A TWO-PARAMETER WIND TUNNEL RIGGING SYSTEM

Thesis by

Bradley H. Young

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FOREWORD

In January of 1935 , definite steps were taken in a two part program to modernize the ten-foot wind tunnel of the Guggenheim Aeronautical Laboratory at the California Institute of Technology. Part one of the program was the design and construction of a new wind tunnel rigging system based on concepts originally laid down by Dr. A.L. Klein, Associate Professor at the same institution. Part two of the program, to be carried on intensively immediately after completion of part one, will be the development of an entirely new force measuring system to replace the present modified steelyard type balances.

In this paper the general problem of wind tunnel testing and equipment will be briefly outlined with the bulk of the discussion then given over to the problems concerning the evolution and design of a specific wind tunnel rigging system. As the system is not yet complete in its final form obviously there can be no description of the project as a finished piece of work. Also, it has been thought inadvisable to present only the system as it exists at present, therefore all the various features or principles that have been considered will be discussed and reason for their discard or adoption made clear. The result should then be a guide or at least an aid to the completion of part one of the modernizing program.

In a latter section of the paper some of the desired features of the contemplated force measuring system will be set down in the hope that they may be a skeletal set of requirements for the second part of the modernizing program.

The author wishes to acknowledge here the aid of those people who have contributed to the solution of the problem and thank them for their help. In particular Dr. Klein, who has had the whole project under supervision, also Dr. E.E. Sechler, Wm. Bowen and Dr. C.B. Millikan, who have contributed largely to more specific phases of the work.

THE WIND TUNNEL AS A SCIENTIFIC INSTRUMENT

Without doubt the major item of equipment in any aeronautical laboratory whether it be set up for research, commercial testing, or both, is a wind tunnel. Briefly a wind tunnel is a device for producing artificially a moving airstream, with the exact manner in which the airstream is produced being dependent on the result desired.

Investigations carried out with the aid of a wind tunnel fall generally in two groups, the first being phenomena peculiar to the airstream itself as it is made to flow over various bodies or boundaries and the second being investigations of the forces exerted on bodies placed in the airstream. Researches made in the first case come under the head of fluid mechanics and in the second case under the more general head of aerodynamics. The division here is not absolutely rigorous, and some instances, can be found where an overlapping exists.

Research in fluid mechanics generally requires a quite different type of apparatus than does research in aerodynamics. Pitot tubes, pitot combs, hot wire sets, smoke producing apparatus, etc., have all found wide application in this field and will not be considered in further detail here.

In the field of aerodynamics the equipment used is somewhat different, generally consisting of the following items which will only be indicated and not described as more detailed information can be found in a number of texts, reports, etc., covering the subject.

1. Wind channel
2. Means of obtaining and controlling the airstream.
3. Adequate model with which to make tests.
4. Means of supporting model in the airstream.
5. Means of measuring forces on the model.
6. Suitable connection between the model and force measuring system.
7. Method of reducing and presenting data obtained. (May be mechanical).

THE PURPOSE OF WIND TUNNEL TESTS

Before going into some of the variables of wind tunnel testing it will probably be well to outline the purpose of such work. Usually wind tunnel testing on models arises from one of two reasons, the first being the desire to predict, particularly with regard to control, stability, and performance, the behavior of a full scale aircraft of conventional type whose construction is contemplated. The second is the investigation of behavior of new and unconventional aircraft types or features whose construction in full scale may or may not be planned. In the first case the tests are usually commercial in the strict sense of the word and the results are highly quantitative. The benefits that accrue here are mostly economic, it being cheaper for the manufacturer to make wind tunnel tests and change his product in the design stage than to forego such tests and make necessary changes after the first plane is completed. All of this may also be true in wind tunnel tests on unconventional types, but in addition the results are qualitative in that properties as well as magnitudes of effects may be brought out that were only suspected before.

PARAMETERS OF WIND TUNNEL TESTING

In tests of both sorts there are a good many parameters that can be used and are used in the course of a complete investigation. These are listed and described as follows.

1. Geometry of the wind tunnel model. This parameter is taken care of by correct model design and construction. With a model made up of parts that can be easily attached and removed the effect of each on the whole can be measured. Generally the first part at least of wind tunnel tests is carried on with the model geometry as one of the parameters. It is usual to make runs on the wing alone, then say wing plus fuselage, then wing plus fuselage plus tail, continuing a piece by piece building up process until the final model configuration is reached. By using this part by part method and evaluating individual effects, an optimum configuration can often be arrived at. This scheme is used to determine the best engine nacelle shape or location, the necessary size of tail surfaces, etc. Ordinarily the model construction is left to the organization having the tests made and is a bigger factor in the test costs than is generally realized. A well made, easily adjusted model contributes greatly to the speed with which runs can be made and therefore, the test's cheapness.

2. The second parameter in wind tunnel testing is the Reynolds number $R = \rho V L / \mu$ where

ρ = Fluid density (air)

V = Velocity of airstream

L = Characteristic length of model

μ = Coefficient of viscosity of fluid (air)

Unfortunately some aircraft characteristics such as the maximum lift and minimum drag coefficients vary considerably with this factor and in order to extrapolate the test data from model to full scale it is necessary to make runs with R as a parameter. R can be varied in a good many ways as can be seen from its expression above. The most common way to change R is to make runs at different values of V; another common way is to vary ρ, the last requiring a tunnel of special construction capable of being "pumped up" to a pressure of perhaps fifteen or twenty atmospheres. Other methods that might be used to vary R are improbable almost to the point of impossibility, involving such difficulties as changing the model scale or using several test mediums with widely varying viscosities.

3. The last parameter is the position of the model relative to the airstream. As shown in Fig. 1 there are three possible axes of rotation, the rolling axis X, the pitching axis Y, and the yawing axis Z. If a wind axes

system is considered, that is if the direction of the free airstream V is always taken along the Y axis, the angle of roll ϕ is no longer a necessary parameter as the relative position of the airstream and model is the same for any value of ϕ . For a wind axes system there are really two position parameters then, the angle of pitch Θ and the angle of yaw ψ . Strictly speaking, for a body axes system there are three parameters of position, the above two plus the angle of roll ϕ .

THE MAGNITUDE AND MEASUREMENT OF THE FORCES

With the test parameters indicated the forces and their measurement can be considered. As in any problem in mechanics the forces to be measured can be broken down into six components and in aerodynamics these forces are designated as follows:

L = Lift force	L = Rolling moment
D = Drag force	M = Pitching moment
C = Side force	N = Yawing moment

In a wind axes system these forces and moments are referred to a set of rectilinear axes through some arbitrary reference point in the airplane, usually the center of gravity. Here one axis is taken parallel to the free airstream, one horizontal, and one vertical. Using body axes the coordinate system has one axis X generally taken through the center of gravity parallel to the thrust axis, one, the Z perpendicular to the X axis, through the center of gravity, and in the plane of symmetry of the airplane. The third axis Y is also taken through the center of gravity and is at right angles to the other two. In Fig. 2 the forces and moments are shown on a body axes system. In an ideal wind tunnel rigging system it should be possible to measure all forces and moments in a resolved state about either set of axes at will. This is not easily possible and the best solution is probably a wind axes system with provision for measuring the pitching moment with reference to both wind and body axes.

The magnitude of the forces and moments depend on items that can be most easily seen in considering the expressions for any of the forces or moments, those for lift and pitching say

$$\text{Lift} = L = C_L \tfrac{1}{2} \rho V^2 S$$

$$\text{Pitching Moment} = M = C_M \tfrac{1}{2} \rho V^2 c S$$

1. C_L, C_m are dimensionless coefficients dependent mainly on model geometry and position relative to the airstream.

2. ρ = Fluid density of air.

3. V = Velocity of airstream.

4. S = Wing area of model

5. C = Chord of wing.

It is obvious that knowing the usual model sizes to be tested in a given wind tunnel, the velocities that can be reached, and from past experience some limiting values of force and moment coefficients to be expected a basis for rational structural design of a wind tunnel rigging is immediately available.

It is very desirable to have the forces measured by the balance system in a resolved state, that is, each force and moment indicated on its individual balance. This is not at all impossible but care must be taken in the resolving system that force interactions are kept small. It may be possible the design of the resolving system is such that in a drag measurement small portions of the lift force add in and with high lifts and low drags considerable errors result. This is only given as an example. All possibilities of this sort must be investigated at least and if serious, steps must be taken in the design to eliminate or reduce such effects to a minimum. Even with the forces being measured in a resolved state there are some additional features that are very desirable. If after the test data is available, it is necessary to make a great many involved computations and corrections to present the data in its final and most useful form the value of the tests is reduced. Such computations take time and increase the cost as well as the chances for errors due to unavoidable inaccuracies and errors due to mistakes. Any thing that can be done to reduce calculation involving rigging factors is of value.

THE PRESENT WIND TUNNEL RIGGING SYSTEM

In the weakness of the wind tunnel rigging system as shown in Fig. 3 lies the instigation of the present problem of a new design. No implication is made here that the present system is poorly designed or built, on the contrary. Airplane design has progressed greatly in the last few years and characteristics that did not interest the airplane manufacturer when the present system was built are becoming more and more vital. Two of these characteristics are the directional stability and control, that is, stability and control around the Z or yawing axis. As can be seen the present system has no provision for using angle of yaw as a parameter. In order to make measurements of yawing moment at angles of yaw the model must be turned on its side and placed in the tunnel as shown in Fig. 4. Using the rigging of Fig. 4, the only measurements that can be made are those of the yawing moment, a one component set up. In addition to being very restricted this system is difficult to install and rig, resulting in slow and expensive tests. The fact that the system of Fig. 3 was limited to use with one position parameter was the prime reason for the decision to design a new system.

REQUIREMENTS OF THE TWO POSITION PARAMETER SYSTEM

When a new rigging was contemplated a set of non-structural requirements were set down. In addition a good many were more or less implied and as the design has progressed new requirements have been added. All of these will be enumerated below and the ones not obvious explained.

ORIGINAL REQUIREMENTS

1. Complete resolution of forces. (All lift on one balance, drag on another, etc.)

2. Ability to make measurements with model in yawed position up to $\psi = +25^\circ$.

3. Trunnions. (It had seemed that a three point support as shown in Fig. 5 would be the most satisfactory).

    1. Wing trunnion spacing variable and easily measurable from 0 cm. to 1.20 m. (This permits models of wide range in size and configuration to be tested.

    2. Ability to run with one main support arm and tail strut. (Necessary for tests on airship models).

    3. Trunnion axis variable from 3" below to 12" above tunnel center line in 3" steps. (To accommodate wide range in high or low wing models).

4. Tail strut (see Fig. 5)

    1. Tail strut length measuring scale to be part of rigging. (For ease and rapidity in setting up model).

2. Tail length fully adjustable from 50 cm. to as long as possible. (To accommodate a wide range of models. The short tail lengths have a particular advantage when making runs of the wing alone type in that no auxiliary arm must be added to the wing and later corrected for in the computations.)

