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AERODYNAMICS LABORATORY
WASHINGTON 7, D.C.

# NOTES ON THE DESIGN, CALIBRATION, INSTRUMENTATION, AND MAINTENANCE OF STRAIN-GAGE BALANCES

by

Robert B. Ormsby, Jr.

November 1953

Aero Report 854

# NOTATION

| | |
|---|---|
| psi | pounds per square inch |
| fs | fiber stress |
| M | moment |
| y | distance from neutral axis to outermost fiber |
| I | section moment of inertia |
| b | width of beam |
| h | height of beam |
| E | Young's Modulus |
| $\delta$ | linear deflection |
| $\mu$ | micro or $10^{-6}$ |
| R | resistance |
| PM | pitching moment |
| NF | normal force |
| SF | side force |
| YM | yawing moment |
| RM | rolling moment |
| AF | axial force |
| $\Delta$PMR | net change in pitching moment meter reading |
| $\Delta$AFR | net change in axial force meter reading |
| $\Delta$NFR | net change in normal force meter reading |

## TABLE OF CONTENTS

## TABLE OF CONTENTS (CONCLUDED)

Aero Report 854

AERODYNAMICS LABORATORY
DAVID TAYLOR MODEL BASIN
UNITED STATES NAVY
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# NOTES ON THE DESIGN, CALIBRATION, INSTRUMENTATION, AND MAINTENANCE OF STRAIN-GAGE BALANCES

by

Robert B. Ormsby, Jr.

## SUMMARY

This report presents a compilation of information for the use of strain gages on wind-tunnel sting balances. Design criteria, gage application instruction, troubleshooting guides, calibration techniques, and indicating equipment are discussed.

## INTRODUCTION

Since the Supersonic Wind-Tunnels Branch of the Aerodynamics Laboratory has performed more or less continuous experimentation on strain-gage balances for about four years, a large amount of information concerning the design, construction, and calibration of such balances has been compiled. It is believed that the general release of this information will be of service to others who are encountering the same problems for the first time.

It will be assumed that anyone concerned with the design of strain-gage balances will be at least familiar with the theory and elementary equations of stress, elongation, etc. contained in Reference 1.

The strain gages referred to in this report are all Baldwin-Southwark products and are available from Baldwin-Lima-Hamilton Corp., 940 Simpson Street, Eddystone 42, Pennsylvania. The strain indicators are likewise all standard production items manufactured by Foxboro for Baldwin.

Reference 2 has introductory information about strain gages but does not contain too much useful material. Reference 3 contains instructions on how to apply all types of Baldwin strain gages and should be required reading for anyone who is applying gages for the first time. The instructions are not directed toward any specific strain-gage application. This report refines these instructions as they apply to strain-gage balances. Reference 4 contains a price list of all Baldwin gages together with pertinent information such as dimensions, gage factors, and type of cement required for each gage.

## MECHANICAL FEATURES

STRAIN GAGES -- The strain gages used are all Baldwin AB-7's, AB-11's, or AB-19's. These are bakelite gages, recommended for long life and stability. A note of caution concerns the use of the AB-19 gage in that it should never be used unless absolutely required by space limitations. It is not so reliable as other gages which are larger. If the AB-19 must be used, it should be used in pairs in each leg of the bridge so that the total bridge resistance is 120 ohms. If the bridge voltage can be halved, this arrangement is unnecessary, and four AB-19's can be used in a bridge.

Generally the AB-11 is more desirable than the AB-7 for the majority of strain-gage balance work because the length of the winding is somewhat shorter. However, the AB-7 is narrower, so the choice reduces to whether length or width is critical. See page 4 for some discussion of paper gages.

ADHESIVES -- The bakelite gages as received from Baldwin include the necessary bakelite cement. This cement requires a six-hour baking cycle with five different temperatures. See Table 1. Furthermore, the gages must be clamped with 125 pounds-per-square-inch pressure while baking.

The Baldwin cement further exhibits the disagreeable property of deterioration with age. When kept under refrigeration, it may remain usable for a year. A deterioration is apparent by inspection in that the caramel-like crystalline appearance changes to that of dark molasses. When the cement has reached this condition, it should be discarded since its holding properties are extremely poor. A balance which had gages cemented on with overage cement promptly lost about half of them during the shock of starting and stopping a supersonic blow.

It might be pointed out that the cement is normally sent with the gages, and its holding power is directly proportional to how long it has remained unrefrigerated in supply channels before being received.

To overcome some of the disadvantages of the Baldwin cement, all gages applied by the Supersonic Wind-Tunnels Branch are bonded with a new adhesive manufactured by the Shell Chemical Corporation, 500 Fifth Avenue, New York, N. Y. It is Epon VI with curing agent A. This is an epoxy resin of which many varieties are marketed. Armstrong's A-1 is indistinguishable from Epon VI by visual examination. These epoxy resins require but forty-five minutes at one temperature and only enough pressure to keep the gages lying flat during the baking. They, furthermore, do not deteriorate with age and require no refrigeration.

Baldwin manufactures gages which are similar in size to the AB series but have a paper base. Typical paper gages are the A-7, A-11, A-19 which are dimensionally similar to the same numbered AB gage. The paper gages are cemented with nitrocellulose cement, a popular example of which is Duco Household Cement. Baldwin markets a similar cement which is somewhat more fluid. Paper gages are relatively inexpensive and are used principally for short experimental purposes since they are not as durable as bakelite gages. A more unusual adhesive is DeKhotinsky cement. It is temperature sensitive, melting and solidifying at about 290°F. It has the advantage of speed of application. If a beam is heated to 300°F, the cement may be melted on, the gage clamped, the beam cooled, all in about five minutes. The gage is ready for wiring and calibration. For a further use of this cement see pages 24 and 25.

## BEAM MATERIAL

The material from which a strain beam is to be made deserves more than casual interest. If the material is steel, it should be one which can be heat treated to a hardness of Rockwell C 35 or better, if good stability and repeatability are to be obtained and retained. Stainless steels are exceedingly poor in this respect with the exception of CRES-5 which can be heat treated to some extent. The principal reason for heat treating is to avoid fatigue failure and hysteresis, which manifests itself by a residual strain in the beam after the load is removed.

Since few aluminum beams have been designed by the Supersonic Wind-Tunnels Branch, no experience is available for comment.

## BALANCE DESIGN

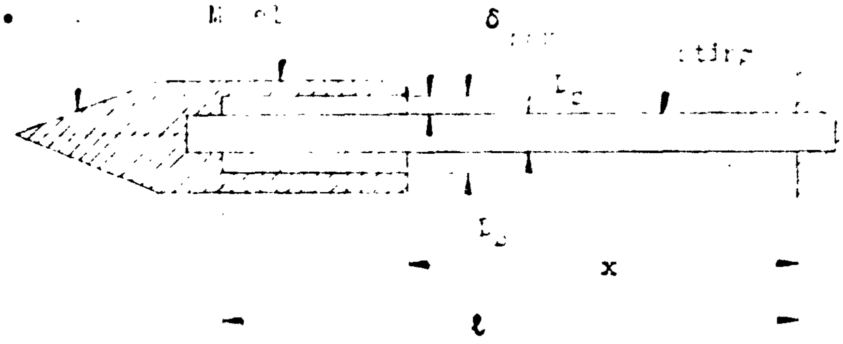
The first design note concerns the undesirability of a bolted-together strain-gage-beam assembly. It is generally best to machine the entire balance out of solid material, or, failing in that, silver solder or braze the elements together. The objection to a bolted-together device is that very subtle changes in the relative placement of two pieces appreciably alter what is considered, for design purposes, a fixed restraint. Where screwed-together fabrication is the only method available, great care in designing connections with emphasis on tapered fits or extra fine threads is absolutely necessary for good results.

FIBER STRESS -- One initial question to be settled in strain-gage balance design is the value of fiber stress to be used. It has been found satisfactory to design for a fiber stress that will give an elongation of between 600 and 700 micro inches per inch. This makes the fiber stress about 20,000 psi in steel and 6,600 psi in aluminum. Knowing the design moment and fiber stress, the area of the cross section of the beam may be found by

$$fs = M \frac{y}{I} \quad \text{and} \quad I = \frac{bh^3}{12}$$

Since by definition, deflection of a loaded beam must occur in order to produce the fiber stress, the order of magnitude of the deflection must be considered. If a sting balance is to pass through the base of a model, there must be sufficient clearance to allow for deflection of the balance under load without fouling; that is, the sting must not contact the base of the model. This deflection changes the angle of attack and yaw, but is easily calibrated and has been found to be no source of error in data reduction.

Since the condition of the sting hitting the model base under large loads may limit the allowable angle of attack or yaw, it is desirable that an optimum condition, if any, be determined.



$D_S$ diameter of sting over distance $\ell - x$

$D_B$ diameter of hole in model base

$\delta = \frac{Px^2}{6EI}(3\ell - x)$ Reference 1 p. 170 Eq. 1

$$I = \frac{\pi D_S^4}{64}$$

Although it will become apparent that these dimensions are not factors affecting the final result, x and $\ell$ are measured from the point of restraint of the sting, usually the quadrant barrel. P is the normal force.

Obviously the maximum allowable deflection is given by

$$\delta_{max} = \frac{D_B - D_S}{2}$$

$$\frac{D_B - D_S}{2} = \frac{64Px^2}{6\pi D_S^4 E}(3\ell - x)$$

$$D_S^4(D_B - D_S) = \frac{64}{3\pi E}(Px^2)\quad(3\ell - x)$$

$$P = \frac{3\pi E\ (D_B D_S^4 - D_S^5)}{64x^2\ (3\ell - x)}$$

$$\text{if } \frac{3\pi E}{64x^2(3\ell - x)} = k$$

$$P = k\ (D_B D_S^4 - D_S^5) = k\ D_B D_S^4 - k\ D_S^5$$

To maximize P we differentiate with respect to $D_S$ and set $dP/dD_S = 0$.

$$\frac{dP}{dD_S} = 4kD_B D_S^3 - 5kD_S^4 = D_S^3(4kD_B - 5kD_S)$$

$$D_S^3\ (4kD_B - 5kD_S) = 0$$

$D_S{}^3 = 0$ is the obvious minimum

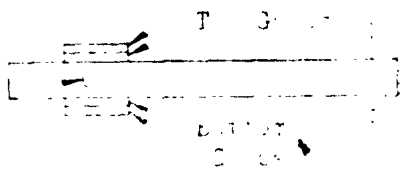
$4kD_B - 5kD_S = 0$ is the maximum

$$D_S = \frac{4}{5} D_B$$

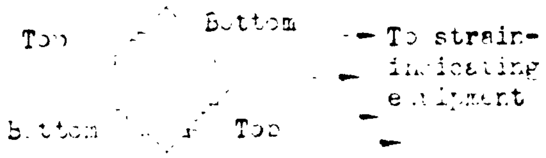
This points out that a given model and sting combination will carry the largest normal force without fouling if the sting diameter is four-fifths the diameter of the hole in the model base. A similar investigation for an applied moment using the moment-deflection equation, $\delta_{max} = \frac{M\ell^2}{2EI}$ shows that the optimum ratio of sting diameter to base-opening diameter is again four to five.

INDIVIDUAL COMPONENTS

Pitching Moment -- The measurement of moments presents the most obvious application of strain gages to a balance system. When four gages are "stacked", good sensitivity is obtained. The moment center will be the electrical center of the four gages.



Moment center will be in this region.



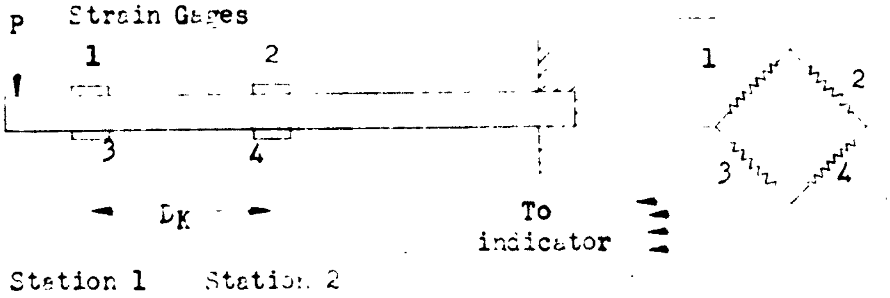
Wiring Schematic Diagrams

The chief disadvantage of this system is that it may not be possible to locate the gages near the desired moment reference point, which is usually the center of gravity of the prototype. This may necessitate a long transfer arm with the result that inherent inaccuracies in the associated forces to be transferred will cause the transferred data to "scatter". This becomes worse as the transfer arm is lengthened.

