Experimental Towing Tank
Stevens Institute of Technology
Hoboken, New Jersey

A ROTATING ARM FOR TOWING MODELS OF SHIPS AND OTHER FORMS IN CIRCULAR PATHS

by

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Prepared for the
David Taylor Model Basin
Navy Department
Washington, D.C.

under Bureau of Ships Contract NObs 22087
Job Order 9

February 1946

Report No. 299

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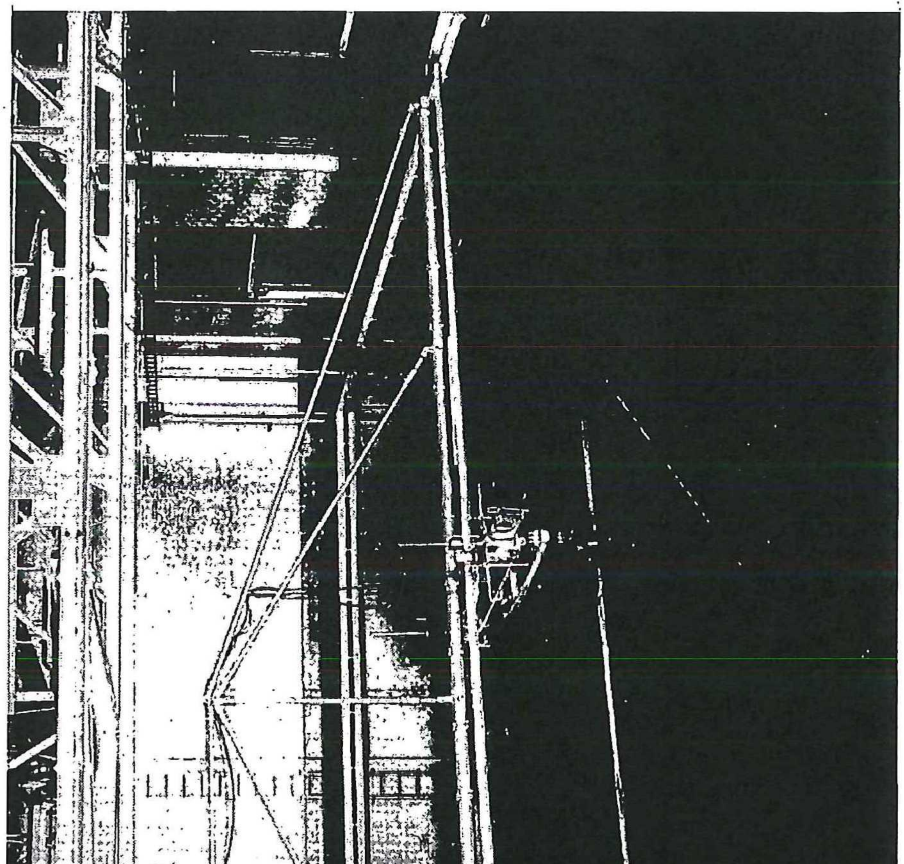


ABSTRACT

A "rotating arm" apparatus, installed in the Maneuvering Tank at the Experimental Towing Tank, Stevens Institute of Technology, provides a means of towing models of ships and other forms in circular paths. The diameter of the circle traversed may be adjusted from ten to sixty-five feet. The speed of rotation may be adjusted from one to six revolutions per minute.

The rotating arm equipment, constructed under Contract NObs 22087 between the United States Navy and the Experimental Towing Tank, was put into operation in October, 1945.

