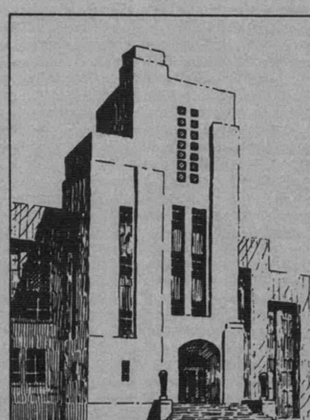
THE DAVID W. TAYLOR MODEL BASIN

UNITED STATES NAVY

MODEL TEST AND FULL-SCALE OBSERVATIONS OF THE LAUNCHING OF THE USS SHANGRI-LA (CV38)

BY J. H. CURRY AND C. G. MOODY



~~RESTRICTED~~

JUNE 1948

REPORT 560

REPORT 560

MODEL TEST AND FULL - SCALE OBSERVATIONS OF THE LAUNCHING OF THE USS SHANGRI - LA (CV38)

BY J. H. CURRY AND C. G. MOODY

JUNE 1948

RESTRICTED

TABLE OF CONTENTS

RESTRICTED

Launching of the USS SHANGRI-LA (CV38) at Portsmouth, Virginia

The vessel was launched in the Elizabeth River from Building Way 1 of the Norfolk Naval Shipyard, 24 February 1944.

This photograph is reproduced by permission of the Norfolk Naval Shipyard.

MODEL TESTS AND FULL-SCALE OBSERVATIONS OF THE LAUNCHING OF THE USS SHANGRI-LA (CV38)

ABSTRACT

The USS SHANGRI-LA (CV38), an aircraft carrier of the ESSEX Class, was successfully launched in restricted waters at the Norfolk Naval Shipyard and brought to rest by chain drags with her bow approximately 200 feet from the end of the ways. The arrangements for launching the SHANGRI-LA had been tested on model scale at the David Taylor Model Basin, and these tests were followed by observations of the movements of the ship when she was launched on 24 February 1944. The data obtained from both the model launching tests and the full-scale observations, which were found to be in good agreement, are given in this report. The technique of the model tests is presented with special reference to the effects of deceleration on the water resistance of a launched ship.

INTRODUCTION

The technique developed for moving a large hull from the building berth to the water is probably adequate to launch the largest ship in prospect of construction. However, the difficulties increase very rapidly with the size of the vessel and the physical limitations of the launching facilities. The greater launching weight of modern ships, which results from the increase in their size and the practice of launching at an advanced state of completion, presents numerous problems that, if not entirely new, are beyond the scope of previous experience. Model tests have been used, in some instances where new data were required, to predict launching performance. The results of these tests have been of value and have added to the general knowledge of the subject.

The use of models for launching tests is relatively new. Some notes on model experiments were included in a paper by Hillhouse and Riddlesworth in the 1917 Transactions of the Institution of Naval Architects (1).* As far as the authors were aware, this was the first attempt to determine the actual motion of a vessel during the process of launching. These tests were made primarily to trace the path of the stern and to determine the extent of a gully which had to be excavated to receive the bow of the vessel as she dropped off the end of the ways. The checking arrangements were reproduced with clumps of brass chain drawn over glass to give a proper coefficient of friction. Way-end pressure was investigated to the extent of using an arrangement of rollers

---

* Numbers in parentheses indicate references on page 31 of this report.

under the keel which would enable the model to tip over the end of the ways if a tipping moment existed. A supplementary article (2) by Hillhouse in 1921 gives additional information about these tests, which were for the battle-cruiser HMS RENOWN. Similar experiments were conducted with models of the SS EMPRESS OF CANADA (2) and the SS TUSCANIA (3).

The first model tests which actually measured the pull of the checking arrangements were run in connection with the launching in 1919 of the battleship USS CALIFORNIA (BB44) at the Mare Island Navy Yard (4)(5). The recording mechanism used for the tests was completely automatic in operation. The model, like the model of the EMPRESS OF CANADA, was made to a scale of 1/8 inch per foot.

In 1925, when the aircraft carrier USS LEXINGTON (CV2) was launched (6), the accelerating and decelerating forces were obtained from an equation which gave the resultant force acting parallel to the ways. Integrating this equation with respect to travel gave the energy relation between the work of the forces. It is significant that the data required to evaluate the factors in the force equation were becoming available at the time. Experiments with chain drags and with small models launched in a tank permitted separation of the drag resistance and the water resistance. The launching tests with models of the LEXINGTON were conducted by members of the Construction Corps of the United States Navy as part of their postgraduate study at the Massachusetts Institute of Technology. Two theses (7) (8) were written on this subject.

Professor William Hovgaard gave a very complete exposition on the energy equation in Reference (9). This equation has been used extensively in connection with launching and launching experiments.

These tests were all made with small models, but the results were of value and some of the data are still in active use, as noted in Reference (10). More recent experiments have been made with models of larger size: The launching model of the SS QUEEN MARY, tested at Clydebank (11), was 16 feet 8 inches long; a model 24.7 feet long was tried before the launching of the German battleship SCHARNHORST (12); and a submarine model 13 feet long was used by the Manitowoc Shipbuilding Company for side-launching experiments (13).

The experience at the Taylor Model Basin has indicated that a large model weighing about 1000 pounds is most suitable for launching tests. A model of this size gives a satisfactory scale factor without being awkward or heavy to handle. Standard 20-foot towing models, with cradles attached, have proved satisfactory. The models of the USS WASHINGTON (BB56), USS NEW JERSEY (BB62), USS AUK (AM57), and USS SHANGRI-LA (CV38) have all been of this length. The launching model of the USS ALABAMA (BB60) was 10 feet long and weighed only 230 pounds, but it was as large as could be used in the small basin available for the tests.

The experiments mentioned in this brief summary represent the essential background of model launching tests. Some of the tests did not yield accurate quantitative data, but nevertheless showed the range of possibilities and gave good comparative results. Ships have been launched in waters of very limited extent. The RENOWN, for example, was launched in the Clyde at Govan, where she was arrested with her bow 60 feet clear of the way ends and her stern 120 feet, in the line of travel, from a stone quay on the opposite shore of the river (3). The launching of this 794-foot ship at an angle into the Clyde, which is only about 450 feet wide in its upper reaches, certainly presented an extraordinary problem for the first model experiments. It is interesting to note that nearly every model launching test has been undertaken because of some restriction in the water available for launching an unusually large ship.

Model launching tests permit tracing the path of the bow at drop-off and of the stern during pivoting at various launching velocities with great facility. The exact path of the stern is difficult to determine by any other means. Calculations made for the SS NORMANDIE, on the basis of static conditions with an allowance for the inertia of the ship, were described by A. See in Reference (14). The possibilities of calculating the maximum immersion of the stern were also brought forward in the discussion of the launching of the QUEEN MARY before the Institution of Naval Architects in 1935 (11). The actual procedure in launching the QUEEN MARY, however, was based upon an exhaustive series of model launching experiments.

The wave profile around a hull changes rapidly during a launching. This is especially true when a vessel's way is abruptly arrested by drag forces in a wave formation caused by her previous motion in launching. The general level of water also fluctuates and a large surging wave may travel ahead of the stern. With these variables and the inertia of the ship to consider, it is evident that the analysis of launching phenomena must be based primarily on model tests and on full-scale observations.

Regarding the technique of model launching tests, it appears that the most satisfactory procedure is to simulate the actual launching on model scale. Then, with similar conditions at every point in the travel, the movements of the model will correspond to those of the ship.

Models towed astern at constant speed do not reflect the actual resistance under launching conditions. In towing tests the waves combined in the resultant wave formation are all generated at the same speed; but in launching the speed of the ship varies while the wave train from one end is being propagated back to the other end. Thus, waves set up at different speeds are superimposed upon each other around the following end of the ship (15) (16). Another basic difference is due to the mass of moving water that accompanies the vessel. When the speed is constant the entrained water simply augments the ship's momentum, but when the speed is changing it affects the resistance. In theory the surrounding water, at every point in the streamline flow, is instantly accelerated or retarded in proportion to the rate of change in the ship's speed. Consequently the effect of the flow about the hull, in increasing the resistance with acceleration and in decreasing it during deceleration, is dynamically equivalent to the effect of adding the virtual mass of the water in streamline motion to the mass of the ship. The eddying mass of dead water that travels with the vessel also adds its effect to the inertia of the ship; but the reactions of this water to the movements of the hull are transmitted through friction and eddy making, as well as through normal pressure. Hence, there is not the positive and instantaneous action or the definite effect that is attributed to the water in streamline motion (17).

It has been established in practice as well as in theory that the retardation of a ship by water resistance is not the same, at a given instantaneous speed, when the velocity is varying as when it is constant. William Froude (18) gave a good example of this difference when he determined the resistance of HMS GREYHOUND by two methods: first by full-scale towing tests, and second from the rate of deceleration of the vessel when she was traveling under her own momentum after casting off the towline of HMS ACTIVE. Froude's estimate of virtual mass, it may be recalled, was based on the difference in the resistance obtained under the two conditions. Therefore, on the basis of theoretical considerations and on the analogy with Froude's GREYHOUND experiments, the method of towing a launching model astern at constant speed is not a proper practice.

The tests made in preparation for the launching of the USS SHANGRI-LA (CV38) were undertaken because of the large size of the vessel and the restricted nature of the waters where she was to be launched. The SHANGRI-LA was not as heavy as the USS ALABAMA (BB60), which had preceded her on the ways of the Norfolk Naval Shipyard, but she was approximately 200 feet longer, and the problem of stopping her was of major importance. The security of the ship also depended to some extent on the way-end pressure and on the path of the bow and of the stern during the launching. For these reasons and to obtain data for future use, the Norfolk Naval Shipyard requested the David Taylor Model Basin to conduct both model tests (19) and full-scale observations (20) of the launching.

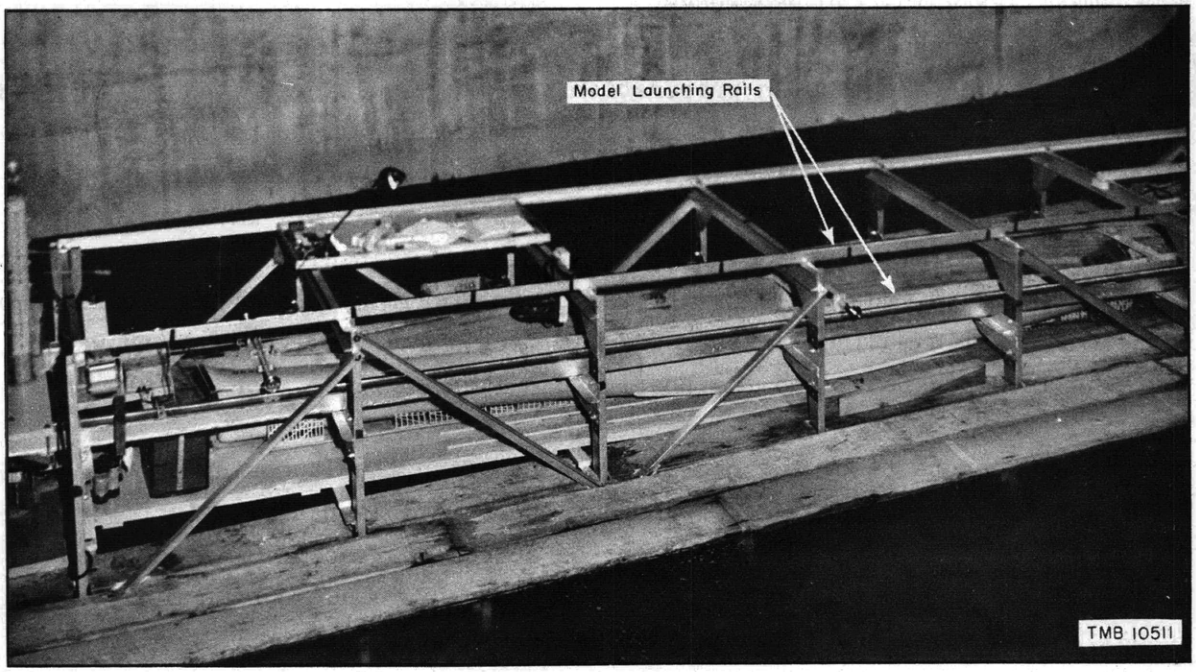


Figure 1 - The Model Ready for Launching

The ways and cradle of the ship were reproduced to simulate the water resistance, full-scale, but the model was actually launched on rails instead of on a greased surface. Four wheels, arranged as shown in Figure 6, were used to carry the model.

A large model, 20 feet in length, was used for the SHANGRI-LA tests to ensure a satisfactory scale factor for the water resistance and other force measurements. The model, Figure 1, was launched, complete with appendages and cradle, under conditions which simulated the launching conditions of the ship. Checking was accomplished by the lifting of weights which represented the chain drag forces.

Full-scale observations of the launching of the ship were recorded by accelerometers and motion-picture cameras. A camera of known focal length was mounted on the ship to obtain bearings of shore objects from which the position of the ship could be established by triangulation. Another camera abreast the end of the ways on shore was used for direct observation of the movements of the vessel. The position of the ship at successive intervals of time was accurately established from these records.

The method of making full-scale observations with accelerometers and motion-picture cameras was developed at the David Taylor Model Basin for use at the launching of the USS ALABAMA (BB60), and the photographic method was first tried at the launching of a small vessel, the USS AUK (AM57). Reference (21) describes the photographic method in detail and may be used to supplement the description of the procedure followed at the launching of the SHANGRI-LA.

MODEL-TEST APPARATUS AND PROCEDURE

The Norfolk Naval Shipyard (22) furnished the data for the tests of the model which were made in preparation for the launching of the ship. These tests were based on an estimated launching weight of 21,500 tons, with the first chain-drag clumps going into action 100 feet before drop-off. Tests were also made with the first drags picked up at drop-off. In each instance the drags represented were seven pairs of 50-ton chain clumps, placed 40 feet apart on the ways and picked up at 30-foot intervals of travel. The distance between clumps in motion was therefore 70 feet. The declivity of the ways was 9/16 inch per foot, and the predicted height of water over the way ends was 15.38 feet.

Other tests of the model were made after the launching of the ship. These post-launching tests were based on the actual launching weight, trim, height of water over the ways, and on the actual drag coefficient derived from the pull of the ship's chain drags against hydraulic dynamometers. The actual launching weight of the SHANGRI-LA was 21,088 tons, with the cradle; and the actual depth of water over the way ends was 15.86 feet.

The tests, described in the following sections, were therefore based on two sets of conditions:

	Estimated	Actual
Launching weight with cradle	21,500 tons	21,088 tons
CG of ship and cradle aft of ⊗	16.8 ft	14.32 ft
Draft forward	13 ft 7 1/2 in	14 ft 1 7/8 in
Draft aft	22 ft 9 1/2 in	21 ft 11 in
Draft mean	18 ft 2 1/2 in	18 ft 7/16 in
Elevation of water surface	95.27 ft*	95.75 ft

* The tidal elevation of mean high water at Portsmouth, Virginia, is 95.27 feet.

THE SHIP MODEL

The launching tests were made with TMB Model 3636 which represented the USS SHANGRI-LA (CV38) and the other aircraft carriers of the ESSEX Class. The length of the model was 20 feet and the linear ratio of ship to model was 41. The launching cradle of the SHANGRI-LA was reproduced to scale and fitted to the model, which was complete with all appendages as shown in Figures 2 and 3. For the launching tests the quadruple propellers were secured in a fixed position. The model was ballasted to correspond to the weight and trim of the ship.

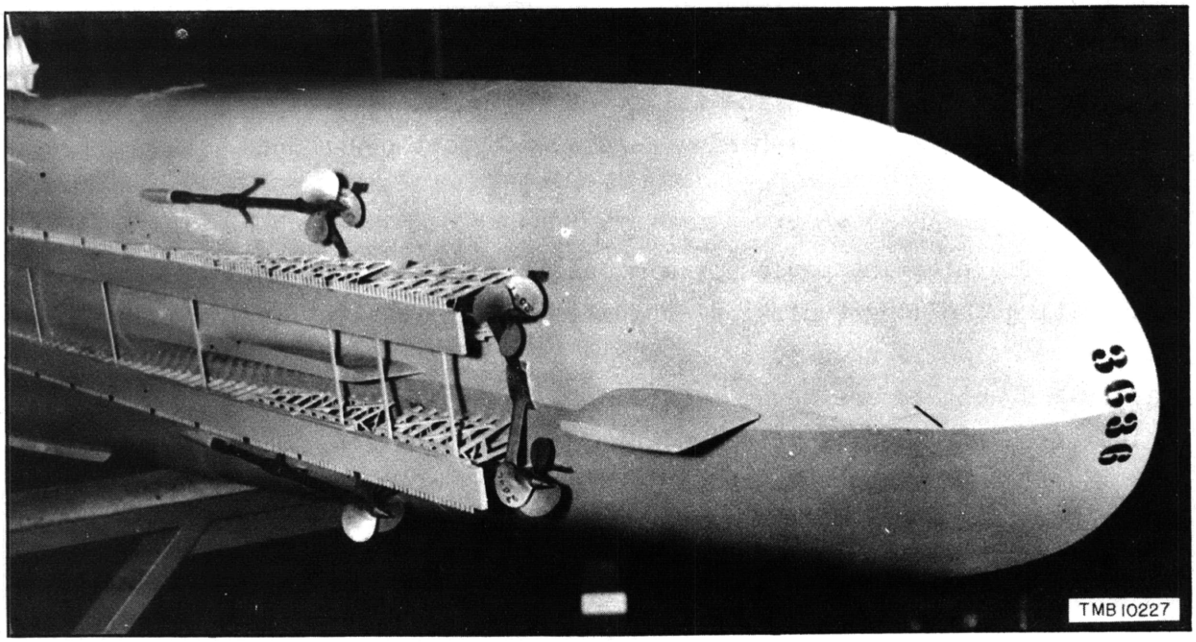


Figure 2 - Stern View of the Model, Showing Appendages

The model was complete with propellers, shafts, shaft struts, rudder, skeg, bilge keels, and launching cradle.