A method of reading moments about a point inaccessible to strain gages will be discussed later.

It is well to note here that an SR-4 strain indicator is calibrated for one active gage. A four-active-gage bridge will give a reading of four times that computed by $fs = M \frac{y}{I}$.

Normal Force or Side Force (Constant-Section Beam)-- The method of reading normal force or side force directly is not as immediately obvious as the above method for moments. There are many ways of building mechanical linkages that will separate the desired forces from moments. Nevertheless, the most satisfactory to date has been a method of applying gages to a simple beam such that the difference of two readings is taken electrically.



The principle of this scheme is that the difference of two moments at two stations is taken. It will be seen that the difference of two moments is directly proportional to the applied force, P. Practically for this to work, the two stations must have equal section characteristics, I/y, and matched gages. If the section characteristics are not equal or if the gages are not matched, the beam will be sensitive to the applied moment. However, this moment interaction probably will be much less than the interaction of a mechanical linkage.

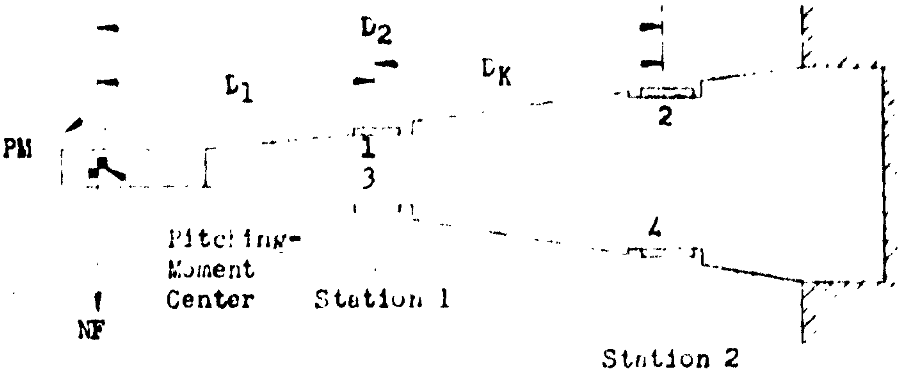
The normal-force sensitivity, or calibration constant is given by:

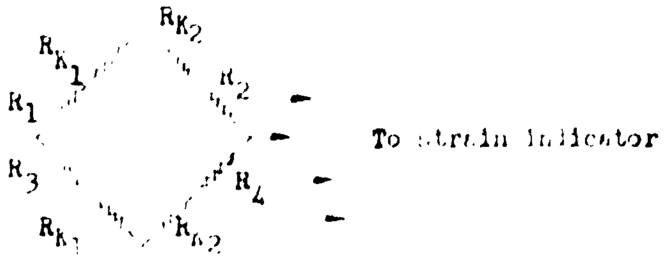
$$\text{SR-4 meter reading in } \frac{\mu\text{ inches}}{\text{inches}} = \frac{2(10^6)}{E}(NF)\,\frac{y}{I}D_K$$

where E is Young's Modulus, y/I is the section property already determined, and $D_K$ is the distance in inches between the forward and aft pairs of gages. NF is, of course, the normal force.

Pitching Moment or Yawing Moment About an Arbitrary Point -- Since for many model-balance installations, the moment gages cannot be placed at the moment reference point, necessitating a transfer, it may be advantageous to utilize a method locating the moment-resolving center at an arbitrary point. The chief disadvantage of this method is that the moment sensitivity drops markedly. Therefore, such a scheme will not be applicable in all cases. But when it can be used, the moment data will be considerably improved.

Since the derivation of the equations governing the design of a beam with the pitch center at an arbitrary point is not of interest generally, only the final equations are included. They have, however, been verified by experiment.





Subscripts 1 and 2 refer to Stations 1 and 2. The section properties y/I at each station are chosen so that the fiber stresses produced by a normal force at the pitching-moment center are equal. That is, $y_1/I_1$ and $y_2/I_2$ are chosen so that $fs_1 = fs_2$ when the balance is loaded by a normal force applied at the pitching-moment center.

The general equation is

$$\text{SR-4 meter reading} = \frac{2(10^6)}{E}(PM)\left\{\frac{y_1}{I_1}\,\frac{R_1}{(R_1+R_{K_1})} - \frac{y_2}{I_2}\,\frac{R_2}{(R_2+R_{K_2})}\right\}$$

The above equation is for the general case, but the equations for the specific instance where it is desired to move the pitch center forward are simplified from the above by setting $R_{K_2} = 0$.

$$\text{Meter reading} = \frac{2(10^6)}{E}(PM)\,\frac{y_2}{I_2}\,\frac{D_K}{D_1}$$

$$R_{K_1} = R_1\left\{\frac{D_1}{D_2}\left(\frac{y_1}{I_1}\Big/\frac{y_2}{I_2}\right) - 1\right\}$$

Similarly to move the pitch center aft, $R_{K_1} = 0$.

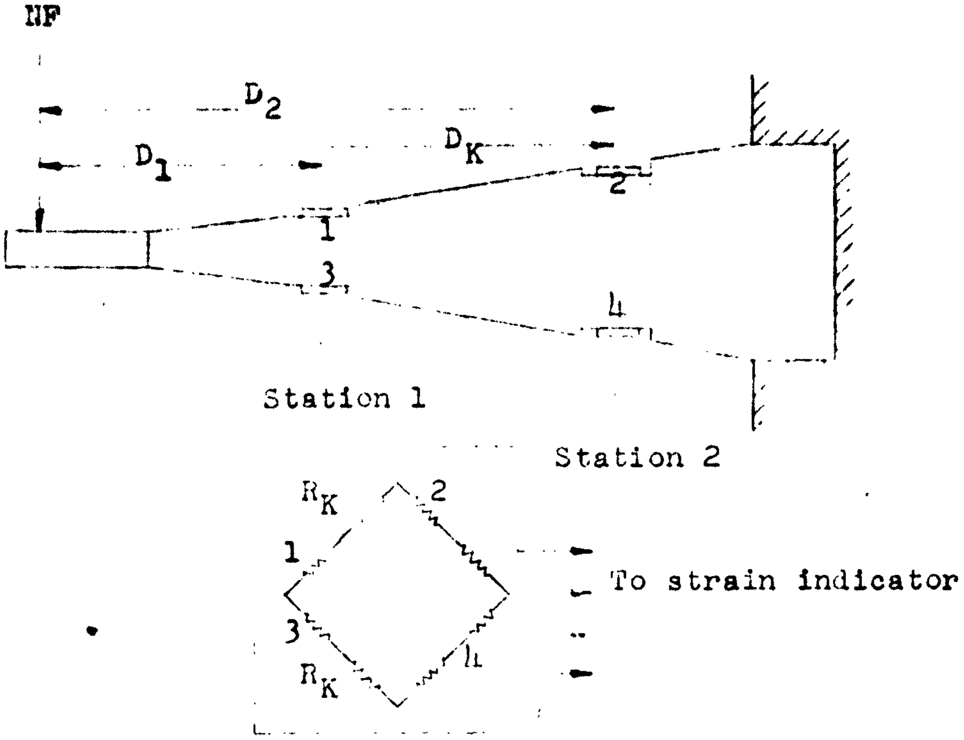
$$\text{Meter reading} = \frac{2(10^6)}{E}(PM)\,\frac{y_1}{I_1}\,\frac{D_K}{D_2}$$

$$R_{K_2} = R_2\left\{\frac{D_2}{D_1}\left(\frac{y_2}{I_2}\Big/\frac{y_1}{I_1}\right) - 1\right\}$$

The above equations give the exact value of resistance needed to move the moment center either forward or aft and, in addition, give the meter sensitivity. An indicator which is not calibrated in microinches per inch like the Baldwins can be so calibrated with the result that the above equations can be used.

Some general information may be verified by making the proper substitutions in the equations. If a beam is of constant cross section and $R_K = 0$ ohm, the moment-resolving point is at infinity; hence, normal force will be read. The most sensitivity to moment for a given moment-center location will result when $R_K = 0$, and the beam is tapered so that any force applied at the desired moment center produces equal fiber stress at Stations 1 and 2. It may be noticed that the sensitivity will increase as the moment center is moved closer to Station 1 by increasing $R_K$, but in each case still more sensitivity will result if the beam is tapered for the new resolving point.

Normal Force on Tapered Beams -- In cases where it is desirable to locate the force gages on the same tapered sections as the moment gages, it is possible to do so by adjusting $R_K$ as shown



The equation for the general case of a tapered beam is:

$$\text{S.-4 Meter reading, } \frac{\mu \text{ inches}}{\text{inch}} = \frac{2(10^6)(NF)}{E}\left(D_1 \frac{y_1}{I_1} \frac{R_1}{R_1+R_K} - D_2 \frac{y_2}{I_2}\right)$$

which, in terms of $D_K$, reduces to

$$\text{Meter reading} = \frac{2(10^6)}{E}(NF)\frac{y_2}{I_2} D_K$$

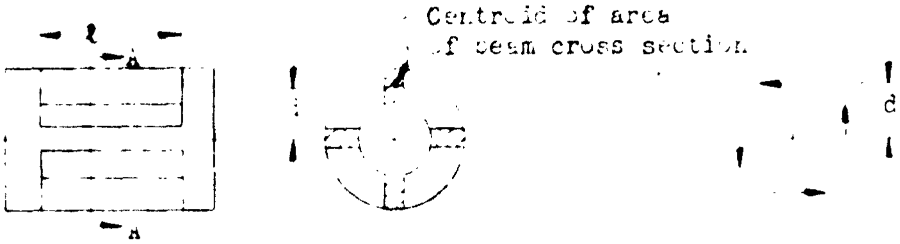
The above equation is used for the design of non-tapered beams since only the section properties at Station 2 and $D_K$ appear. When this equation is used for a tapered beam, the following equation gives the value of $R_K$ necessary to make the bridge insensitive to moment.

$$R_K = R_1 \quad \left(\frac{y_1}{I_1}\Big/\frac{y_2}{I_2}\right) - 1$$

In all cases the sensitivity of a normal-force beam varies directly as the distance between stations and inversely as the I/y at Station 2.

Rolling Moment -- Two general schemes for reading rolling moment are employed. The first is a small cage which is a part of the beam used to read forces and moments. In some cases, the rolling moments are so high that an external roll unit is used.

The simplified design criterion for cage-type roll units is as follows:



In the above diagram it is seen that a rolling moment is restrained by four equal forces. The value of the force F, is given by:

$$4Fd = \text{design rolling moment, or } F = \frac{RM_{design}}{4d}$$

The design equations then are:

$$\text{Maximum moment} = \frac{F\ell}{2} \text{ (occurs at ends of beam)}$$

$$\delta_{max} = \frac{F\ell^3}{12EI}$$

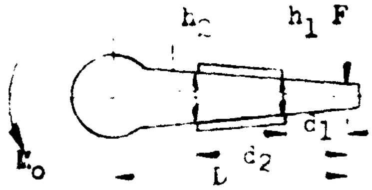
The above moment can then be used in $fs = M\frac{y}{I}$ to determine $\frac{y}{I}$.

After the design is completed, the unit must be checked to ensure that it will carry the other forces and moments.

The above method makes several simplifying assumptions, the principal one being that the beams are not torsionally stressed.

When the loads on a balance are likely to be large, a ball-bearing-type roll unit is employed. The ball bearings restrain all forces and moments except rolling moment which is restrained by a cantilever beam having strain gages attached. The over-all scheme is identical to that by which most hinge moments are measured on various surfaces such as elevators, rudders, etc.

