFF( 2,1) = - ALPHA (2)
     IF ( LM . EQ. 2 ) GOTO 7011
     DO 7012 I = 3, LM
7012 COEFF (I,1) = - ALPHA (I) *COEFF(I-1,1)-BETA(I-1)*COEFF(I-2,1)
7011 KT = 2
     DO 7013 J = 2,LM
     KT = KT +1
     COEFF ( KT- 1, J) = 1.0
     KW = KT
     IF ( KT . GT. LM) GOTO  7013
     DO 7015 I = KW, LM
7015 COEFF(I,J  = COEFF(I-1,J-1) -ALPHA(I)*COEFF(I-1,J)-
     1BETA(I-1)*COEFF(I-2,J)
7013 CONTINUE
     DO 7014 I = 1, LM
     SS = 0.0
     DO 7019 J =I, LM
7019 SS = SS + A(J)*COEFF( J,I)
     CKOF (I) = SS*AA
7014 CONTINUE
     GOTO 7020
7006 CKOF (1) = A(1)*AA
7020 DO 7021 I = 1,LOUT
     QQ = XOUTP (I)
     IF ( QQ .EQ. 0.0) GOTO 7024
     PQ = 0.0
     DO 7023 J = 2,LM
     JM = J - 1
7023 PQ = PQ + CKOF(J)* ( QQ**JM)
     GOTO 7022
7024 PQ= 0.0
7022 YOUT (I) = PQ + CKOF (1)
7021 CONTINUE
     RETURN
     END
```