NEED FOR A ROTATING ARM

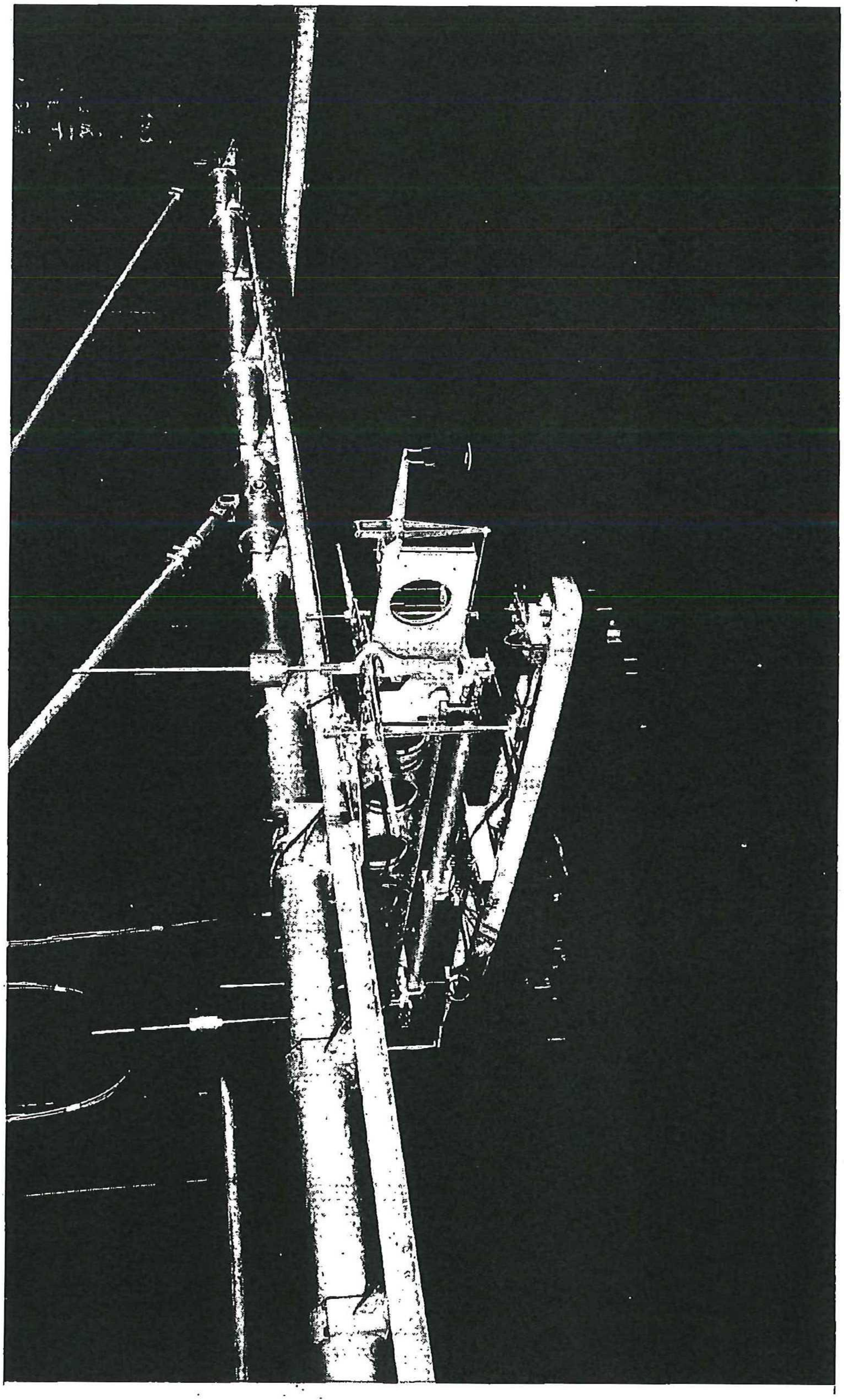
For many years considerable attention has been given to the hydrodynamics of ships moving in circular paths. In particular, the David Taylor Model Basin and the Experimental Towing Tank have jointly furthered these studies both by analytical work and model tests. As the investigations progressed, it became apparent that existing test techniques did not supply sufficient data to determine completely the forces acting. Furthermore, the analytical approach could advance further if supplementing experimental data could be supplied.

In 1942, a seventy-five foot square maneuvering tank, known as Tank No. 2, was built at the Experimental Towing Tank under the sponsorship of the NDRC for tactical tests of ship models. The test technique developed for these studies involved the use of free-running models carrying their own propulsive and steering equipment. It was thus possible to observe both the steering and turning characteristics of models directly. In addition, measurements of the lateral force acting on the rudders were made with a dynamometer carried in the model. However, no other force measurements could be obtained readily while the model was in circular motion.

It was apparent that need existed for a type of instrumentation comparable to that used in a towing tank where a model can be towed by a carriage equipped with a system of dynamometers for measuring the lateral and longitudinal forces acting on the hull. To state the problem another way, a towing carriage capable of traveling in circular paths was required.

This need had been recognized at the Experimental Towing Tank in 1939, at which time a small-scale rotating arm apparatus was constructed and used in a limited number of tests which were conducted in a swimming pool. The arm could be extended to cover a maximum diameter of 20 feet. It carried indicators at its outer end, but was useful only for work with models of about 27 inches length and a little more than one pound displacement.