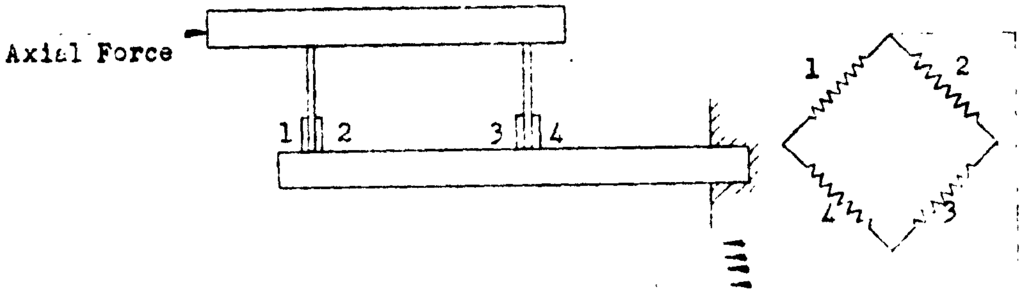
The design of the sensing beam is quite simple



If a moment, $M_o$, is applied to the beam, it is restrained by a force, F, such that $Fd = M_o$. Knowing F and $h_1$, $h_2$ may be determined by $fs = M\frac{Y}{I}$, since $M_1 = Fd_1$ and $M_2 = Fd_2$, the thickness is known and is constant. The region $d_2 - d_1$ is occupied by the gage itself. A quick check is necessary to show that the minimum cross section is sufficient to carry the shear due to load F.

Axial Force -- Before proceeding with the details of the latest axial-force unit now in use, it is well to examine more commonly used ideas.

The most simple design is one that usually occurs to someone who is designing an axial-force unit, thus:

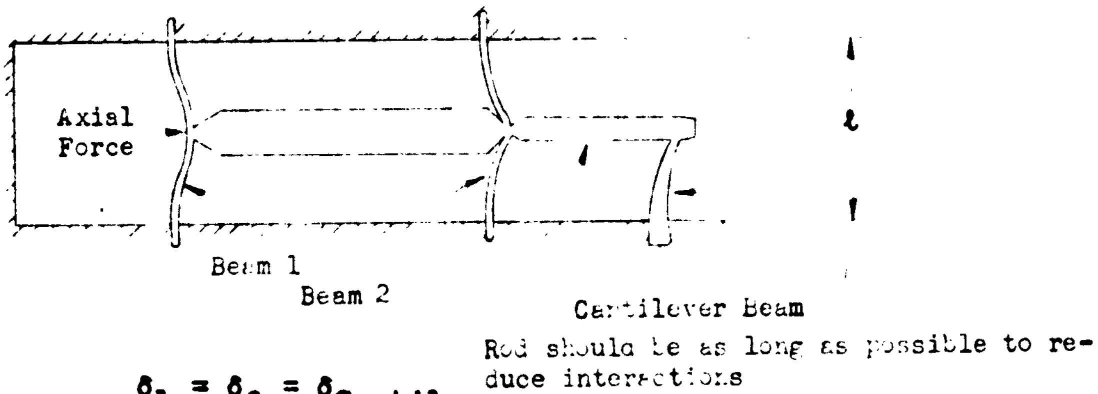


The resulting interactions usually preclude satisfactory use of such a unit.

In an endeavor to eliminate the interactions, the author designed a unit which has worked satisfactorily. See Figure 1 and sketch on page 17. The model is mounted on the one-inch-diameter member that connects the webs. All loads except axial force are carried by the webs as shear or direct tension and compression. Axial force produces bending in the webs. The axial motion is transmitted by the rod to the cantilever beam to which strain gages have been cemented. The rod is prestressed in tension upon assembly by an amount greater than the maximum design axial force. This prevents compression buckling as well as "oil canning" as the axial-force sign changes. A stiffener has been added to make the supporting structure more rigid. The stiffener must not touch the member that supports the model nor the tension rod. The interactions of this unit are lower than for any other scheme for reading axial force attempted by this facility. Currently, investigations are under way to evaluate different transducers to replace the strain gages so that a 5/8-inch-diameter unit may be practical.

The transducers under consideration are of the linear-motion differential-transformer type and of the unbonded strain-gage type exemplified by the Statham model G14-16-150.

The design procedure is to solve for the stresses in the cantilever beam thus:



$$\delta_1 = \delta_2 = \delta_{\text{Cantilever}}$$

$$\delta_1 = \frac{F_1 \ell^3}{192EI}, \quad \delta_2 = \frac{F_2 \ell^3}{192EI}, \quad \delta_{\text{cantilever}} = \frac{F_3 (\frac{\ell}{2})^3}{3EI}$$

$$F_1 + F_2 + F_3 = \text{Design axial force}$$

Since Beams 1 and 2 are identical and $F_1$ can be assumed equal to $F_2$, the structure can be solved by two simultaneous equations:

$$\frac{F_1 \ell^3}{192EI} = \frac{F_3 (\frac{\ell}{2})^3}{3EI}$$

$$2F_1 + F_3 = \text{Design axial force}$$

Knowing $F_3$ the design of the beam is identical to the method on page 16 for cantilever beams.

It should be noted that there is a patent pending on this unit.

## PRACTICAL CONSIDERATIONS

**Application of Gages** -- All gages are applied in accordance with the instructions received with the cement. Tables of baking times, etc, appear in Table 1.

There are some points of interest that have been verified by experience. In a given strain-gage bridge, all gages should have the same or nearly the same gage factors in order to avoid undue sensitivity to temperature. Matching of resistances is desirable so that all meters or indicators will balance at approximately the center of the scale.

After matching gages, the next step is trimming to proper dimensions. After trimming it is desirable to check resistance. In fact, after every operation during which a gage could be damaged, it is wise to check resistance so that the time and trouble of mounting and wiring gages will not be wasted.

If the cement used is of the epoxy resin type, it, of course, must be mixed prior to using. Hardening begins immediately after mixing, and although it can be used for several hours after mixing it cannot be mixed one day and used the next.

Since the gages must be clamped while the cement is setting, some attention must be paid to the preparation of the clamps. As is pointed out in Reference 3, a pressure from 100 to 200 pounds per square inch is desirable and above 25 pounds per square inch is mandatory. For the epoxy resins, only enough pressure to ensure the gage lying flat is necessary; but, in either case, the pressure should be transmitted to the gage through a rubber pad in order to avoid uneven pressure on the gage.

The gages and beam must be entirely free of any grease or dirt and therefore should be cleaned with acetone or an equivalent solvent. After being cleaned, the gages and beam must not be touched.

In the case of the bakelite gages and cements, it is easy to apply too much cement, particularly if previous experience has been with paper gages and nitro-cellulose cement. The bakelite gages do not absorb cement while a paper gage does.

During the application a little attention to keeping the gage leads free and out of the cement will save hours later on.

Probably the most annoying phase of gage application is the application of the spring clamps. At this point the gages are likely to slide not only to some undesirable location but completely off the beam. Good design of clamps will obviate this, and a clamp which is firmly attached to the beam at some other point will not allow the gage to slide as the pressure is applied.

Baking for proper cycle is important. See Table 1 for recommended baking cycles of common adhesives. Upon removal from the oven, the bridge circuits should be checked for high resistance (over 30 megohms) between the gages and the beam. If the resistance is less than 10 megohms, the stability of the bridge will not be good.

When the actual wiring of a six-component balance is begun, careful planning as to the scheme of wiring will be worth while. After haphazardly wiring three of the six components, the remaining wiring will be bulky and very untidy. The wiring must be arranged so that a direct pull on the wires does not exert a pull on the gage leads.

An additional note concerns provision for getting the wires or strain-gage leads out of the balance. Frequently too little thought is given to this point. Although stranded wire is undesirable since individual strands may break, the flexibility and small size makes its use almost mandatory. The wire used is REX "NONSTRIP" WIRE TYPE JR, AWG 30, WHITE and has an over-all diameter of 0.02 inch. It is manufactured by Rex Corporation at Cambridge, Massachusetts. Colored wire can be obtained in lengths of 25,000 feet. However, since the white wire may be dyed with a plastic dye to facilite coding of components, etc., only white wire has been ordered. The dye is obtained from FRY PLASTICS, Los Angeles, California.

Table 2 shows the absolute minimum space required for mounting various gages. Also indicated is the desired minimum, the difference being that if absolutely necessary the gages can be mounted on the smaller space, but wherever possible the larger space should be provided in order to make the task of mounting gages easier.

**Waterproofing** -- After wiring, the next step is waterproofing. If the gages are paper, waterproofing is absolutely necessary where stability for several days is required; if the gages are bakelite, waterproofing is necessary only if they are to be used over a period of months. But the general performance will be improved noticeably if they are waterproofed.

A word of caution is necessary here concerning a deleterious effect of waterproofing. If the gages are mounted on a thin web, say 0.030 inch thick, a heavy coating of a waterproofing material will cause a calibration to display the symptoms of friction. The reason is that the waterproof coating is as thick as the metal the gages are mounted on, or thicker, and will carry a portion of the stress. But being plastic rather than elastic, the waterproofing will not allow the beam to return to zero and will restrain it slightly. On a beam made of steel and having a cross section of about 1/2 by 1/2 inch, or larger, a 1/16-inch coating will not carry any calculable portion of the load. The above point will influence to some extent the choice of a waterproofing agent.

Various waterproofing agents have been tested to determine ease and speed of application, resistance to water, complexity of application techniques, and effect on gage reading repeatability. See Table 3.

Shellac has the advantage of being suitable for very thin applications on very thin beams. As is to be expected, the thin waterproofing is not as impervious to water as the thicker applications.

A final point is: Never apply waterproofing materials unless the gages are thoroughly dry. To ensure initial dryness, immediately before application of any waterproofing compound, heat the beam to a temperature which is sufficiently high to drive off any moisture but which will not damage the wiring insulation.

Final Checking -- After completion of waterproofing, the balance should be checked for proper resistance of each leg of each bridge and for very high (preferably above 30 megohms) resistance from gage to beam.

The completed gage circuits should be connected to a sensitive strain indicator. If the reading on the indicator is constant over a period of five minutes after allowing sufficient time for gages and meter to warm up and if the initial reading repeats after the beam is hand loaded in each direction, the beam may be calibrated.

## BALANCE CALIBRATION

Calibration-Stand Design -- The design of a calibration stand should include consideration of the following details:

Deflections of the stand should be at a minimum.

The weights should be easily stacked and unstacked.

Any pulleys should have as little friction as possible.

A stranded wire in tension will tend to twist if it is restrained from doing so, thereby exerting a moment on the balance. This occurs when the wire is passed over a pulley.

The point at which weights are applied must be known exactly.

The angle that a balance assumes under a given load must be known and provision made for relevelling, after each load application, the part of the balance which carries the model. In addition, the angular change of the balance support platform must be determined. This is easily done by using a gunner's quadrant.

Provision for rolling the balance must be included. There are two reasons why this is so. First, the balance must be level in roll so that applied normal force is normal to the balance; and second, if combined normal force and side force are to be applied, this is most easily done by rotating the balance and applying one load.

Provisions should be designed into the calibration stand for raising or lowering the balance support with respect to the loading wires in the event that a balance having a mounting axis appreciably above or below the loading axes must be calibrated.

Interactions -- If interactions are to be determined accurately, only pure forces and moments should be applied. For moments this is done by applying equal up and down loads at separate stations so that the total normal force is zero at all times. Similarly when normal force, for instance, is applied, it should be applied at the pitching-moment center so that the resultant moment is zero.

Unfortunately there is no accurate analytic method for predicting interactions. The only certain way is to build a given unit and try it. However, there are several general design points which will reduce interactions. Two of these points apply to actual design of the balance structure itself, while two are external to the balance and enable further improvement when necessary.

If two (or four) gages are placed on a beam or structure so that when they are wired together in a circuit the gage outputs cancel each other when loaded by an undesired force but add to give a desired indication, the interactions are then eliminated by cancellation. The most elementary example of this is a two- or four-gage bridge mounted on a beam for reading pitching moment. If the beam is loaded axially all the gages are stressed in the same direction, whereas pitching moment stresses the top gage(s) oppositely from the bottom one(s). Therefore, a Wheatstone bridge would have no unbalance due to the axial force, but would indicate only the pitching moment.

Since gage location frequently has quite an effect on interactions the following method will aid in reducing interactions by allowing the gages to be moved and recemented. Bakelite gages put on with the previously mentioned deKhotinsky cement can be moved by reheating the beam and slipping the gages to a new location determined by the results of the calibration. This has been done as many as five times after which the deKhotinsky cement was removed and the gages cemented with Epon VI. The calibration performed while the gages were attached with the deKhotinsky cement was normal in every respect, there being no extraordinary zero shifts or irregularities in calibration. As a matter of interest, if a gage application is desired in a hurry, deKhotinsky cement is the fastest method since, as soon as the beam cools, it is ready for use.