5. No counterweight attached to the model. See Fig. 3. (Handling of 300 lbs. or so of counterweight every time the model is changed is a laborious process. Also, if the stability of the system under load depends on the magnitude of the counterweight attached to the model, there is too much chance for the tunnel operators to make errors of judgment leading to disastrous results.

6. Rigging stiffness. (The interaction of forces mentioned before is largely dependent on this item and for small errors stiffness should be high.

   1. Fore and aft, equal to present
   2. Lateral, minimum five times present
   3. Pitching, " " " "
   4. Rolling, " " " "
   5. Other stiffness not less than present

(At the time the above criteria were established the values of "present stiffness" were unknown.)

7. Rigging stable for all possible load combinations. (This requirement resulted from accidents that had been experienced with the system of Fig. 3 where the forces were such as to cause the rigging to rotate around the forward corner of the

frame and become unstable. The model would then pull loose and be carried downstream.)

8. Tail strut vertical adjustment. (To facilitate rigging)

   1. Fine motion
   2. Wide range of adjustment
   3. Measuring scale incorporated for adjusting
   4. Tail strut easily removable

9. Trunnion support arms windshielded, streamlined, and arranged so as to have the major axis of cross-section parallel to the wind axis. (This is necessary if the air flow over the model at angles of yaw is to be affected the minimum amount by the support arms and their windshielding. It also keeps the tare drag, or drag due to the support arms and their interference with the model invariant with angles of yaw to the greatest possible extent.)

10. Tail strut windshield must move vertically with tail strut. (This is another measure taken to keep the tare drag low and it is hoped fairly constant for all angles of pitch. In modern aircraft the drag is low and if the tare drag is a large portion of that measured by the balances the drag of the model is obtained by subtraction of two quantities of nearly equal magnitude leading to the usual large errors. Hence, the constant effort to have the tare drag = constant = 0.)

11. Angle of pitch a parameter. Range from $\Theta = +60^\circ$ to $\Theta = -30^\circ$.

IMPLIED REQUIREMENTS

1. Low cost.
2. Ability to use present set of balances.
3. Operation of rigging to be as fool proof as possible. This requirement is made necessary by the large percentage of mechanically inexperienced student help used in running tests.
4. Design such that construction can be carried out to the greatest possible extent in the laboratory shops.
5. No major structural changes to be made in the tunnel or in the building housing the tunnel.
6. Design such that breakage of any part shall not cause collapse of the whole system. Also parts replacement in case of breakage or abnormal wear should be reasonably easy.
7. Accuracy and sensitivity as great as possible.

ADDED REQUIREMENTS

1. Provision for making increases in tail length up to 10 feet. This was thought advisable in case airship tests were to be made in the future.
2. Constant static moments in pitch and roll for all angles of pitch and yaw. This means that with the air at rest in the tunnel and the model run through various angles of pitch and yaw the readings on the pitching and rolling moment balances should remain constant. Actually the readings on all balances should remain constant, however, the meeting of this condition is difficult only in the cases of the pitching and rolling moments.

STRUCTURAL REQUIREMENTS

The first step in formulating structural requirements was to set up the maximum load conditions that could be expected. In this respect a rather long range viewpoint was taken and efforts made to plan for future needs as well as present. An upper limit was set on tunnel speed and model size then past wind tunnel reports were consulted for limiting cases on force and moment coefficients. The result was a set of maximum applied loads with values as follows:

V = Velocity	= 300 ft./sec.
b = Wing Span	= 9 ft.
c = Wing Chord	= 3 ft.
S = Wing Area	= 27 $ft.^2$

C_L = + 2.00	− 0.50	C = 0.08	(±)
C_D = + 0.50	− 0.02	C_m = 0.30	(±)
C_c = + 0.20	− 0.20	C_n = 0.06	(±)

Lift =	5780 Lbs ↓	1445 Lbs ↑
Drag =	1445 Lbs →	58 Lbs ←
Side Force =	580 Lbs ⇄	

Rolling Moment =	25,000 in Lbs ↺ ↻
Pitching Moment =	31,200 in Lbs ↺ ↻
Yawing Moment =	18,700 in Lbs ↺ ↻

Model Weight (Max.) = 400 Lbs

C.G. 20 in aft of trunnions

With the maximum applied loads determined four design criteria were established.

1. On those members whose strength alonge is important the design shall be made on the basis of the ultimate strength of the materials used with the design loads equal to twice the maximum applied loads.

2. On members whose deflections are important the deflections shall be such that errors introduced in the drag shall be not greater than 0.1% of the drag load and errors in the other forces and moments shall be 0.5% or less wherever possible.

3. Moving parts subject to wear shall be designed to operate for forty hours per week over a ten-year period without replacement.

4. Members coming under none of the above three groups shall be made to withstand a normal amount of rough usage and handling.

EVOLUTION OF THE RIGGING TO SATISFY REQUIREMENTS

In this section the rigging will be broken into parts and the changes made and reasons for them will be shown. As a starting point the system as originally conceived by Dr. Klein and shown in Fig. 6 will be used. An explanation of this arrangement which was in no way supposed to be final but more a basis for change is as follows. The model, a wing as shown, was supported by two arms and a tail strut. The support arms were carried on the under side of a large cross tube which in turn was fastened to a gib or slide on the under side of the semi-circular yaw track. The tail strut was carried at the upper end by the tail boom, the tail boom being held in bearings on the cross tube. Mounted on the tail boom was a geared motor unit (not shown) to turn the incidence drive worm. On the same axis of rotation as the tail strut the incidence worm gear was carried. The lower portion of this member was made so as to form a lever, the lever being connected through the pitching moment bell crank to the pitching moment wire. Any moment tending to rotate the model about the trunnion axis (the pitching moment) was carried through the tail strut, the tail boom, the worm and worm gear, the pitching moment bell crank and finally the pitching moment wire. In this way the magnitude of load in the pitching moment wire was a measure of the pitching moment around the trunnion axis. If the tail strut length is equal to the distance from trunnion axis to tail boom axis, and the tail arm length is equal to the effective tail boom length a parallelogram arrangement is maintained between these parts, then if the tail boom is rotated through a given angle in pitch the model will also rotate through the same angle in pitch. A selsyn motor mounted so as to show the angular relationship between the cross tube and tail boom can be used to indicate remotely the angle of attack of the model in the tunnel. (The selsyn is not shown in Fig. 6). For changes in angle of yaw it was planned to shut down the tunnel, unclamp the cross tube and slide it to a new position on the circular yaw track. The support arms would then be unclamped and reset with their axes parallel to the tunnel axis. It can be seen that while this could be done in a reasonable time changes in angle of yaw would still be much slower than changes in angle of pitch. The axis of rotation of the parts of rigging moving in yaw was to be the pitching moment wire, made in this way no changes in rigging support need be made with angles of yaw. The rigging was to be connected to the balances by six supports, one for each force component. These forces were resolved as taken off the rigging in the following way:

1. Drag. The only restraint on the rigging'fore and aft is through the drag-rolling moment torque tube. The forward end of this tube is connected through a universal joint to the vertical arm of a right angled bell crank as shown. Then if a member is carried from the horizontal arm of the bell crank to the drag balance the load indicated on the balance will be a measure of the air force exerted on the model and rigging to move them down stream, i.e. the drag.

2. Side Force. The rigging is restrained laterally only by the side force wire which is carried over a sector and then to the side force balance.

3. Rolling Moment. At the forward end of the drag-rolling moment torque tube an arm extends horizontally. A member is attached to this arm that connects to the rolling moment balance and the tendency of the rigging and model to rotate around the rolling axis is measured in this way. It can be seen that the rolling moment about an axis through some point in the model, the C.G. say, will have to be arrived at by computations involving the side force and the distance from the reference point in the model to the rolling axis. In this sense then the rolling moment is not wholly resolved.

4. Yawing Moment. At the upper end of the lift-yawing moment torque tube an arm is extended horizontally and a member attached that is carried over a bell crank to the yawing moment balance. The whole rigging is thus restrained in yaw by torsion in the lift-yawing moment member and loads on the yaw balance will be a measure of the yawing moment around this tube axis. If moments around any other arbitrary axis are desired computations must be made involving the distance between the arbitrary and torque tube axis and the side force.

5. Lift. The only restraint on the rigging vertically is through the front lift and pitching moment wires and the lift-yawing moment torque tube. The lift yawing moment tube is hung from the center of main lift beam which is anchored at the rear end and hung on the lift balance at the front end. Any load in the lift-yawing moment member will register then as one half this amount on the balance. The load in the front lift wire is split in half by the front lift beam and therefore registers one-half its value on the lift balance. The load in the pitching moment wire is doubled by the lower pitching moment beam, halved to its original value by the upper pitching moment beam, is put in to the main lift beam at the midpoint and thus registers as half its value on the lift balance. With this arrangement the lift balance records at all times one-half the vertical rigging load.

6. Pitching Moment. The aft end of the upper pitching moment beam is hung on the pitching moment balance which for this reason indicates the load in the pitching moment wire.

It can be seen that all of the forces are measured around wind axes with the exception of the pitching moment, this being measured with respect to body axes.

VARIOUS OVERHEAD SUPPORT SYSTEMS.

One of the first changes found necessary in the system of Fig. 6 was in the part between the yaw track and the balances. Calculations of the size tubes necessary for the drag-rolling moment and lift-yawing moment members showed that the arrangement would probably not be satisfactory. Using tubes of a reasonable size and wall thickness gave small enough deflections in roll and yaw but it was felt that the difficulty in building shake or "slop" free universal joints at each end would be too great. In addition to deflection troubles it was feared that the friction in the great number of bearings used would reduce the sensitivity too much. A way was sought to take out the rolling and yawing moments by other than pure torques resulting in the arrangement shown schematically in Fig. 7. Here the yaw and roll wires are attached directly to the circular yaw track. As the rolling moment wire now carries a portion of the lift it must be added in some way to the lift balance, similarly, the load in the yawing moment wire must be added to the side force if complete mechanical force resolution is to be maintained. A change was also made in the geometry of the upper support beam so that the load on the lift balance would be one-third of the total instead of one-half as shown in Fig. 6. This was thought more satisfactory in view of the fact that the balances were designed to carry a maximum load of 2000 lbs. while the maximum applied lift load was to be about three times this amount, namely 5780 lbs. A more detailed layout of the upper beam revealed that a far from simple knife edge arrangement as shown in Fig. 8 would probably be necessary. Anything as complex as is shown is almost sure to be bad and an analysis of stresses in the system also showed that for a main beam as long as the layout called for deflections would be unreasonably large. This same analysis showed that the loads in the front and rear lift members were a direct function of their spacing and for the arrangement planned excessive. If the spacing were increased by lengthening the horns to which the members were attached, the horn deflections became excessive. About this time, it was decided to abandon the plan to resolve the forces mechanically in the rigging system itself. An alternative is to resolve forces either mechanically or electrically after they are regisgered on the balances. Done in this way the resolving will not affect the accuracy and sensitivity with which force readings are made. A solution for reducing the loads in the front and rear lift members was obtained by running a bridge member across the yaw track aft of the pitching moment axis; in addition, this bridge member will provide needed rigidity to the yaw track. The long main beam was discarded in place of two shorter and far more stiff beams for deflection reasons mentioned before with a final arrangement of the overhead support system as shown in Fig. 9. A summary of changes from the original is as follows:

1. Discard of rolling and yawing moment torque tubes.
2. Discard of total mechanical resolution of forces.
3. Distance between front and rear lift supports increased.
4. Rear lift member horn discarded for bridge member.
5. Long upper lift beam discarded in favor of a short, two-beam system.