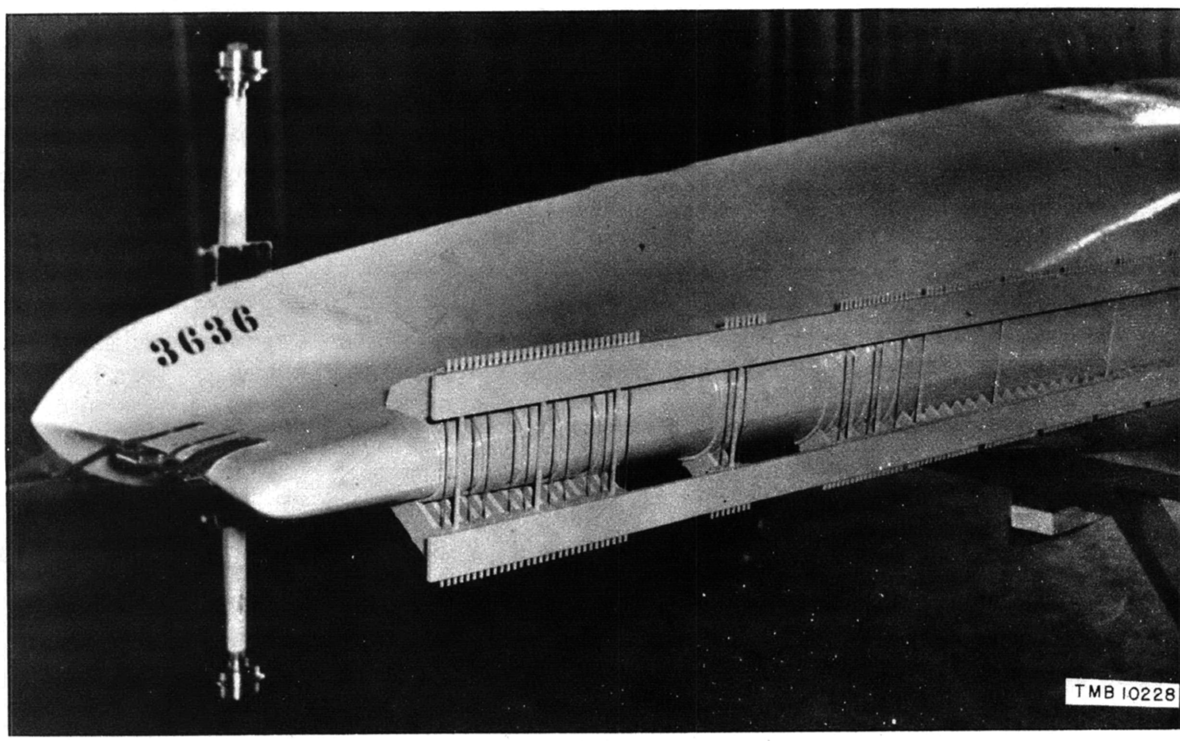


Figure 3 - Bow View of the Model Showing Sliding Ways and Cradle

The axle supporting the model at the fore poppet was free to pivot athwartships at the center of the main deck.

The model was left in rough-sawn shape on the inside and no attempt was made to reduce its weight for the launching tests. The bare hull of the model weighed 484 pounds. The weight of the model with fittings was 526 pounds, and the maximum launching weight was about 699 pounds.

PITCHING PERIOD OF MODEL

The pitching period of a model is made to agree with that of a ship by adjusting the longitudinal distribution of the ballast in the model. Bifilar suspension is used to swing the model horizontally about its center of gravity and weights are moved back and forth in the ends until the proper period of oscillation is obtained.

The equation which relates the radius of gyration to the period of oscillation is

$$k = \frac{bt}{4\pi}\sqrt{\frac{g}{l}}$$

where k is the radius of gyration in feet,

b is the distance between the suspending lines in feet,

l is the length of the suspending lines in feet,

t is the time of a complete period of oscillation in seconds, and

g is the acceleration of gravity in feet per second per second.

The derivation of the equation is indicated in Reference (23).

The radius of gyration of the SHANGRI-LA was assumed, on the basis of general information (2) (8) (24), to be 190 feet for longitudinal pitching about the center of gravity. A longitudinal radius of gyration of 165 feet, however, was found to be about the maximum that could be represented on model scale for launching tests. This value was considered to represent the pitching inertia of the ship with sufficient accuracy, and no attempt was made to remove wood from the inside of the model to gain a larger margin of weight for ballasting the ends.

LAUNCHING ARRANGEMENTS

The model launching ways, Figure 4, were located in the turning end of the shallow-water basin where the width was ample to avoid interference from the basin walls. The bottom of the building slip was reproduced with steps, ways, and other features all made to scale except the height of the ground ways, which was reduced to give clearance for the passage of the sliding ways. The adjacent piers were not represented in detail but the walkways on each side produced a similar restriction of the water. The depth of water in the basin corresponded to the mean depth of 40.5 feet in the river, but the actual bottom, Figure 5, was not simulated beyond the sill at the end of the ways. A board was placed across the end of the run to represent the opposite shore.

The model was launched on rails with a declivity of 9/16 inch per foot. The ball bearings of the four wheels which carried the model were kept out of the water by placing the rails high on each side of the model. The wheels at the fore poppet were carried by an axle attached to the model at the center of the deck where the model was free to pivot athwartships to a

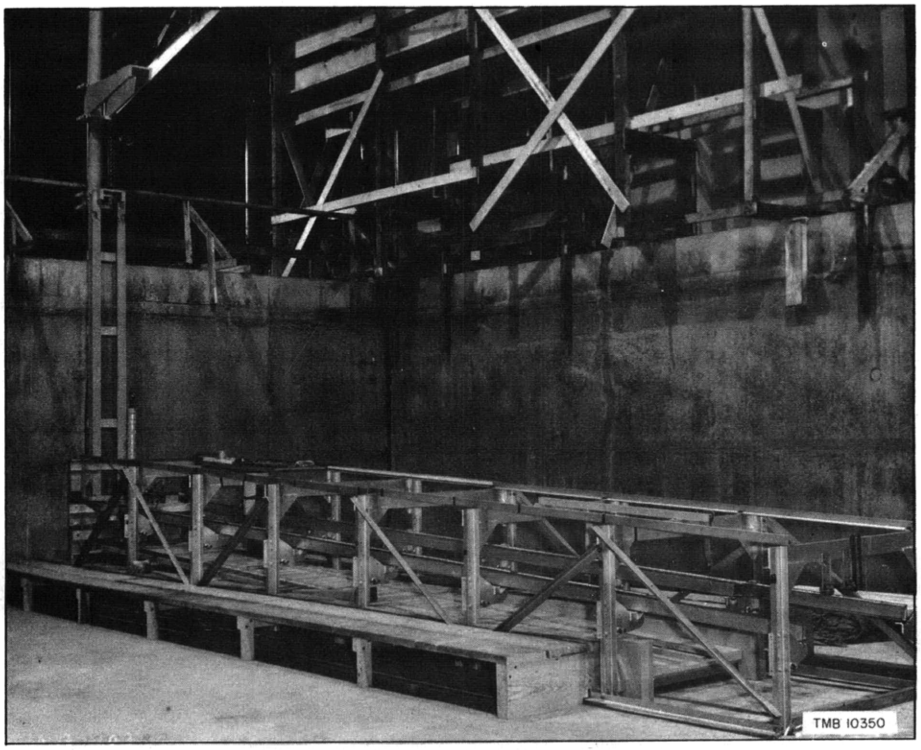


Figure 4 - The Model Launching Ways

The steps in the bottom of the slip were reproduced from the building ways of the ship. The model launching tracks are shown at the midheight of the steel structure.

limited extent. The other two wheels were carried by axles attached to the model on each side, aft of the center of gravity, as shown in Figure 6. The rails which served as the model launching ways were built up of structural shapes in the form of box girders, with tracks machined on the upper sides for the rollers. The forward and after wheels ran on separate tracks located inboard and outboard on each way. The inboard tracks corresponded in length to the ways of the ship, whereas the outboard tracks extended beyond the way ends to support the after wheels until the stern became water-borne. With

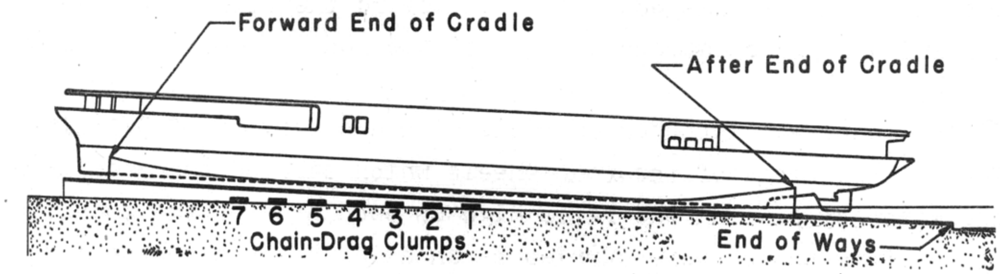


Figure 5 - The Ship on the Ways and at Rest in the Water

The contour of the river bottom is shown along the vessel's line of travel from the ways.

this arrangement, the forward wheels dropped off or floated off the tracks at the point where the fore poppet left the ways. In the series of tests there was always a drop-off at the way end. The arrangement of double tracks, which proved very satisfactory, is shown in Figures 7 and 8. The model could not tip over the end of the ways but any tendency to tip would be indicated by the way-end pressure and by the travel at which pivoting occurred.

Constant test conditions and a low coefficient of friction were maintained by keeping the tracks and bearings dry.

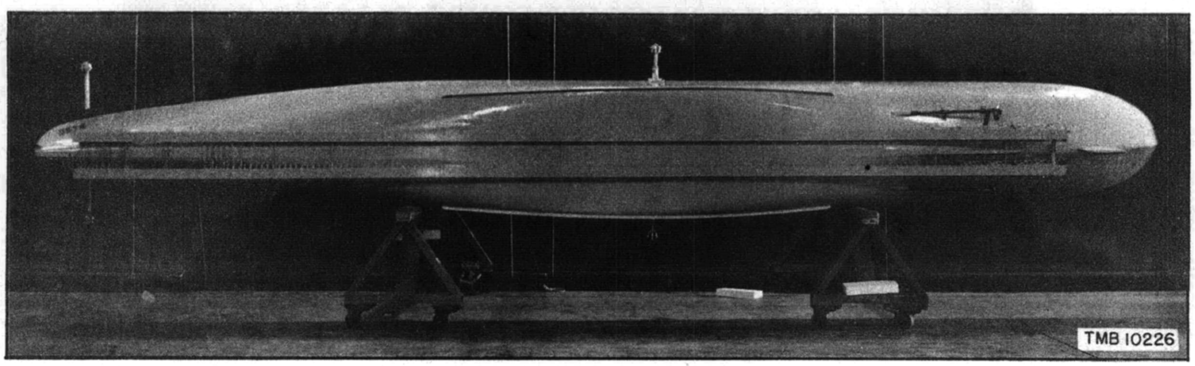
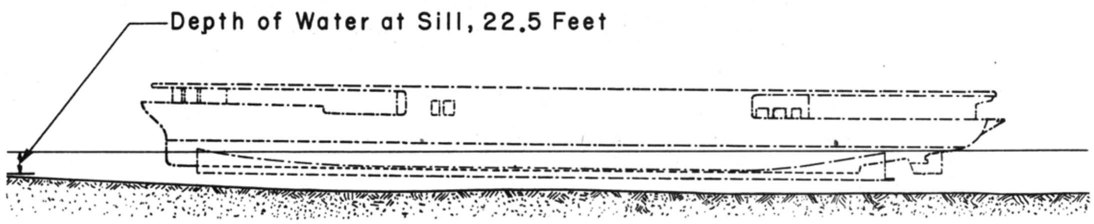


Figure 6 - Bottom View of the Launching Model

The model was supported on rollers located at the fore poppet and aft of the center of gravity. These rollers ran on the rails shown in Figure 1.



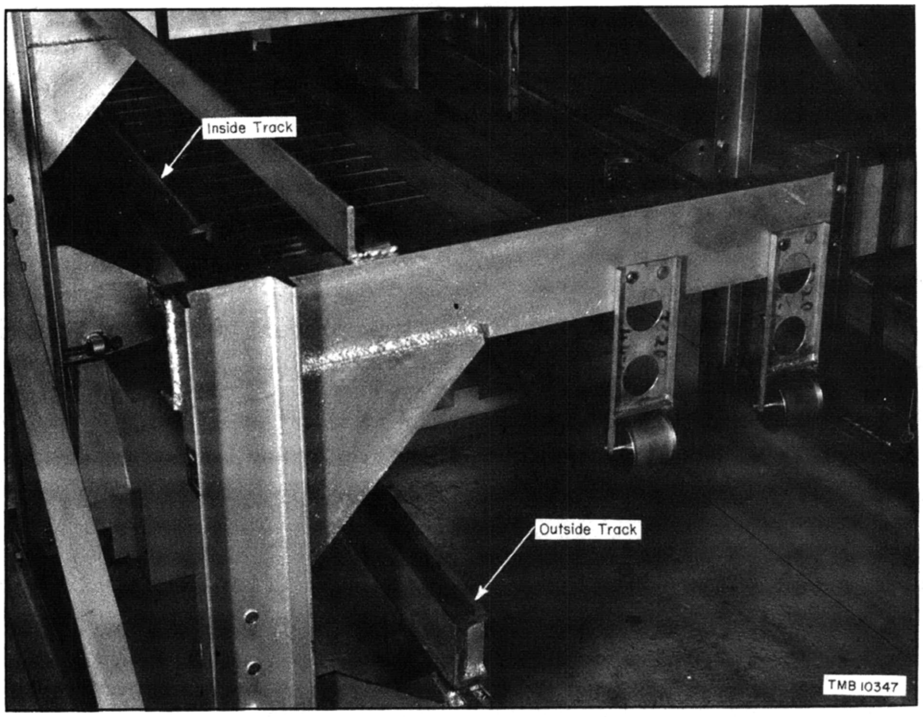


Figure 7 - The Launching Tracks

The outside tracks were extended to support the after rollers of the model until the stern lifted at the pivot point. The rollers in the right foreground of the picture served as guides for the lines that activated the distance recorder.

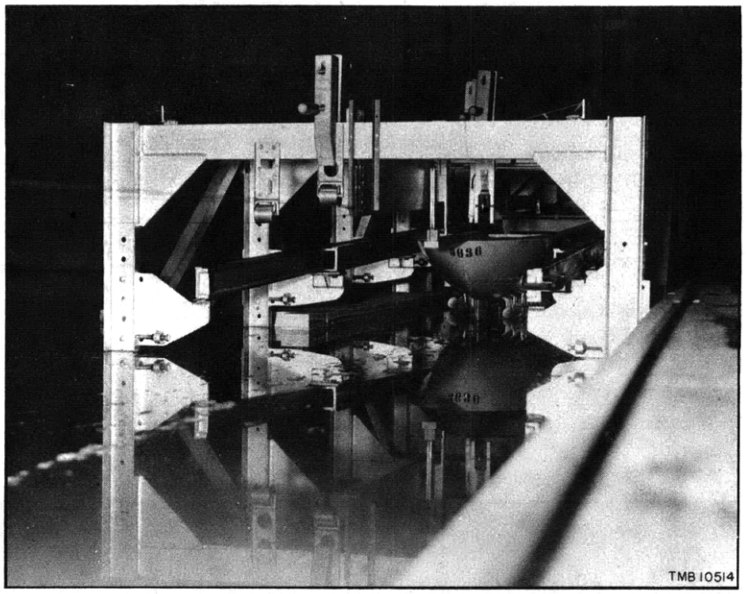


Figure 8 - Stern View of the Model on the Ways

Model 3636 was a 20-foot towing model equipped with a cradle for the launching tests.

LAUNCHING VELOCITY

The coefficient of friction of the rollers was less than one-half of one per cent. Consequently, the model could launch itself at a velocity corresponding to a higher speed than would be attained by the ship on ways of the same declivity. Lower drop-off velocities were easily obtained by retarding the model with external forces while on the ways. Runs made in this way, at different drop-off velocities and with known decelerating forces, covered the possible range of the coefficient of sliding friction for the launching of the ship.

To make these data more comprehensive, however, runs were made with the model accelerated to still higher drop-off velocities.

The method of applying a decelerating force was to attach a known weight to a small wire cable which led over a sheave and under a guide wheel to a fitting on the bow of the model. An accelerating force was applied by a similar arrangement of falling weights, with an additional sheave to reverse the direction of pull.

Both the accelerating forces and the decelerating forces were automatically released at the point of drop-off. The only exception was in one series of tests, made after the launching of the ship, where a decelerating force was released after a travel of 235 feet to scale and a second decelerating force after a travel of 405 feet to scale. The additional force was used to duplicate, as nearly as possible, the early part of the velocity-distance curve of the ship. In all of the other tests, the model started relatively faster than the ship. Predictions of the ship's travel are usually obtained with sufficient accuracy, however, when the overall coefficient of friction on the ways is the same for the model and the ship.

CHECKING ARRANGEMENTS

To check the model, weights equivalent to the chain-drag forces on the ship were lifted at points corresponding to the travel at which the drags were picked up. Figure 9 shows the arrangements of weights, consisting of

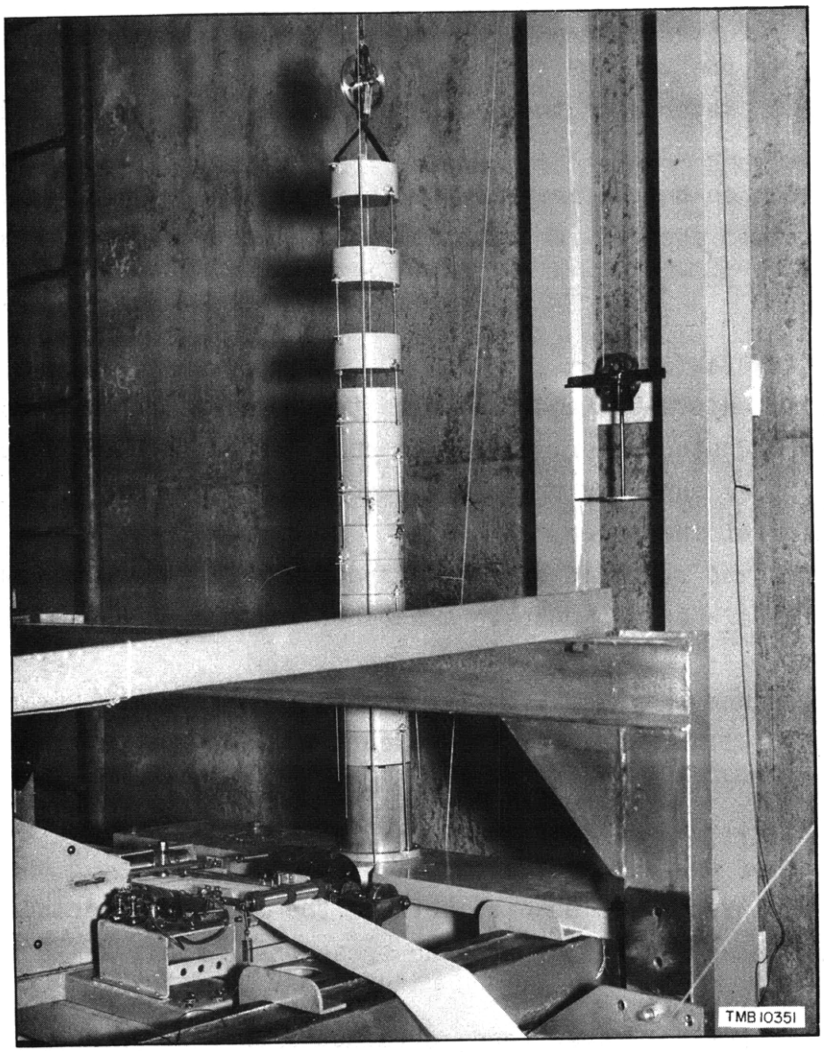


Figure 9 - Drag Weights and Speed-Control Weights

Weights were lifted in steel cups to simulate the drag forces that arrested the ship. Weights on the scale pan in the wooden tower regulated the speed of the model on the ways.

steel cups loaded with lead to the required weight, and the rods used to pick up the successive weights at proper intervals. The end of the taut piano wire used to lift the weights was picked up by a fitting on the bow of the model at the point in the travel where the first drag force was applied. Tests were made with different arrangements of drags and with the drag weights varied to cover the range of coefficient of friction of chain drags for this launching. These runs were made at nominal coefficients of friction which varied from the actual values given in the results by the small amount of the friction in the sheaves. The actual tension in the drag wire, including friction and inertia forces was automatically recorded.