As the name implies, structural separation removes interactions by allowing only the desired force or moment to stress the strain gages. The best example of this is the external roll unit in which the ball bearings carry everything but rolling moment which is restrained by the rolling-moment beam.

If normal force, say, causes an interaction into axial force, it may be electrically cancelled by "bleeding" or shunting a small portion of the normal force signal and injecting it into the axial-force circuit so that it "bucks" or cancels the interaction signal in the axial-force circuit. So far this method has not been tried at TMB, but the NACA at Langley Field has used it. Direct current must be used for this scheme.

If the interactions are linear, the correction consists of multiplying a constant by the interacting component and subtracting the result from the desired component.[6] The constant used is the slope of the interaction curve plotted so that the ordinate is indicated reading on one component due to the load applied on another component which is plotted as the abscissa. See the section on calibration procedure.

If an interaction is non-linear, the corrections must be taken from a curve keeping in mind the following point. As the model configuration is changed, the change in weight of the model will shift the initial point on the interaction curve causing a different value of interaction to be read for a given load increment. Since the interaction corrections become very complex if non-linear, balance units are rejected if the interactions are non-linear.

Calibration Procedure -- Calibrating a balance gives the following information, all of which is necessary for accurate reduction of the data: (1) the calibration constant for each component, (2) the interactions between components, (3) the location of the moment-resolving centers of the moments, and (4) the angular deflections due to various loads.

The actual calibration can best be described as a series of steps.

1. Check meter sensitivity and attach and balance Wagner ground if necessary. (Use calibration box for sensitivity check.) See page 31.
2. Level balance in the pitch plane with a precision level.
3. Roll the balance until the yawing-moment meter gives no indication when a large pitching moment is applied. This levels the balance in roll. If a large pitching-moment

interaction into normal force exists, this is not a proper method.

4. Apply a large normal force at various longitudinal stations. The station at which the pitching-moment meter remains stationary when the normal force is applied is the pitching-moment center. Measure and record this point. Unless it is known that the yawing-moment center is more than a quarter of an inch away, there is no need to similarly locate the yawing-moment center since such a misalignment will merely result in a nominal interaction of side force into yawing moment.

5. Make sure that all devices for hanging weights are not bent or damaged so that it is certain the weights are being applied at the proper point(s).

6. Set all meters to proper gage factor which will be the gage factor that was used in Step 1.

7. Check all pulleys to make sure that they are friction free as far as possible.

8. Make sure all components are connected with the proper sign: if positive normal force is applied, a positive reading occurs on the meter.

9. At the pitching center, apply normal force, both positive and negative. Read all meters and angle indicator. See Figure 2. If an axial-force unit is included in the balance, the balance must be exactly level as each reading is taken, otherwise a component of normal force will be read on the axial-force meter and incorrectly attributed to interaction.

10. Apply positive and negative pitching moment, making sure that there is no resultant normal force. The obvious way to accomplish this is by applying equal up and down loads. Level and record angular deflection after each load.

11. Calibrate side-force and yawing-moment components in the same manner as normal-force and pitching-moment components making sure that yaw-angle change is recorded.

12. Calibrate rolling-moment component, again by application of equal up and down loads applied at equal distances from the balance center line. The change in roll angle due to rolling moment is usually so small that no determination of it is necessary.

13. Calibrate axial-force component. This is the one component where any angle determination is meaningless. If the applied force is not exactly coaxial with the balance center line, some interactions will be read on other components. The general finding is that actual axial force does not cause interaction with any component and any readings on other meters are disregarded.

Computation Procedure -- The method of data reduction for a balance calibration depends principally on the techniques involved during the actual application of weights. The method that follows is related to the preceding instructions.

The sample data shown are for a three-component balance but the principles are the same for any number of components. If an SR-4 indicator is used without auxiliary equipment, the zero, or load-off readings, will be of the order of 10,000. Thus it is necessary to subtract the initial reading from the subsequent load-on readings to obtain the net difference due to load. If a zero-shifter circuit is connected, the initial reading is set to exactly 10,000 and only the net differences are recorded as shown. Since Dynalog equipment has built-in zero adjustment, only net values are read as shown in Table 4. The values from Table 4 are plotted directly as in Figure 3. This gives the primary calibration constants which are the reciprocals of the slopes of (a) the net meter readings versus applied loads for each component and (b) the applied loads versus the deflection angles.

It might be well to discuss the deflection history further at this point. The change in angle due to applied moment is a constant; that is, practically speaking, it is independent of location of the applied couple. If a normal force is applied at any point other than the moment center, it is equivalent to determining the angle increments resulting from application of both a pure normal force and a pitching moment. The angle change is found by adding these increments.

The calibration constants are used to convert the interaction meter readings in Tables 4a, 4b, and 4c to pounds and inch-pounds as in Table 4d. These are plotted in Figures 3f and 3g which give the interaction constants.

All of the information should be summarized as in Table 5.

Examination of the plotted data will indicate the general repeatability of an average balance.

## ELECTRICAL INSTRUMENTATION

GENERAL TYPES OF INDICATING EQUIPMENT -- Standard strain-gage indicators fall into one of two groups, those using alternating current to excite the bridge, and those using direct current. All TMB Supersonic Wind-Tunnels indicators are standard Baldwin items and fall into the a-c category and more particularly, into the phase-shift type. Phase shift is used to make the indicators relatively insensitive to changes in applied bridge voltage. While there is a definite advantage in having low sensitivity to voltage changes, a disadvantage occurs in phase-shift-detection systems because once a strain-gage bridge has four active elements, no further increase in sensitivity is possible. In other a-c and d-c systems, if more gages are placed in each leg of the Wheatstone bridge, more voltage may be applied with an attendant increase in output.

The general controversy over a.c. and d.c. can be resolved only by picking the system best suited for a given application. Some of the points to consider are the following:

Direct current:

1. Is not subject to "beating" effects due to different oscillator frequencies in multiple installations.
2. Does not require any Wagner ground arrangement.
3. May be injected directly into an analog computer.
4. Can be wired so the interactions are electrically cancelled.

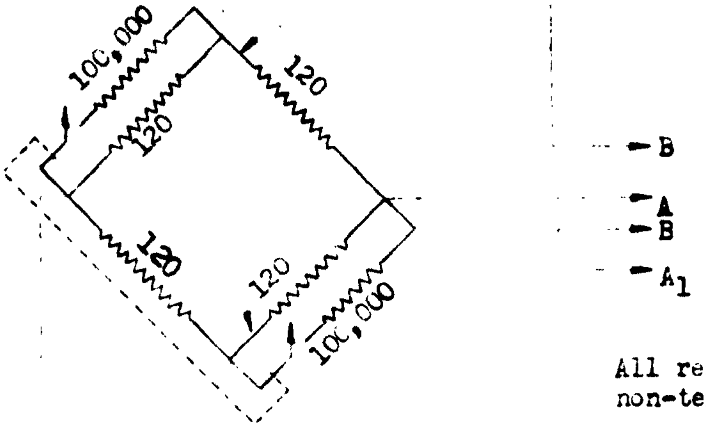
5. Can be made more sensitive by raising bridge voltage.
6. If used with appropriate filter networks is free from effects of model vibration.

Alternating current:

1. Is cheaper.
2. Does not require long warm-up period.
3. Does not necessitate special soldering techniques to eliminate thermocouple effects.

Some systems are neither solely a.c. nor d.c. They use d-c bridge excitation and a-c amplification thus realizing most of the advantages of each.

METER STANDARIZATION -- It has been found necessary to check the meter calibration which is changed generally by two things in addition to equipment malfunctioning. The first is an intentional change produced by changing the gage-factor knob on the SR-4 or Dynalog. The second change is undesirable and is produced by the resistance of lead wires. If a balance is calibrated with short leads to the indicator and upon tunnel installation is connected with long leads, the calibration constants will be altered appreciably. To detect this change, a standard calibration box has been constructed. The wiring diagram is as follows:



All resistors are precision non-temperature-sensitive types

The box is used by connecting it to the indicator to be checked in the normal hookup manner for strain gages. The double pole switch is closed, simulating a large strain-gage load. The resulting indicator deflection is noted.

A usual sequence of operations is as follows:

Step 1. Immediately before a balance calibration, the standard box is connected directly to the indicator to be used, since the balance also will be directly connected. The gage factor of this indicator is set at 2.00. The total deflection due to closing the switch is recorded.

Step 2. Immediately after the balance calibration, Step 1 is repeated. This will show up any progressive internal malfunctioning of the indicator.

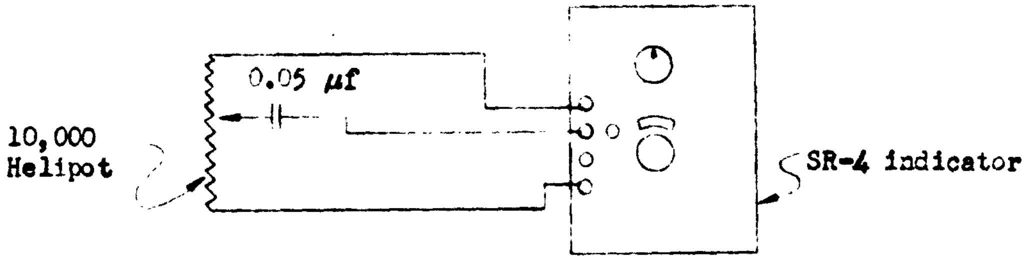
Step 3. Immediately before the balance is installed in the tunnel, the standard box is connected through all the cables, terminals, etc. The instrument gage factor is changed until closing the switch produces the same net reading as in Steps 1 and 2.

Step 4. Immediately after the test program is completed, Step 3 is repeated to detect any progressive equipment malfunctioning.

The values of resistance shown will result in a total deflection of approximately 1180 microinches per inch when connected to an SR-4 or Dynalog. If another double-pole switch is provided to break the circuit at the points marked "X", the box can be used to check two active-element bridges using the leads A', B, B. The resulting meter deflection will be half that for four elements.

It must be pointed that if Wagner grounding is necessary for reasons outlined on page 34, it must be done when the standard box is being used as well as with the balance.

WAGNER GROUND -- After everything is checked and the bridge circuit attached to the SR-4 indicator, the balancing knob should be turned to see that the meter response is sufficient. Normally, turning the balance knob 150 microinches per inch will cause the meter hand to go from one end of the scale to the other. If it takes over 300 microinches to produce this, the probability is that a Wagner ground is necessary. The usual circuit for a Wagner ground is as follows.

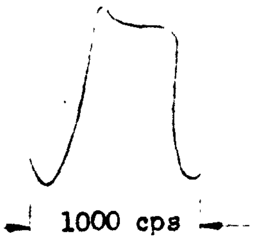


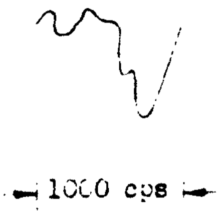
The adjustment of the Wagner ground requires an oscilloscope although when many indicators are to be adjusted frequently, a "tuning-eye" vacuum tube together with associated circuit components can be fabricated that will replace the oscilloscope. The adjustment of the Wagner ground by using the tuning eye is relatively simple. The Helipot and balancing knob on the indicator are turned simultaneously to keep the meter needle on scale. This is continued until the tuning eye closes; that is, until the shadow is a minimum.

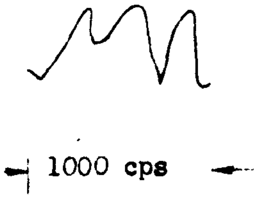
Adjustment by watching the oscilloscope is a little more difficult but more information is obtained. The oscilloscope is plugged into the scope jack on the SR-4 or attached to the detector signal leads on indicators not having a scope jack.

The Helipot and balancing knob are adjusted as above until the amplitude of the wave form on the scope is a minimum.

The following oscilloscope patterns were obtained in actual practice.







The pattern at the left shows the need for a Wagner ground adjustment. The middle pattern is after partial adjustment. The right wave form shows the best balance obtainable with a simple r-c circuit. Note that the amplitude decreases as better balance is obtained. Ideally the pattern at the right would be a horizontal straight line, while the figure shows the worst case. Usually the balanced condition will produce a wave form between these extremes with the wave form indicating how good the balance is.