The loads are now taken off in the following manner:

1. Total lift = Σ 3 times lift + rolling moment + pitching moment balances.
2. Total drag = Drag balance

3. Side force = $\sum$ Side force + yawing moment balances.

4. Pitching moment = Pitching moment balance.

5. Rolling moment = Rolling moment balance times dr.

6. Yawing moment = Yawing moment balance times dy.

In addition to the arrangement shown in Fig. 9, plans are being made to carry the front and rear lift wires each directly to a balance so that use of the beams can be done away with for models with small total lift.

THE INCIDENCE VARYING MECHANISM.

As originally laid out the mechanism for changing the angle of attack was as shown in Fig. 10. It was seen almost at once that the arrangement would be unsatisfactory. The incidence mechanism in the system of Fig. 3 utilizes a reduction between the motor, with a normal speed of 8000 r.p.m., and the tail boom of 29,664 to 1 giving a tail boom speed of 0.37 r.p.m. As this system had proven very satisfactory it was decided to use about the same tail boom rotational speed in the new system. With gears of any reasonable size the reduction could not be obtained as shown in Fig. 10.

Fig. 11 shows a reduction laid out with a lead screw and worm drive, the end of the screw being fastened to steel tape passing over a pulley sector. This was abandoned because of the high stresses developed in a tape of any reasonable width. In Figs. 12 to 15 are shown various gear reductions contemplated having a spur and pinion gear in the final stage. These were discarded because no simple way could be determined to eliminate backlash. A worm drive in the last stage was decided to be necessary and this resulted in the arrangements of Figs. 16 and 17. Other reasons for the change to a worm drive were that greater strength could be obtained for a given gear size and also the mechanism could be disengaged. The reason for disengagement lies in the development of the zero static moment device and will be discussed later. The incidence mechanism in its present stake is that shown in Fig. 17. Various other arrangements not shown were tried, most of them involving planetary gear systems of one sort or another.

VARIOUS PITCHING MOMENT SYSTEMS.

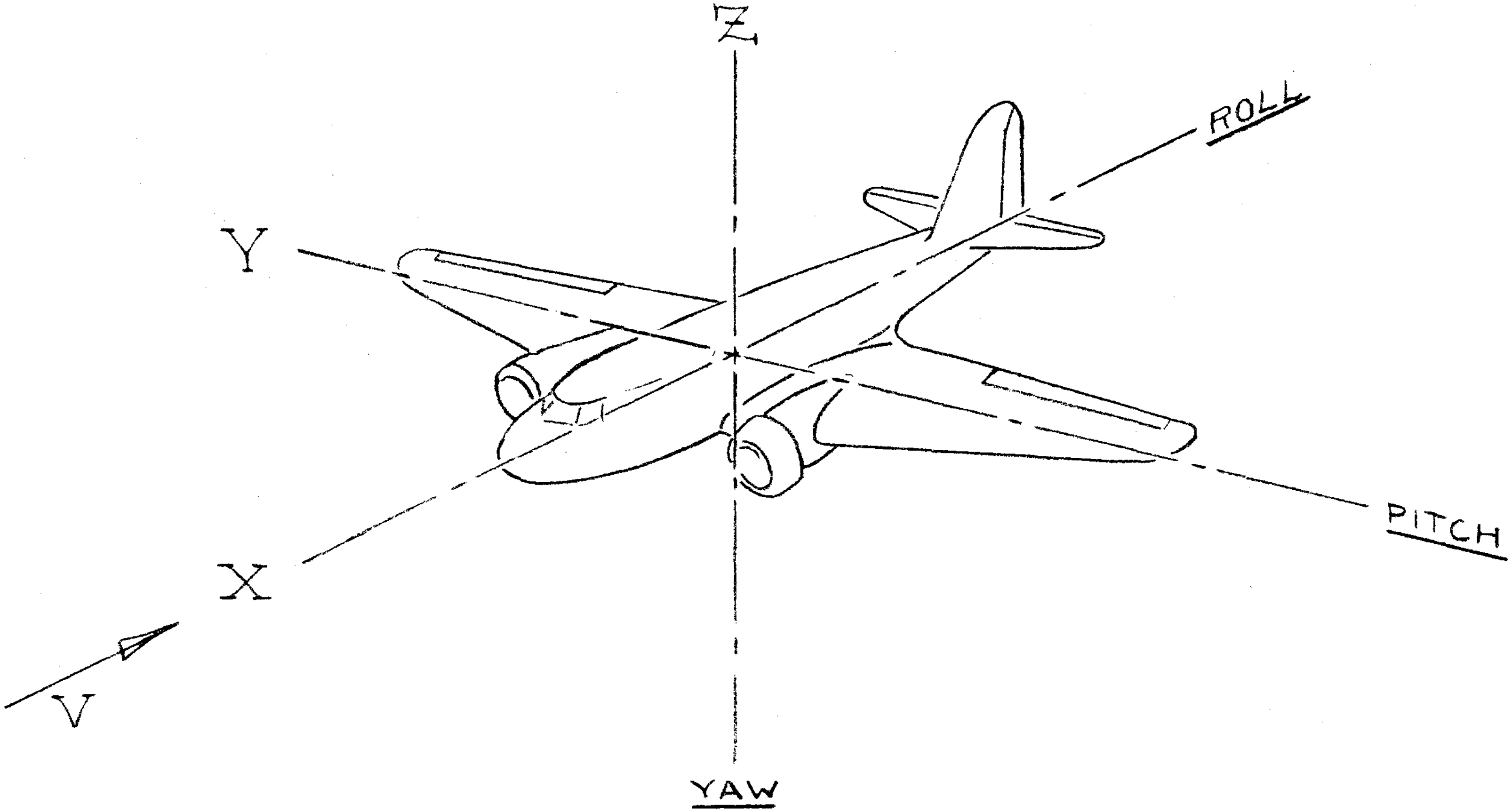
The original method of taking out the pitching moment has been shown in Fig. 6 and previously described. It was found, for the loads to be carried, that this bell-crank system became too large and could not be placed in the space allowed; also, the large number of joints would cause an undesirable decrease in sensitivity. An overhead beam was laid out as shown schematically in Fig. 18. This device was laid out with an eye to simplicity and clearance problems, but was discarded after making a preliminary stress analysis. The mechanical advantage of the system was so small that loads in the pitching moment wire ran to 12,000 lbs. Another arrangement of an overhead beam was tried as shown in Fig. 18. The mechanical advantage of this is such that a load of 1000 lbs. applied at a tail arm length of 58 inches shows as a 1000 lb. load in the pitching moment wire. This arrangement is being retained at the present time. In the wind tunnel rigging system in use at present, it is necessary, with no air flowing in the tunnel, to run through the angle of attack range and record the moment balance reading for various angles. As the model angle changes the effective moment arm of its weight changes and causes this change in static moment which must be recorded and corrected for in calculation of the desired pitching moment. The balances do not operate successfully unless the tunnel is running, and for this reason the determination of the static moment is laborious, long and a possible source of error in computation. With a two-parameter system of this type, it would be necessary to determine the static moments both in roll and yaw for every angle of pitch in every angle of yaw, an obviously undesirable situation. To eliminate this, a counter-weight system has been provided as shown in Fig. 20. By setting the system at zero angle of attack and adjusting the horizontal position of the counter-weight for balance, then going to some other angle of attack and adjusting only the vertical position of the counter-weight for balance, it will be found that the system is in balance for all angles of attack and the reading of the moment balance will not change due to change in position of the model and rigging weight. With this arrangement, using always the same amount of counter-weight on the pitching moment system, the moment of the model weight and those parts of the rigging moving in angle of attack will be constant for any set-up. To eliminate the static moment in roll fixed counter-weights can be mounted on arms extending forward from the ends of the cross tube. When once adjusted, the fixed counter-weights need not be disturbed so long as the magnitude of the pitching moment counter-weight is not changed. Changes in model weight will make no difference.

SUPPORT ARMS AND ALIGNING SYSTEM.

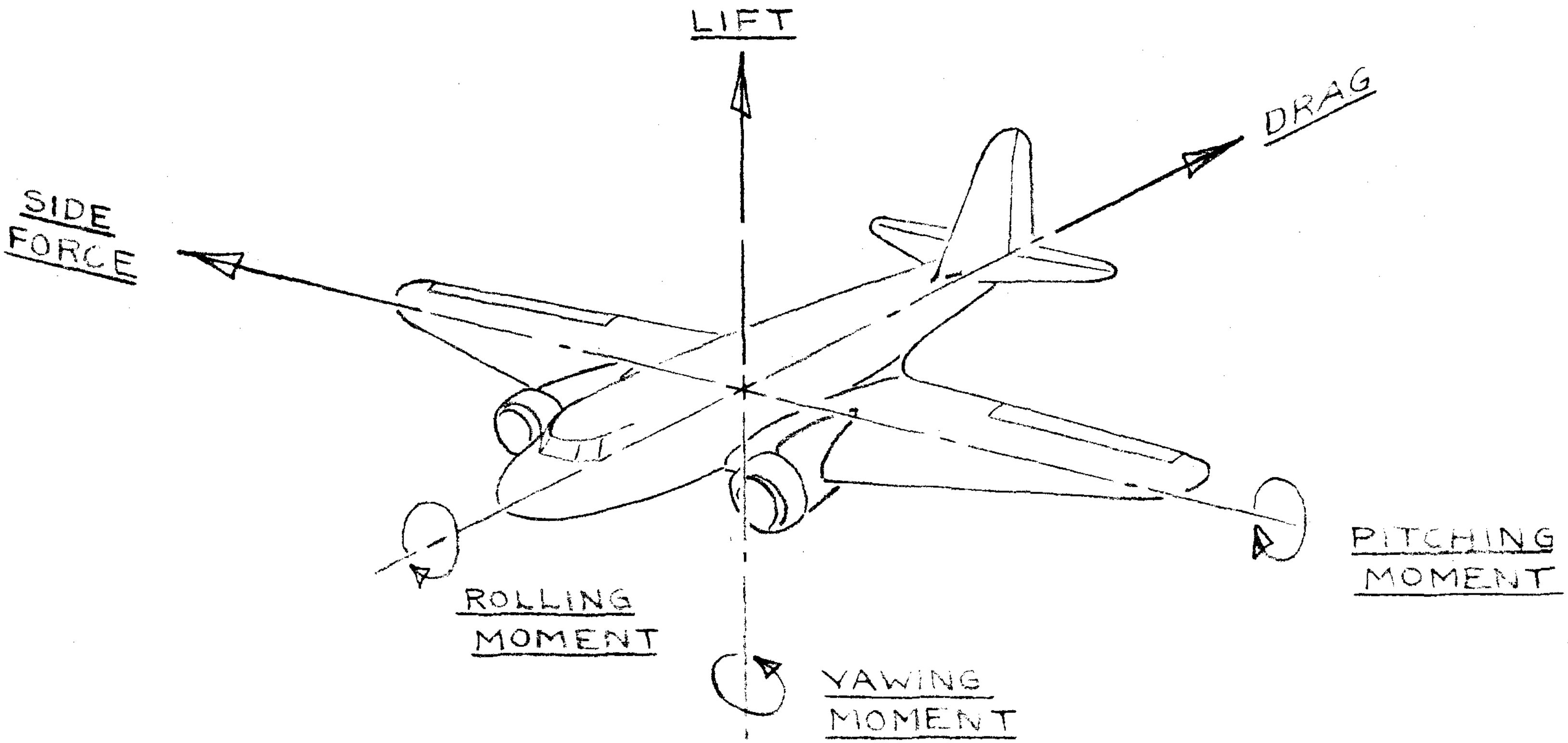
The support arms have not changed basically to any great extent from the original plan. The lower part of the arm will probably be solid for about 20 in. and removable from the upper part of heavy bent and welded sheet steel. By having a lower removable section variable "vertical" trunnion spacing can be provided and it is thought that rigging can be facilitated. In order to keep the tare drag and side forces low and nearly constant, the support arms are to be rotated about a vertical axis through the trunnion points so that their major axis (longitudinal) will be always parallel to wind axes. Originally it was planned to simply shut down the tunnel between runs at angles of yaw, unclamp and manually rotate the support arms, re-clamp and proceed with another run. With the decision to make yaw a remotely controlled parameter a parallelogram linkage was designed to maintain support arm alignment. This was discarded as being too bulky in favor of a worm sector and worm drive on the upper end of the arm designed to work simultaneously with the yaw drive and possible on a power bleed-off from that source.