It was decided, therefore, to install in Tank No. 2, a new and enlarged rotating arm, large enough to tow the five to eight foot models ordinarily used at the Experimental Towing Tank. It should also be able to carry the necessary complement of dynamometers needed for a complete picture of the hydrodynamics of a form traveling in a circular path.



DESIGN OF THE ROTATING ARM APPARATUS

General Specifications

In January 1945 the Experimental Towing Tank undertook the design and installation of a rotating arm apparatus under the following general specifications:

(1) Provision for Dynamometers

The arm should be equipped to carry suitable force measuring dynamometers. Either existing "towing tank" dynamometers or instruments especially designed for the arm might be used.

(2) Turning Diameters

Minimum diameters of about two ship lengths were desired - ten feet for a five-foot model. Maximum diameters were limited by the seventy-five foot diameter of the tank and by the mechanical problems incident to building an arm of great radius.

(3) Speed of Rotation

The speed of rotation of the arm was to be adjustable from one to six revolutions per minute, so that the speed ranges for models traveling at the extreme maximum and minimum diameters would be amply covered.

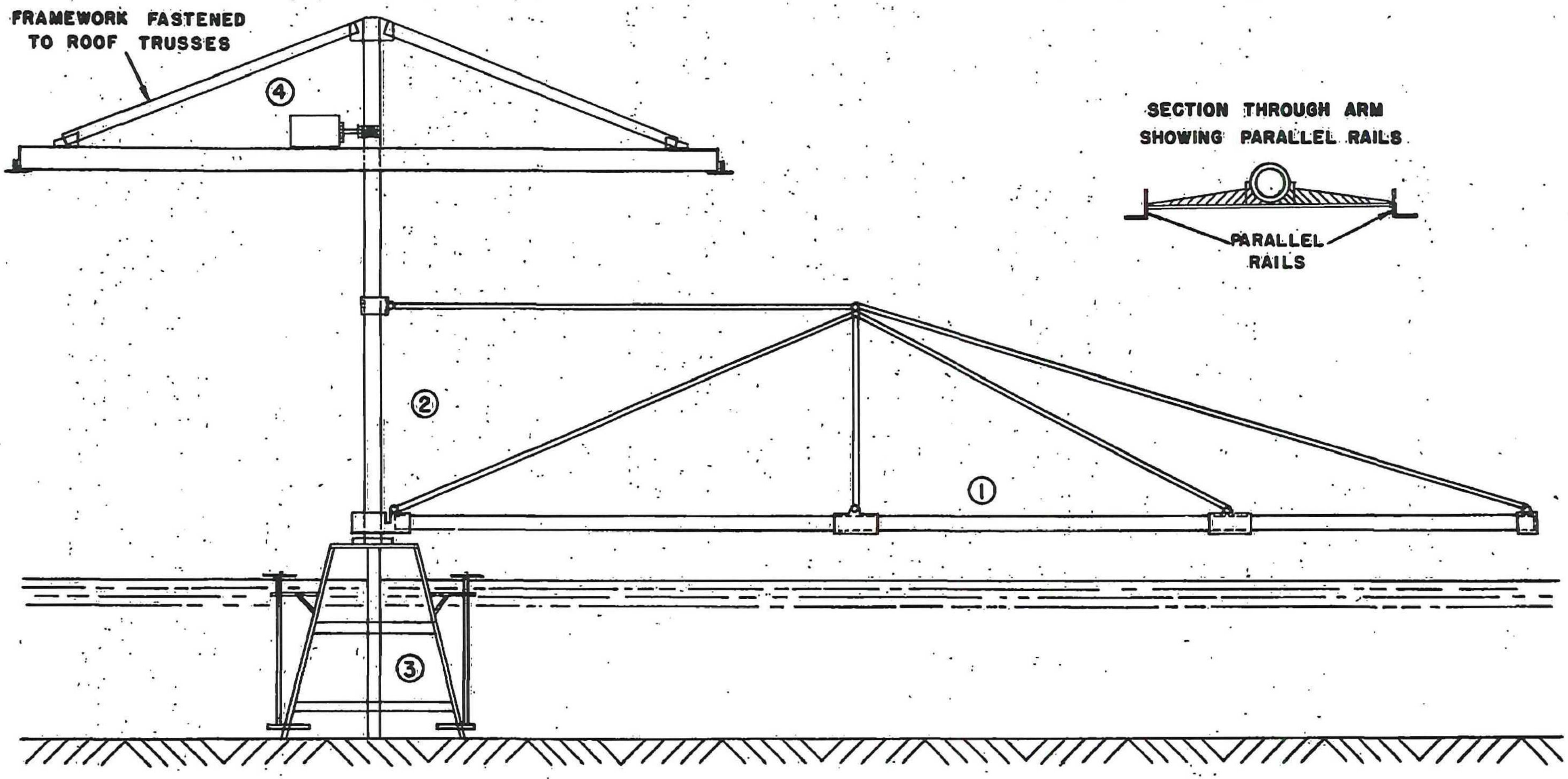
(4) Acceleration

In order to obtain a complete test run within 360° of turn, and thus avoid running a model in its wake, sufficient drifing power was to be provided to accelerate the arm to test speed within 90°. Originally it was felt that some sort of catapult might be required to accomplish this, but actual operation showed that proper manipulation of the speed controls obviated this need.

Alternate Design Considerations

A number of alternate designs for the arm were considered. From the standpoint of lightness, a lattice construction appeared attractive. However, to insure a satisfactory degree of stiffness for the structure as a whole, unduly complicated systems of guy wires were indicated. Furthermore, none of the lattice arrangements gave much promise of torsional stiffness of the horizontal

DIAGRAMMATIC SKETCH OF THE ROTATING ARM



arm. Such stiffness would be needed to counteract the drag of the model being towed, especially if the model were an underwater body such as a torpedo or submarine.

Design considerations finally pointed to the desirability of constructing the arm of duraluminum tubing. Original thoughts that suitable material would be unobtainable because of the war were dispelled when a quantity of tubing of the proper type was located in "excess stock". The tubing, prepared for a project which had since been cancelled, measured five inches in outside diameter and had a quarter inch wall. Its outer surface had been ground, making it admirably suited for the application.

Features of the Final Design

A general assembly drawing, on the opposite page, shows the principal features of the rotating arm structure. They are:

(1) a horizontal duraluminum arm with a simple system of stiffening struts,

(2) a vertical steel shaft with bearings top and bottom and with suitable keyways for transmitting the driving torque to the arm,

(3) a welded steel supporting base, mounted in the center of the tank,