It was considered important to have the speed of the model correspond very closely to that of the ship at every point in the travel during launching. The movement of water with the motion of the model, the variations in wave formation, and the general level of water around the stern, as well as the inertia forces, would then be comparable with the conditions at the launching of the ship. The method adopted for simulating the chain drag forces retarded the model at a rate corresponding to that of the ship.

RECORDING MECHANISM

Time, distance, and drag-wire tension were automatically recorded on a strip of wax-coated paper, driven at constant speed by a synchronous motor, Figure 10. Steel scribers traced through the opaque wax surface, leaving a line the color of the paper.

Time was recorded by a standard Navy break-circuit chronometer, acting through a solenoid to operate a scriber which marked seconds on the moving paper.

Distance traveled was also recorded on the paper, adjacent to the time record. A light line was stretched taut over the path of the model and around two horizontal sheaves to form an endless belt. This line was attached, through a swivel, to a fitting on the deck of the model near the center of gravity. One of the sheaves with contact pins, making four break-circuit contacts per revolution, was used to actuate the recording scriber of the chronograph. The contacts were adjusted to break the circuit as soon as the model started to move.

The constant paper feed, obtained from the synchronous motor, made it possible to use a chart for reading the velocities directly from the chronograph record.

The pull of the drag wire was recorded on the moving paper by a scriber on the lever arm of the dynamometer, Figure 9. A fixed scriber traced the base line from which the pull was measured. The drag force was measured

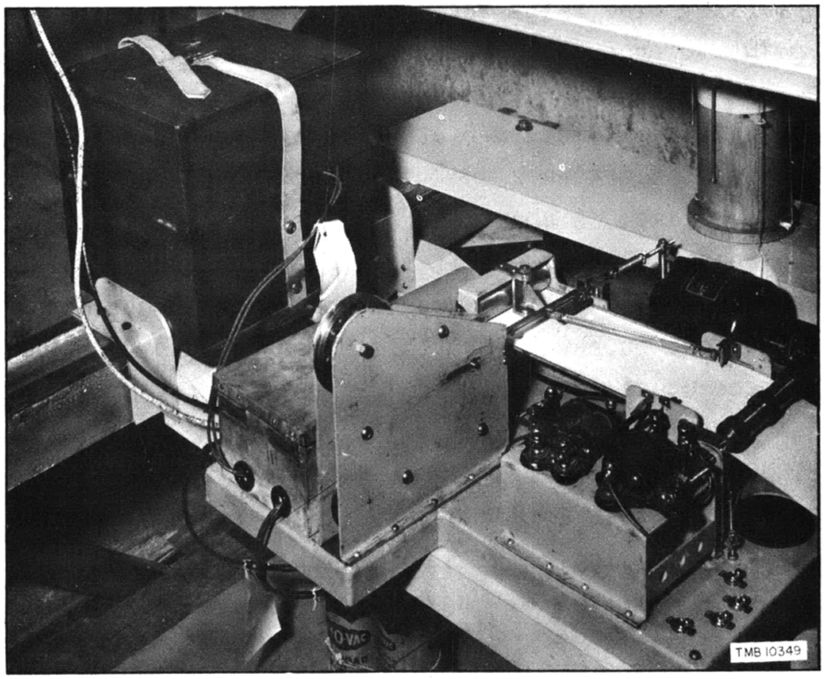


Figure 10 - The Recording Instruments

The chronograph recorded time, distance, and drag resistance.

by leading two parallel parts of the wire, from guide wheels, over a floating sheave connected to a spring. Movement of the sheave against the action of the spring varied directly with the tension in the wire.

TRACES OF BOW AND OF STERN

The movements of the bow and of the stern were recorded during the model runs on a board which was erected on edge over the basin along the centerline of the ways. A second board placed about 1 1/2 inch from the first was hinged to give access to the record. Light flexible masts on the model, at the forward perpendicular and over the after end of the sliding ways, ran between these boards. Scribers attached to the upper ends of the masts were pressed against one board by a roller, with a spring connection, bearing on the other board. The dip of the bow and the maximum immersion of the cradle were recorded by the traces of these scribers.

WAY-END PRESSURE

A satisfactory method of measuring way-end pressure was developed for these tests. The shims fitted underneath the outside tracks were removed beyond the end of the ways. This left the after wheels supported on cantilever beams, the deflection of which was measured by an Ames gage at the outboard end of one rail. The rails were calibrated to determine the load required at any point to produce a given deflection at the end of the beam. With the rigid rails used the effect of this deflection on the alignment of the ways was negligible. A motion-picture camera recorded the travel of the wheels over this section of track and the corresponding deflection shown on the dial of the Ames gage. A chart was used to find the load on the after wheels from these data. The moment of the total pressure on these wheels about the forward rollers equals the moment of weight minus the moment of buoyancy about the fore poppet. With this moment the way-end pressure can be calculated by the usual methods.

WATER RESISTANCE

Values of the coefficient of water resistance C_R can be derived from the test data by solving one of the following equations:

$$\frac{W+D}{g}a = (W-B)\sin\theta - f(W-B)\cos\theta - \frac{C_R}{106.1}B^{\frac{2}{3}}V^2 - f'D \qquad [1]$$

$$\frac{W+D}{g}a = -\frac{C_R}{106.1}B^{\frac{2}{3}}V^2 - f'D \qquad [2]$$

$$\frac{W+D}{g}\times\frac{V_2^2-V_1^2}{2} = (W-B)\sin\theta\cdot s - f(W-B)\cos\theta\cdot s - \frac{C_R B^{\frac{2}{3}}}{106.1}\left(\frac{V_1^2+V_2^2}{2}\right)S - f'Ds \qquad [3]$$

$$\frac{W}{g}\left(\frac{V_2^2-V_1^2}{2}\right) = \int(W-B)\sin\theta\,ds - \int f(W-B)\cos\theta\,ds - E - \frac{C_R}{106.1}\int B^{\frac{2}{3}}V^2\,ds - \int T\,ds \qquad [4]$$

$$\frac{C_R}{106.1} = \frac{\int(W-B)\sin\theta\,ds - \int f(W-B)\cos\theta\,ds - E - \int T\,ds}{\int B^{\frac{2}{3}}V^2\,ds} \qquad [5]$$

$$C_R = \frac{(35.95\,B)^{\frac{1}{3}}}{S}\log_e\left(\frac{V_1}{V_2}\right) \qquad [6]$$

where W is the weight of the ship with cradle in tons,
D is the weight of drags in action in tons,
g is the acceleration of gravity in feet per second per second,
B is buoyancy in tons of fresh water,
a is acceleration in feet per second per second,
V is velocity in feet per second,
S is travel in feet,
s is a small increment of travel,
θ is the angle of declivity of the ways in degrees,
f is the coefficient of way friction,
f' is the coefficient of drag resistance,
T is the tension in the drag lines in tons,
C_R is the coefficient of fresh water resistance,

$$C_R = \frac{2240\,R_W}{\rho(35.95B)^{\frac{2}{3}}V^2} = \frac{106.1\,R_W}{B^{\frac{2}{3}}V^2}$$

R_W is the fresh water resistance in tons,

$$R_W = \frac{C_R}{106.1} B^{\frac{2}{3}} V^2$$

ρ is the density in foot-pound-second units,

$$\rho = \frac{62.34}{32.17} = 1.9378 \text{ for fresh water}$$

E is the energy absorbed by weights retarding the speed of the model on the ways. For one weight,

$$E = d_1 S_1 + \frac{d_1 v_1^2}{2g}$$

d_1 is the weight of the retarding drag in tons,

v_1 is the velocity in feet per second of the retarding drag weight when released, and

S_1 is the travel in feet of the weight when released.

Equation [1] gives the general relation between the forces of acceleration, gravity, way friction, drag friction, and water resistance.

Equation [2] gives the relation of the forces remaining after the fore poppet leaves the ways.

Equation [3] is the energy equation where the change in kinetic energy over a small increment of travel is the difference between the work of gravity and the energy absorbed by the action of friction, buoyancy, water resistance, and the drag forces. V_1 is the initial velocity and V_2 is the final velocity over the interval of travel.

Equation [4] is the energy equation in a convenient form for analyzing the results of model tests. The forces and the function $B^{\frac{2}{3}} V^2$ of water resistance are integrated with respect to distance over the desired travel, and the change in kinetic energy is calculated from the initial velocity V_1 and the final velocity V_2. The resulting solution gives the mean value of C_R between the limits of the graphical integration.

Equation [5] gives the value of C_R over the entire launching travel. Where the initial and final velocities are both zero, no change in kinetic energy enters into the equation except in connection with weights used to regulate the speed of a model on the ways. The arresting force of a retarding weight is affected by its inertia. The kinetic energy of the weight when released is equal to the energy absorbed from the model by the action of the force accelerating the weight. This energy is included in the term of E of Equations [4] and [5].

Reference to the energy equation will be found in the chapter on launching, by Professor Keith, in "Principles of Naval Architecture" (25) and in the papers on launching of the LEXINGTON, (6), QUEEN MARY (11), MARIPOSA (26), and NIEUW AMSTERDAM (27). Equation [3] in the form given here is due to J.M. McNeill, who used it with a similar coefficient of water resistance K in his paper on the launching of the QUEEN MARY (11).

There are three coefficients in general use for water resistance. Keith's coefficient C, like the admiralty coefficient, is in the denominator. Coefficient C_R, in the equations given here, varies directly with the resistance and is a dimensionless coefficient based on other factors in foot-pound-second units. Coefficient K in the paper on the launching of the QUEEN MARY was derived from measurements of displacement and resistance in tons. The relation between these coefficients is

$$\frac{C_R}{106.1} = \frac{1}{C} = K$$

Equation [6] was derived from the differential equation of motion for a model or ship proceeding under its own momentum. This relationship was used in Reference (28) to determine the rate of retardation of the battleship WASHINGTON.

The derivation of Equation [6] is as follows:

$$-\rho\Delta\frac{dv}{dt} = C_R\rho\Delta^{\frac{2}{3}}v^2$$

$$-\Delta^{\frac{1}{3}}v\frac{dv}{v\,dt} = C_R v^2$$

Since $v\,dt = ds$

$$C_R\int_0^s ds = -\Delta^{\frac{1}{3}}\int_{v_1}^{v_2}\frac{dv}{v}$$

$$C_R = \frac{\Delta^{\frac{1}{3}}}{S}\log_e\left(\frac{v_1}{v_2}\right)$$

where Δ is displacement in cubic feet and the other symbols are as given on pages 16 and 17.

Reference (29) gives the derivation of a similar equation for calculating the distance that a ship will travel when checked by definite drag forces.

MODEL-TEST RESULTS

The results of the model tests are given in Figures 15 through 32 which constitute Appendix 1. The launching travel predicted from the tests is shown in Figure 17. Data derived from the launching of the ship are shown in Figures 33 and 34 which constitute Appendix 2.

TIME-DISTANCE-VELOCITY-ACCELERATION

In Figures 20 through 28 time, velocity, acceleration, and drag resistance are plotted on the basis of travel for different drag coefficients and arrangement of chain drags. In Figure 27 data are also given for the model running free.

WATER RESISTANCE

All the data on water resistance apply to the ship with cradle and all appendages. The retarding effect of still air is included in the value given for the resistance of the water.

The general results of the model tests indicate that the coefficient of water resistance beyond the way ends is appreciably less with high coefficients of drag resistance than with the ship running free. With very abrupt checking the effect of the wake around the hull is to maintain the momentum of the ship.

The overall coefficient of water resistance for the ship running free, without drags, was found to be 0.063 over a travel of 531 feet after drop-off. Over the first 200 feet of this travel the coefficient of water resistance is 0.071. These values of C_R are based on Run 78, Figure 27, and were derived by the method of Equation [6].

The mean value of C_R derived from model tests in which the actual launching conditions were simulated is 0.140. This is an overall value obtained from a solution of Equation [5] over the entire travel of 1115 feet. A mean value of C_R from start to drop-off of 0.159 was obtained from a solution of Equation [4] between these limits. These coefficients are based on data from Figure 28 and on the rolling friction obtained from Figure 19. The relative amount of energy absorbed by way friction, water resistance, and drag resistance was approximately as follows:

Way friction	27 per cent
Water resistance	52 per cent
Drag resistance	21 per cent

Figure 29 contains a comparative plot of water resistance after drop-off expressed in terms of R/V^2 on the basis of velocity for the eight runs with a drag coefficient of 0.30. The dispersion of the results shown in the figure is attributed primarily to the hydrodynamic conditions obtained at the various launching speeds and with the alternate drag arrangements. In addition there were small irregularities in the basic data which were found to be accentuated in the process of deducing the resistance. Hence the method of Equations [4] and [5] was developed to base subsequent resistance coefficients on more comprehensive data than Equation [2], which depends on instantaneous values of the acceleration, or Equation [3], which depends on the change in kinetic energy over small intervals of travel.

CHECKING ARRANGEMENTS

The relation between travel and drop-off velocity for various combinations of chain-drag coefficient is shown in Figure 15 with the first drags picked up 100 feet before drop-off and in Figure 16 with the first drags picked up at drop-off. Values obtained from Figure 15 at a drop-off velocity of 15.3 feet per second are plotted in Figure 17 to show the relation between travel and chain-drag coefficient at the actual launching velocity of the ship. All these data are based on the estimated launching weight of 21,500 tons and on the use of seven pairs of 50-ton chain clumps picked up at 30-foot intervals. Other data, Figure 28, are from tests with model drag weights arranged to simulate the measured chain-drag forces of the ship.

The peaks and hollows in the records of drag tension, Figures 20 through 28, result from the sudden application of the loads causing fluctuations in the tension of the drag wire and from the inertia in the oscillating arm of the instrument. These variations appear erratic, but the total work of the drag forces obtained by integrating the area under the curves agrees closely with the work required to lift the drag weights, being slightly higher in each instance because of the energy absorbed by the friction of the sheaves. In calculating the overall drag coefficients, the chain clumps were assumed to have no effect for 50 feet as they descended into the mud beyond the end of the ways. Only a few values however were affected by this assumption.

The values of peak tension from model tests, shown in Figure 18, were of general interest in the early stages of the investigation but were not expected to predict the tension in the chain-drag cables of the ship.

Under all the conditions covered by these tests, the coefficient of friction of the chain drags was less than unity. The drag weights required to check the model were therefore relatively lighter than the chain drags of the ship. It does not appear that this difference is of any consequence, although the retardation is affected by the inertia of the drag weights, acceleration increasing and deceleration decreasing the tension in the drag lines. The overall work of the inertia forces is zero, nevertheless, for the kinetic energy of the weights is zero at the beginning and at the end of the travel, Equations [3] and [4]. It should be noted that the records of drag tension show the actual pull, with inertia forces included.

FRICTION OF WAYS

Figure 19 shows the coefficient of rolling friction for the model, obtained from runs with the rollers mounted on a dummy model which traveled the greater part of the length of the tracks before entering the water. With water resistance eliminated the coefficient of friction was derived from the acceleration. Speed-control weights were used to vary the velocity of the runs.

The dummy model was simply an oblong wooden block, proportioned to suit the model wheels and to have its center of gravity in the right location. A small amount of ballast was used to adjust the weight.

The launching tests were simplified by the low coefficient of friction attained with ball-bearing rollers on machined tracks. Velocities corresponding to higher coefficients of friction were easily obtained by retarding the model on the ways. Runs with the model accelerated required more apparatus and were less satisfactory. However, the model ran smoothly and no difficulty was experienced in attaining the maximum desired speed.

The external accelerating and decelerating forces applied to the ship model may be treated as part of the resistance corresponding to the sliding friction of the ship.

PATHS OF BOW AND STERN

Figure 30 shows the paths of the bow and stern obtained from the model tests. The results are based on the assumed displacement of 21,500 tons and on the elevation of 95.27 feet of mean high water. The calculated travel at which the ship would pivot under these conditions was 524.6 feet.

The experiments showed that the path of the stern and the maximum immersion varied with velocity, but that the point at which the stern began to lift was practically the same for all velocities. The tests of the model,

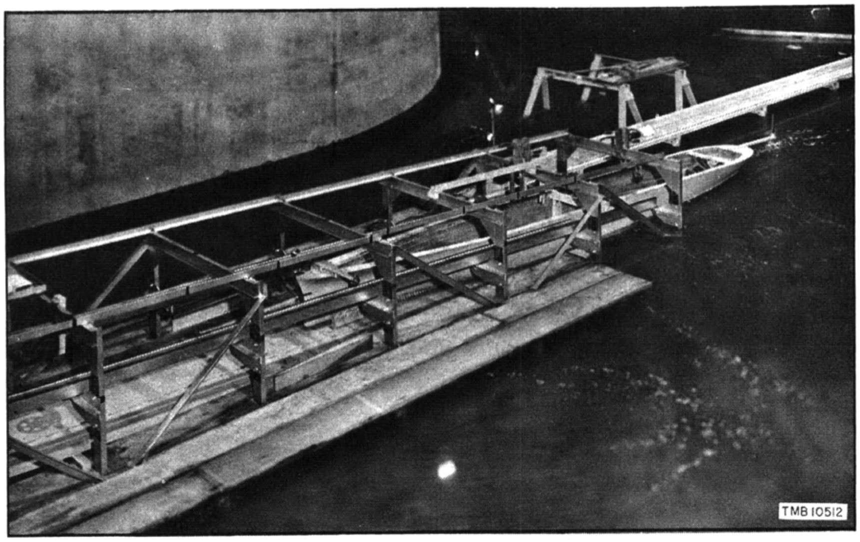


Figure 11 - The Model Launching into the Basin

When the stern became water-borne the model pivoted about the rollers at the fore poppet.