```
$DATA
  3  1  1  7  2  4  4  4
1.04692.04763.03884.0000
1.04752.04293.03924.0000
  7 .2000
  2  3  1
 29.00 31.00 33.00 36.00 39.00 42.00 45.00
FREQ 29.0 BETA ANGLE  96.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 29.0G4G4V  .08  .17F 29.0G4G4H -.22 -.20F 29.0G4G4Q -.54 -.63
2MO.1  F 29.0G4G4V  .48-1.35F 29.0G4G4H -.67  .87F 29.0G4G4Q-2.71 2.38
3MO.2  F 29.0G4G4V  .92-2.80F 29.0G4G4H-1.19 1.89F 29.0G4G4Q-4.55 4.82
9MO.3  F 29.0G4G4V 1.15-4.22F 29.0G4G4H-1.56 2.90F 29.0G3G2Q-4.65 4.29
FREQ 32.0 BETA ANGLE  96.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 32.0G4G4V  .08  .20F 32.0G4G4H -.22 -.20F 32.0G4G4Q -.70 -.75
2MO.1  F 32.0G4G4V  .58-1.16F 32.0G4G4H -.70  .96F 32.0G4G4Q-3.20 2.76
3MO.2  F 32.0G4G4V 1.08-2.53F 32.0G4G4H-1.18 2.07F 32.0G4G3Q-4.88 4.37
9MO.3  F 32.0G4G4V 1.40-3.85F 32.0G4G4H-1.55 3.12F 32.0G2G2Q-4.00 4.43
FREQ 34.0 BETA ANGLE  96.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 34.0G4G4V00.05  .23F 34.0G4G4H -.25 -.22F 34.0G4G4Q -.80 -.93
2MO.1  F 34.0G4G4V 0.66-1.20F 34.0G4G4H -.78  .97F 34.0G4G4Q-3.48 2.68
3MO.2  F 34.0G4G4V 0.98-2.67F 34.0G4G4H-1.20 2.16F 34.0G3G3Q-4.40 4.28
9MO.3  F 34.0G4G4V 1.61-3.98F 34.0G4G4H-1.78 3.22F 34.0G2G2Q-4.10 4.62
FREQ 36.0 BETA ANGLE  96.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 36.0G4G4V  .08  .18F 36.0G4G4H -.28 -.22F 36.0G4G4Q -.98 -.97
2MO.1  F 36.0G4G4V  .68-1.21F 36.0G4G4H -.80 1.00F 36.0G4G4Q-3.78 2.58
3MO.2  F 36.0G4G4V 1.15-2.68F 36.0G4G4H-1.33 2.22F 36.0G3G3Q-4.50 4.43
9MO.3  F 36.0G4G4V 1.65-4.00F 36.0G4G4H-1.86 3.33F 36.0G2G2Q-4.40 4.62
FREQ 39.0 BETA ANGLE  96.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 39.0G4G4V  .07  .23F 39.0G4G4H -.23 -.23F 39.0G4G4Q -.80-1.25
2MO.1  F 39.0G4G4V  .72-1.22F 39.0G4G4H -.80 1.03F 39.0G4G4Q-3.87 2.58
3MO.2  F 39.0G4G4V 1.27-2.67F 39.0G4G4H-1.31 2.38F 39.0G3G3Q-4.70 4.42
9MO.3  F 39.0G4G4V 1.75-3.92F 39.0G4G4H-1.78 3.75F 39.0G2G2Q-4.55 4.87
FREQ 42.0 BETA ANGLE  96.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 42.0G4G4V -.05  .20F 42.0G4G4H -.45 -.29F 42.0G4G4Q -.90-1.33
2MO.1  F 42.0G4G4V  .58-1.22F 42.0G4G4H-1.14 1.40F 42.0G4G4Q-3.93 3.05
3MO.2  F 42.0G4G4V 1.03-2.65F 42.0G4G4H-1.77 2.87F 42.0G2G3Q-3.70 4.70
9MO.3  F 42.0G4G4V 1.45-4.00F 42.0G4G4H-2.22 4.30F 42.0G2G1Q-4.65 2.90
FREQ 45.0 BETA ANGLE  96.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 45.0G4G4V -.07  .25F 45.0G4G4H -.33 -.35F 45.0G4G4Q -.85-1.45
2MO.1  F 45.0G4G4V  .70-1.42F 45.0G4G4H-1.18 1.30F 45.0G4G4Q-4.26 3.03
3MO.2  F 45.0G4G4V 1.35-3.00F 45.0G4G4H-2.00 2.88F 45.0G2G3Q-3.95 4.85
9MO.3  F 45.0G4G4V 1.90-4.42F 45.0G4G4H-2.56 4.35F 45.0G1G1Q-2.95 3.15
FREQ 29.0 BETA ANGLE  95.0ROTATION SAME1 OPP2 SAME1
1MO.0  F 29.0G4G4V  .50 -.08F 29.0G4G4H  .02 -.25F 29.0G4G4Q -.18-1.05
2MO.1  F 29.0G4G4V-1.00 -.25F 29.0G4G4H -.32  .60F 29.0G4G4Q -.72 1.07
3MO.2  F 29.0G4G4V-2.55 -.45F 29.0G4G4H -.70 1.58F 29.0G4G4Q-1.22 3.12
9MO.3  F 29.0G4G4V-3.20 -.45F 29.0G4G4H -.92 2.53F 29.0G4G3Q-1.50 3.97
FREQ 32.0 BETA ANGLE  95.0ROTATION SAME1 OPP2 SAME1
1MO.0  F 32.0G4G4V  .47  .02F 32.0G4G4H  .03 -.30F 32.0G4G4Q -.13-1.20
2MO.1  F 32.0G4G4V -.90 -.40F 32.0G4G4H -.40  .68F 32.0G4G4Q -.88 1.18
3MO.2  F 32.0G4G4V-2.28 -.73F 32.0G4G4H -.78 1.70F 32.0G4G4Q-1.55 3.57
9MO.3  F 32.0G4G4V-3.68-1.00F 32.0G4G4H-1.00 2.70F 32.0G4G3Q-1.80 4.48
FREQ 34.0 BETA ANGLE  95.0ROTATION SAME1 OPP2 SAME1
1MO.0  F 34.0G4G4V  .50  .02F 34.0G4G4H  .02 -.33F 34.0G4G4Q -.12-1.21
2MO.1  F 34.0G4G4V -.93 -.33F 34.0G4G4H -.40  .73F 34.0G4G4Q -.98 1.28
3MO.2  F 34.0G4G4V-2.32 -.81F 34.0G4G4H -.80 1.80F 34.0G4G4Q-1.65 3.73
9MO.3  F 34.0G4G4V-3.70-1.05F 34.0G4G4H-1.13 2.87F 34.0G4G3Q-2.18 4.63
FREQ 36.0 BETA ANGLE  95.0ROTATION SAME1 OPP2 SAME1
1MO.0  F 36.0G4G4V  .49  .01F 36.0G4G4H  .02 -.33F 36.0G4G4Q -.13-1.30
2MO.1  F 36.0G4G4V -.98 -.40F 36.0G4G4H -.38  .78F 36.0G4G4Q -.93 1.42
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3MO.2  F 36.0G4G4V-2.50 -.70F 36.0G4G4H -.70 1.97F 36.0G4G4Q-1.52 4.10
9MO.3  F 36.0G4G4V-3.86-1.07F 36.0G4G4H-1.10 3.02F 36.0G4G3Q-2.08 5.00
FREQ 39.0 BETA ANGLE  95.0ROTATION SAME1 OPP2 SAME1