WINDSHIELDS AND CONNING TOWER.

In order to keep the tare forces and moments as small as possible, it was decided to windshield the support arms and tail strut to the greatest possible extent. This then calls for a windshield system that will closely follow the support members both in pitch and in yaw. Details of a system for doing this have not been considered so completely as have details of the rigging proper. Directly on top of the tunnel it is proposed to mount a large circular track carrying a platform to rotate in yaw simultaneously with the rigging. On this will be mounted the windshielding and such drives and controls as are necessary. This platform will also serve as a place to stand while rigging adjustments are being made. In order that the windshielding may have small clearances on the support members it should have the same reference frame as the rigging proper. For this reason suspension from the same ceiling beams that support the rigging will probably be advisable. As with most other details that of windshield control has not been decided upon. Those that are being considered are synchronous drive, simple contact control, and a photo-electric coupled thyratron control.



							TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			AXES OF ROTATION OF THE AIRPLANE				FIG. 1
			NAME				DRAWING NO.



MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	TOLERANCES .010 OR UNLESS OTHERWISE NOTED

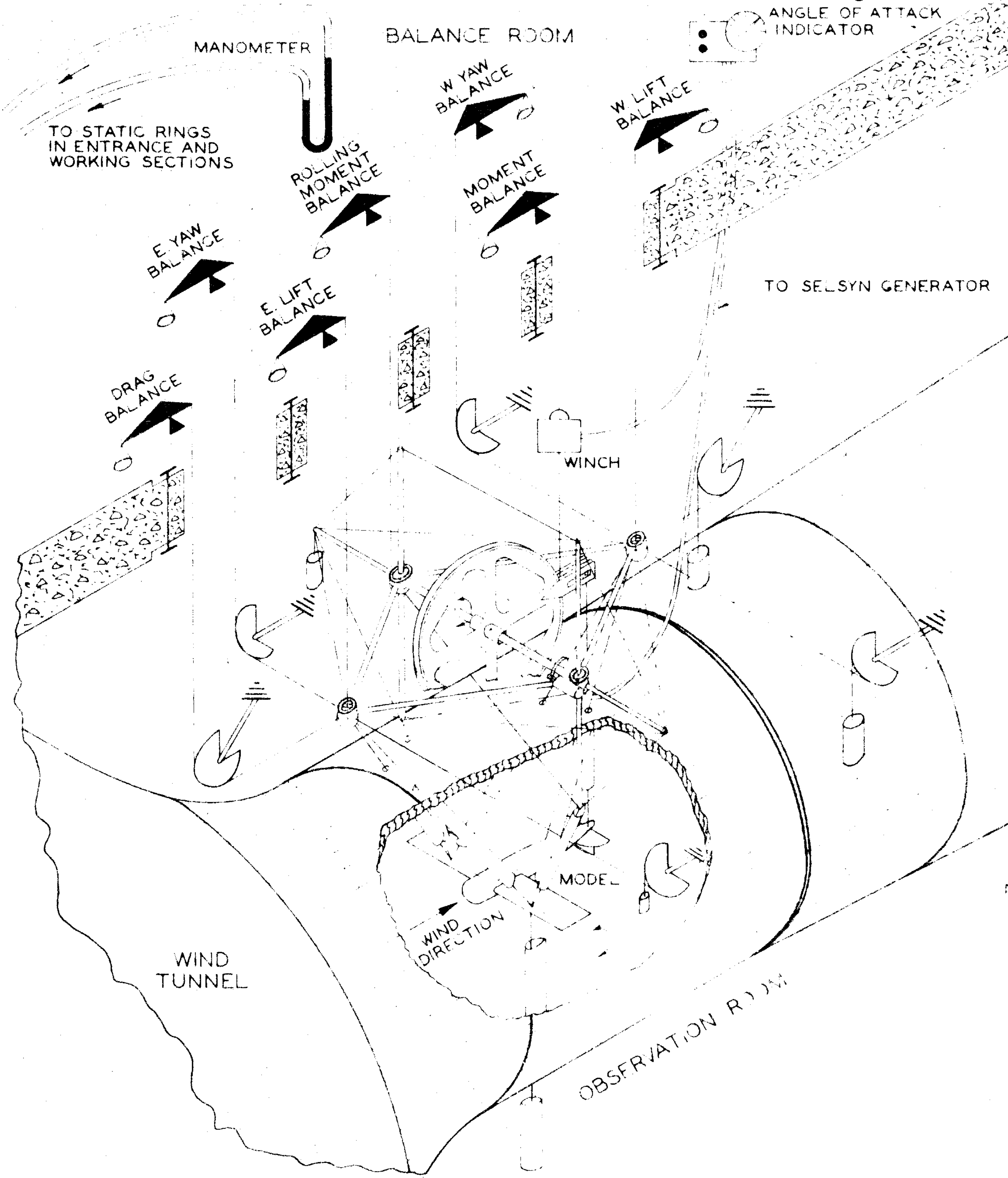
GUGGENHEIM AERONAUTICAL LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

FORCES AND MOMENTS ~ BODY AXES

NAME

FIG. 2

DRAWING NO.



SIX COMPONENT SETUP FOR TEN FOOT WIND TUNNEL TESTS
AT GUGGENHEIM AERONAUTICS LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

FIG.