Figure 11, indicated that the ship would pivot from 8 to 19 feet beyond the point calculated for static conditions. This close agreement is consistent with the results of the NEW JERSEY launching experiments and with tests made for the QUEEN MARY in the experimental tank of her builders, John Brown and Company.

Observations of ship launchings indicate that vessels pivot in advance of the calculated pivot point when launched in confined waters and further down the ways under normal launching conditions. The data, however, are not sufficiently comprehensive for this generalization to be implicitly accepted. The discussion by James B. Hunter of his paper on the launching of the TSS MARIPOSA (23) is of particular interest in this connection. Other data on the subject are given in References (3) and (11).

WAY-END PRESSURE

Figure 31 shows curves of way-end pressure for the predicted depth of water over the way ends of 15.38 feet, which corresponds to the mean high water elevation of 95.27 feet at the Norfolk Navy Yard. These data were derived from the model tests by the procedure indicated in the description of the apparatus. The model was launched at various speeds corresponding to those given for the ship in Figure 31. Calculated values of the way-end pressure under static conditions are included for comparison with the experimental results.

HEIGHT OF WAVE AT OPPOSITE SHORE

The size of the wave that would be propagated by the launching of the ship was estimated from the height of the model wave at a board placed diagonally across the end of the run to represent the Berkeley shore, on the opposite side of the river. Figure 32 indicates the variations in height of wave with the speed of the ship leaving the ways and with the distance traveled before coming to rest.

FULL-SCALE DATA

The USS SHANGRI-LA (CV38) was launched in the Southern Branch of the Elizabeth River from Building Way 1 of the Norfolk Naval Shipyard in Portsmouth, Virginia, on 24 February 1944. The data pertaining to the actual full-scale launching of the vessel are presented in the following sections.

DIMENSIONS OF SHIP

The general dimensions of the SHANGRI-LA are:

Length, Overall	888 feet 9 1/8 inches
Length between Perpendiculars	820 feet
Beam, Molded	93 feet
Breadth, Flight Deck	109 feet
Designers LWL above Bottom of Keel	26 feet 7 7/8 inches
Displacement at DWL	33,500 tons

THE LAUNCHING AT NORFOLK NAVAL SHIPYARD

The SHANGRI-LA, Frontispiece, was built in a concrete berth of the sunken type with a removable floodgate at the lower end. This arrangement permitted the ways to be greased out of water for their entire length before the gate was removed to launch the ship. However, the concrete construction of the slip did not permit the chain drags to be hauled over ground and they were consequently arranged to be pulled over the concrete bottom of the building berth and then over intermittent concrete bearers with dirt and gravel in the interstices. The launching of the USS ALABAMA (BB60) had shown that the sloping bottom of the river bed afforded very poor holding ground for chain drags. It was therefore considered advisable to place the chain drag-clumps for the SHANGRI-LA well up the ways, where they would not be dragged over the sill at the outboard end of the launching slip into the mud of the river bottom.

The ground ways, which had a declivity of 9/16 inch per foot and an effective width of 7 feet, were lubricated with a base coat of stearine 1/2 inch thick and a slip coat of grease 1/4 inch thick. The average initial pressure on the ways was 2.1 tons per square foot. The vessel was checked by seven pairs of 50-ton chain drags placed 40 feet apart on the ways and picked up at 30-foot intervals of travel. The first drags were arranged to go into action 100 feet before drop-off, when the ship had traveled 769 feet from the initial position on the ways.

When the ship was launched, the chain-drag cables were arranged to pull against the pistons in small hydraulic cylinders attached to the hull, Figure 12. High-speed motion pictures gave a continuous record of the gage pressures from which the drag forces were computed. The overall coefficient of chain-drag friction obtained from this record was 0.477.

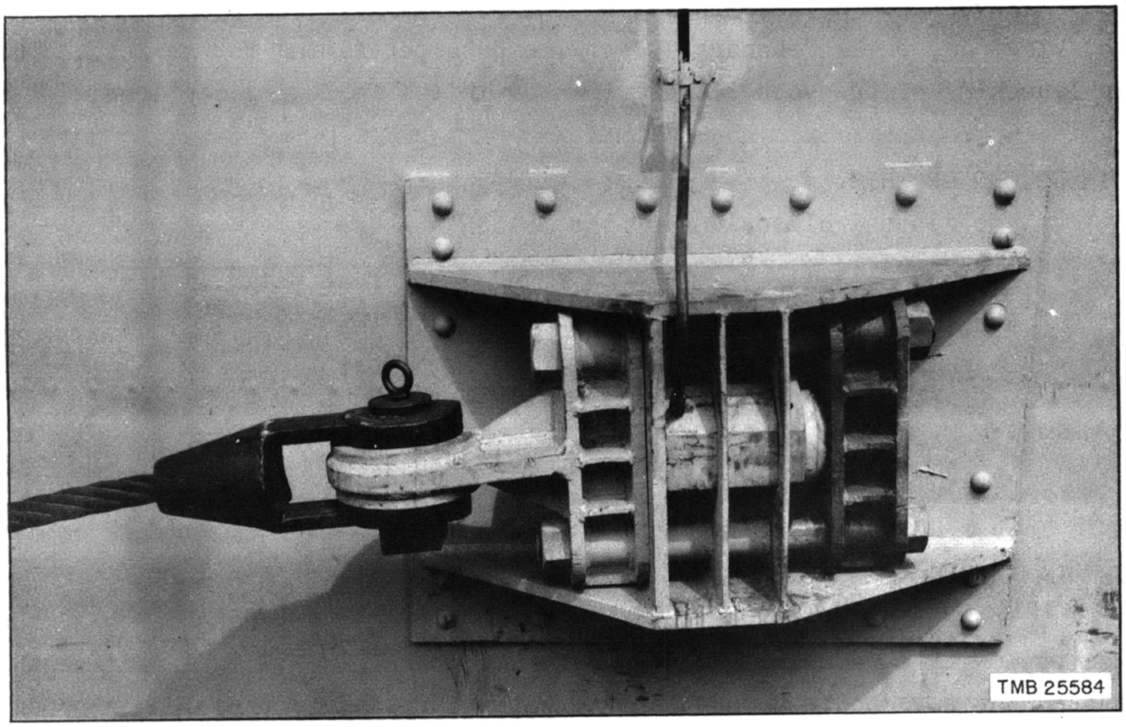


Figure 12 - Hydraulic Dynamometer

The chain-drag force was obtained from the fluid pressure on the piston against which the drag line pulled.

The base coat was found to be in excellent condition after the launching, with a film of the slip coat remaining on the surface. The coefficient of sliding friction was estimated from the hydraulic pressure on the pistons of the launching triggers to be about 0.010 or 0.012. It should be noted that this method of evaluating the way friction is subject to error from the friction of the piston packing.

The following data were compiled by the Norfolk Naval Shipyard after the launching of the SHANGRI-LA:

Launching weight with cradle	21,088 tons
CG of ship and cradle aft of ⊠	14.32 feet
Draft forward	14 feet 1 7/8 inch
Draft aft	21 feet 11 inches
Draft, mean	18 feet 7/16 inch
Elevation of water	95.75 feet
Depth of water over way ends	15.86 feet
Average initial pressure on ways	2.10 tons per square foot
Maximum way-end pressure	3.40 tons per square foot
Pivoting pressure on ways	4140 tons
Maximum velocity	22 feet per second
Drop-off velocity	15.3 feet per second
Travel to stop*	1094 feet
Total energy absorbed by drags, estimated	175,673,352 foot-pounds
Mean coefficient of drag resistance	0.477

The ship was launched in water which had a specific volume of 35.48 cubic feet per ton. The model tests were made in fresh water.

The chain drags were pulled over concrete, then over steel plates covering the trigger pits, and finally over 18-inch concrete bearers, spaced 30 inches apart, with dirt and gravel packed between. No drags were pulled into the mud bottom of the river or over the wood at the lower end of the building slip.

Other data compiled by the Norfolk Naval Shipyard are given in Reference (30). The launching environs and the observation stations are shown in Figure 13.

ACCELEROMETER AND CAMERA OBSERVATIONS

Observers from the Taylor Model Basin recorded the launching movements of the SHANGRI-LA.

The acceleration of the ship during the launching operation was measured by two accelerometers. One accelerometer was attached rigidly to the deck of the vessel; the second one was mounted on the top of a vertical-axis gyro. The gyro provided a level base throughout the launching period, independent of the changing declivity of the deck during pivoting. The first of these instruments recorded the variations in acceleration from the instant

* The total distance that the ship traveled was determined by the Norfolk Naval Shipyard from the final position of the chain-drag clumps on the building ways.

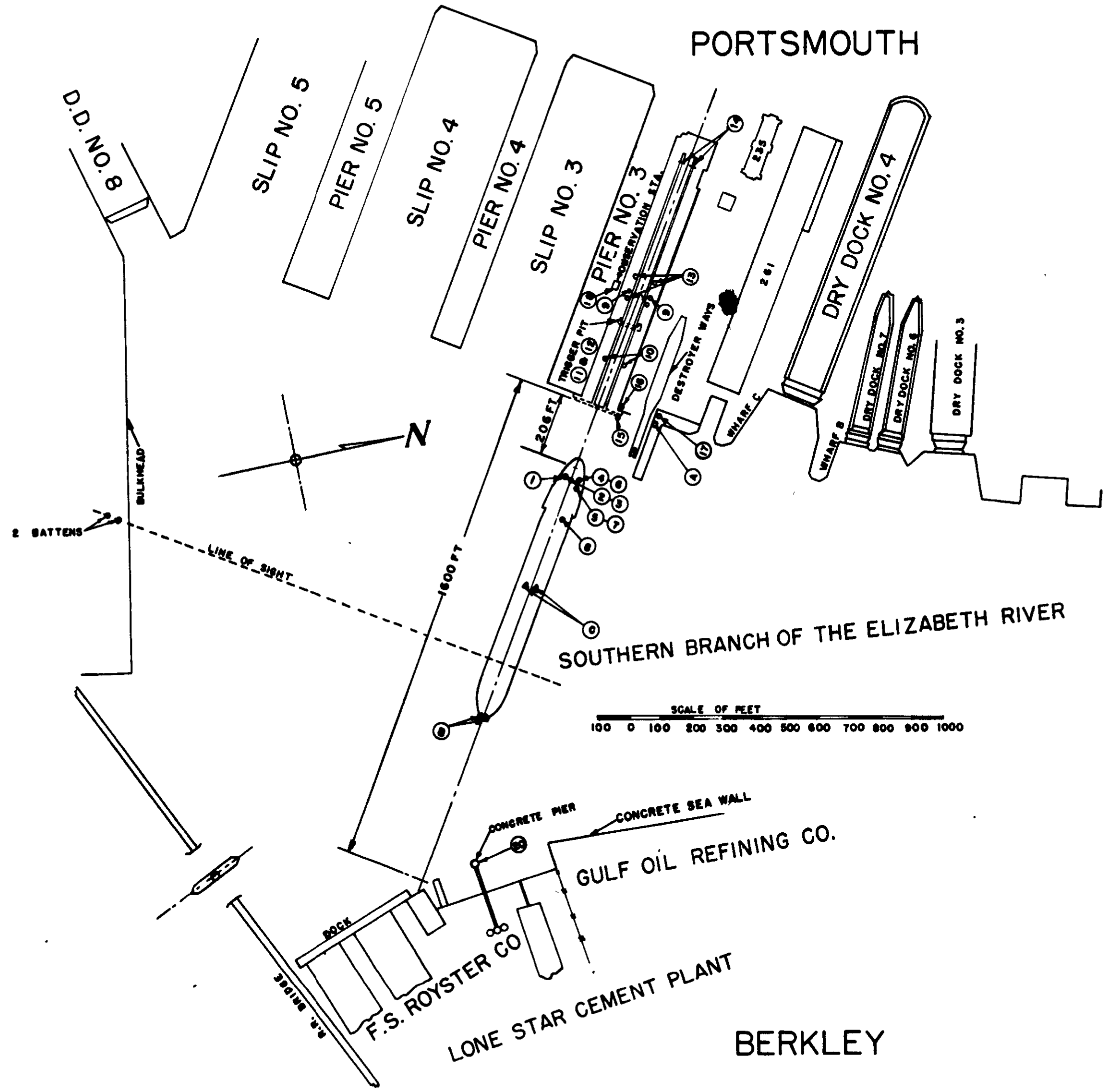


Figure 13 - The Launching Environs and Observation Stations

Based on a Norfolk Naval Shipyard drawing and on U.S. Engineering Department N-1-8064 (3).

STATION IDENTIFICATION

Norfolk Naval Shipyard Stations on Ship

1. Crushing - forecastle deck at Frame 8 port
2. Chronograph - forecastle deck at Frame 10 center
3. Pivoting - forecastle at Frame 10 center
4. Speed - forecastle deck starboard, 11 feet forward Station 2
5. Speed - forecastle deck starboard, 22 feet aft Station 4
6. Speed - at Station 4
7. Speed - at Station 5
8. Chain-Drag Cable Tensions - main deck at Frame 41 starboard

Norfolk Naval Shipyard Stations on Shore

9. Creep and deflection - forward end of sliding ways to trigger pit
10. Creep and deflection - trigger pit aft to way ends
11. Trigger pressures - located in trigger pit
12. Deflection of ways - located in trigger pit
13. Dog shores
14. Starting jacks
15. Tide and temperature - at northeast end of building ways
16. Water-level indication - end of building ways (north side)
17. Motion-picture camera on Wharf C
18. Recording-Control Station
19. Chain-Drags - located overhead in crane structure
20. Launching wave - Lone Star cement plant pier

David Taylor Model Basin Stations

A. Motion-picture camera on Wharf C opposite end of buildings ways
B. Two motion-picture cameras on stern gun sponson on main deck.
C. Two accelerometers located in machinery room amidships

of release until pivoting began, and the second one recorded accelerations and decelerations throughout the run until the vessel came to rest in the water.

The distance traveled after release was obtained by a 70 mm motion-picture camera mounted on the after gun sponson. This camera was trained on the opposite shore with at least three prominent objects whose location was accurately known always in its field. A 35 mm stand-by camera on the after gun sponson was not used. In addition, a 35 mm motion-picture camera was set up on a nearby pier opposite the way ends to record the initial movement of the ship, the movement of the hull when pivoting, and the dip of the bow during drop-off.

The vertical drop of the forefoot as the poppet left the ways was determined by the movement of the 29-foot waterline relative to a target in line with the way end. These data were recorded by the 35 mm camera referred to in the preceding paragraph.

All the experimental data were correlated by placing a stop watch in the field of view of all cameras and checking the rate of the watches by photographing them simultaneously before and after the launching. Corrections were made, where necessary, to agree with the time recorded by the 70 mm camera.

RESULTS OF FULL-SCALE OBSERVATIONS

The data recorded by the gyro-accelerometer were plotted against time in Figure 33; and the area under the resulting curve was integrated mechanically to obtain the velocity curve, shown by a solid line. The fixed-base accelerometer data were essentially the same and were not plotted. The time-distance curve was differentiated to obtain a supplementary velocity curve, shown by a broken line. Shore-camera observations and ship-camera triangulations were plotted to obtain the time-distance curve. The take-up of each chain clump caused a momentary deceleration of approximately 0.1 foot per second per second. The distances at which the chain drags became effective, shown on BuShips plan CV38-S0602-301714, agree with the breaks in the acceleration curve.

Figure 33 indicates that the stern began to lift at a travel of 512 feet. This distance is in good agreement with the calculated travel of 509 feet, at which the stern would lift under comparable static conditions. The point at which pivoting occurred was substantiated in a general way by the Norfolk Naval Shipyard's crushing indicator, which showed that the initial crushing of the spruce strips in the fore poppet occurred at a travel of 530 feet.

The coefficient of total resistance and the path of the forward perpendicular after drop-off are shown in Figure 34. The coefficient of resistance was calculated by the formula

$$\phi = \tan\theta - \frac{a}{g\cos\theta} \quad \text{or} \quad g\sin\theta = \phi\, g\cos\theta + a$$

where ϕ is the coefficient of resistance,

θ is the declivity of the ways in degrees,

a is the acceleration in feet per second per second, and

g is the acceleration of gravity in feet per second per second.

The coefficient of resistance varied from 0.0242 at the beginning of the motion to 0.020 when maximum acceleration was reached. The calculation was not carried beyond this stage because the stern of the vessel had become well immersed in the water and the retarding force was no longer an indication of the friction force. The vertical drop of the bow was less than the drop indicated by the preliminary tests because the tidal elevation was 0.48 foot higher.

COMPARISON OF TEST RESULTS AND FULL-SCALE OBSERVATIONS

The tests made in preparation for launching the ship were based on the estimated launching weight of 21,500 tons and on 15.38 feet of water over the way ends, which corresponds to the elevation at mean high water of 95.27 feet. The actual launching weight of the USS SHANGRI-LA was 21,088 tons and the actual tide was 0.48 foot above mean high water.

The total distance that the ship traveled was estimated by the Norfolk Naval Shipyard from the final position of the chain-drag clumps on the building ways. A travel of 1094 feet was established from this datum, which indicates that the ship stopped with the forward perpendicular 197 feet from the end of the ways. The data obtained with motion-picture cameras by observers from the Taylor Model Basin showed a total travel of 1103 feet. The drop-off velocity was 15.3 feet per second.

The final model tests were made after the launching of the ship. These tests were based on the actual launching weight, trim, height of water over the ways, and the overall drag coefficient derived from the pull of the chain-drag cables against hydraulic gages. The travel obtained from these tests was 1115 feet for a drop-off velocity of 15.3 feet per second.

Data obtained from model tests are compared with full-scale observations in Figure 28.

CONCLUSIONS

The experience at the Taylor Model Basin has shown that the most satisfactory procedure in model launching tests is to simulate the actual launching conditions. This procedure appears to be especially advantageous where the ship is abruptly checked by drags, for under these conditions the wake of entrained water around the hull and the other dynamic effects may combine to make the water resistance appreciably less than would be shown by astern-towing tests.