1MO.0  F 39.0G4G4V  .52  .02F 39.0G4G4H  .02 -.34F 39.0G4G4Q -.15-1.37
2MO.1  F 39.0G4G4V-1.00 -.41F 39.0G4G4H -.36  .78F 39.0G4G4Q -.98 1.42
3MO.2  F 39.0G4G4V-2.52 -.75F 39.0G4G4H -.78 2.10F 39.0G4G4Q-1.70 4.41
9MO.3  F 39.0G4G4V-3.97-1.10F 39.0G4G4H-1.10 3.28F 39.0G4G2Q-2.27 3.68
FREQ 42.0 BETA ANGLE  95.0ROTATION SAME1 OPP2 SAME1
1MO.0  F 42.0G4G4V  .52 -.03F 42.0G4G4H -.08 -.50F 42.0G4G4Q -.20-1.59
2MO.1  F 42.0G4G4V-1.10 -.26F 42.0G4G4H -.43 1.15F 42.0G4G4Q-1.20 1.80
3MO.2  F 42.0G4G4V-2.69 -.59F 42.0G4G4H -.91 2.58F 42.0G4G4Q-1.86 4.79
9MO.3  F 42.0G4G4V-4.20 -.80F 42.0G4G4H-1.32 3.95F 42.0G4G2Q-2.35 4.08
FREQ 45.0 BETA ANGLE  95.0ROTATION SAME1 OPP2 SAME1
1MO.0  F 45.0G4G4V  .60  .02F 45.0G4G4H  .06 -.50F 45.0G4G4Q -.06-1.60
2MO.1  F 45.0G4G4V-1.20 -.42F 45.0G4G4H -.60 1.08F 45.0G4G4Q-1.25 1.75
3MO.2  F 45.0G4G4V-3.00 -.82F 45.0G4G4H-1.20 2.60F 45.0G4G4Q-2.25 4.92
9MO.3  F 45.0G4G4V-4.63-1.22F 45.0G4G4H-1.75 4.05F 45.0G4G2Q-2.73 4.23
FREQ 29.0 BETA ANGLE   0.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 29.0G4G4V 0.0  0.0 F 29.0G4G4H 0.0  0.0 F 29.0G4G4Q 0.0  0.0
2MO.1  F 29.0G4G4V-1.29-1.90F 29.0G4G4H .007-.002F 29.0G4G4Q  .10 0.07
3MO.2  F 29.0G4G4V-2.97-3.42F 29.0G4G4H .013-.005F 29.0G4G4Q  .18  .13
9MO.3  F 29.0G4G4V-3.53-5.29F 29.0G4G4H .020-.010F 29.0G4G4Q  .27  .19
FREQ 32.0 BETA ANGLE   0.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 32.0G4G4V 0.0  0.0 F 32.0G4G4H 0.0  0.0 F 32.0G4G4Q 0.0  0.0
2MO.1  F 32.0G4G4V -.98-1.90F 32.0G4G4H  .01  .01F 32.0G4G4Q  .08  .07
3MO.2  F 32.0G4G4V-1.73-3.70F 32.0G4G4H  .01  .01F 32.0G4G4Q  .16  .14
9MO.3  F 32.0G4G4V-2.43-5.55F 32.0G4G4H  .02  .02F 32.0G4G4Q  .24  .22
FREQ 34.0 BETA ANGLE   0.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 34.0G4G4V 0.0  0.0 F 34.0G4G4H 0.0  0.0 F 34.0G4G4Q 0.0  0.0
2MO.1  F 34.0G4G4V -.98-1.90F 34.0G4G4H  .01  .01F 34.0G4G4Q  .08  .04
3MO.2  F 34.0G4G4V-2.08-3.70F 34.0G4G4H  .02  .02F 34.0G4G4Q  .14  .08
9MO.3  F 34.0G4G4V-2.71-5.62F 34.0G4G4H  .03  .03F 34.0G4G4Q  .20  .12
FREQ 36.0 BETA ANGLE   0.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 36.0G4G4V 0.0  0.0 F 36.0G4G4H 0.0  0.0 F 36.0G4G4Q 0.0  0.0
2MO.1  F 36.0G4G4V -.98-1.99F 36.0G4G4H -.01  .01F 36.0G4G4Q  .06  .01
3MO.2  F 36.0G4G4V-1.73-3.95F 36.0G4G4H -.02  .02F 36.0G4G4Q  .13  .03
9MO.3  F 36.0G4G4V-2.60-5.86F 36.0G4G4H -.03  .03F 36.0G4G4Q  .20  .05
FREQ 39.0 BETA ANGLE   0.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 39.0G4G4V 0.0  0.0 F 39.0G4G4H 0.0  0.0 F 39.0G4G4Q 0.0  0.0
2MO.1  F 39.0G4G4V-1.04-2.00F 39.0G4G4H 0.01 0.02F 39.0G4G4Q  .08  .05
3MO.2  F 39.0G4G4V-1.84-3.96F 39.0G4G4H  .03  .06F 39.0G4G4Q  .16  .10
9MO.3  F 39.0G4G4V-2.55-5.93F 39.0G4G4H  .05  .11F 39.0G4G4Q  .24  .14
FREQ 42.0 BETA ANGLE   0.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 42.0G4G4V 0.0  0.0 F 42.0G4G4H 0.0  0.0 F 42.0G4G4Q 0.0  0.0
2MO.1  F 42.0G4G4V-1.20-2.03F 42.0G4G4H  .04 -.04F 42.0G4G4Q  .11 -.11
3MO.2  F 42.0G4G4V-2.30-3.80F 42.0G4G4H  .07 -.08F 42.0G4G4Q  .20 -.21
9MO.3  F 42.0G4G4V-2.95-6.14F 42.0G4G4H  .10 -.12F 42.0G4G4Q  .31 -.31
FREQ 45.0 BETA ANGLE   0.0ROTATION SAME1 OPP2 OPP 2
1MO.0  F 45.0G4G4V 0.0  0.0 F 45.0G4G4H 0.0  0.0 F 45.0G4G4Q 0.0  0.0
2MO.1  F 45.0G4G4V-1.11-2.31F 45.0G4G4H  .01 -.01F 45.0G4G4Q  .20 -.15
3MO.2  F 45.0G4G4V-1.97-4.40F 45.0G4G4H  .04 -.02F 45.0G4G4Q  .42 -.30
9MO.3  F 45.0G4G4V-2.55-4.99F 45.0G4G4H  .07 -.03F 45.0G4G4Q  .62 -.45
  1  4  4
  1.00  1.00  1.00  1.00
  1.00  1.00  1.00  1.00
MODEL NO 4287 TEST NO 1234 BLADES 4. DISP 100.0 PROP POS   5.0D RUD NONE
  7  2  1
 11 3.600 435 29.0G4G4 0.00 -.39 29.0G4G4 1.44-1.00 29.0G4G4-4.12 3.55
 12 3.830 465 31.0G4G4  .10 -.35 31.0G4G4 1.49-1.03 31.0G4G4-4.17 3.60
 13 4.010 495 33.0G4G4  .15 -.30 33.0G4G4 1.80-1.05 33.0G4G4-5.36 3.85
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  14 4.100 540 36.0G4G4  .13 -.25 36.0G4G4 2.19-1.09 36.0G4G4-6.29 4.35
  15 4.370 585 39.0G4G4  .09 -.28 39.0G4G4 2.18-1.11 39.0G4G4-6.84 4.71
  16,4.640 630 42.0G4G4  .13 -.34 42.0G4G4 2.09-1.35 42.0G4G4-6.90 4.75
  17 4.970 675 45.0G4G4  .20 -.32 45.0G4G4 2.20-2.10 45.0G4G4-6.45 4.48