If any low frequency beating is present the wave forms shown will fluctuate up and down at the lower frequency.

METER BEATING -- A somewhat startling development occurs when a multicomponent balance is attached to several SR-4 indicators, one component to each indicator. When all the meters are turned on, each meter hand flutters back and forth from one end of the scale to the other. The reason is that the SR-4 has a 1000-cycle-per-second oscillator. When the leads from several indicators are bundled together in a common cable and the gage windings are in close proximity to each other on a common piece of metal, there is sufficient cross coupling between the various oscillators beating at approximately 1000 cps that the difference beat shows up on the meter. If one meter has an oscillator frequency of 996 cps and another has 1001 cps, the needles of both meters will fluctuate five times per second. As additional meters are hooked up, the beating becomes more random and violent. The only sure cure is to have a common oscillator-amplifier built. The signal from the common oscillator (also 1000 cps) is amplified and injected into each oscillator of each indicator. The output from the amplifier is increased until the meters stop beating at which point the common oscillator is now "driving" the others, all at the same frequency.

As a temporary expedient when there are not more than two or three indicators involved, it is possible, if a large supply of oscillator tubes, 1B6's, is available, to substitute tubes until, by chance, all oscillators are operating at the same or nearly the same frequency. This is not recommended as an efficient process, but it has been done when necessary and it has worked. It might be noted that next to getting the oscillators to operate at the same frequency, making them operate at greatly different frequencies is desirable in that the meters cannot follow a high frequency "beat". Even if the difference is as little as 15 cps, the meter needle cannot follow it.

## TROUBLESHOOTING

If the balance does not perform properly initially, or if it develops troubles later, the procedure is the same.

The first step is to check the resistances of the bridge legs and resistance from gage circuits to the metal on which they are mounted. Never apply more than 22½ volts to any strain gage during this process, however. Some Wheatstone bridges and some continuity checkers apply more than this. If the balance is already attached to an SR-4 Type L indicator, a quick check as to whether there is a low resistance path from gage to beam is to touch the scope jack on the front panel of the indicator. If the meter needle moves when this is done, there is a leak to ground, if the meter is steady, there is only a slight leak to ground, or none at all. The best check, of course, is to completely disconnect the leads from the indicator and use a circuit analyzer or test set.

If, during the hand loading of the balance or during calibration, the zero (initial reading) does not repeat, the trouble will fall into three general classes; but, before attempting to determine which, it is well to make certain that the zero nonrepeatability is not due to random fluctuations. This may be done by watching the meter for a period of several minutes with no loads applied. If the meter is not steady, the zero non-repeatability is due to random fluctuations.

The causes of random fluctuations can usually be divided also into three classes. The first is a resistance that is changing at random. This may be due to a broken strand in the leads to a gage, it may be a poorly soldered joint, or it may be a poorly screwed-down terminal post. In any event it will be hard to find since the resistance change will be of the order of 0.01 ohm at most. Trial and error works best. Securing all connections tighter, and wiggling leads to see if any particular one seems to cause the trouble will usually be successful.

The second cause of random zero variations is power-supply fluctuations. If the SR-4 indicator is connected to the new small portable power supplies without the batteries "floating on the line"; i.e., batteries also connected, the meter is almost certain to exhibit unsteady characteristics. If the power variation is large it can be detected by switching the SR-4 from "ON" to "A" or "B". Whichever of these voltages is varying will, of course, be seen.

The third cause of random meter readings is thermal effects. If a gage installation is temperature sensitive and random air currents pass warmer or cooler air over the gages, the meter will respond. To determine if this is the trouble, the balance should be placed out of air currents caused by fans, air-conditioning equipment, open windows, etc, and wrapped thoroughly with heavy cloth. This will reduce the random variation to a steady progressive change if temperature sensitivity is the culprit. The only complete cure for this trouble is to redesign the gage installations with more attention to having all gages mounted close together on the same piece of metal and checking to see that all gages have identical gage factors. It may be possible by thermal insulation to use a beam which is overly temperature sensitive (all balances exhibit temperature sensitivity if subjected to a severe enough temperature range). A new Baldwin gage, the self-compensated gage, will prove useful wherever it can be used.

The first cause of zero nonrepeatability aside from random fluctuations is the obvious one where bearings are likely to cause friction. In this case, the zero will not come back to its initial reading; i.e., if the load causes a positive deflection of the meter, the reading will remain slightly positive after the load is removed; if the load is negative, the meter will indicate a small negative reading after the load is removed. To determine if the trouble is caused by friction, the structure supporting the balance should be tapped with a soft-faced mallet. This vibration will usually cause the meter to return to zero. This does not always mean that the gage is not fit for use, since in the running of any wind tunnel, a certain amount of vibration is present. However, some discretion must be exercised and the vibration must be continued during calibration. The cure is obvious: eliminate the cause of friction.

Another cause for zero nonrepeatability displays the same symptoms as those stated above. If a waterproofing material is applied too heavily to a small beam, the balance will exhibit "friction" troubles. Frequently, if this is the cause, after letting the beam stand for a few minutes, the meter will creep back to its original reading. To remedy this, some of the waterproofing must be removed. This has been done successfully by immersing the balance in solvent which removes the waterproofing but does not injure the wiring insulation, the gages, or the beam itself.

If the beam is loaded positively and when the load is removed, the meter goes to a slightly negative reading, the cause is slippage occuring either inside the gage or in the bond from gage to metal. Again, the meter may tend to return to the initial reading if let stand for a few minutes. In cases where the slippage is not severe and a load is applied and immediately removed, there will be no evident zero nonrepeatability, but if the load is left on the beam for several minutes, the failure to return to zero will be almost proportional to the time the load was applied. There is no simple repair for a slipping gage. It must be replaced.

If at any time the indicator cannot be zeroed, the usual reason is that a lead is broken somewhere in the gage circuit. This can be detected with an ohmmeter.

The final point to remember is, in all cases of doubt as to whether the gage or the indicator is at fault, reconnect the gage to a different indicator and see if the faulty performance continues. In 95 cases of SR-4 malfunctioning out of 100, the troubles are usually one of two things: a dirty slide wire which shows up as erratic needle behavior as the knob is turned, or generally poor performance caused by weak or inoperative vacuum tubes.

If a check of a calibration indicates a slope change, several items must be checked.

1. If the gage factor on the meter is not set at the same value as for the original calibration, a slope change will result.
2. If the indicator is incorrectly set as a type K indicator when using a four-gage bridge, a large slope change will result on reconnecting the meter as a type L.
3. If the Wagner ground adjustment is incorrect by a large amount, a measurable slope change will result.
4. If the resistance of the wires connecting balance to indicator changes, the calibration will change.

Practically this means that, wherever possible, a calibration should be performed with the balance connected to the indicator through the same wires as will be used during test.

Aerodynamics Laboratory
David Taylor Model Basin
Washington, D. C.
November 1953

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1. Timoshenko, S., and MacCullough, Gleason, H.: Elements of Strength of Materials. D. Van Nostrand Company, Inc., 2nd edition, August 1943.

2. Anon: Baldwin SR-4 Strain Gage Bulletin 279, Baldwin-Lima-Hamilton Corporation.

3. Anon: How to Apply SR-4 Strain Gages, Baldwin-Lima-Hamilton Corp. Bulletin 279-B.

4. Anon: Baldwin-Southwark Domestic Price List Baldwin-Lima-Hamilton Corp.

## TABLE 1

### Baking Cycles for Various Cements

duPont Cement or Duco Household Cement

1. Apply cement and clamp to hold gage flat
2. Air-dry for 1 hour
3. Remove clamp and air-dry for 2 hours
4. Dry at 110° to 120° F for 3 hours
5. Dry at 160° to 170° F for 6 to 8 hours

Total - 12 to 14 hours.

Bakelite Cement

1. Clamp at 125 psi
2. One hour at 140° F
3. Two hours at 175° F
4. Two hours at 250° F
5. Remove clamp and bake one hour at 300° F

Total - 6 hours

Epoxy Resin Cement (Epon VI)

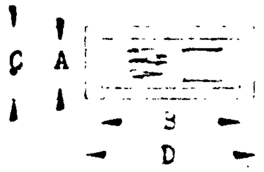
1. Clamp with only enough pressure to hold gage flat
2. Forty-five minutes at 200° F

Total - 3/4 hours

## TABLE 2

### Trim Dimensions of SR-4 Gages

| Gage Type | Number of Gages on One Side of Beam | Minimum* and Desired | Gage Width "A" in inches | Gage Length "B" in inches | Flat** Width "C" in inches | Flat Length "D" in inches |
|---|---|---|---|---|---|---|
| AB-7 | 1 | MIN | 3/16 | 3/8 | 7/32 | 13/32 |
| | | DES | 5/16 | 9/16 | 11/32 | 5/8 |
| | 2 | MIN | 3/16 | 7/16 | 7/32 | 1/2 |
| | | DES | 5/16 | 13/16 | 11/32 | 29/32 |
| AB-11 | 1 | MIN | 3/16 | 1/4 | 7/32 | 9/32 |
| | | DES | 9/32 | 1/2 | 5/16 | 9/16 |
| | 2 | MIN | 3/16 | 5/16 | 7/32 | 3/8 |
| | | DES | 9/32 | 11/16 | 5/16 | 25/32 |
| AB-19 | 1 | MIN | 1/8 | 3/16 | 5/32 | 7/32 |
| | | DES | 3/16 | 3/8 | 7/32 | 7/16 |
| | 2 | MIN | 1/8 | 1/4 | 5/32 | 5/16 |
| | | DES | 3/16 | 1/2 | 7/32 | 19/32 |



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* Reduction of a gage to "desired" dimensions is accomplished quite readily, while trimming to "minimum" dimensions requires considerably greater care and effort.

** Flat width and flat length refer to the flat rectangle that must be provided for mounting bakelite gages.

## TABLE 3

### Waterproofing Agents

| Rating Scale | Efficiency of Waterproofing |
|---|---|
| Excellent | under water 6 weeks |
| Good | under water 3 weeks |
| Fair | under water 1 week |
| Poor | under water less than one week |
| Unsatisfactory | |

| Material | Efficiency* | Ease of Use | Efficiency** | Ease of Use |
|---|---|---|---|---|
| Shellac | E | F | Depends upon thickness applied | E |
| G.E. air drying varnish | G | G | | E |
| G. E. baking varnish | P | G | | E |
| Insulex | G | G | | E |
| Ten-X | E | G | | U |
| Wax | F | F | | U |
| Glyptal | G | F | | U |

* Application thickness determined by maximum waterproofing efficiency.

