CENTRAL SCIENTIFIC COMPANY

OPERATING INSTRUCTIONS

Experimental Crane Boom
No. 74300

1. Introduction

The Experimental Crane Boom (74300) is designed to be set up as a model crane or derrick when it is used with the recommended accessories. Use it to study force and torque methods of solving problems involving bodies in static equilibrium.

2. Description

The apparatus consists of a compression spring scale that serves as the crane boom when it is set up with the proper accessories. The scale has a range of 15kg, graduated in tenths of a kilogram. The lower end of the crane boom ends in a bent rod around which the apparatus pivots. Chains and cords for applying the load and supporting force are attached to the upper end of the scale. Supplied with the apparatus is a hook collar (72410-03), which is used to suspend a pull-type spring scale.

Not supplied with the apparatus, but required for operation, are: a spring scale, masses, mass hanger, clamps, a rod, and a pulley. If you don't have these items, we recommend the Central Scientific products listed in Section 6, "Accessories."

3. Theory

A body at rest when under the action of forces is said to be in static equilibrium. In order to obtain this state two important conditions must be fulfilled:

(1) For a body to be in equilibrium as far as *linear* motion is concerned, the *vector* sum of all the external forces acting upon it must be zero. This statement can be put in several equivalent forms such as

  (a) the vector polygon representing all the external forces must be a closed figure

  (b) the *resultant* of all the external forces must be zero

  (c) the algebraic sum of all the component forces in any direction must be zero — specifically, the algebraic sum of the horizontal and vertical components must each equal zero.

(2) For the body to be in equilibrium as far as its *rotary* motion is concerned, the algebraic sum of the *torque*s of all the coplanar forces about any axis perpendicular to the plane must be zero.

In this experiment both of these conditions are used in the calculation of the thrust in the boom of the crane and the tensional force in the rope, assuming the load to be lifted and the dimensions of the crane are known quantities. For example, consider the forces acting upon the point **O** in the crane in Figure 1.

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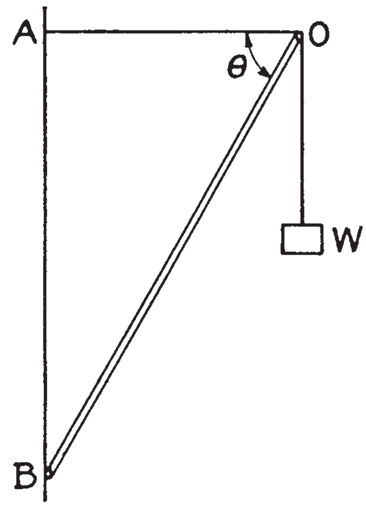

Figure 1

Let the force in the rope be represented by $\mathbf{F_1}$ and that in the boom by $\mathbf{F_2}$. The directions of their actions on **O** are shown in Figure 2.

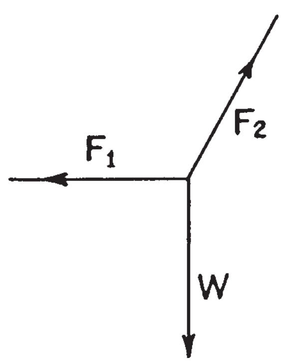

Figure 2

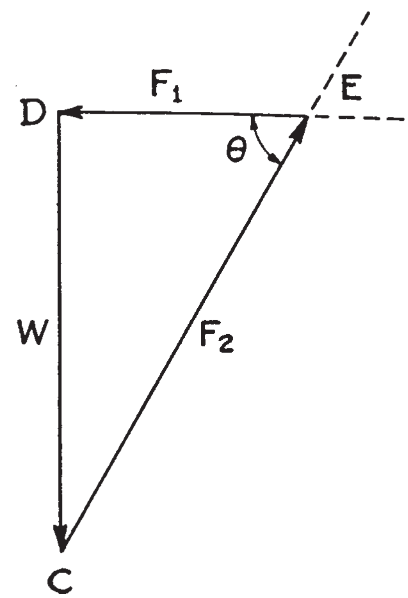

Figure 3

Notice that both the magnitude and direction of **W**, but only the directions of $\mathbf{F_1}$ and $\mathbf{F_2}$ are known. But since the point **O** is in equilibrium under the action of these three external forces, their vector sum must be zero and the vector polygon representing the forces must be a closed figure. Hence, the polygon shown in Figure 3 may be constructed by drawing, first, a vector **DC** to a suitable scale to represent the known weight **W**; second, a line **ED** in the direction (here horizontal) of the force in the rope; and third, a line **CE** in the direction of the force in the boom.