FREQ 29.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
1MO.    F 29.0G4G4V 0.    0.  F 29.0G4G4H 0.    0.  F 29.0G4G4Q 0.    0.
2MO.100F 29.0G4G4V-1.29-1.90F 29.0G4G4H 0.01-0.00F 29.0G4G4Q 0.10 0.07
3MO.200F 29.0G4G4V-2.97-3.42F 29.0G4G4H 0.01-0.00F 29.0G4G4Q 0.18 0.13
9MO.300F 29.0G4G4V-3.53-5.29F 29.0G4G4H 0.02-0.01F 29.0G4G4Q 0.27 0.19

   THE ABOVE PRINT OUT IS THE INPUT DATA



FREQ 29.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
   VA            VB            HA            HB            QA            QB
INPUT  FIT   INPUT  FIT   INPUT  FIT   INPUT  FIT   INPUT  FIT   INPUT  FIT
 0.   -0.11   0.   -0.04   0.    0.00   0.    0.00   0.    0.00   0.    0.00
-1.29 -1.33  -1.90 -1.78   0.01  0.01  -0.00 -0.00   0.10  0.09   0.07  0.07
-2.97 -2.56  -3.42 -3.52   0.01  0.01  -0.00 -0.01   0.18  0.18   0.13  0.13
-3.53 -3.79  -5.29 -5.26   0.02  0.02  -0.01 -0.01   0.27  0.27   0.19  0.19