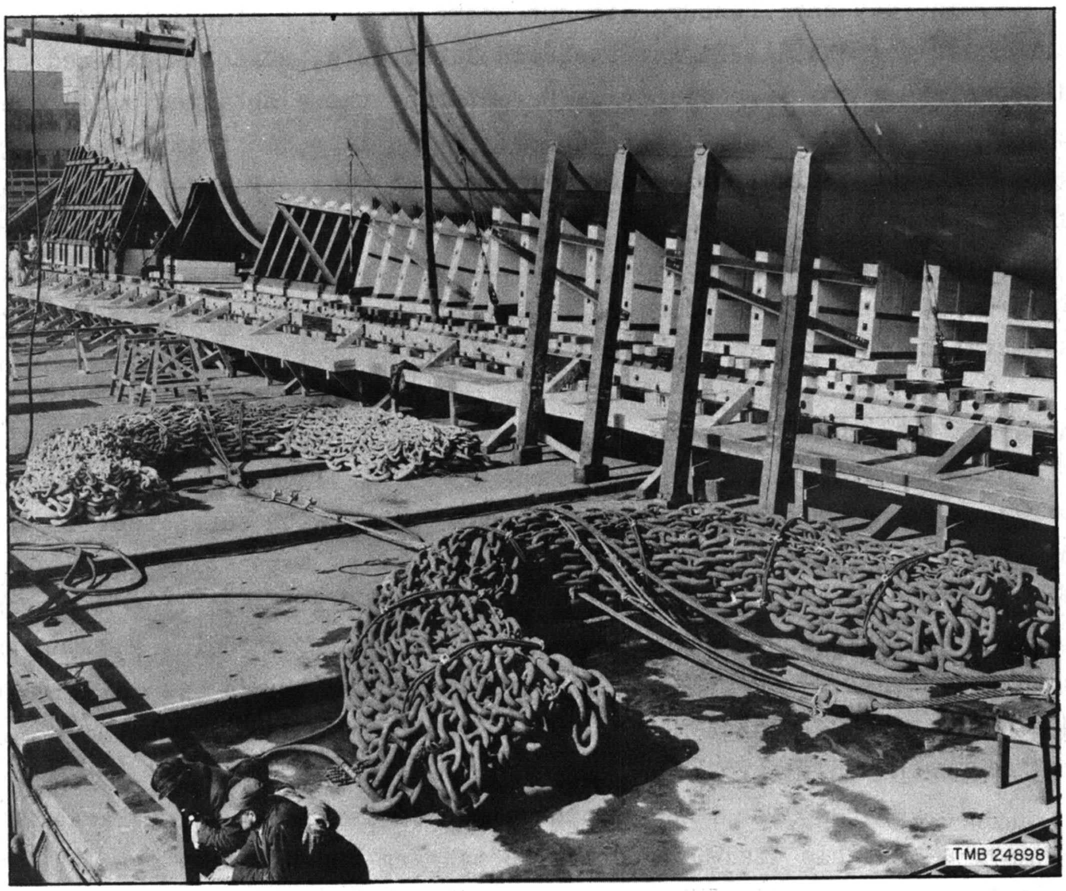
The experiments with the model of the SHANGRI-LA indicated that the water resistance was so markedly reduced when the ship was checked by chain drags that it could only be predicted by an actual launching test in which the drag forces were simulated. When the model was arrested within a distance of approximately 200 feet to scale from the way ends, the coefficient of water resistance was found to be reduced more than 50 per cent from the value obtained when the model, without drags, was allowed to run free after leaving the ways.

The way-end pressure did not prove to be a critical factor in the launching of the SHANGRI-LA and the calculated data, which were based on static conditions, were not appreciably different from those obtained under the dynamic conditions of the tests. The SHANGRI-LA was launched from a building slip of the sunken type with a concrete wall on each side. The restricting effect of the walls on the movements of the water, and on the way-end pressure and the pivoting of the ship, could be predicted only by launching a model under similar conditions. The method of measuring the way-end pressure appeared to be satisfactory.

Friction on the model ways was reduced to a minimum and kept constant from day to day by locating the ways high on each side of the model. The ball bearings of the four wheels on which the model was launched were consequently kept dry and their retarding effect was determined with sufficient accuracy from calibration runs. If the more usual method of supporting the model on wheels under the cradle at the height of the nominal grease line had been followed, the bearings would have been subjected to the corroding and fouling effects of the water. Constant test conditions would have been difficult to maintain and some method of measuring and recording the drag of the wheels during each run would have been desirable.

In general, the test procedure was satisfactory. The large 20-foot model gave a suitable scale factor for obtaining quantitative results, and the agreement between the data from the model tests and the full-scale observations was good. It is usually desirable to reproduce the contours of the river bottom but in this instance there was little difference between the actual depth and the mean depth, which was represented. It should be noted that a launching model represents the ship in a relatively light condition, and that sufficient ballast must be provided to adjust the trim of the model and its dynamic reactions. The hull of a launching model may therefore have to be light.

The frictional resistance of the rough surface of the cradle and of the portion of the hull over which the cradle was fitted, Figure 14, was considered to vary as the square of the speed. The frictional resistance of the remaining surface of the hull might have been separated from the residuary resistance in calculating the resistance of the ship, but it appeared that sufficiently close results would be obtained with data from tests of a large model by expanding the total resistance as the cube of the linear ratio. It should be noted that the model was launched in fresh water, whereas the ship was set afloat in water that was partly salt. The difference in density would compensate to some extent for any inaccuracy in the method of expansion of the frictional resistance from model to ship.



Reproduced by permission of the Norfolk Naval Shipyard.

Figure 14 - View of Launching Cradle and Drag Clumps

Each chain drag was laid down in the form of a horseshoe.

The methods used to obtain full-scale data were satisfactory except that there was a time lag in the accelerometer data. This discrepancy was attributed to a precession of the gyroscope on which the accelerometer was mounted. The curve obtained from the accelerometer data is of considerable interest nevertheless, because the fluctuations in acceleration are very clearly shown.

ACKNOWLEDGMENTS

The model tests were conducted by J.H. Curry, who designed the apparatus; the full-scale observations were directed by S.C. Gover, and the analysis and the report were prepared by C.G. Moody.

REFERENCES

(1) "On Launching," by P.A. Hillhouse and W.H. Riddlesworth, Transactions of the Institution of Naval Architects, Vol. 59, 1917, pp. 172-201.

(2) "Model Launching Experiments," by P.A. Hillhouse, The Shipbuilder, February 1921.

(3) "Launch Velocities and Drags," by P.A. Hillhouse, Transactions of the Institution of Engineers and Shipbuilders in Scotland, Vol. 66, November 1922, pp. 52-77.

(4) "Launching of Ships in Restricted Water," by Capt. H.M. Gleason, USN, and Lt. Comdr. H.E. Saunders, USN, Transactions of the Society of Naval Architects and Marine Engineers, Vol. 27, 1919, pp. 201-214.

(5) "Launching of Ships in Restricted Waters," by Lt. Comdr. H.E. Saunders, USN, Transactions of the Society of Naval Architects and Marine Engineers, Vol. 28, 1920, pp. 21-30.

(6) "Launch of the Airplane Carrier USS LEXINGTON," by S.W. Wakeman, Transactions of the Society of Naval Architects and Marine Engineers, Vol. 34, 1926, pp. 139-161.

(7) "Analysis of the Launching of the USS LEXINGTON by Model Experiments," by J.C. Huske and W.H. Magruder, Thesis, Massachusetts Institute of Technology, 1926.

(8) "Analysis of the Launching of the USS LEXINGTON by Model Experiments," by H.A. Ingram and L.D. Whitgrove, Thesis, Massachusetts Institute of Technology, 1927.

(9) "The Launch of the Airplane Carrier USS SARATOGA," by E.H. Rigg, Transactions of the Society of Naval Architects and Marine Engineers, Vol. 33, 1925, pp. 147-160. Comments by William Hovgaard on p. 156.

(10) Discussion by Professor Henry H.W. Keith of Reference (13), pp. 101-102. Transactions of the Society of Naval Architects and Marine Engineers, Vol. 50, 1942.

(11) "Launch of the Quadruple-Screw Turbine Steamer QUEEN MARY," by J.M. McNeill, Transactions of the Institution of Naval Architects, Vol. 77, 1935, pp. 1-27.

(12) "Ablauf des Schlachtschiffes Scharnhorst" (Launching of the Battleship SCHARNHORST), by F. Riecke, VDI-Zeitschrift, Vol. 81, No. 13, 1937, TMB Translation 105, October 1942.

(13) "Side Launching on the Great Lakes, Model Experiments and Practice," by J.H. Fahey, Transactions of the Society of Naval Architects and Marine Engineers, Vol. 50, 1942, pp. 81-125.

(14) "Launching of the NORMANDIE," by A. See, Transactions of the Society of Naval Architects and Marine Engineers, Vol. 41, 1933, pp. 316-340.

(15) Comments by R.E. Froude on "The Effect of Acceleration on Ship Resistance," by C.E. Stromeyer, Transactions of the Institution of Naval Architects, Vol. 47, Part 1, 1905, p. 185.

(16) Comments by R.E. Froude on "A New Method of Research on Fluid Resistance and Ship Propulsion," by H. Wellenkamp, Transactions of the Institution of Naval Architects, Vol. 50, 1908, pp. 234-236.

(17) Comments by R.E. Froude on "The Accelerated Motion of Bodies in Water, with Special Application to the Rolling of Ships," by A.W. Johns, Transactions of the Institution of Naval Architects, Vol. 51, 1909, pp. 191-193.

(18) "On Experiments with HMS GREYHOUND," by William Froude, Transactions of the Institution of Naval Architects, Vol. 15, 1874, p. 36 ff.

(19) Norfolk NavShipYard RESTRICTED letter, CV38/S6(1-MDH-9/13) of 19 August 1943, to TMB.

(20) Norfolk NavShipYard RESTRICTED letter, CV38/S6(1-MDH-10/25) of 24 September 1943, to TMB.

(21) "Launching Data for the USS AUK (AM57) and Photographic Methods Used in Obtaining Them," by J.G. Thews, TMB Report R-50, December 1941.

(22) The correspondence on the SHANGRI-LA Launching is in TMB File S6. Original data are filed in the TMB Record Vault, under Miscellaneous 884.

(23) "Dynamics," by Horace Lamb, p. 164, in 1920 Reprint of First Edition.

(24) "General Design of Warships," by William Hovgaard, p. 100. Spon, London, 1920.

(25) "Principles of Naval Architecture," Rossell and Chapman, Vol. 1, chapter on launching, by H.H.W. Keith.

(26) "Notes on the Launching of the TSS MARIPOSA," by J.B. Hunter, Transactions of the Society of Naval Architects and Marine Engineers, Vol. 39, 1931, pp. 131 and 133.

(27) "Launch of the Twin-Screw Turbine Steamer NIEUW AMSTERDAM," by G.M. Chambers, Transactions of the Institution of Naval Architects, Vol. 80, 1938, p. 209.

(28) "Retardation of Vessels after Launching," by Dr. K.E. Schoenherr, EMB Report R-24, May 1940. The results of tests in the Washington Model Basin with a model representing BB55 and BB56.

(29) "Launching of USS NEW JERSEY and USS WISCONSIN," by Rear Admiral Alan J. Chantry, Jr., USN, Society of Naval Architects and Marine Engineers, 1944.

(30) Report on the Launching of the USS SHANGRI-LA (CV38) by the Norfolk Navy Yard, Bureau of Ships CV38-S0602-302205, 18 pp., June 1944.

(31) "Launching Model Tests of the USS NEW JERSEY (BB62) Preliminary Report," TMB Report R-76, November 1942.

(32) "Experiments with Sidewise Launching of a Pontoon - Model Tests," by J.H. Curry, TMB CONFIDENTIAL Report R-100, May 1943.

(33) "Model Experiments to Determine Behavior of a 50-Foot Transfer Barge during Launching." by S.H. Brooks and Dr. K.E. Schoenherr, TMB CONFIDENTIAL Report R-82, July 1943.

(34) "A Note on the Direct Measurement of the Virtual Mass of Ship Models," by T.B. Abell, Transactions of the Institution of Naval Architects, Vol. 72, 1930, pp. 303-309.

(35) "Notes on Launching Problems, with Particular Reference to Modern Conditions," by E.H. Rigg and E.A. Hodge, the Philadelphia Section of the Society of Naval Architects and Marine Engineers, 1942.

(36) "Vorausbestimmung der Bewegungsvorgänge beim Stapellauf grosser Schiffe" (Prediction of the Movements of Large Ships in Launching), by H. Stemmer, Schiffbau, Schiffahrt und Hafenbau, Vol. 41, No. 17, 1940; TMB Translation 100, May 1942.

(37) "Stapellaufversuche mit zwei Schiffmodellen" (Launching Tests with Two Ship Models), by Henry Stemmer, Schiffbau, Schiffahrt und Hafenbau, 1937; TMB Translation 182.

(38) "On Launching Calculations, with Special Reference to the Effect of Camber," by John Smith, Transactions of the Institution of Naval Architects, Vol. 51, 1909, pp. 198-213.

(39) "Launching Declivities for Ships, and Their Influence upon Poppet and Way-End Pressures," by A. Hiley, Transactions of the Institution of Naval Architects, Vol. 55, Part 1, 1913, pp. 181-200.

(40) "Notes on Launching," by William Gatewood, Transactions of the Society of Naval Architects and Marine Engineers, Vol. 26, 1918, pp. 89-95.

(41) "Launch of the AORANGI," by P.A. Hillhouse, Shipbuilding and Shipping Record, September 1924.

(42) "Launching Data," C & R Bulletin No. 15, May 1939.

(43) "The Effect of Size of Towing Tank on Model Resistance," by J.P. Comstock and C.G. Hancock, Transactions of the Society of Naval Architects and Marine Engineers, Vol. 50, 1942, pp. 149-197. Of interest in connection with the effect of restricted width and depth of channel on launching.

APPENDIX 1

DATA FROM MODEL TESTS OF THE LAUNCHING OF THE USS SHANGRI-LA (CV38)

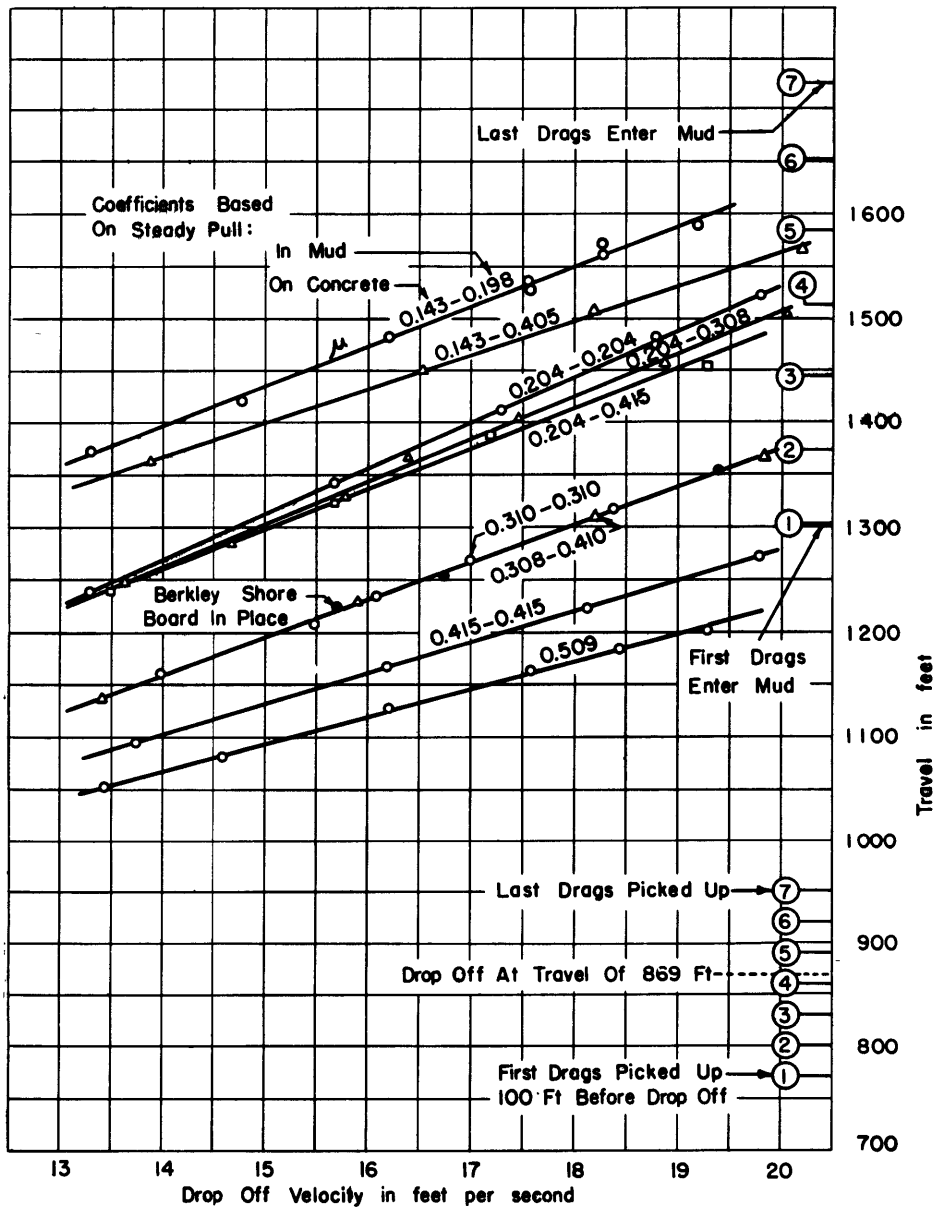


Figure 15 - Relation between Travel and Drop-Off Velocity for Various Combinations of Chain-Drag Coefficient

The data in this figure are based on the tests which show the first drags picked up 100 feet before drop-off. The lowest curve was added 8 July 1944, after the launching of the ship.