The figure must be a closed polygon for the body to be in equilibrium and hence the intersection at **E** of the lines **ED** and **CD** determines the length of the vectors representing $\mathbf{F_1}$ and $\mathbf{F_2}$. The vector triangle **CED** is similar to the figure of apparatus **BOA** since their sides are respectively parallel; note, however, that the triangles are not *identical.* (Much confusion can be avoided by a clear differentiation between the two figures; a vector figure should not be superimposed upon a figure of apparatus until the student is thoroughly familiar with this field.) If a graphical solution is desired the lines **ED** and **CE** may be scaled off to the same scale as was used in constructing **DC**, and thus the values of $\mathbf{F_1}$ and $\mathbf{F_2}$ are immediately obtained. If an analytical solution is to be used it may be obtained in various ways. For example, since the vector triangle **CED** is similar to the figure of apparatus **BOA**, the sides are respectively proportional and

$$F_2 / W = OB / AB \quad \text{or} \quad F_2 = W (OB / AB) = W \csc \theta \qquad (1)$$

and similarly

$$F_1 / W = AO / AB \quad \text{or} \quad F_1 = W (AO / AB) = W \cot \theta \qquad (2)$$

The values of $\mathbf{F_1}$ and $\mathbf{F_2}$ can also be obtained from a consideration of the torques due to the external forces acting upon the crane. The common convention is to consider torques producing counter-clockwise rotation as positive and those producing clockwise rotation as negative. Hence in Figure 4 the force **W** will produce a negative torque about point **B**, while $\mathbf{F_1}$ will cause a positive torque.

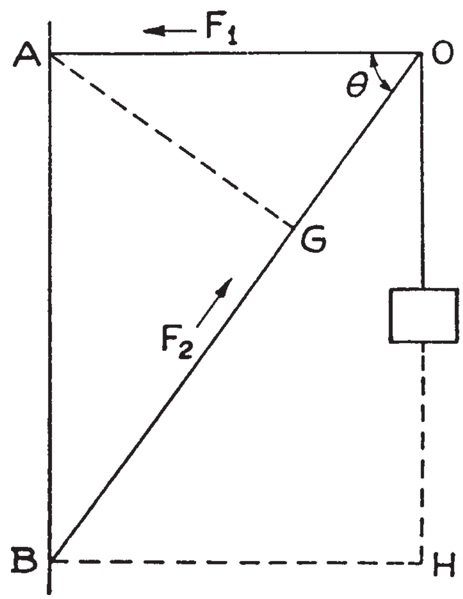

Figure 4 Illustrating the torque method used in solving for forces in the Model Crane.

When the second condition for equilibrium is applied and the sum of the torques about the point **B** is equated to zero

$$-W \times BH + F_1 \times AB + F_2 \times 0 = 0 \qquad (3)$$

Similarly, writing the expression for the torques about **A**

$$-W \times AO + F_2 \times AG + F_1 \times 0 = 0 \qquad (4)$$

Knowing **W** and the various distances, Equations (3) and (4) may be solved for $\mathbf{F_1}$ and $\mathbf{F_2}$.

Similar procedures can be used to solve for “unknown” forces in terms of the known load and dimensions of the apparatus for various configurations of the crane.

4. Operation

4A. Experimental

1. Arrange the experimental crane as in Figure 1. Make the point **B**, at which the lower end of the crane boom is supported, as nearly as possible vertically below the intersection of the horizontal and vertical cords at **A**. Be sure that the entire assembly is in the vertical plane (view it from a short distance). Have the collar **O** about halfway between the ring and the scale when no load is attached. Using a right-angle triangle, a square, or a protractor, make sure that the rope is horizontal.

2. With zero load attached measure with a meter stick provided with vernier jaws the dimensions of the crane, namely, the distances **AO**, **OB**, and **AB**. Read both balances to obtain "zero" or "tare" corrections necessary because of the weight of the boom. Always tap the boom to reduce its friction before taking its final readings. It is a good idea in the record of this experiment to draw a rough sketch of the crane on the data sheet, recording on the sketch all the necessary data.

3. After the no-load readings have been recorded, attach a rather large load (say 10kg, including the scale pan) for **W**. It will now be necessary to move upward both the collar **O** and the vertical spring balance **S** in order to restore the configuration of the crane to its original values. After this has been accomplished tap the boom and record its reading and also that of the balance. By subtracting the appropriate "no-load" values recorded in Part 2, the corrected load values are obtained. These are to be used as the experimental values of the forces $\mathbf{F_1}$ and $\mathbf{F_2}$.

4. Repeat the above procedure with the crane in other configurations, particularly those in which the apparatus does not form a right-angle triangle.