FREQ 32.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
1MO.    F 32.0G4G4V 0.    0.  F 32.0G4G4H 0.    0.  F 32.0G4G4Q 0.    0.
2MO.100F 32.0G4G4V-0.98-1.90F 32.0G4G4H 0.01 0.01F 32.0G4G4Q 0.08 0.07
3MO.200F 32.0G4G4V-1.73-3.70F 32.0G4G4H 0.01 0.01F 32.0G4G4Q 0.16 0.14
9MO.300F 32.0G4G4V-2.43-5.55F 32.0G4G4H 0.02 0.02F 32.0G4G4Q 0.24 0.22

   THE ABOVE PRINT OUT IS THE INPUT DATA



FREQ 32.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
   VA            VB            HA            HB            QA            QB
INPUT  FIT   INPUT  FIT   INPUT  FIT   INPUT  FIT   INPUT  FIT   INPUT  FIT
 0.   -0.08   0.   -0.02   0.    0.00   0.    0.00   0.    0.00   0.   -0.00
-0.98 -0.88  -1.90 -1.86   0.01  0.01   0.01  0.01   0.08  0.08   0.07  0.07
-1.73 -1.69  -3.70 -3.71   0.01  0.01   0.01  0.01   0.16  0.16   0.14  0.14
-2.43 -2.49  -5.55 -5.55   0.02  0.02   0.02  0.02   0.24  0.24   0.22  0.22


FREQ 34.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
1MO.    F 34.0G4G4V 0.    0.  F 34.0G4G4H 0.    0.  F 34.0G4G4Q 0.    0.
2MO.100F 34.0G4G4V-0.98-1.90F 34.0G4G4H 0.01 0.01F 34.0G4G4Q 0.08 0.04
3MO.200F 34.0G4G4V-2.08-3.70F 34.0G4G4H 0.02 0.02F 34.0G4G4Q 0.14 0.08
9MO.300F 34.0G4G4V-2.71-5.62F 34.0G4G4H 0.03 0.03F 34.0G4G4Q 0.20 0.12

   THE ABOVE PRINT OUT IS THE INPUT DATA
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FREQ 34.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
   VA             VB             HA             HB             QA             QB
INPUT  FIT    INPUT  FIT    INPUT  FIT    INPUT  FIT    INPUT  FIT    INPUT  FIT
 0.    -0.06   0.    -0.01   0.     0.00   0.     0.00   0.     0.01   0.     0.00
-0.98 -0.98  -1.90 -1.87   0.01   0.01   0.01   0.01   0.08   0.07   0.04   0.04
-2.08 -1.90  -3.70 -3.74   0.02   0.02   0.02   0.02   0.14   0.14   0.08   0.08
-2.71 -2.83  -5.62 -5.60   0.03   0.03   0.03   0.03   0.20   0.20   0.12   0.12


FREQ 36.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
1M0.    F 36.0G4G4V 0.    0.  F 36.0G4G4H 0.    0.  F 36.0G4G4Q 0.    0.
2M0.100F 36.0G4G4V-0.98-1.99F 36.0G4G4H-0.01 0.01F 36.0G4G4Q 0.06 0.01
3M0.200F 36.0G4G4V-1.73-3.95F 36.0G4G4H-0.02 0.02F 36.0G4G4Q 0.13 0.03
9M0.300F 36.0G4G4V-2.60-5.86F 36.0G4G4H-0.03 0.03F 36.0G4G4Q 0.20 0.05

   THE ABOVE PRINT OUT IS THE INPUT DATA



FREQ 36.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
   VA             VB             HA             HB             QA             QB
INPUT  FIT    INPUT  FIT    INPUT  FIT    INPUT  FIT    INPUT  FIT    INPUT  FIT
 0.    -0.04   0.    -0.02   0.    -0.00   0.     0.00   0.    -0.00   0.    -0.00
-0.98 -0.90  -1.99 -1.97  -0.01 -0.01   0.01   0.01   0.06   0.06   0.01   0.01
-1.73 -1.75  -3.95 -3.93  -0.02 -0.02   0.02   0.02   0.13   0.13   0.03   0.03
-2.60 -2.61  -5.86 -5.88  -0.03 -0.03   0.03   0.03   0.20   0.20   0.05   0.05


FREQ 39.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
1M0.    F 39.0G4G4V 0.    0.  F 39.0G4G4H 0.    0.  F 39.0G4G4Q 0.    0.
2M0.100F 39.0G4G4V-1.04-2.00F 39.0G4G4H 0.01 0.02F 39.0G4G4Q 0.08 0.05
3M0.200F 39.0G4G4V-1.84-3.96F 39.0G4G4H 0.03 0.06F 39.0G4G4Q 0.16 0.10
9M0.300F 39.0G4G4V-2.55-5.93F 39.0G4G4H 0.05 0.11F 39.0G4G4Q 0.24 0.14