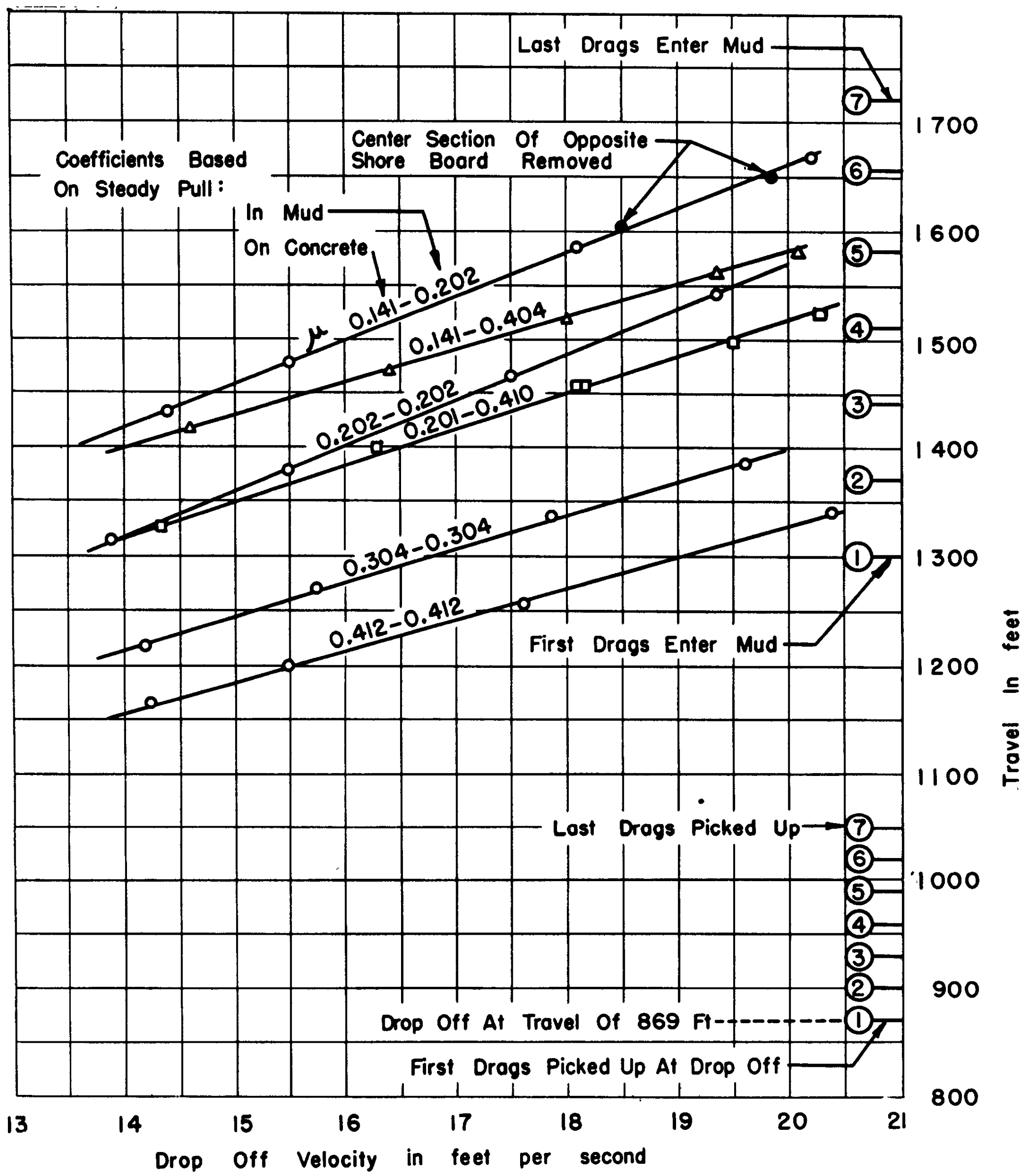


Figure 16 - Relation between Travel and Drop-Off Velocity for Various Combinations of Chain-Drag Coefficient

The data in this figure are based on the tests which show the first drags picked up at drop-off.

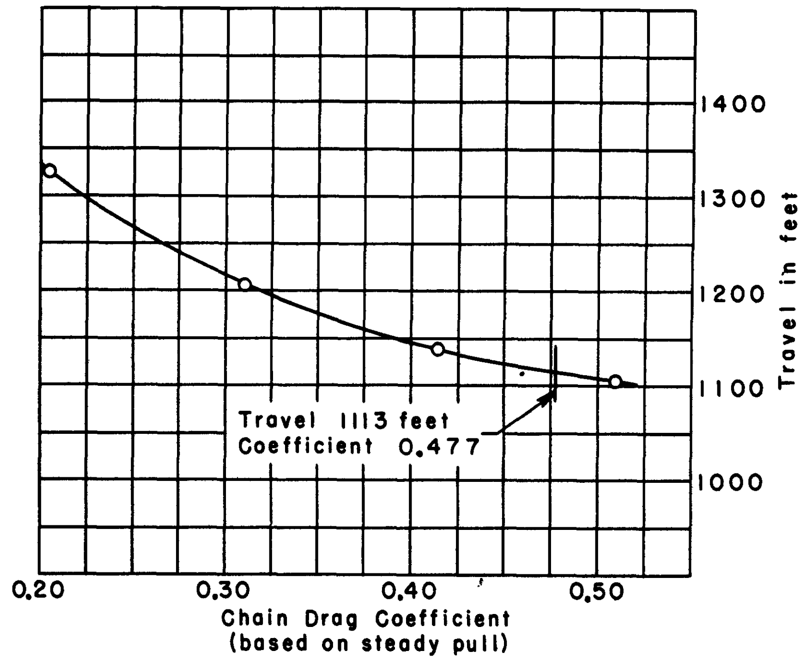


Figure 17 - Relation of Travel to Chain-Drag Coefficient for a Drop-Off Velocity of 15.3 Feet Per Second

The travel predicted for the actual chain-drag coefficient of 0.477 with the first drags picked up 100 feet before drop-off was 1113 feet.

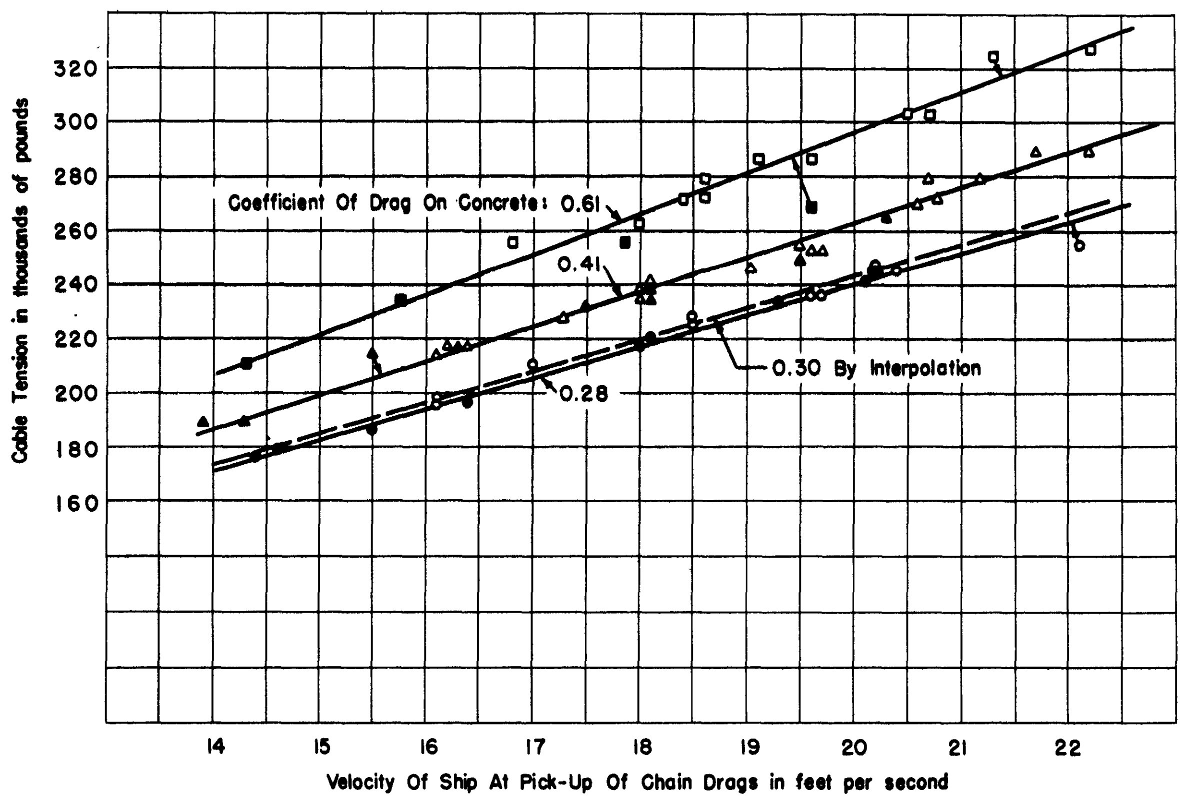


Figure 18 - Peak Cable Tension at Pick-Up of First Chain Drag

The data are for a 50-ton drag.

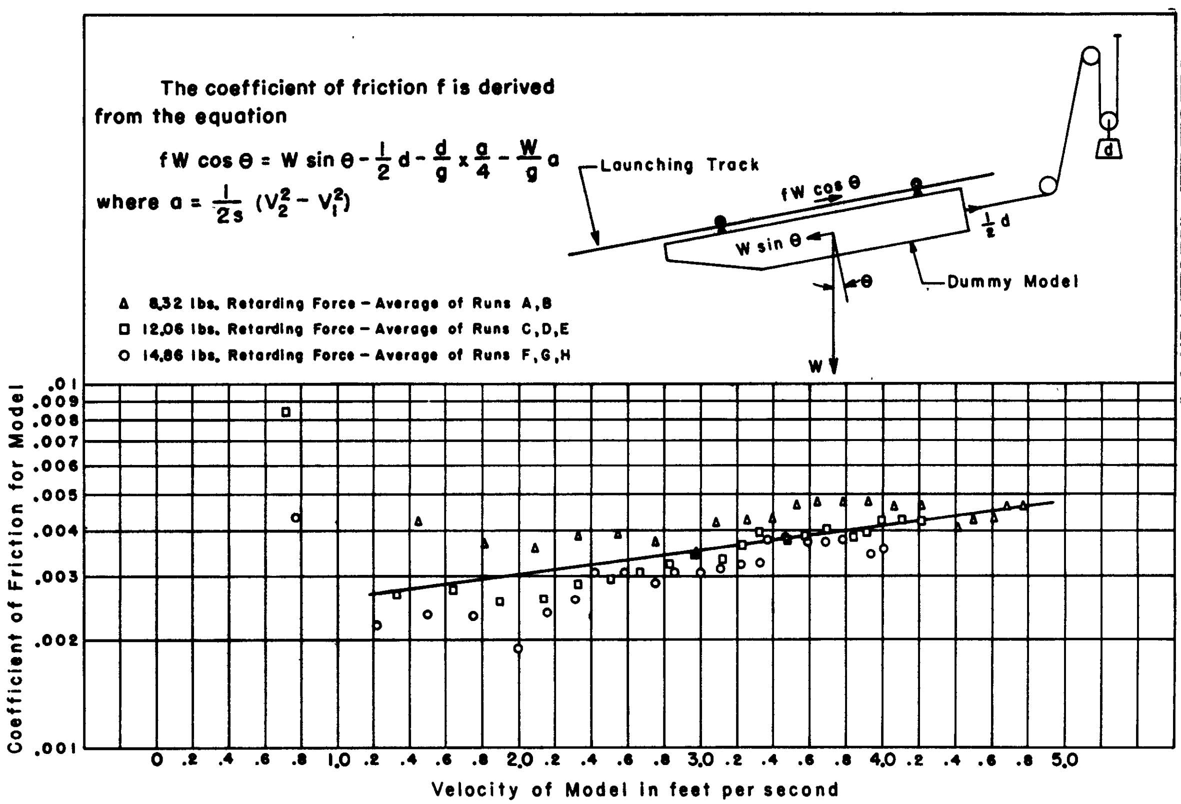


Figure 19 - Coefficient of Rolling Friction

The friction was deduced from tests out of water with the dummy model.

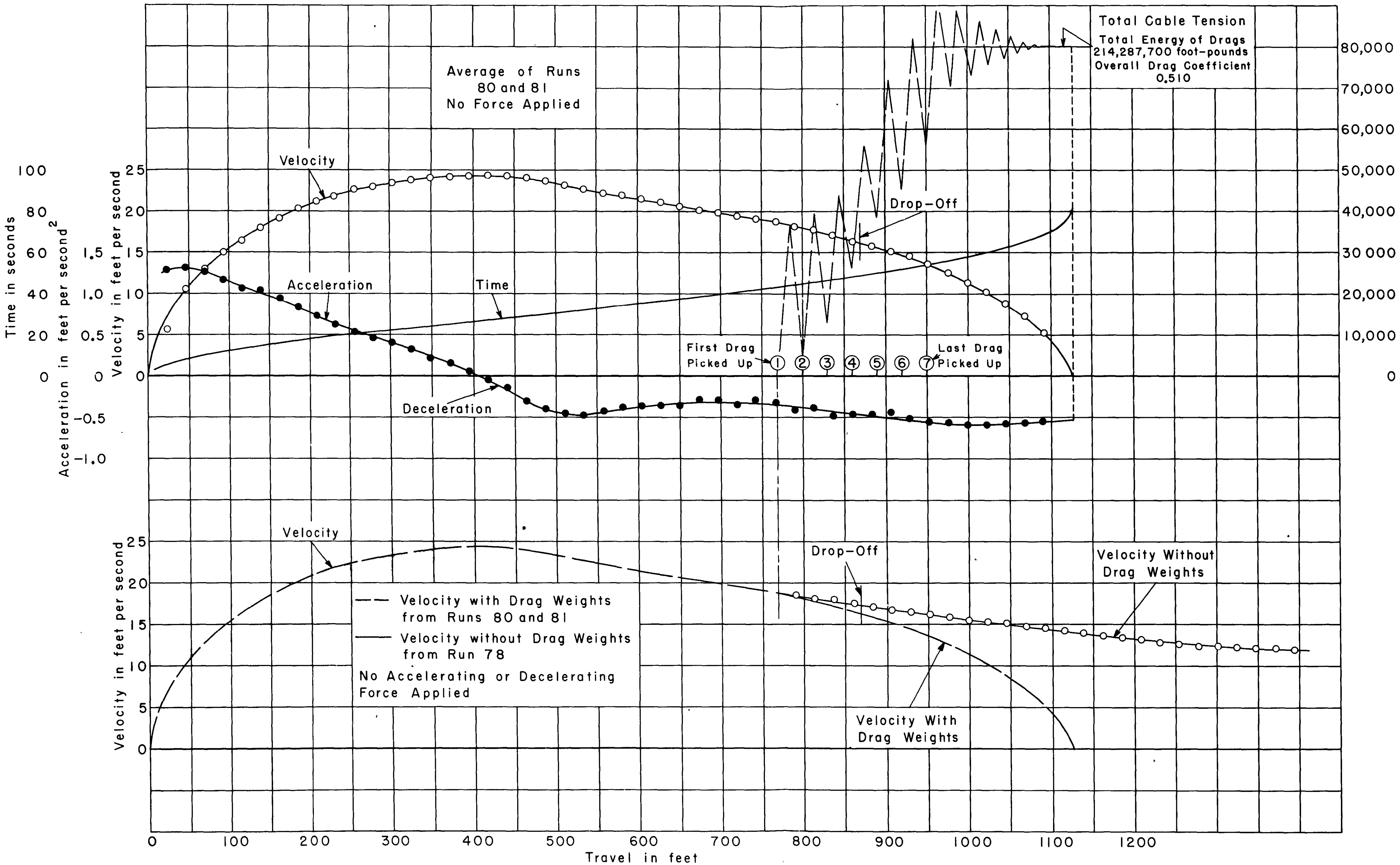


Figure 27 - Launching Data Deduced from Model Tests

The data are for drop-off velocities of 17.3 and 16.2 feet per second, and for nominal chain-drag coefficients of 0.50 on concrete and 0.50 in mud; first drags picked up 100 feet before drop-off.

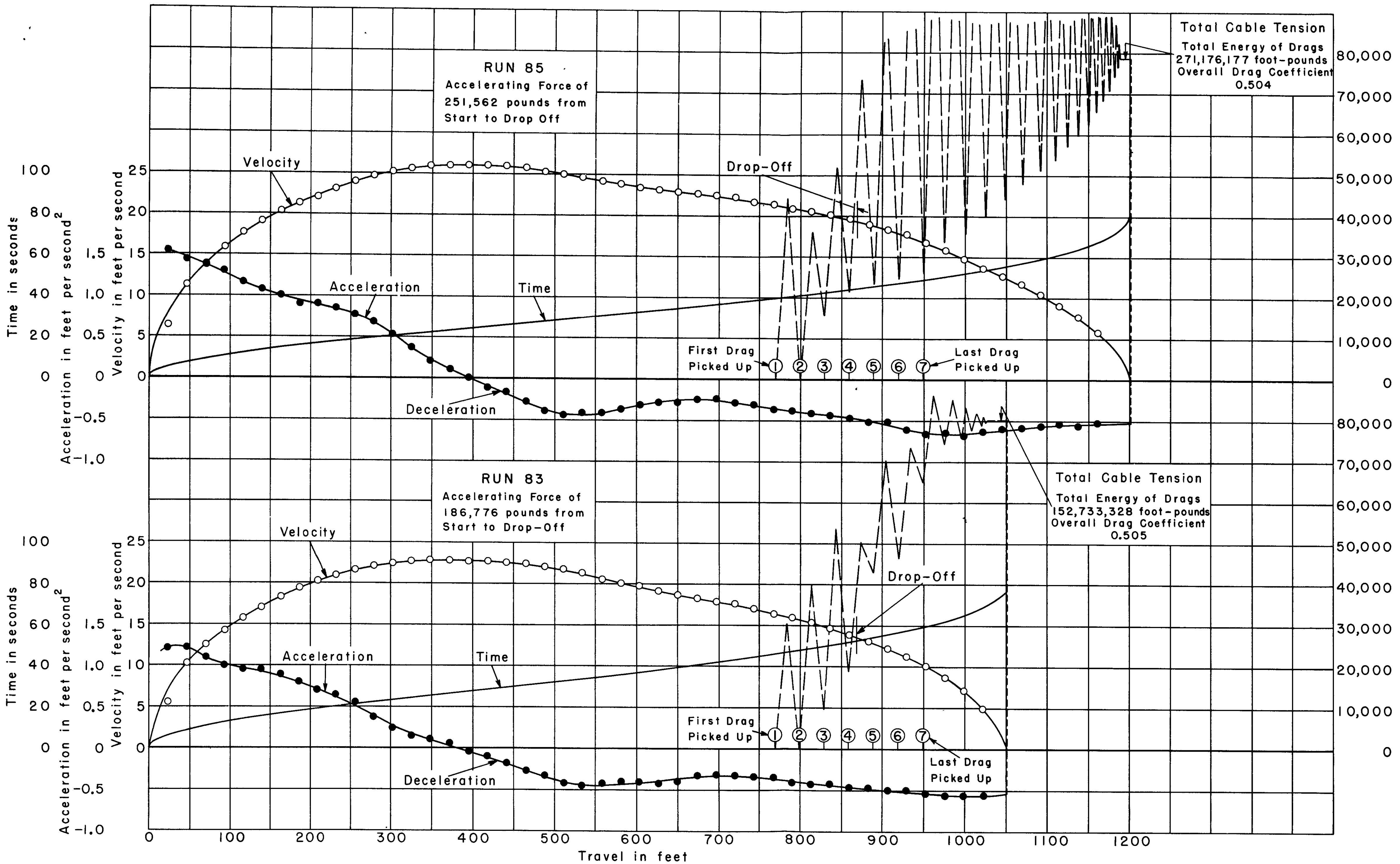


Figure 26 - Launching Data Deduced from Model Tests

The data are for drop-off velocities of 13.6 and 19.3 feet per second, and for nominal chain-drag coefficients of 0.50 on concrete and 0.50 in mud; first chain drags picked up 100 feet before drop-off.