DWG. WT 26

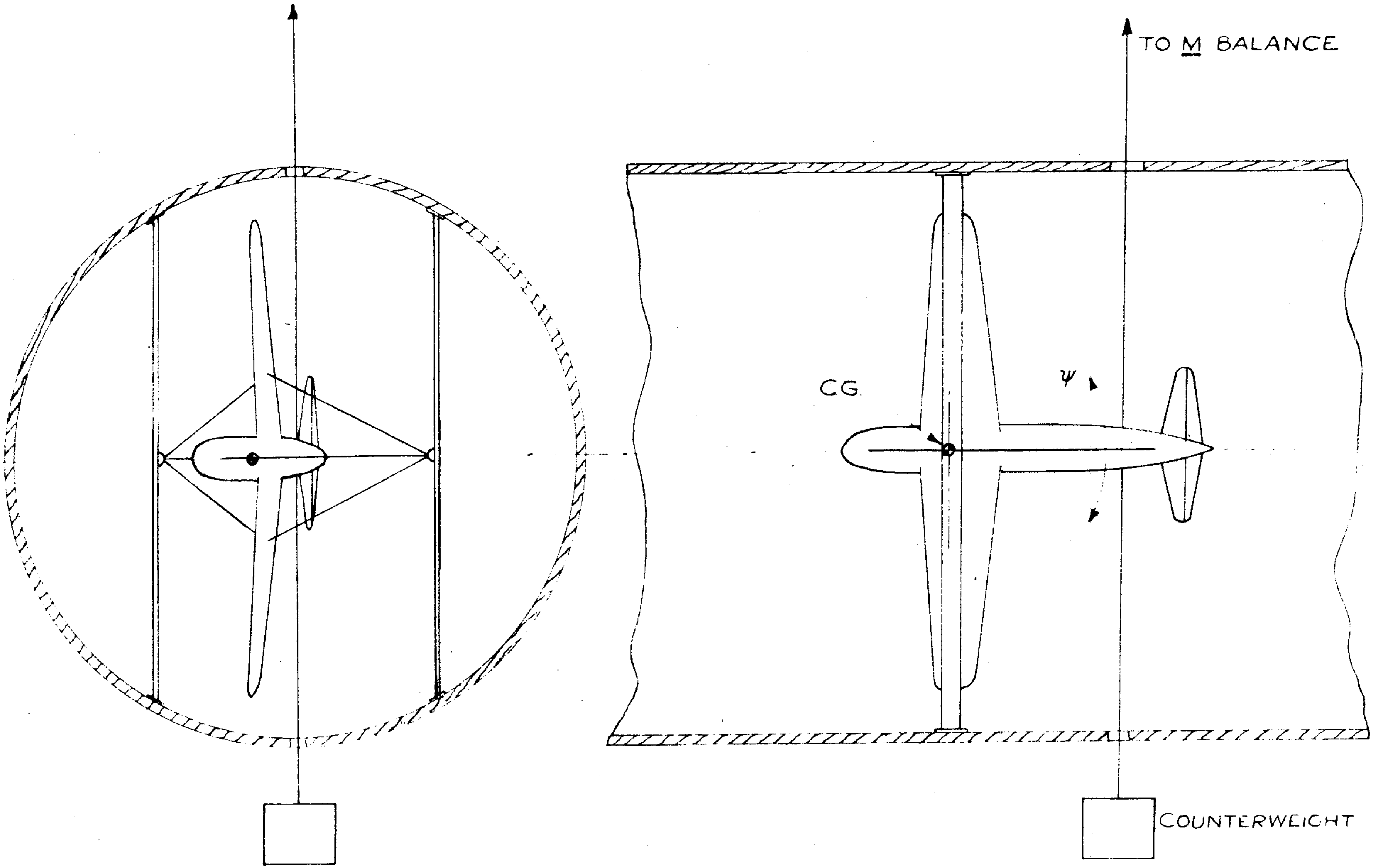
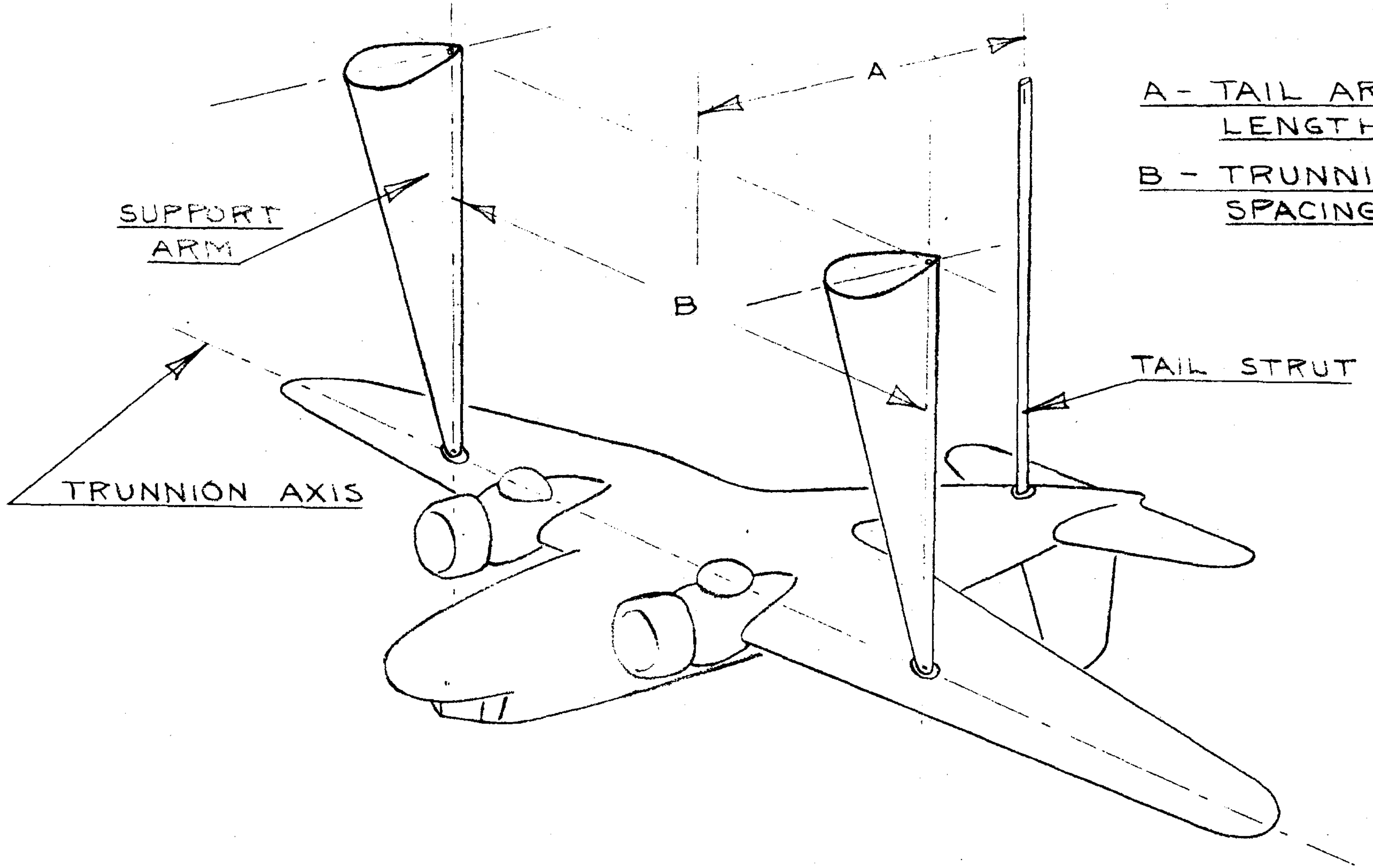
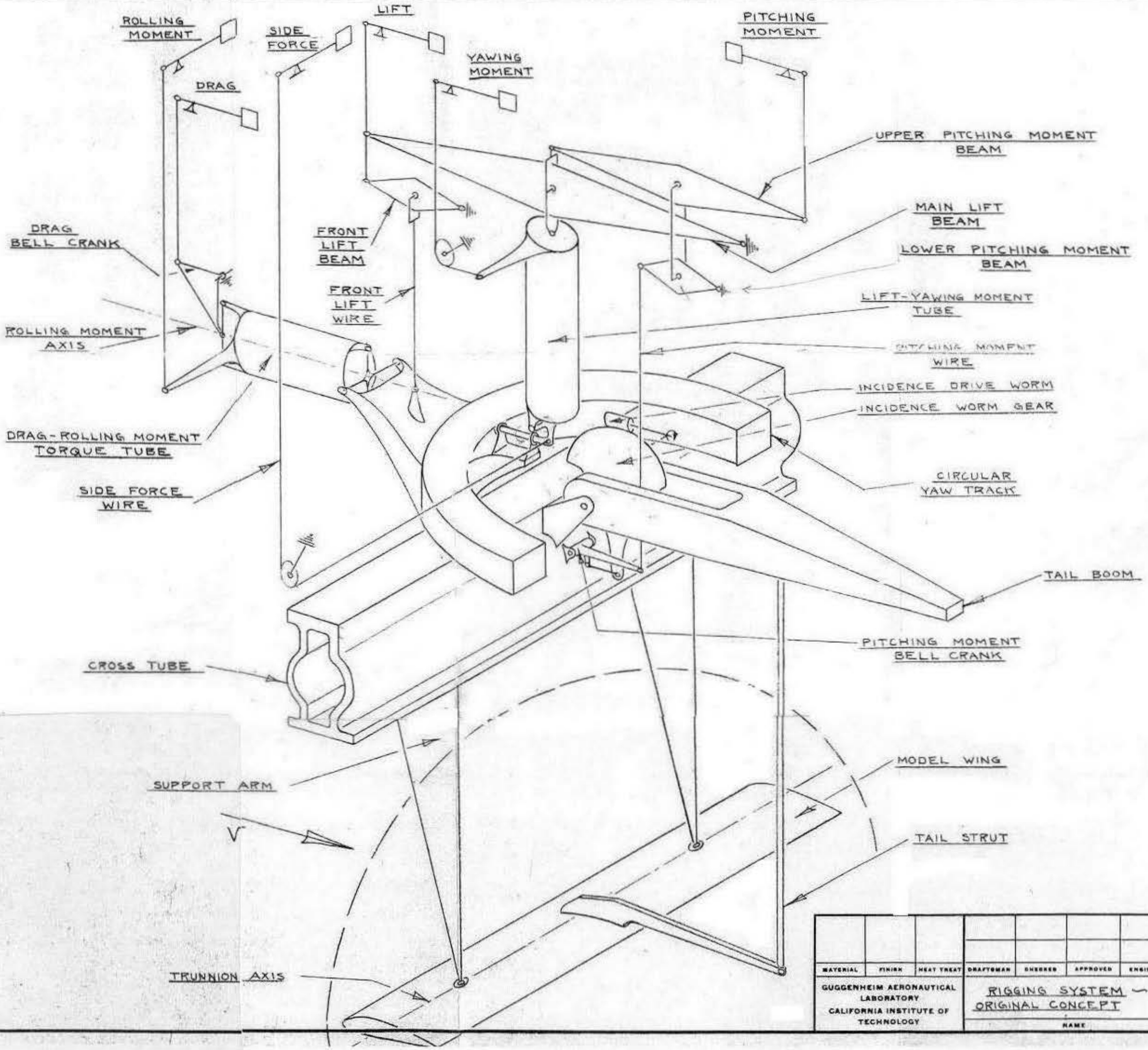