4B. Interpretation of Data

The major objective of this experiment is to compute the values of $\mathbf{F_1}$ and $\mathbf{F_2}$, assuming as known only the value of **W** and the geometrical dimensions of the crane. This should be done by the following three methods:

(a) *Torque Method*. Make a good sketch of the crane on graph paper, to a large scale. By writing the equations of torques about points **A** and **B**, respectively, the values of $\mathbf{F_1}$ and $\mathbf{F_2}$ can be calculated from the known values of **W** and the appropriate lever arms. The lever arm of $\mathbf{F_2}$ about the axis **A** is easily expressed in terms of the distance **AO** and the angle **AOB**.

(b) *Graphical Vector-Polygon Method*. Draw a *vector* triangle (something like Figure 3) having its sides parallel, respectively, to the directions of the forces about **O**. *Use a large scale.* Since the magnitude of **W** is known the values of $\mathbf{F_1}$ and $\mathbf{F_2}$ may be immediately obtained by scaling off the appropriate vectors.

(c) *Analytical Vector Method*. Calculate the values of $\mathbf{F_1}$ and $\mathbf{F_2}$ from the trigonometry of the figure used in Part (b), or use simple proportions as described in the theory.

Note the percentage differences between the *experimental* values of $\mathbf{F_1}$ and $\mathbf{F_2}$ and the average of the *calculated* values obtained in (a), (b), and (c).

In the report of the experiment resolve the forces **W**, $\mathbf{F_1}$, and $\mathbf{F_2}$ into **X** and **Y** components and check the first condition for equilibrium by noting whether their respective algebraic sums are equal to zero. (This need be done for only one of the arrangements used. Do not select the case where $\mathbf{F_1}$ is horizontal.)

4C. Questions

1. Why was it desirable in this experiment to have the load chosen so a maximum reading was obtained on the scales?

2. Three unequal forces act upon a body at a point so the body is in equilibrium. If the magnitude of two of the forces be doubled, how must the third force be changed to preserve equilibrium? Justify conclusion by diagrams.

3. Draw a diagram showing the vector polygon of the forces acting upon a ladder that leans against a smooth vertical wall and rests upon the rough ground. (Note: The thrust of the ground is *not* along the ladder, and the wall cannot exert a force parallel to its surface.)

4. What configuration of the crane would make **W**, $\mathbf{F_1}$, and $\mathbf{F_2}$ all equal? Explain reasoning and illustrate by a vector diagram.

5. Which of the following completes this statement correctly?

   For a body to be in equilibrium the body _________.

   (a) must be at rest
   (b) must move with uniform acceleration
   (c) must have uniform linear and rotary velocity
   (d) cannot be acted upon by external forces
   (e) must have the sum of the upward forces acting upon it just equal to its weight

6. A crane boom of negligible weight is 20 ft. long. It makes an angle of 30° with a vertical mast. The tie rope, fastened from the upper end of the boom to the wall, makes an angle of 90° with the boom. The maximum tensile force that the rope can safely stand is 5.0 tons. What is the maximum load the crane can support and the thrust in the boom for this load? Solve by both an analytical-vector method and a torque method.

7. A derrick boom 30 ft. long weighs 400 lbs. and is hinged at the bottom to a vertical mast. The boom is held in position by a rope attached at the top, the rope making an angle of 90° with the boom, and the boom making an angle of 30°, with the mast at the hinge. If a load of 1 ton is carried at the top of the boom, what is the force exerted on the hinge?

8. A crane is constructed with a 200-lb. uniform boom **B** 30 ft. long attached to a vertical mast **A**. The cable **C** is fastened to the mast at a point 20 ft. above the place where **B** is hinged to **A**. The boom inclines 30° to the vertical, and **C** is attached to **B** at a point 10 ft. from the upper end of the boom. Find the thrust of **B** against **A** and the pull on **C** when a load of 1kg is attached to the upper end of **B**. Solve by the graphical method.

5. Maintenance

The Experimental Crane Boom needs no special maintenance. If you should experience any difficulty with this piece of equipment, please contact Central Scientific Company, giving details of the problem. To ensure better service, please do not return any item to Central Scientific Company until we have sent you authorization.

6. Accessories

Description	Cat. No.
15kg/30 lb. Spring Scale	05800
Slotted 1kg Mass	09655-02
Slotted 2kg Mass	09655-03
Slotted 5kg Mass	09655-04
Heavy Duty Mass Hanger	09660-01
2cm x 184cm Steel Rod	72205-03
Right-Angle Clamp	72310-02
Ball-Bearing Collar Mounted Pulley	75663
Table Clamp	72345

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