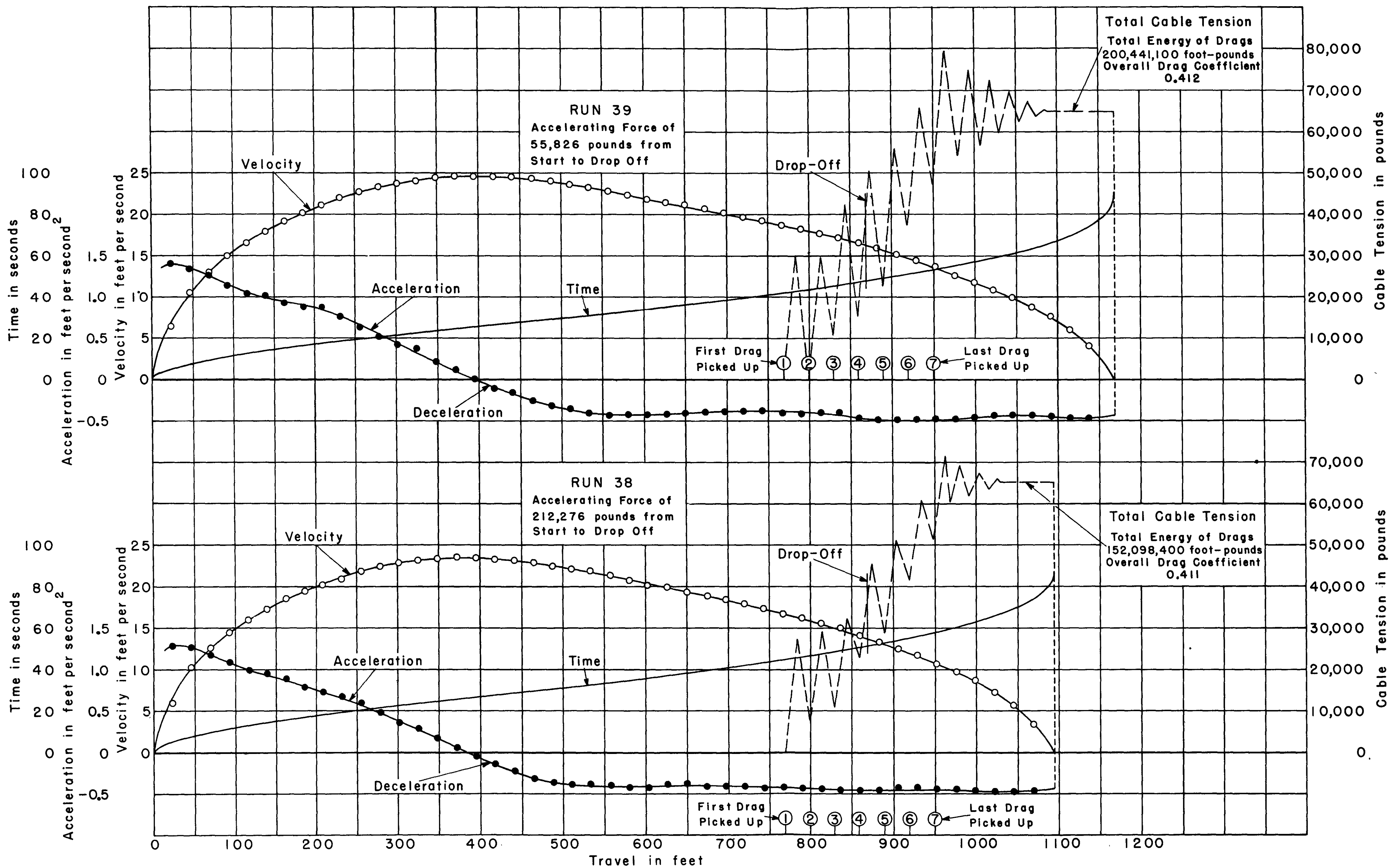


Figure 25 - Launching Data Deduced from Model Tests

The data are for drop-off velocities of 18.3 and 20.0 feet per second, and for nominal chain-drag coefficients of 0.40 on concrete and 0.40 in mud; first chain drags picked up 100 feet before drop-off.

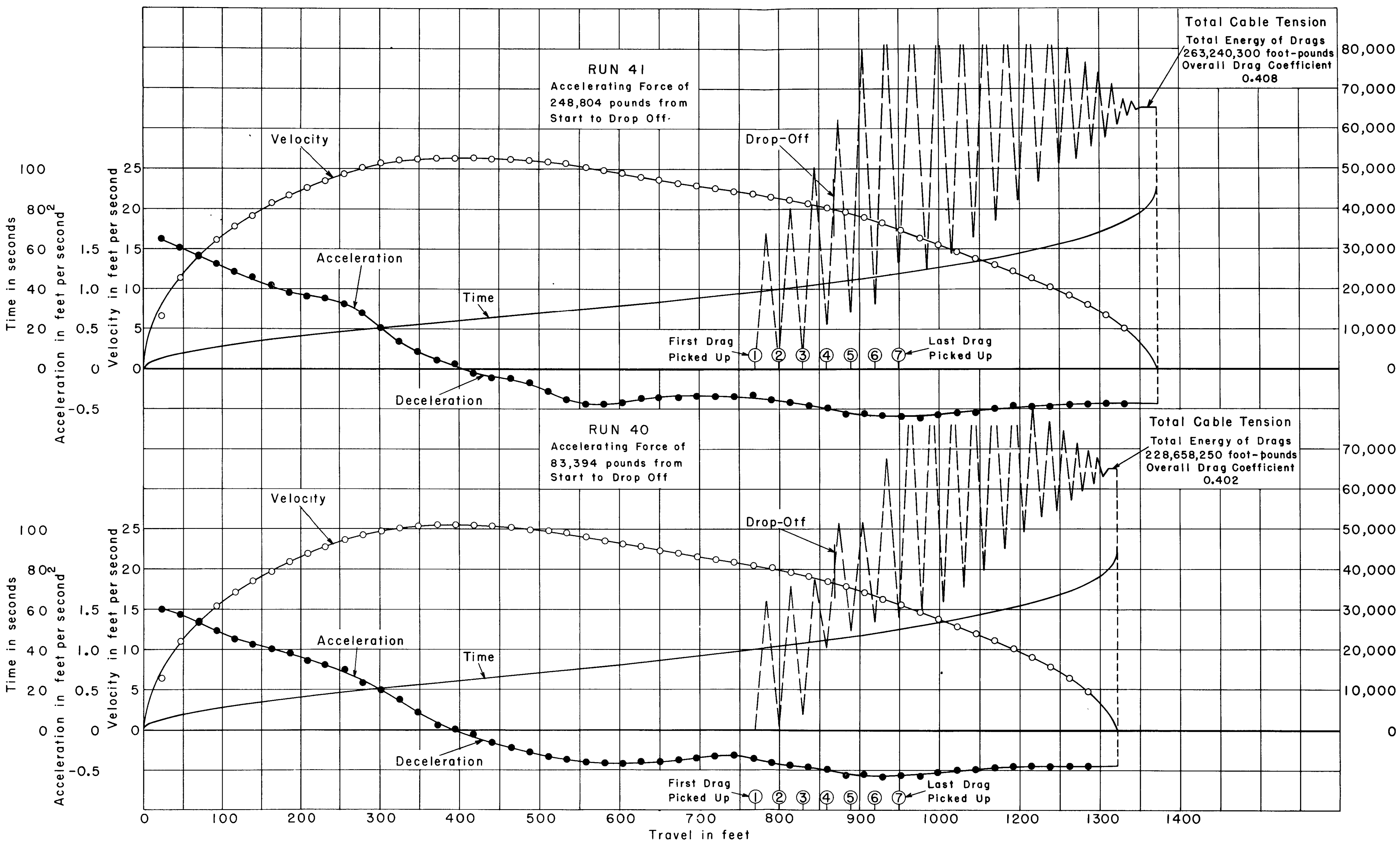


Figure 24 - Launching Data Deduced from Model Tests

The data are for drop-off velocities of 13.8 and 15.3 feet per second, and for nominal chain-drag coefficients of 0.40 on concrete and 0.40 in mud; first chain drags picked up 100 feet before drop-off.

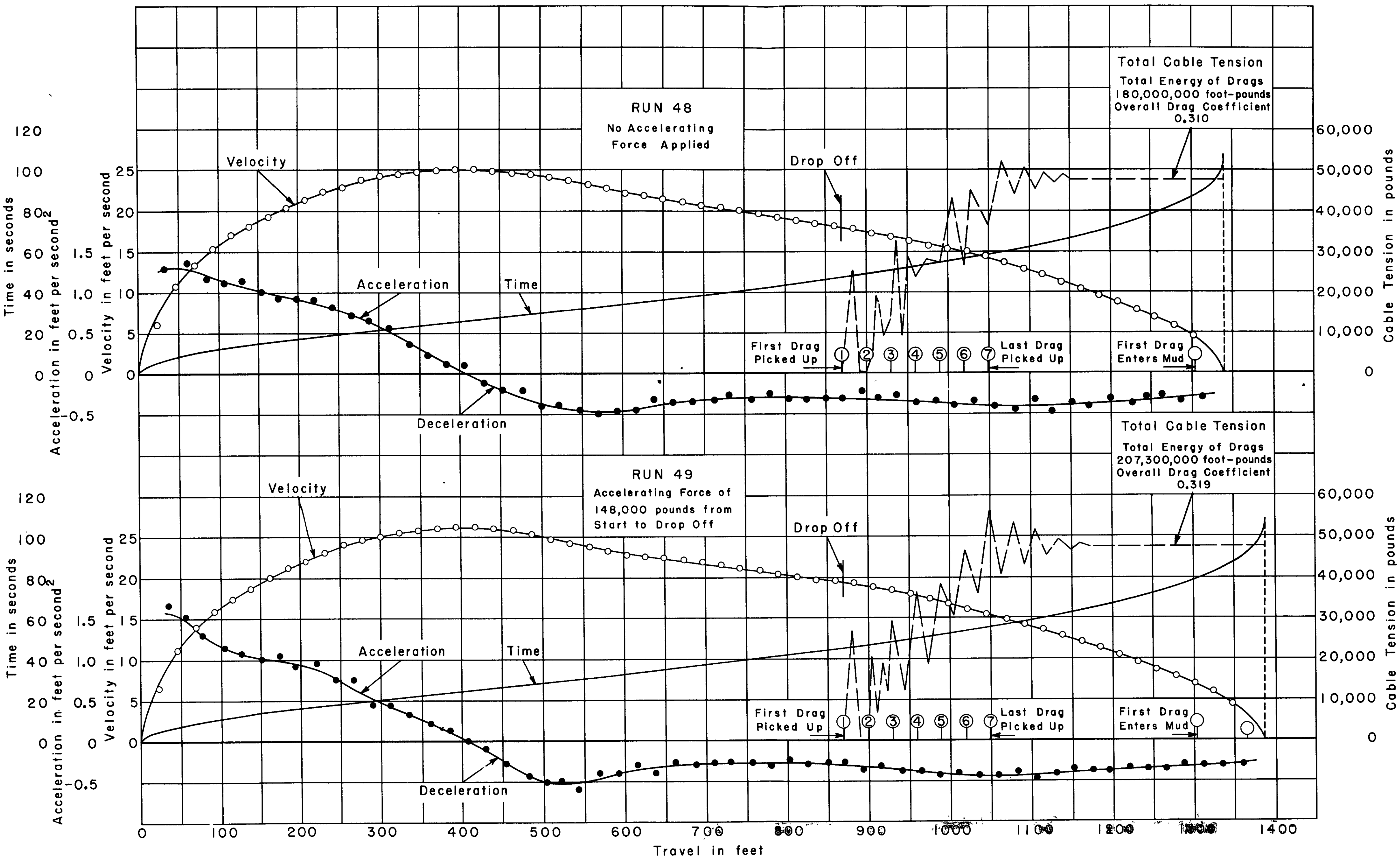


Figure 23 - Launching Data Deduced from Model Tests

The data are for drop-off velocities of 17.9 and 19.3 feet per second, and for nominal chain-drag coefficients of 0.30 on concrete and 0.30 in mud; first chain drags picked up at drop-off.

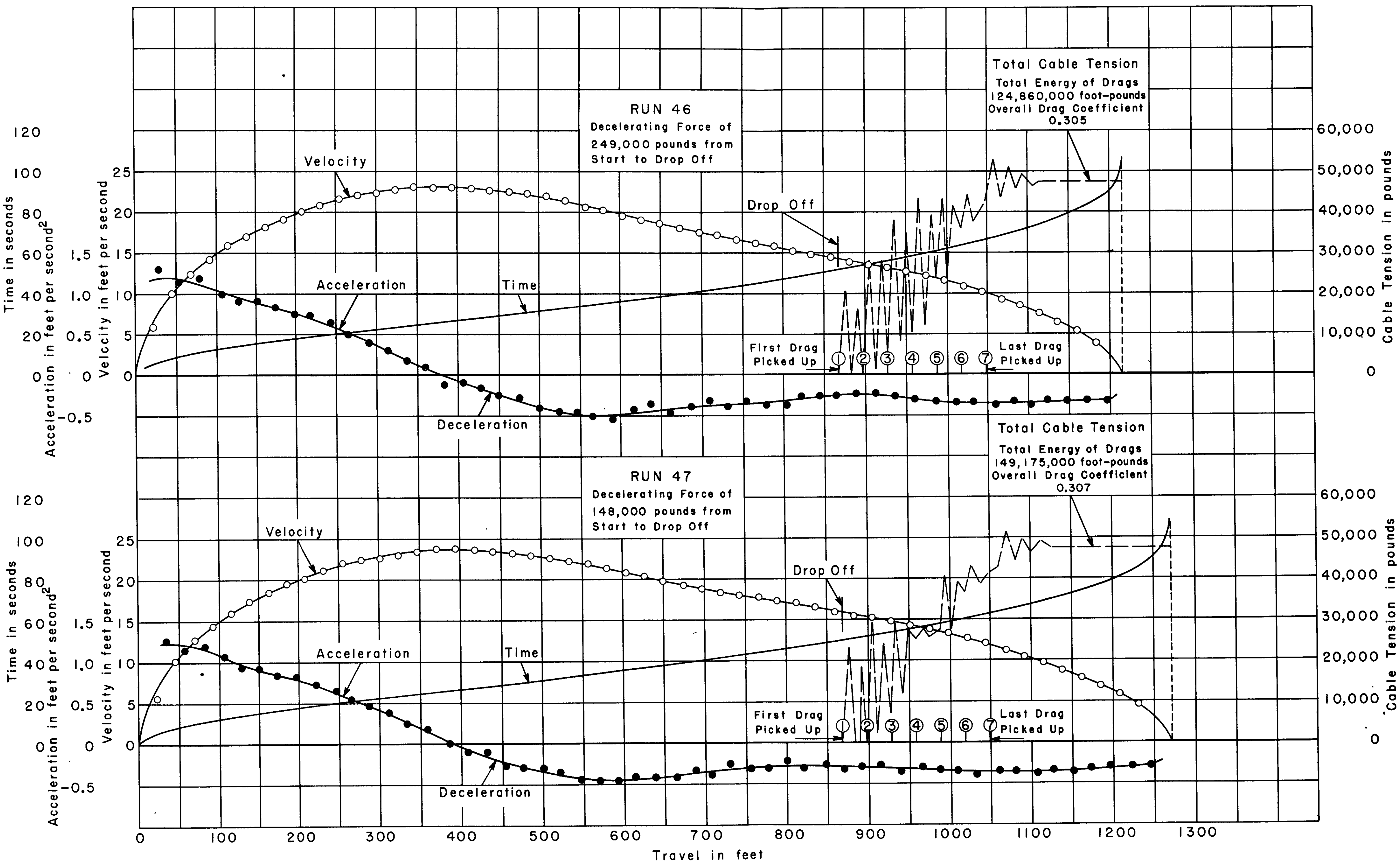


Figure 22 - Launching Data Deduced from Model Tests

The data are for drop-off velocities of 14.3 and 16.0 feet per second, and for nominal chain-drag coefficients of 0.30 on concrete and 0.30 in mud; first chain drags picked up at drop-off.

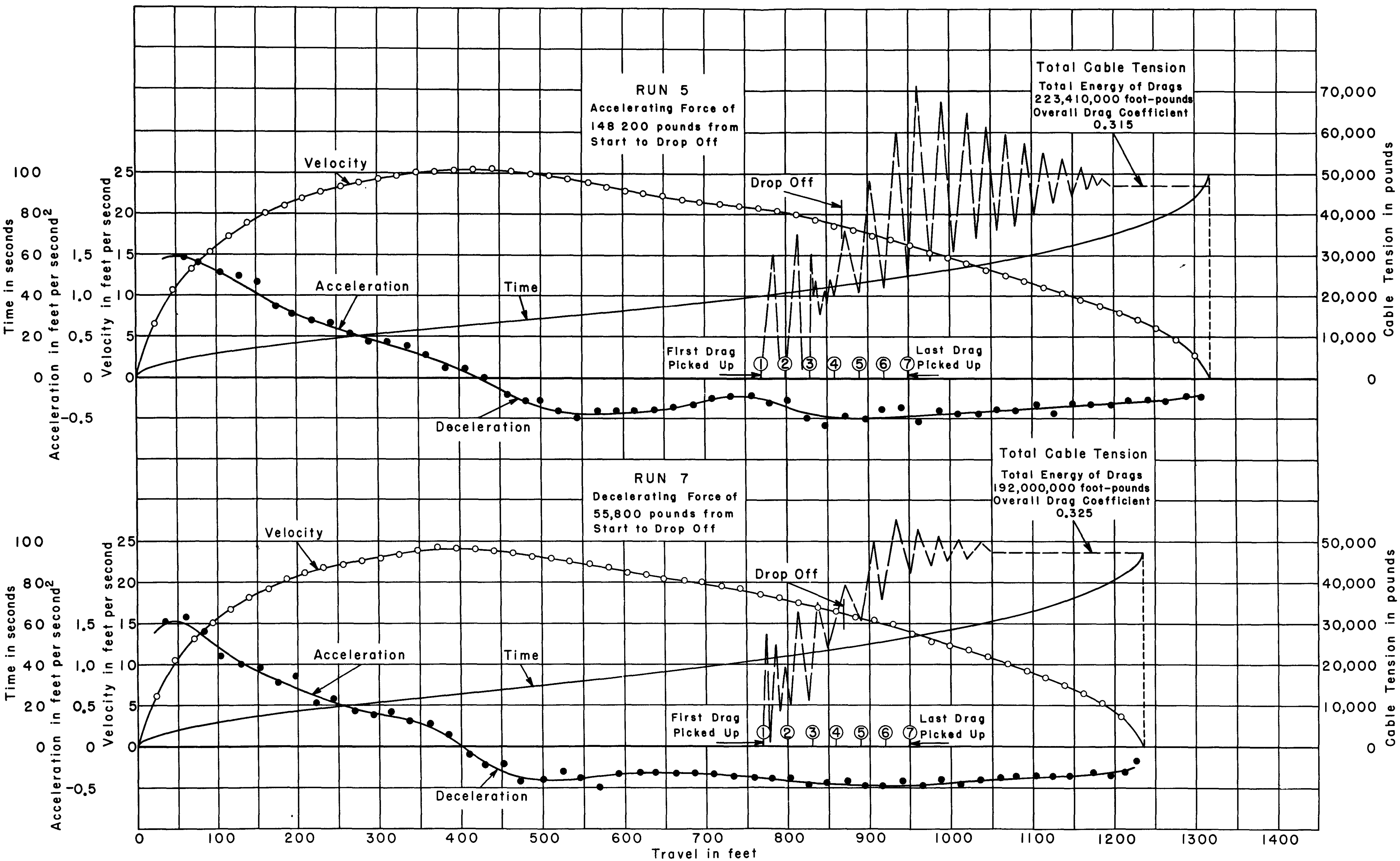


Figure 21 - Launching Data Deduced from Model Tests

The data are for drop-off velocities of 16.2 and 18.5 feet per second, and for nominal chain-drag coefficients of 0.30 on concrete and 0.30 in mud; first chain drags picked up 100 feet before drop-off.