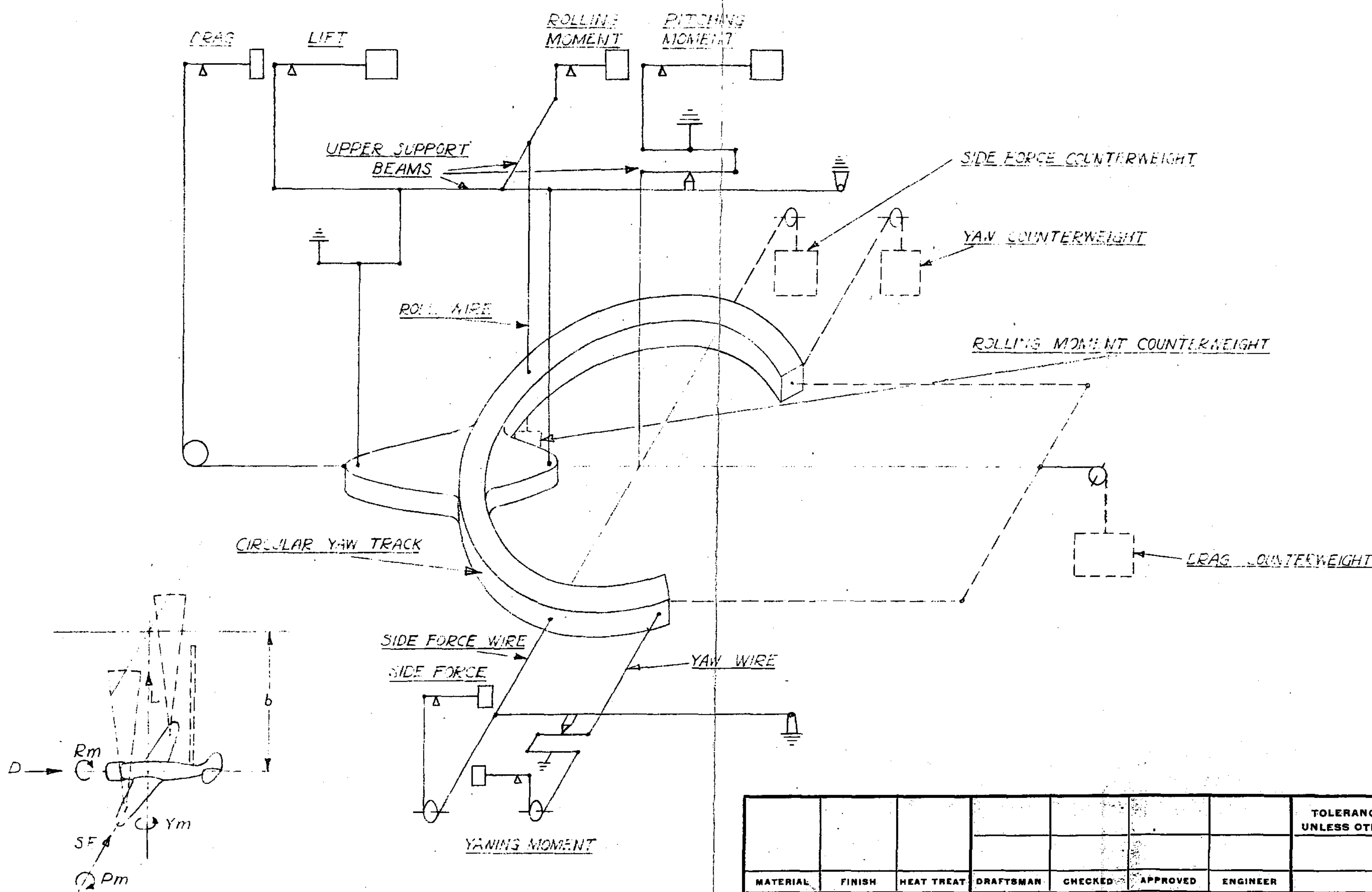
DIAGRAM SHOWING RIGGING FOR YAW-AT-YAW



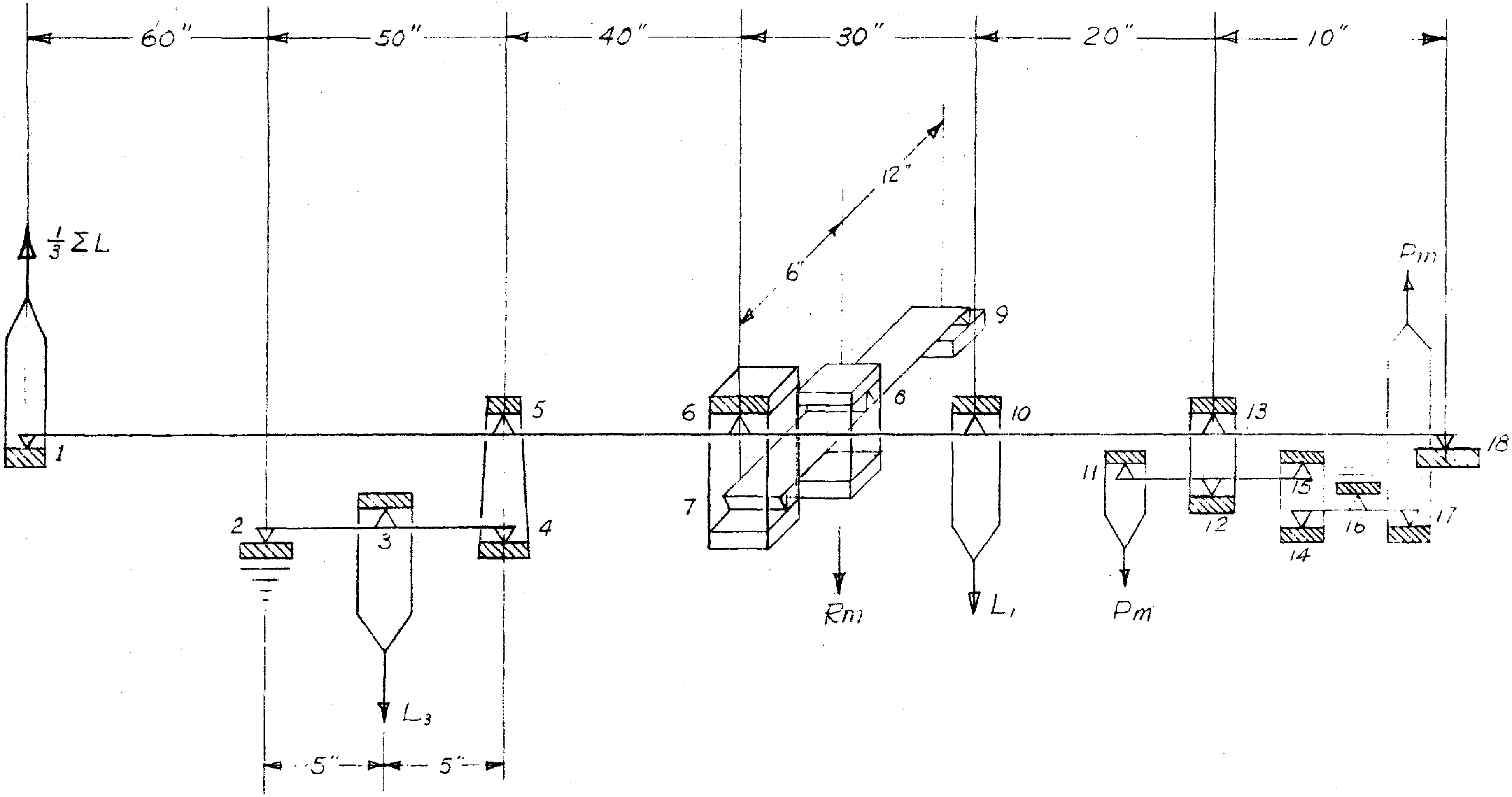
							TOLERANCES .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			THREE POINT MODEL SUSPENSION				FIG. 5
			NAME				DRAWING NO.



MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	TOLERANCES ± .010 OR ±, UNLESS OTHERWISE NOTED
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			RIGGING SYSTEM – ORIGINAL CONCEPT				FIG. 6
			NAME				DRAWING NO.



							TOLERANCES ± .010 OR 1/64 UNLESS OTHERWISE NOTED
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			FORCE RESOLVING SYSTEM				FIG. 7
			NAME				DRAWING NO.



MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	TOLERANCES ± .010 OR 1/64 UNLESS OTHERWISE NOTED