(4) a drive assembly, located at the top of the vertical shaft, including a gear box and motor.

The horizontal arm is fitted on either side with parallel rails to which a carriage can be attached, at any attitude and any radius. The carriage, in turn, carries dynamometers and other test equipment. The arm, together with the stiffening struts, is mounted on the vertical drive shaft in such a way that the arm can be moved vertically. This provides an adjustment accomodating various arrangements of dynamometers and models wiich might involve different spacings between the arm and the water surface.

The vertical drive shaft can be properly plumbed by shifting its lower bearing horizontally. The upper bearing of the shaft is supported by a frame-work fastened to the roof trusses of the building. Near the top of the vertical shaft, a slip-ring and brush assembly supply the means for connecting electrical instruments on the arm with a stationary point on shore. Initially, nine conductors were provided for, but the slip-ring design is of a multi-deck sandwich form, so that additional circuits can be added at a later date.

At its lower end, the vertical shaft is supported by a three-legged steel supporting base, bolted to the tank floor for easy removal.

The drive mechanism, which is located at the top of the shaft, is a variable speed motor and a reduction gear. The motor speed is electronically controlled, the desired speed being selected by a potentiometer. The accuracy in speed regulation is of the order of 1%. The specified speed range of the arm and the characteristics of the drive motor call for reduction gear ratio of 652.5 : 1. However, a pair of externally mounted gears between the motor and gear box allow an extension of the speed range above 6 r.p.m. An over-riding, or "free-wheeling", clutch protects the high-ratio gear box from damage which might be caused by the arm's coasting; the motor can thus drive the arm, but the arm cannot drive against the worm of the gear box when the power is cut off. As an additional protection, a shear pin, interposed between the arm and the clutch, serves as an overall guard against damage to any part of the drive system caused by a shock or impact load.

OPERATION OF THE ROTATING ARM

The rotating arm has been in use since October 1945. Its operation has not only been quite satisfactory, but has exceeded expectations.

The outstanding operating characteristic is its extremely smooth motion and freedom from vibration. Use of certain "towing tank" dynamometers on the arm, for example, reveal greater steadiness of scale readings than those encountered on the towing tank carriage.

The practical outcome of this stability of operation has been the successful use of "small motion" dynamometers especially designed for use on the arm. These instruments embody stiff springs which defelct over a maximum range of a few hundreths of an inch. Their motion is detected and transmitted by electronic means through the slip rings to a shore station. Simultaneous readings of resistance, lateral, and rudder forces acting on the hull may thus be obtained while the model (with or without self-propulsion) is being towed by the arm.