** Application thickness determined by need for minimum restraint of thin beam.

## TABLE 4

### Sample Calibration of a Balance
### (a) Pitching Moment

Date 5/7/52

Gage Factor 2.00

Meter Deflection with
Standard Calibration
Box 1170

Balance A

Component Pitching Moment

| Applied Load inch-pounds | Meter Readings | | | Δα* |
|---|---|---|---|---|
| | NF | PM | AF | |
| 0 | 0 | 0 | 0 | 0 |
| 20 | 4 | 181 | -2 | -6 |
| 40 | 8 | 365 | -4 | -10 |
| 60 | 12 | 547 | -7 | -19 |
| 80 | 15 | 730 | -10 | -24 |
| 100 | 19 | 914 | -12 | -31 |
| 80 | 14 | 732 | -10 | -25 |
| 40 | 7 | 366 | -4 | -12 |
| 0 | 0 | 0 | 0 | -1 |
| 0 | 0 | 0 | 0 | 0 |
| -20 | -3 | -181 | -1 | 6 |
| -40 | -8 | -365 | -2 | 11 |
| -60 | -11 | -546 | -3 | 19 |
| -80 | -15 | -731 | -5 | 23 |
| -100 | -19 | -914 | -6 | 29 |
| -80 | -15 | -732 | -5 | 24 |
| -40 | -7 | -365 | -4 | 10 |
| 0 | -1 | 0 | -2 | 0 |

* angle change in minutes due to applied load

## TABLE 4 (Continued)

### (b) Normal Force

Data 5/7/52

Gage Factor 2.00

Meter Deflection with
Standard Calibration
Box 1170

### Balance A

### Component Normal Force

| Applied Load in pounds | Meter Readings NF | PM | AF | Δα* |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 10 | 120 | -1 | 2 | -4 |
| 20 | 238 | -1 | 4 | -7 |
| 30 | 361 | 0 | 6 | -12 |
| 40 | 482 | 0 | 9 | -15 |
| 50 | 599 | -1 | 10 | -18 |
| 60 | 721 | -1 | 13 | -23 |
| 40 | 480 | 0 | 10 | -17 |
| 20 | 239 | -1 | 3 | -9 |
| 0 | 2 | -1 | -1 | -1 |
| 0 | 0 | 0 | 0 | 0 |
| -10 | -119 | 1 | 1 | 4 |
| -20 | -238 | 1 | 4 | 8 |
| -30 | -360 | 0 | 5 | 11 |
| -40 | -481 | 1 | 8 | 16 |
| -50 | -599 | -1 | -9 | 19 |
| -60 | -719 | 0 | -11 | 23 |
| -40 | -482 | -1 | 8 | 17 |
| -20 | -240 | 0 | 3 | 7 |
| 0 | -2 | 1 | 0 | 0 |

* angle change in minutes due to applied load

## TABLE 4 (Continued)

### (c) Axial Force

Date 5/7/52

Gage Factor 2.00

Meter Deflection with Standard Calibration Box 1170

Balance A

| Applied Load in pounds | Meter Readings NF | PM | AF | Δα* |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 5 | 0 | 0 | 87 | 0 |
| 10 | 0 | 0 | 174 | 0 |
| 15 | 1 | 0 | 259 | 0 |
| 20 | 1 | 0 | 346 | 0 |
| 25 | 1 | 1 | 432 | 0 |
| 30 | 1 | 0 | 521 | 0 |
| 20 | 1 | 0 | 348 | 0 |
| 10 | 1 | 1 | 174 | 0 |
| 0 | 1 | -1 | 0 | 0 |

* angle change in minutes due to applied load

## TABLE 4 (CONCLUDED)

### (d) Interaction Determination

Date of Calibration 5/7/52

Balance A

| PM Load in inch-pounds | $NF^{*}_{PM}$ in pounds | $AF_{PM}$ in pounds | NF Load in pounds | $PM_{NF}$ in inch pounds | $AF_{NF}$ in pounds | AF Load in pounds | $PM_{AF}$ in inch pounds | $NF_{AF}$ in pounds |
|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20 | 0.33 | -0.12 | 10 | -0.11 | 0.12 | 5 | 0 | 0 |
| 40 | 0.67 | -0.23 | 20 | -0.11 | 0.23 | 10 | 0 | 0 |
| 60 | 1.00 | -0.40 | 30 | 0 | 0.35 | 15 | 0 | 0.08 |
| 80 | 1.25 | -0.58 | 40 | 0 | 0.52 | 20 | 0 | 0.08 |
| 100 | 1.58 | -0.69 | 50 | -0.11 | 0.58 | 25 | 0.11 | 0.08 |
| 80 | 1.17 | -0.58 | 60 | -0.11 | 0.75 | 30 | 0 | 0.08 |
| 40 | 0.58 | -0.23 | 40 | 0 | 0.58 | 20 | 0 | 0.08 |
| 0 | 0 | 0 | 20 | -0.11 | 0.17 | 10 | 0.11 | 0.08 |
| | | | 0 | -0.11 | -0.06 | 0 | -0.11 | 0.08 |
| 0 | 0 | 0 | | | | | | |
| -20 | -0.25 | -0.06 | 0 | 0 | 0 | | | |
| -40 | -0.67 | -0.12 | -10 | 0.11 | 0.06 | | | |
| -60 | -0.92 | -0.17 | -20 | 0.11 | 0.23 | | | |
| -80 | -1.25 | -0.29 | -30 | 0 | 0.29 | | | |
| -100 | -1.58 | -0.35 | -40 | 0.11 | 0.46 | | | |
| -80 | -1.25 | -0.29 | -50 | -0.11 | 0.52 | | | |
| -40 | -0.58 | -0.23 | -60 | 0 | 0.63 | | | |
| 0 | -0.08 | -0.12 | -40 | -0.11 | 0.46 | | | |
| | | | -20 | 0 | 0.17 | | | |
| | | | 0 | 0.11 | 0 | | | |

* $NF_{PM}$ is read as indicated normal force due to applied pitching moment.

## TABLE 5

## Balance Calibration Constants

Balance A

Date of Calibration: 5/7/52

Calibrated by: J. Doe

W. Smith

L. Jones

Serial Number of Strain Indicator H 250134

Gage Factor 2.00

Meter Sensitivity 1170

Pitching moment center is: 2.432 inches behind forward face of balance.

Calibration constants computed by R. Brown

PM = 0.1099

NF = 0.0833

AF = 0.0575

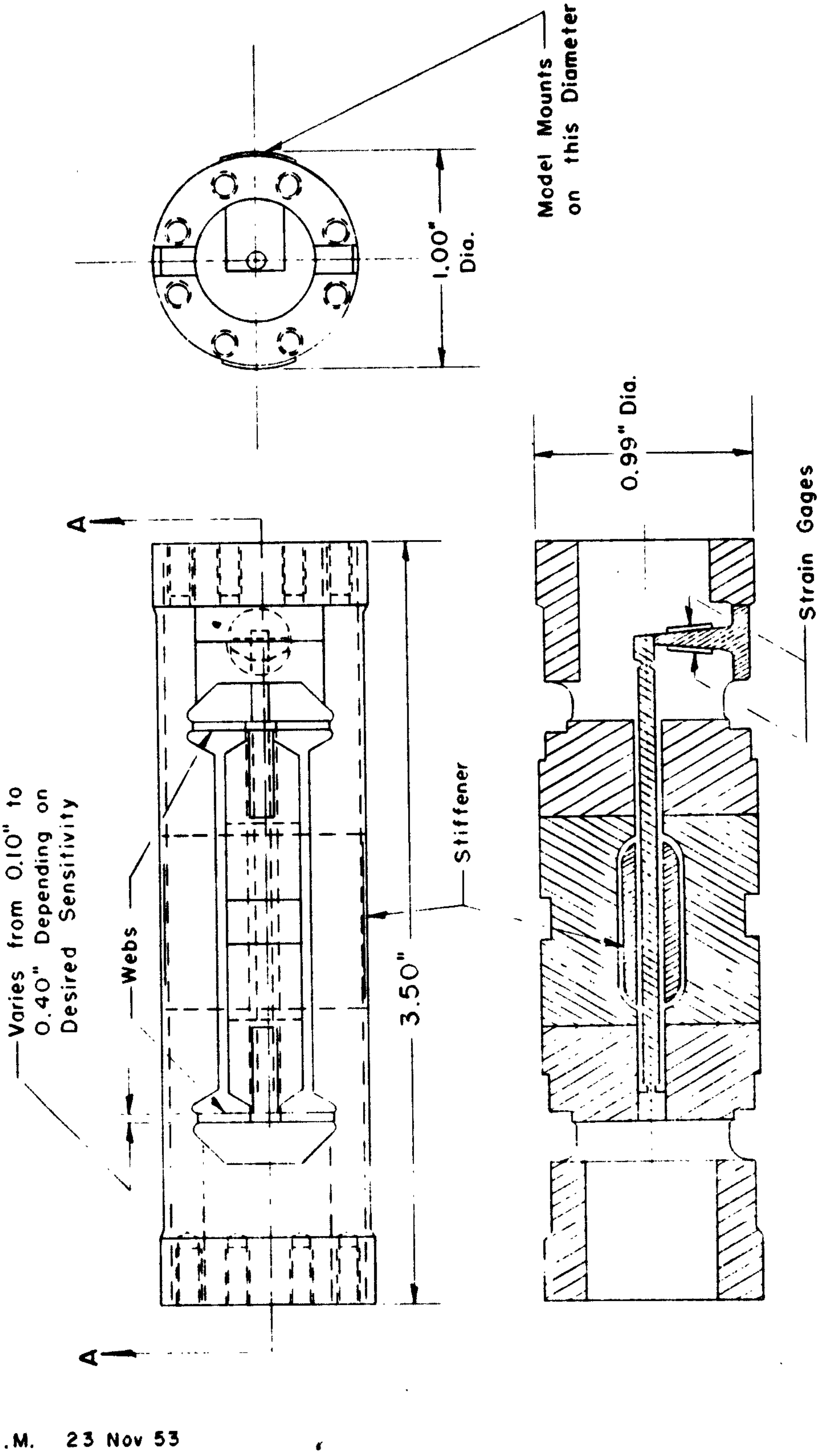
$\Delta\alpha_{PM}$ = -0.0050

$\Delta\alpha_{NF}$ = -0.0063

Interactions

| | | |
|---|---|---|
| $PM^{*}_{NF}$ = 0 | $NF_{PM}$ = 0 | $AF_{PM}$ = 0<br>0.0136 |
| $PM_{AF}$ = 0 | $NF_{AF}$ = 0 | $AF_{NF}$ = 0.0093 |
| $PM_{YM}$ = | $NF_{YM}$ = | $AF_{YM}$ = |
| $PM_{SF}$ = | $NF_{SF}$ = | $AF_{SF}$ = |
| $PM_{RM}$ = | $NF_{RM}$ = | $AF_{RM}$ = |

* $PM_{NF}$ is read as indicated pitching moment due to applied normal force or interaction of normal force into pitching moment.