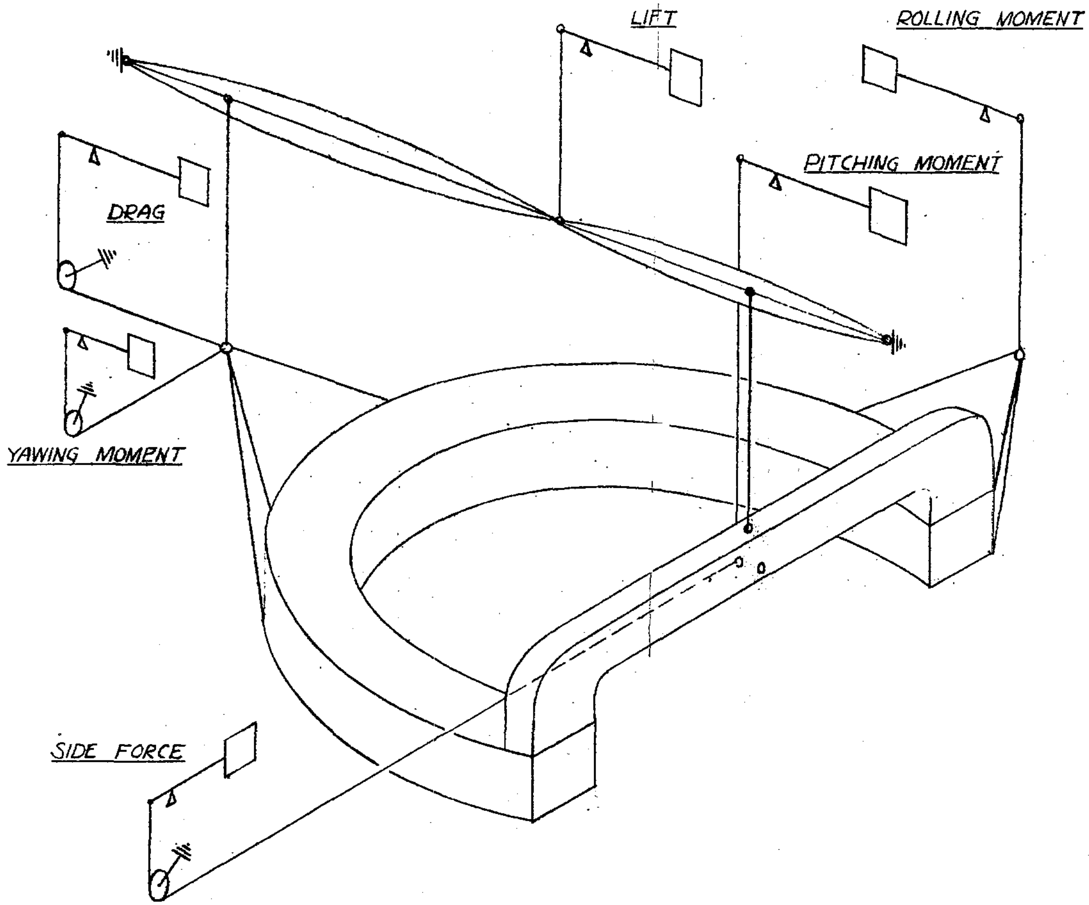
GUGGENHEIM AERONAUTICAL LABORATORY
CALIFORNIA INSTITUTE OF TECHNOLOGY

UPPER BEAM
KNIFE-EDGE ARRANGEMENT

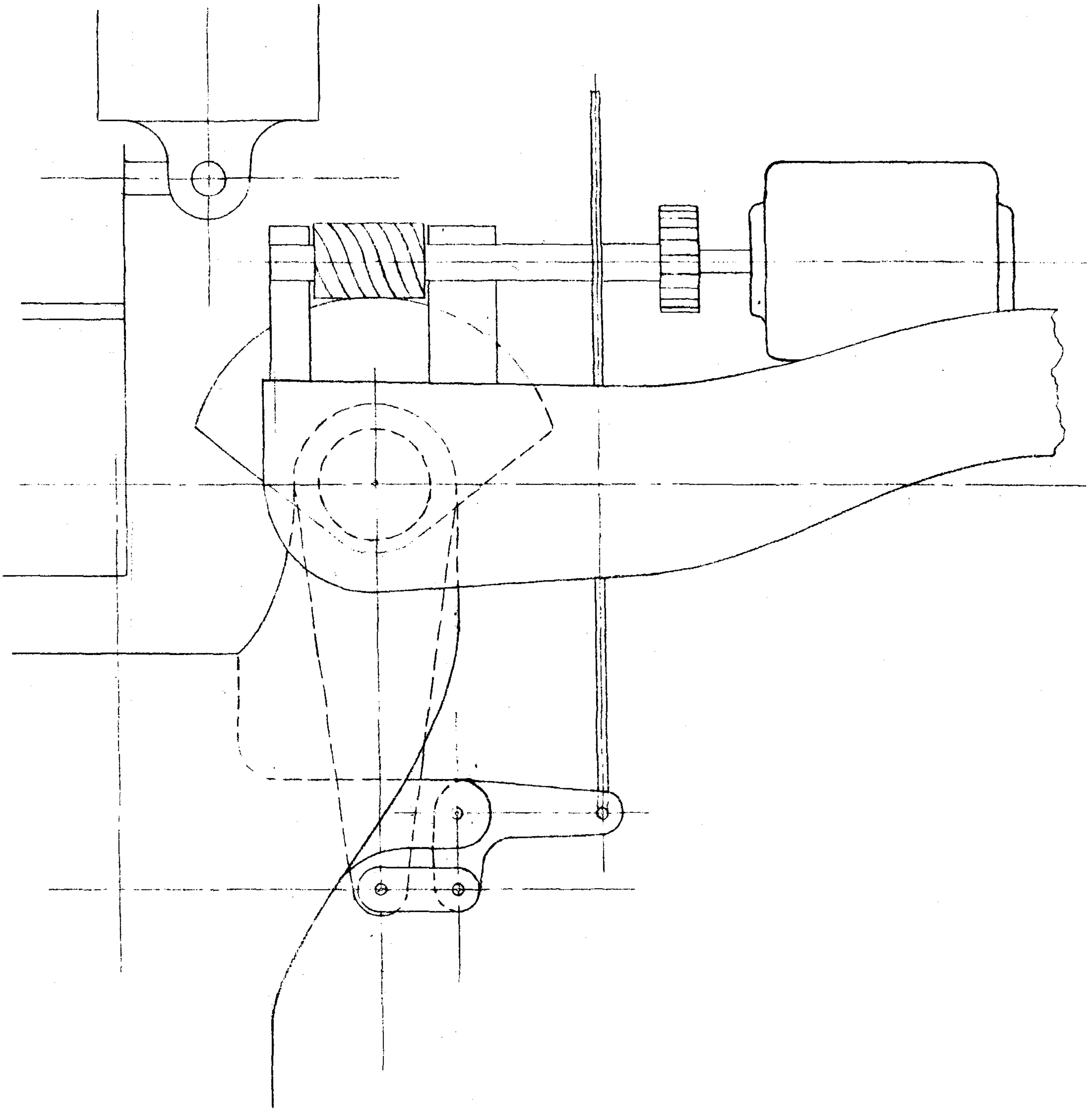
NAME

FIG. 8

DRAWING NO.



							TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			SHORT BEAM OVERHEAD SUPPORT				FIG. 9
			NAME				DRAWING NO.



ORIGINAL I.V.M. SYSTEM

FIG. 10

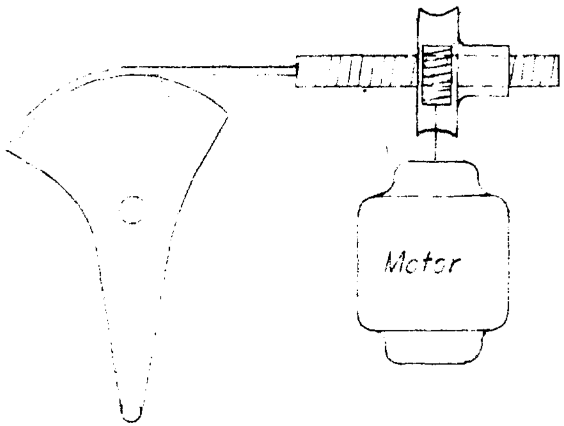


Fig. 11
Lead Screw – Tape I.V.M.

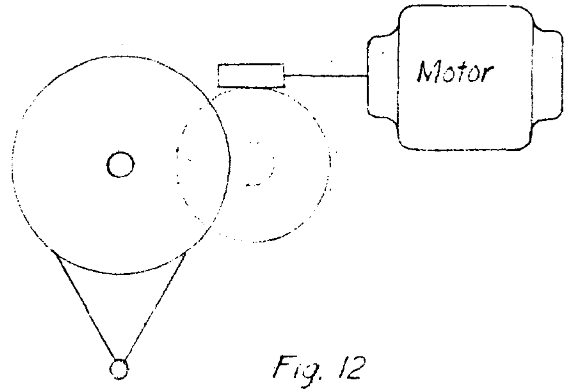


Fig. 12
Spur and Worm I.V.M.

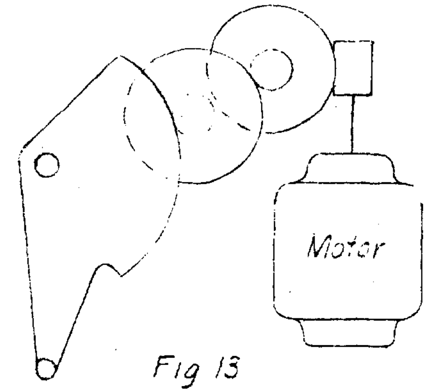


Fig 13
Spur and Worm Gear I.V.M.

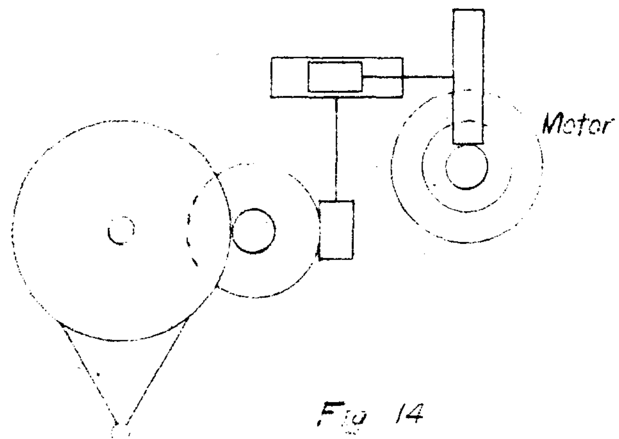


Fig 14
Spur and Worm I.V.M.

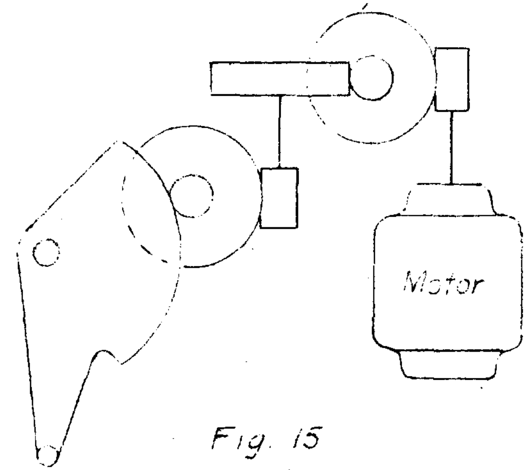


Fig. 15
Spur and Worm I.V.M.

MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			SOME PROPOSED I.V.M. SYSTEMS				FIG. 11–15
			NAME				DRAWING NO.

FIG. 17

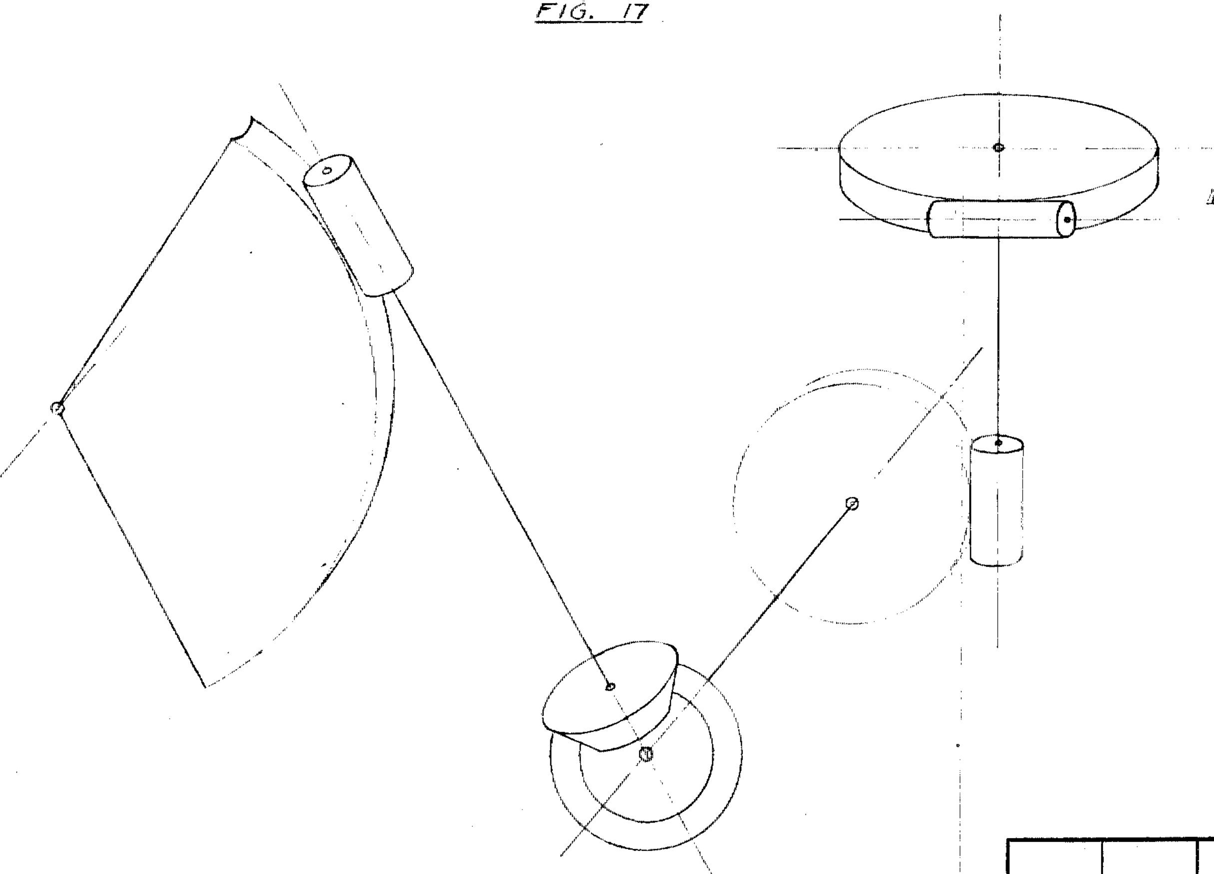
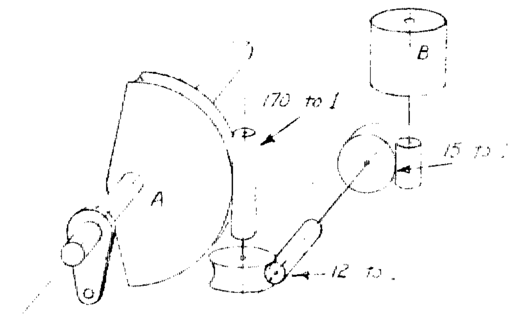
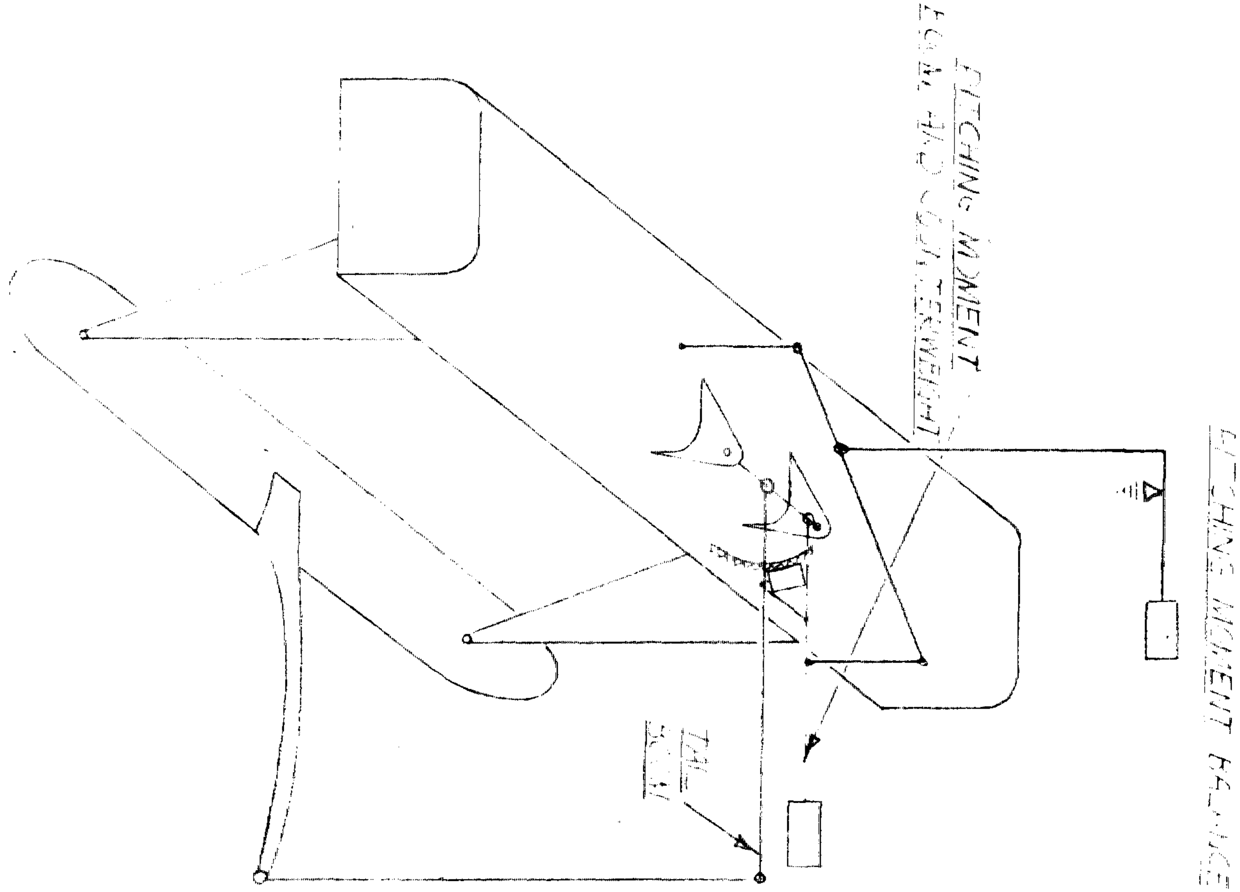