   THE ABOVE PRINT OUT IS THE INPUT DATA



FREQ 39.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
   VA             VB             HA             HB             QA             QB
INPUT  FIT    INPUT  FIT    INPUT  FIT    INPUT  FIT    INPUT  FIT    INPUT  FIT
 0.    -0.09   0.    -0.01   0.    -0.00   0.    -0.01   0.     0.00   0.     0.00
-1.04 -0.93  -2.00 -1.98   0.01   0.01   0.02   0.03   0.08   0.08   0.05   0.05
-1.84 -1.78  -3.96 -3.96   0.03   0.03   0.06   0.07   0.16   0.16   0.10   0.10
-2.55 -2.62  -5.93 -5.93   0.05   0.05   0.11   0.10   0.24   0.24   0.14   0.14


FREQ 42.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
1M0.    F 42.0G4G4V 0.    0.  F 42.0G4G4H 0.    0.  F 42.0G4G4Q 0.    0.
2M0.100F 42.0G4G4V-1.20-2.03F 42.0G4G4H 0.04-0.04F 42.0G4G4Q 0.11-0.11
3M0.200F 42.0G4G4V-2.30-3.80F 42.0G4G4H 0.07-0.08F 42.0G4G4Q 0.20-0.21
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9M0.300F 42.0G4G4V-2.95-6.14F 42.0G4G4H 0.10-0.12F 42.0G4G4Q 0.31-0.31

   THE ABOVE PRINT OUT IS THE INPUT DATA




FREQ 42.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
   VA                VB                HA                HB                QA                QB .
INPUT  FIT     INPUT  FIT     INPUT  FIT     INPUT  FIT     INPUT  FIT     INPUT  FIT
 0.    -0.12    0.     0.04    0.     0.00    0.    -0.00    0.     0.00    0.    -0.00
-1.20 -1.11   -2.03 -1.98    0.04   0.04   -0.04 -0.04    0.11   0.10   -0.11 -0.11
-2.30 -2.11   -3.80 -4.00    0.07   0.07   -0.08 -0.08    0.20   0.21   -0.21 -0.21
-2.95 -3.10   -6.14 -6.02    0.10   0.10   -0.12 -0.12    0.31   0.31   -0.31 -0.31


FREQ 45.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
1M0.   F 45.0G4G4V 0.    0.   F 45.0G4G4H 0.    0.   F 45.0G4G4Q 0.    0.
2M0.100F 45.0G4G4V-1.11-2.31F 45.0G4G4H 0.01-0.01F 45.0G4G4Q 0.20-0.15
3M0.200F 45.0G4G4V-1.97-4.40F 45.0G4G4H 0.04-0.02F 45.0G4G4Q 0.42-0.30
9M0.300F 45.0G4G4V-2.55-4.99F 45.0G4G4H 0.07-0.03F 45.0G4G4Q 0.62-0.45

   THE ABOVE PRINT OUT IS THE INPUT DATA




FREQ 45.0 BETA ANGLE   0. ROTATION SAME 1 OPP 2OPP 2
   VA                VB                HA                HB                QA                QB
INPUT  FIT     INPUT  FIT     INPUT  FIT     INPUT  FIT     INPUT  FIT     INPUT  FIT
 0.    -0.13    0.    -0.37    0.    -0.01    0.    -0.00    0.    -0.00    0.    -0.00
-1.11 -0.98   -2.31 -2.07    0.01   0.02   -0.01 -0.01    0.20   0.21   -0.15 -0.15
-1.97 -1.83   -4.40 -3.78    0.04   0.04   -0.02 -0.02    0.42   0.41   -0.30 -0.30
-2.55 -2.68   -4.99 -5.48    0.07   0.07   -0.03 -0.03    0.62   0.62   -0.45 -0.45
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    PRINT OUT OF THE GENERATED RESPONSES AT INPUT MICROMETER SETTINGS
FREQ  MICRO    VA     VB      HA     HB      QA     QB
29.0  .      -0.10  -0.09  -0.00   0.00    0.00   0.00
29.0  .1000  -1.23  -1.79   0.01  -0.00    0.10   0.06
29.0  .2000  -2.36  -3.49   0.01  -0.00    0.20   0.12
29.0  .3000  -3.48  -5.19   0.02  -0.01    0.30   0.18