Section A-A

Patent Applied For

Figure 1 - Details of Axial-Force Unit

P.K.M. 23 Nov 53

Figure 1

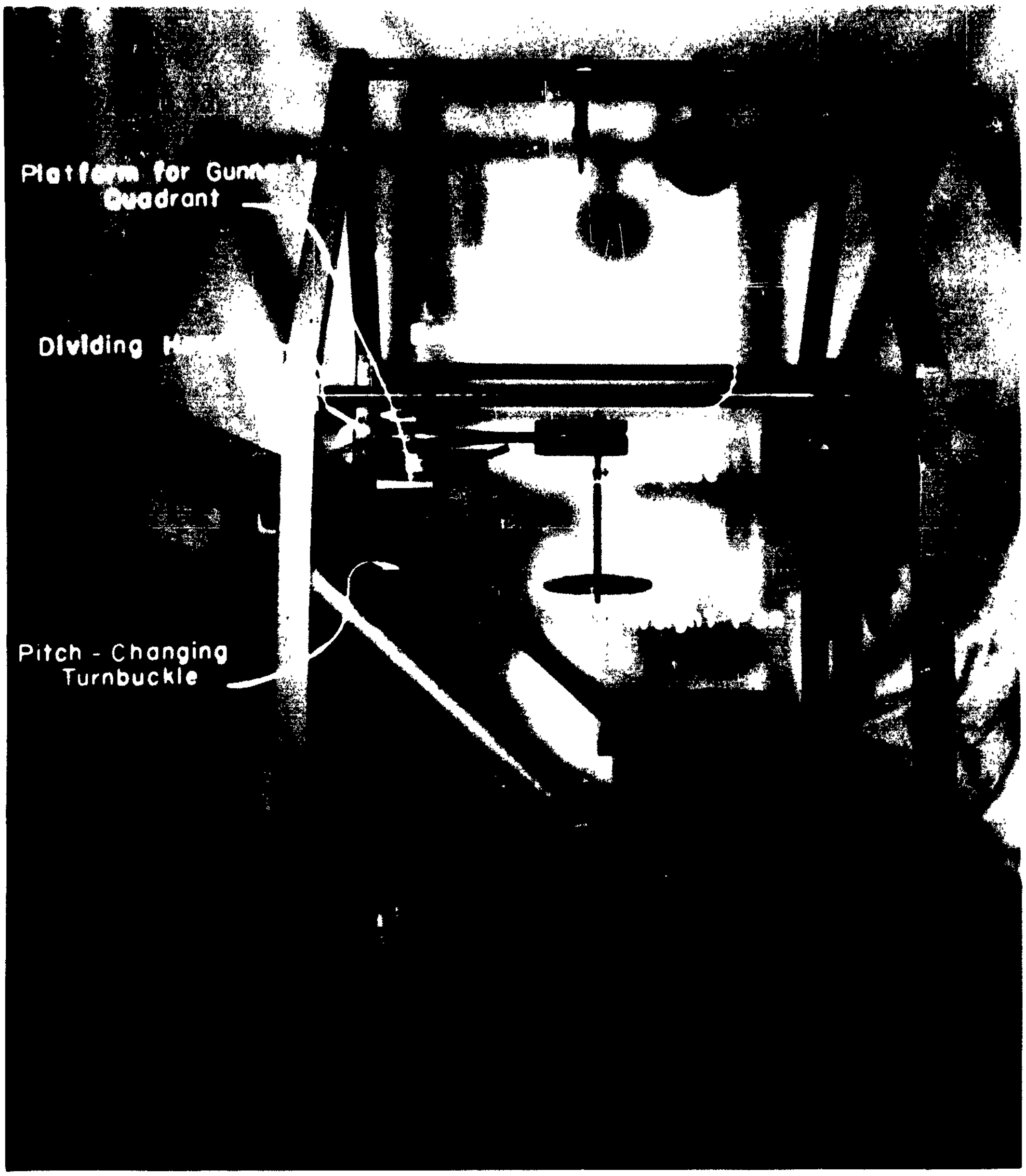
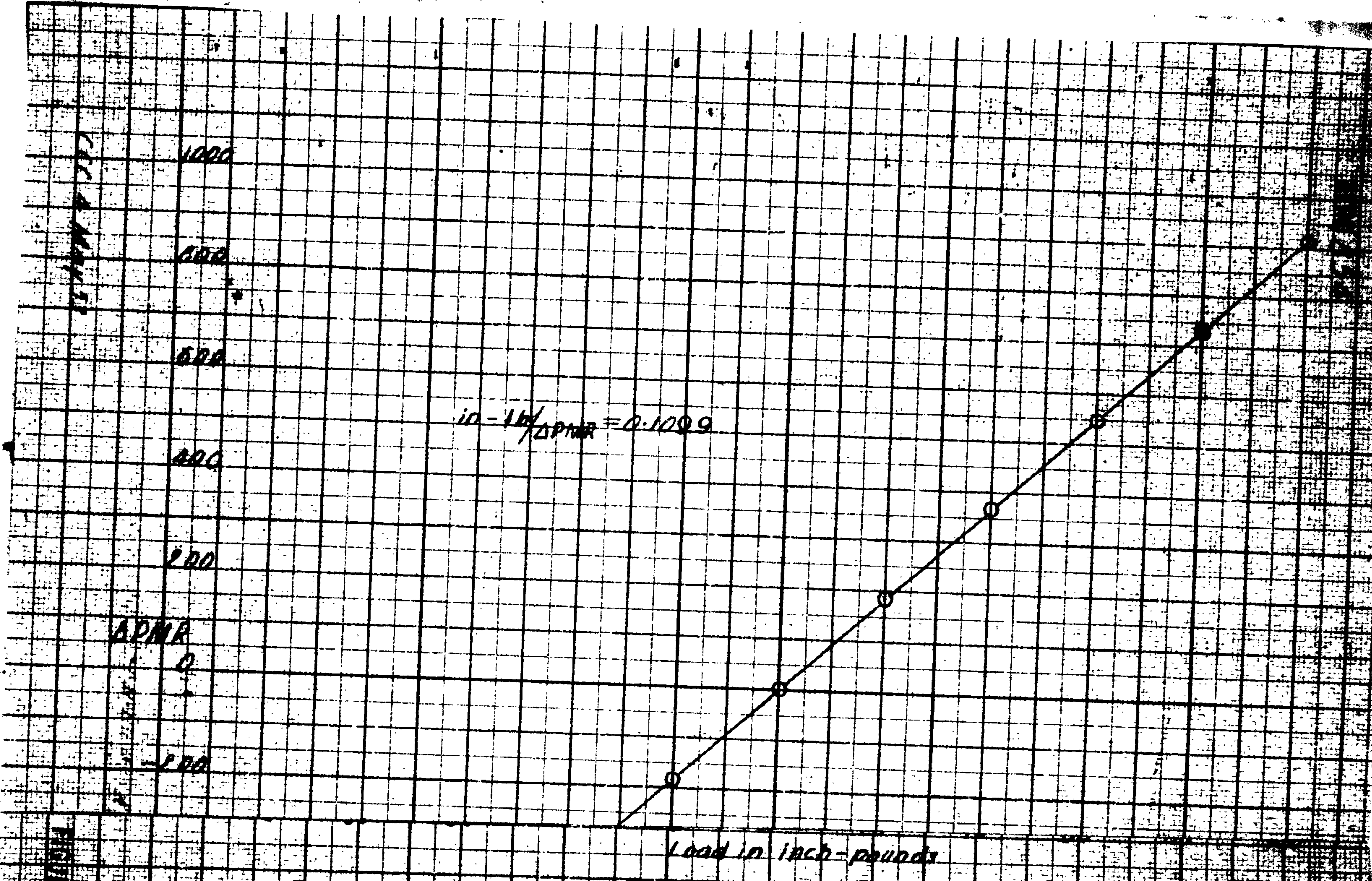


Figure 2 - Photograph of Balance Calibration Stand

NP21-54715 15 October 1953



CCC 4 May 53

Figure 5.-- Determination of Balance Calibration Constants.

(a) Calibration of Pitching Moment Balance.

FIGURE 5a

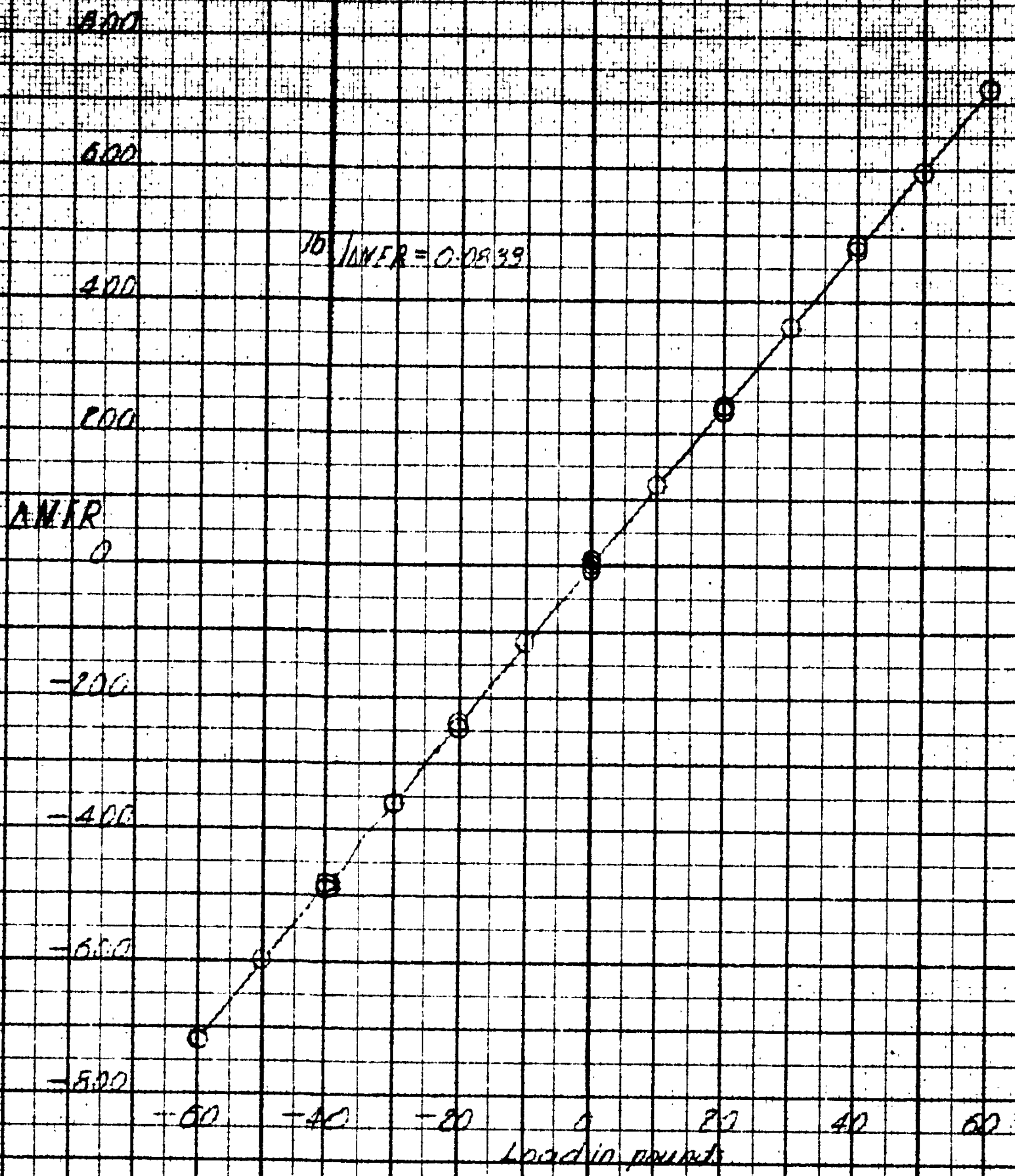


Figure 3 (Continued)

(b) Calibration of Normal-Force Balance

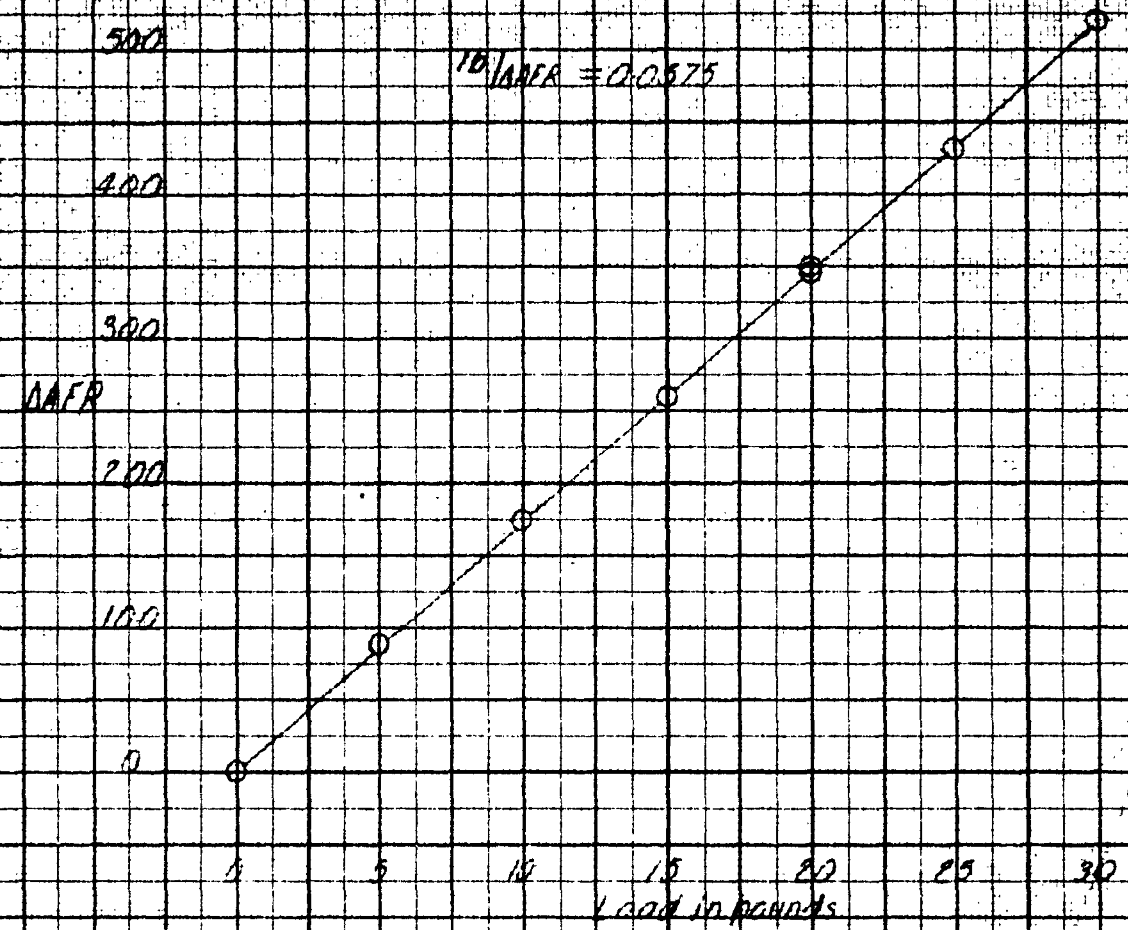


Figure 9 (Continued)