FIG. 16

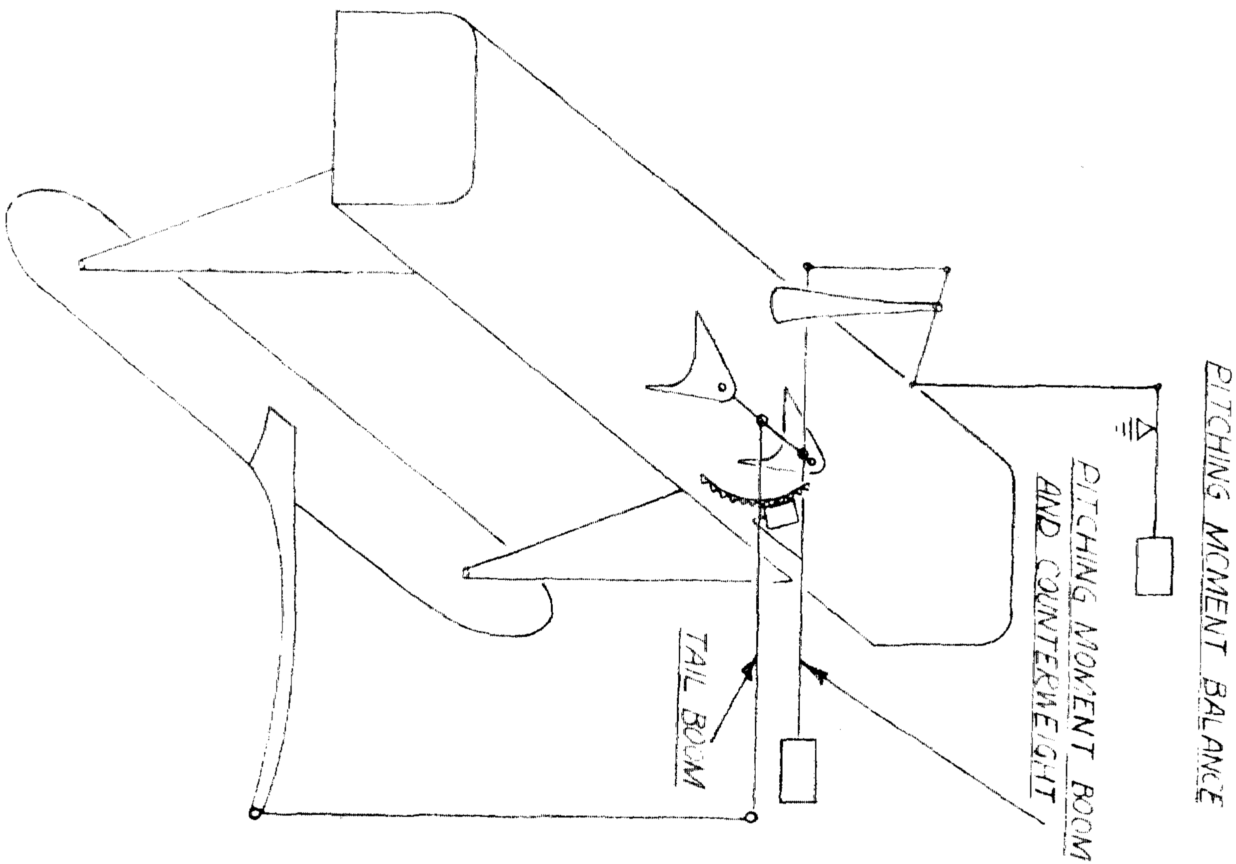


AB ratio 12 × 15 × 170 = 30,600

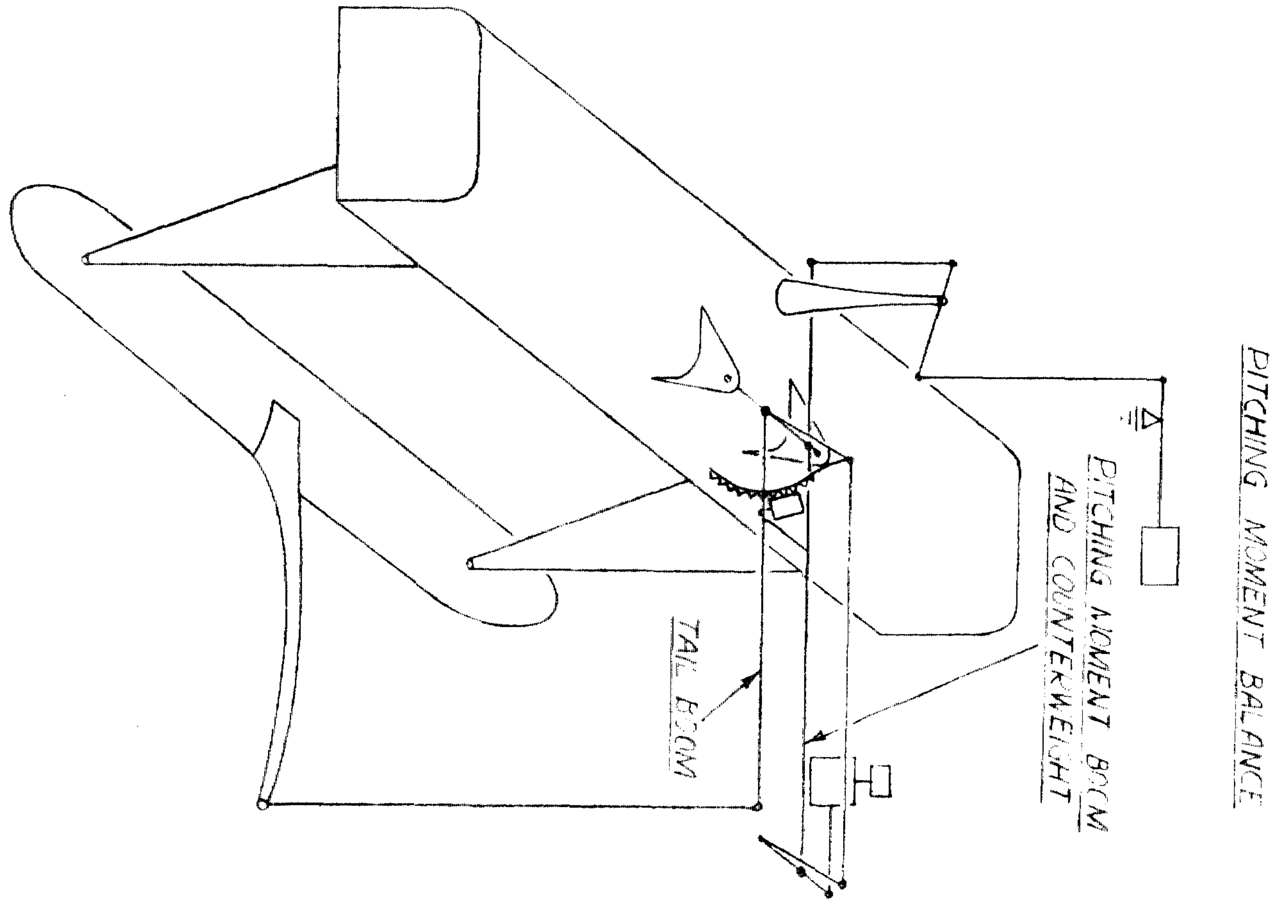
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			SPUR AND WORM I.V.M.				FIG 16-17
			NAME				DRAWING NO.



							TOLERANCES ± .010 OR 1/64 UNLESS OTHERWISE NOTED
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			OVERHEAD BEAM PITCHING MOMENT ARRANGEMENT				FIG. 13
			NAME				DRAWING NO.



							TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			REVISED OVERHEAD BEAM PITCHING MOMENT ARRANGEMENT				FIG 19
			NAME				DRAWING NO.



							TOLERANCES ± .010 OR $\frac{1}{64}$ UNLESS OTHERWISE NOTED
MATERIAL	FINISH	HEAT TREAT	DRAFTSMAN	CHECKED	APPROVED	ENGINEER	
GUGGENHEIM AERONAUTICAL LABORATORY CALIFORNIA INSTITUTE OF TECHNOLOGY			STATIC MOMENT COUNTERWEIGHT SYSTEM				Fig 2C
			NAME				DRAWING NO.