32.0  .      -0.08   0.00   0.00  -0.00    0.00   0.00
32.0  .1000  -1.05  -1.86   0.00   0.01    0.07   0.06
32.0  .2000  -2.03  -3.72   0.01   0.02    0.14   0.13
32.0  .3000  -3.00  -5.58   0.01   0.02    0.21   0.19


34.0  .      -0.07   0.03   0.00  -0.00    0.00  -0.00
34.0  .1000  -0.97  -1.90   0.01   0.01    0.06   0.06
34.0  .2000  -1.88  -3.83   0.01   0.02    0.12   0.11
34.0  .3000  -2.78  -5.75   0.02   0.03    0.18   0.17


36.0  .      -0.06   0.03   0.00  -0.00    0.00  -0.00
36.0  .1000  -0.92  -1.93   0.01   0.01    0.06   0.04
36.0  .2000  -1.78  -3.90   0.01   0.02    0.12   0.08
36.0  .3000  -2.64  -5.87   0.02   0.04    0.19   0.11


39.0  .      -0.08  -0.01  -0.00  -0.00    0.00  -0.00
39.0  .1000  -0.91  -1.98   0.01   0.01    0.08  -0.01
39.0  .2000  -1.74  -3.95   0.02   0.01    0.17  -0.01
39.0  .3000  -2.57  -5.92   0.04   0.02    0.25  -0.02


42.0  .      -0.10  -0.12  -0.00  -0.00   -0.00  -0.00
42.0  .1000  -0.96  -2.02   0.02  -0.01    0.13  -0.07
42.0  .2000  -1.82  -3.93   0.04  -0.01    0.25  -0.14
42.0  .3000  -2.68  -5.83   0.06  -0.01    0.38  -0.21


45.0  .      -0.14  -0.28  -0.00  -0.00   -0.00  -0.00
45.0  .1000  -1.08  -2.05   0.03  -0.02    0.19  -0.16
45.0  .2000  -2.02  -3.83   0.06  -0.05    0.38  -0.31
45.0  .3000  -2.96  -5.60   0.09  -0.07    0.58  -0.47
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   VERTICAL   A  COMPONENT
COEFFICIENTS      POWERS OF    FREQUENCY      ECCENTRICITY
   -1.3328861                      0               0
   -1.2662709                      0               1
    0.1187694                      1               0
    0.1399708                      1               1
   -0.3400348                      2               0
   -0.2837035                      2               1


   VERTICAL   B  COMPONENT
COEFFICIENTS      POWERS OF    FREQUENCY      ECCENTRICITY
   -2.9389382                      0               0
   -2.9626066                      0               1
   -0.1506672                      1               0
   -0.0549964                      1               1
    0.1499673                      2               0
    0.3561660                      2               1


  HORIZONTAL A   COMPONENT
COEFFICIENTS      POWERS OF    FREQUENCY      ECCENTRICITY
    0.0131643                      0               0
    0.0129877                      0               1
    0.0174043                      1               0
    0.0192849                      1               1
    0.0124009                      2               0
    0.0146024                      2               1


  HORIZONTAL B   COMPONENT
COEFFICIENTS      POWERS OF    FREQUENCY      ECCENTRICITY
    0.0153672                      0               0
    0.0176991                      0               1
   -0.0158760                      1               0
   -0.0146155                      1               1
   -0.0344298                      2               0
   -0.0376658                      2               1


   TORSIONAL  A  COMPONENT
COEFFICIENTS      POWERS OF    FREQUENCY      ECCENTRICITY
    0.0998357                      0               0
    0.0992099                      0               1
    0.0674994                      1               0
    0.0696466                      1               1
    0.1210082                      2               0
    0.1203140                      2               1


   TORSIONAL  B  COMPONENT
COEFFICIENTS      POWERS OF    FREQUENCY      ECCENTRICITY
    0.0373415                      0               0
    0.0388246                      0               1
   -0.1634018                      1               0
   -0.1623925                      1               1
   -0.1082471                      2               0
   -0.1106234                      2               1


        FREQUENCY     RANGE    29.0000     TO     45.0000
      ECCENTRICITY    RANGE    0.          TO      0.3000
                END OF EVALUATION FOR ONE SET OF ANGLE
```

```
DATA IN A FORM SUITABLE FOR USE WITH XFSC CALIBRATION SECTION
CPS    MIC  BETA ROT    VA     VA     HA     HB     QA     QB

 29.0.2000 95.0SAME1 -2.71 -0.41 -0.73  1.82 -1.04  4.18
 29.0.2000  0. OPP 2 -2.36 -3.49  0.01 -0.00  0.20  0.12
 29.0.2000 96.0OPP 2  0.80 -2.93 -0.94  2.08 -4.04  5.95