(c) Calibration of Axial-Force Balance

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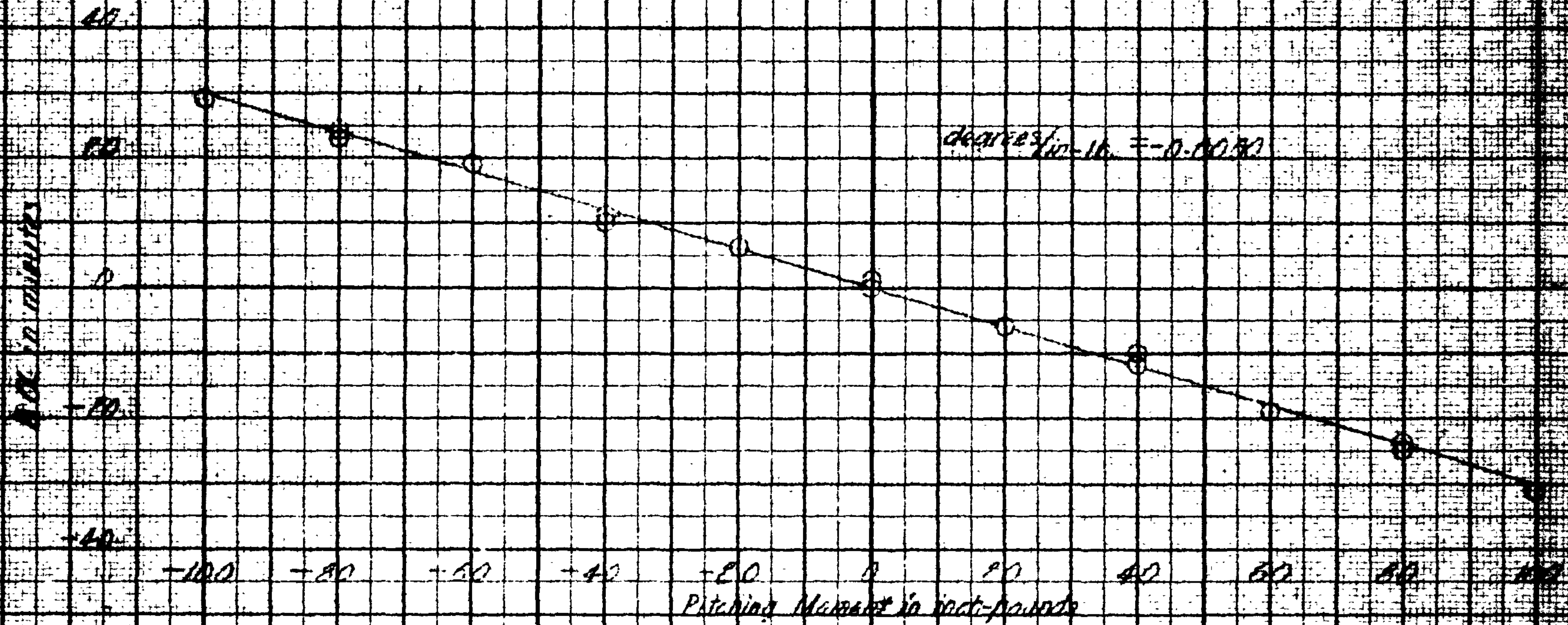

Figure 3 (Continued)

(d) Increment of Angular Deflection due to Pitching Moment

FIGURE 3d

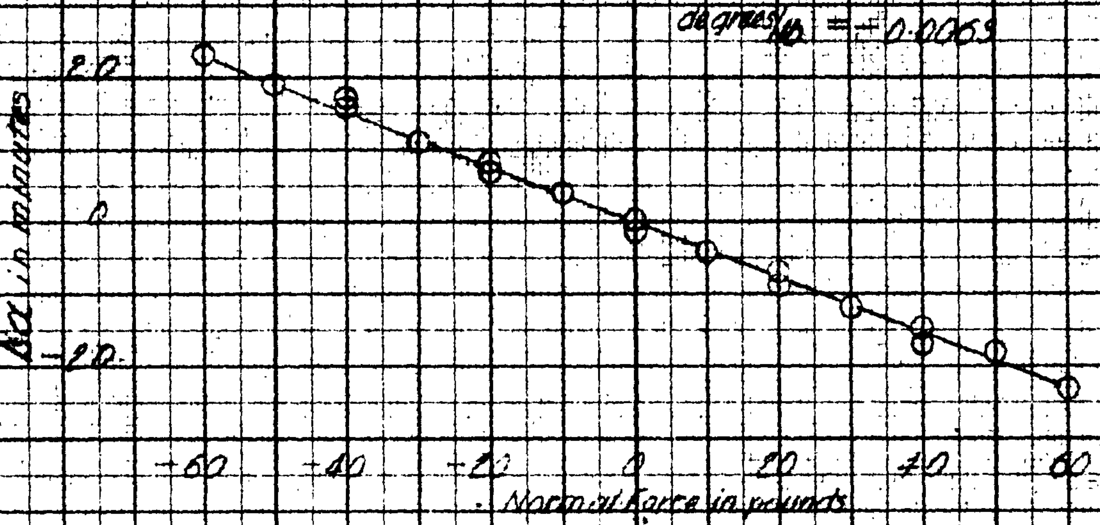

Figure 3 (Continued)

(e) Increment of Angular Deflection due to Normal Force

CCC 6 May 53

FIGURE 3 e

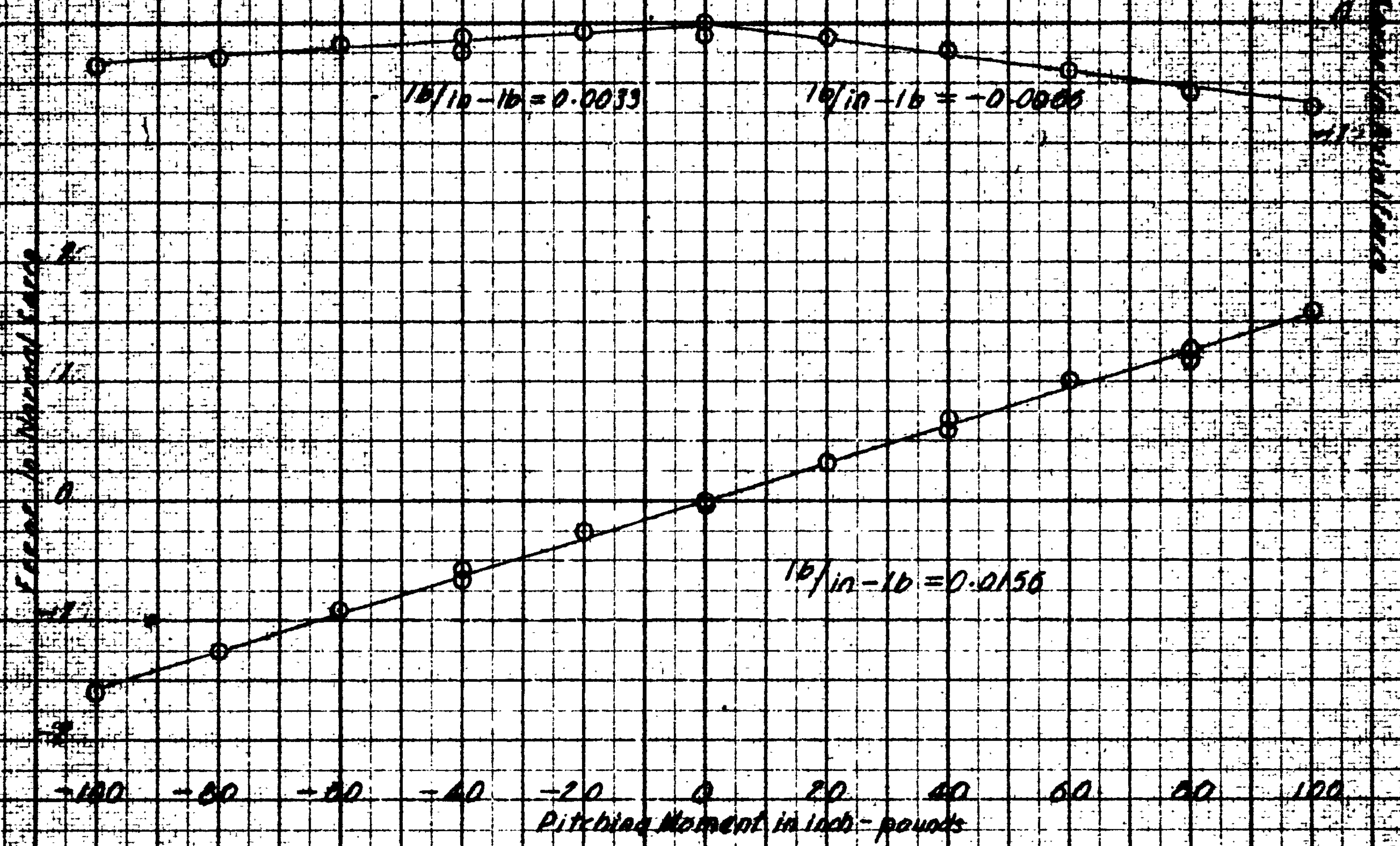

Figure 3 (Continued)

(f) Determination of Interaction of Pitching Moment into Normal and Axial Force

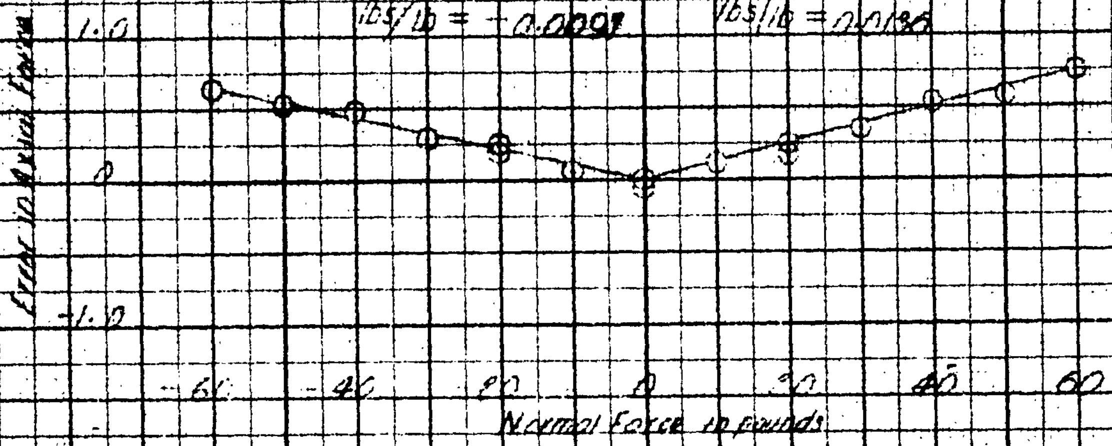

Figure 3 (Concluded)

(a) Determination of Interaction of Normal Force into Axial Force

CCC 5 May 51

x-refs: Wind tunnel balances see Strain gage balances
Balances see Strain gage balances

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DTMB Aero Rpt 854

David W. Taylor Model Basin.
NOTES ON THE DESIGN, CALIBRATION, INSTRUMENTATION, AND MAINTENANCE OF STRAIN-GAGE BALANCES, by Robert B. Ormsby, Jr. Wash., Nov 1953. [3]41 l. incl. illus. [9]plates (photo., diagr., graphs) 5 tables. 4 refs. (Aerodynamics Lab. Aero Rpt 854)

Compilation of information acquired by the Supersonic Wind-Tunnels Branch through experimentation in the last four years. The strain gages are all Baldwin-Southwark products and the strain indicators all manufactured by Foxboro for Baldwin.

I. Ormsby, Robert B. Jr.
1. STRAIN GAGE BALANCES
2. STRAIN GAGES, ELECTRICAL
3. STRAIN GAGES (BALDWIN-SOUTHWARK)
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