 31.0.2000 95.0SAME1 -2.73 -0.53 -0.70  1.93 -1.14  4.51
 31.0.2000  0. OPP 2 -2.12 -3.65  0.01  0.01  0.16  0.13
 31.0.2000 96.0OPP 2  0.87 -2.84 -0.93  2.16 -4.31  6.16


 33.0.2000 95.0SAME1 -2.78 -0.63 -0.69  2.05 -1.24  4.84
 33.0.2000  0. OPP 2 -1.95 -3.77  0.01  0.02  0.13  0.12
 33.0.2000 96.0OPP 2  0.95 -2.78 -0.94  2.27 -4.59  6.42


 36.0.2000 95.0SAME1 -2.88 -0.73 -0.73  2.27 -1.39  5.32
 36.0.2000  0. OPP 2 -1.78 -3.90  0.01  0.02  0.12  0.08
 36.0.2000 96.0OPP 2  1.04 -2.76 -1.00  2.46 -5.05  6.86


 39.0.2000 95.0SAME1 -3.03 -0.77 -0.81  2.53 -1.54  5.79
 39.0.2000  0. OPP 2 -1.74 -3.95  0.02  0.01  0.17 -0.01
 39.0.2000 96.0OPP 2  1.13 -2.81 -1.12  2.69 -5.56  7.38


 42.0.2000 95.0SAME1 -3.24 -0.76 -0.95  2.82 -1.70  6.24
 42.0.2000  0. OPP 2 -1.82 -3.93  0.04 -0.01  0.25 -0.14
 42.0.2000 96.0OPP 2  1.21 -2.93 -1.29  2.95 -6.10  7.97


 45.0.2000 95.0SAME1 -3.49 -0.69 -1.14  3.15 -1.86  6.67
 45.0.2000  0. OPP 2 -2.02 -3.83  0.06 -0.05  0.38 -0.31
999.9.2000 96.0OPP 2  1.28 -3.12 -1.52  3.26 -6.69  8.65
```

```
MODEL NO    TEST NO     BLADES   DISP   PROP LOC      RUDDER
 4287          1234        4.     100.0    5.00 DIA     NONE


       PRINT OUT OF TEST RUN RECORDINGS
RUN    SPEED    RPM     FREQ  GAIN    VA     VB     FREQ  GAIN     HA     HB     FREQ  GAIN     QA     QB
 11    3.600   435.     29.0  G4G4   0.    -0.39    29.0  G4G4    1.44  -1.00    29.0  G4G4  -4.12  3.55
 12    3.830   465.     31.0  G4G4   0.10  -0.35    31.0  G4G4    1.49  -1.03    31.0  G4G4  -4.17  3.60
 13    4.010   495.     33.0  G4G4   0.15  -0.30    33.0  G4G4    1.80  -1.05    33.0  G4G4  -5.36  3.85
 14    4.100   540.     36.0  G4G4   0.13  -0.25    36.0  G4G4    2.19  -1.09    36.0  G4G4  -6.29  4.35
 15    4.370   585.     39.0  G4G4   0.09  -0.28    39.0  G4G4    2.18  -1.11    39.0  G4G4  -6.84  4.71
 16    4.640   630.     42.0  G4G4   0.13  -0.34    42.0  G4G4    2.09  -1.35    42.0  G4G4  -6.90  4.75
 17    4.970   675.     45.0  G4G4   0.20  -0.32    45.0  G4G4    2.20  -2.10    45.0  G4G4  -6.45  4.48
RUN    SPEED    RPM        VA     VB     HA     HB     QA      QB
 11    3.600   435.        0.05  -0.39   1.37  -1.10  -3.76    3.37
 12    3.830   465.        0.07  -0.34   1.62  -0.99  -4.66    3.73
 13    4.010   495.        0.09  -0.31   1.82  -0.95  -5.41    4.02
 14    4.100   540.        0.12  -0.28   2.05  -1.00  -6.23    4.36
 15    4.370   585.        0.14  -0.28   2.18  -1.19  -6.70    4.57
 16    4.640   630.        0.16  -0.30   2.21  -1.52  -6.81    4.64
 17    4.970   675.        0.17  -0.34   2.15  -1.98  -6.57    4.59
```

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A very brief description is given of a technique which involves the use of elastical isolation of the model stern to evaluate propeller-excited vibratory forces on models. The method of analyzing the results obtained in the experiments is given in detail and its application is illustrated by an example.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Propeller-excited vibratory forces						
Influence Coefficients						
Response Coefficients						
Force Coefficients						
Propeller forces						
Use of response data directly in analysis						
Use of response data with minor adjustments						
Use of manually faired calibration data						
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