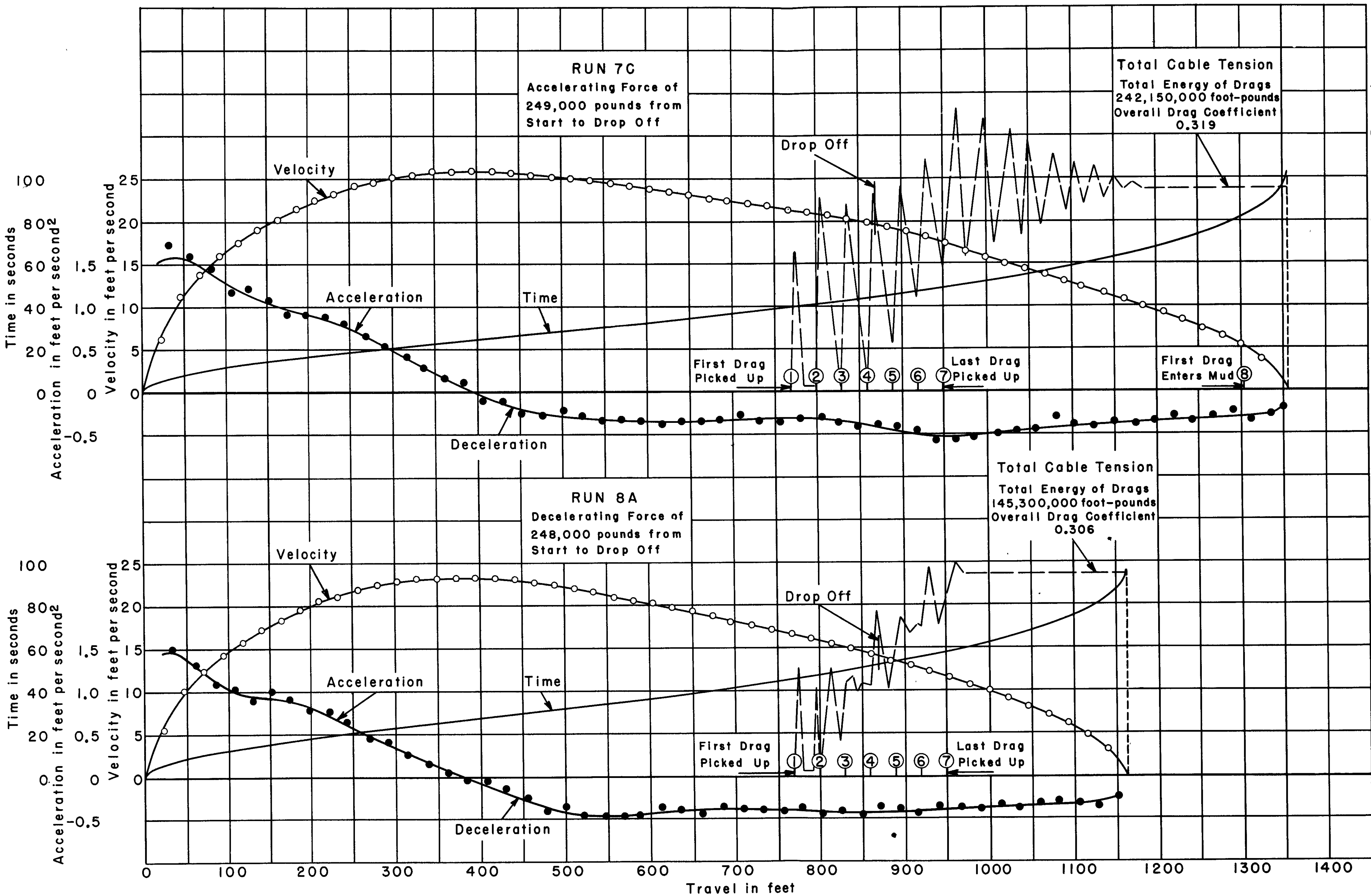


Figure 20 - Launching Data Deduced from Model Tests

The data are for drop-off velocities of 14.0 and 19.5 feet per second, and for nominal chain-drag coefficients of 0.30 on concrete and 0.30 in mud; first chain drags picked up 100 feet before drop-off.

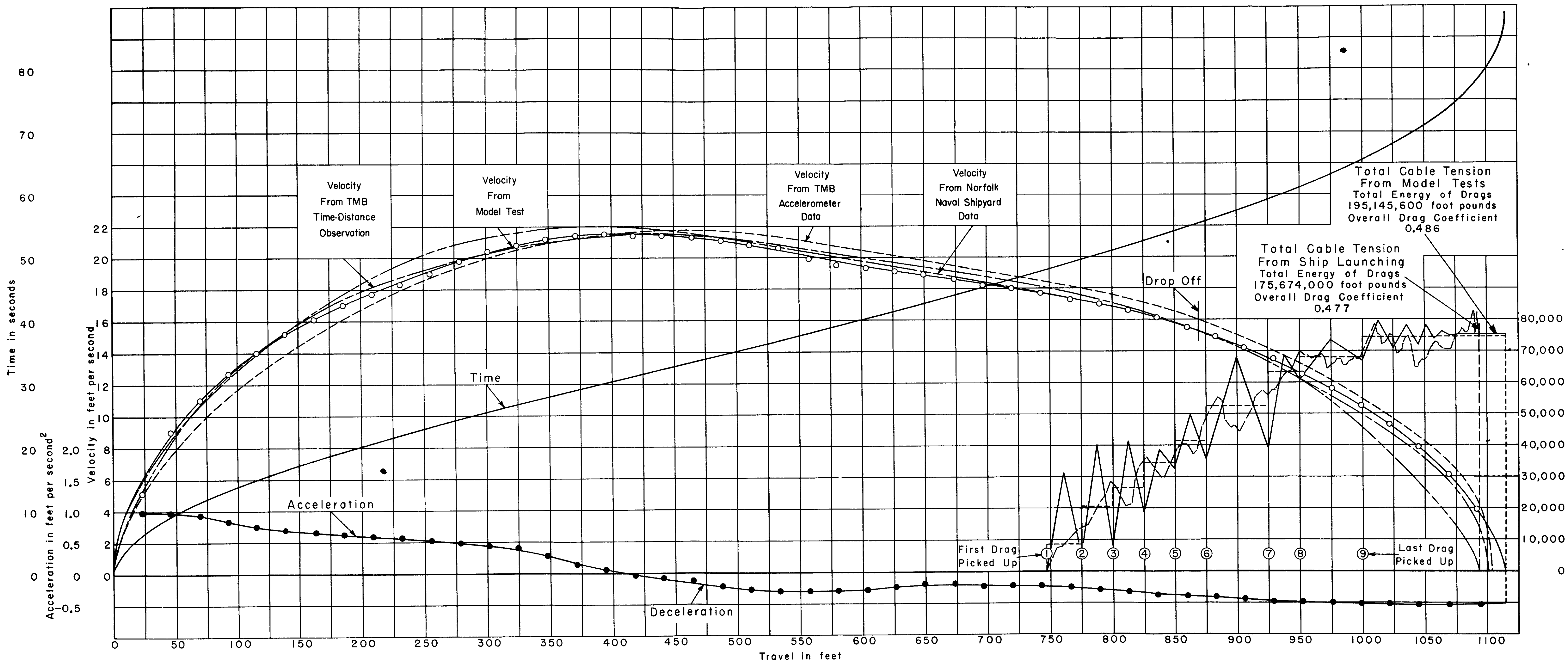


Figure 28 - Launching Data from Model Tests Compared with Full-Scale Observations

The model data are from the tests conducted after the launching of the ship; the full-scale data are from the Taylor Model Basin's accelerometer and motion-picture camera observations and the Norfolk Naval Shipyard's chronograph record.

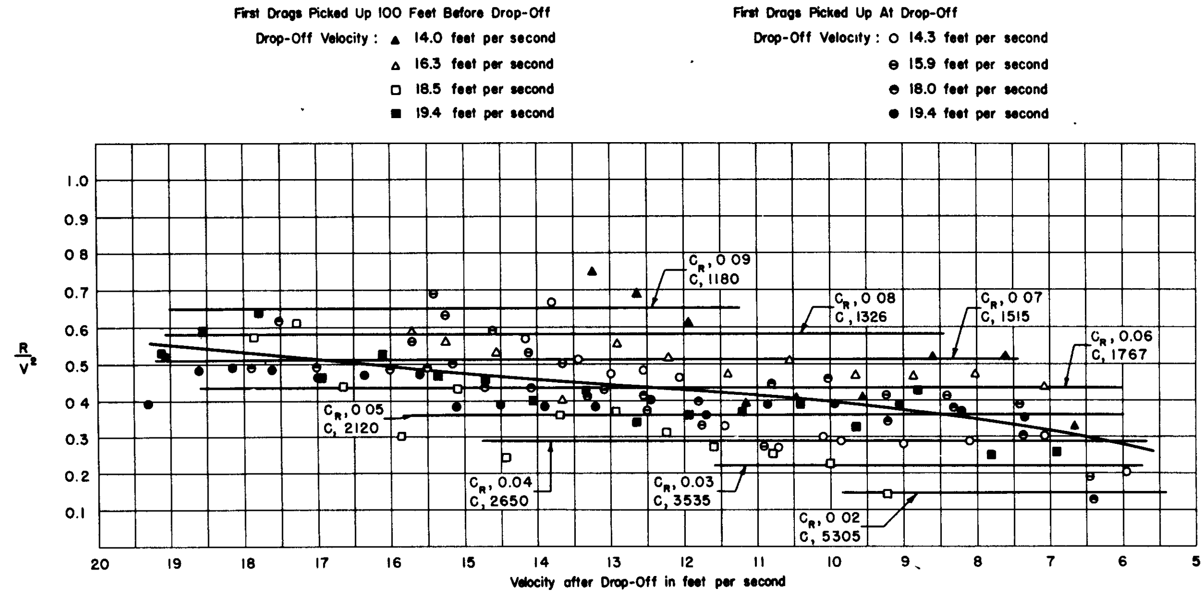


Figure 29 - Comparative Plot of Water Resistance After Drop-Off For the Eight Runs with a Drag Coefficient of 0.30

The plot is based on model tests run at various speeds and with alternate drag arrangements.

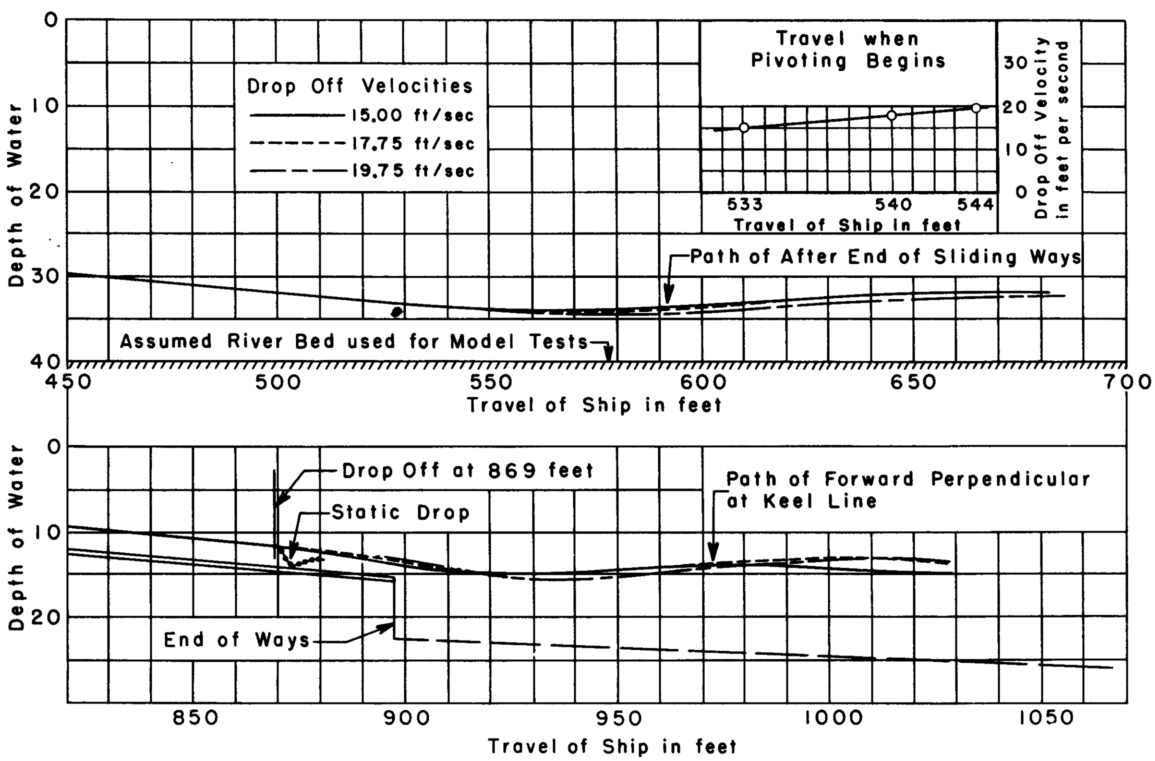


Figure 30 - Path of the Bow During Drop-Off and of the After End of the Sliding Ways During Pivoting

The model tests conducted to trace the movements of the ends were based on the estimated launching weight and trim of the ship and on the MHW tidal elevation of 95.27 feet.

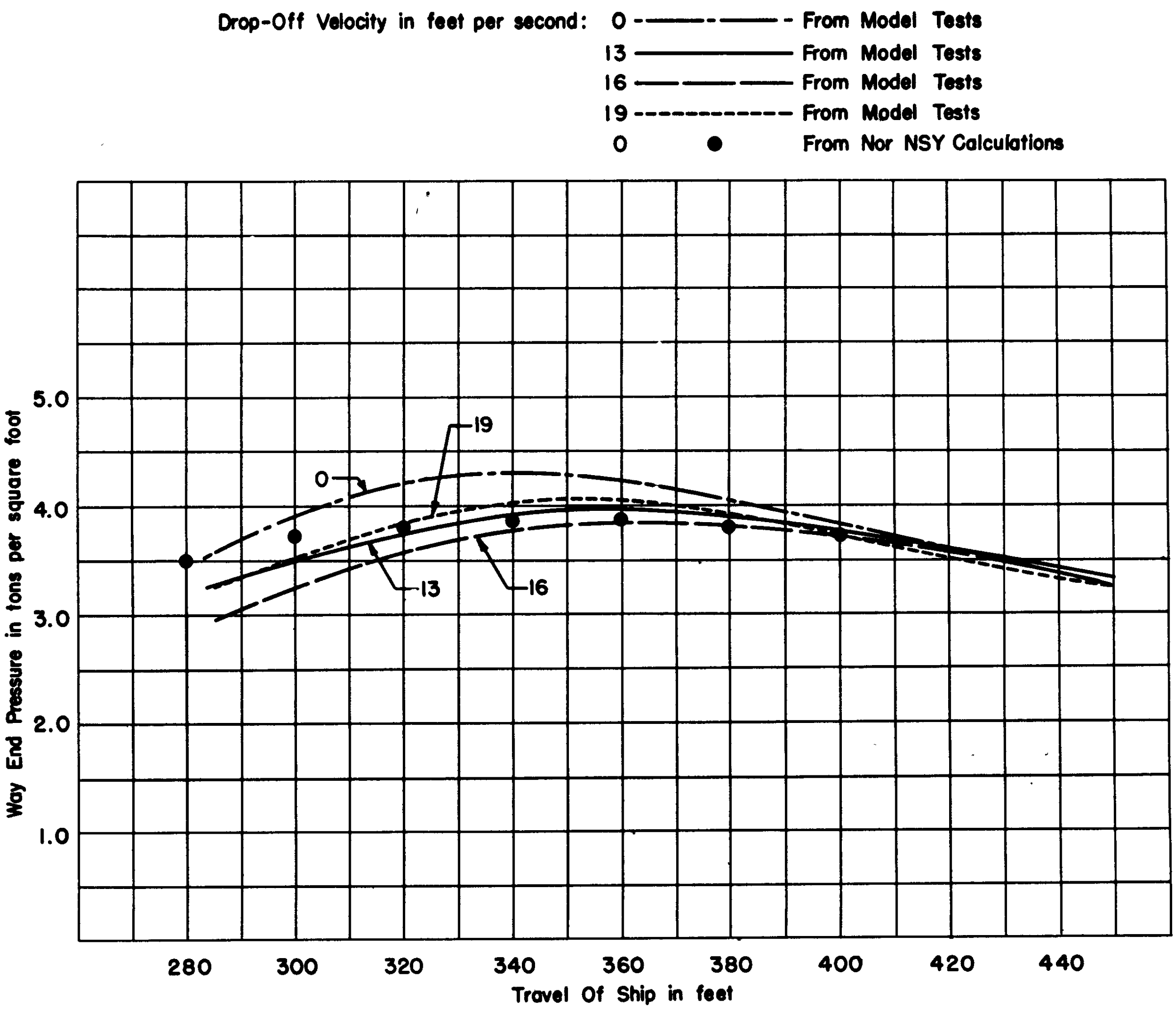


Figure 31 - Way-End Pressure

The data on way-end pressure are for the estimated launching weight and trim of the ship and for the mean high water depth of 15.38 feet over the way ends.

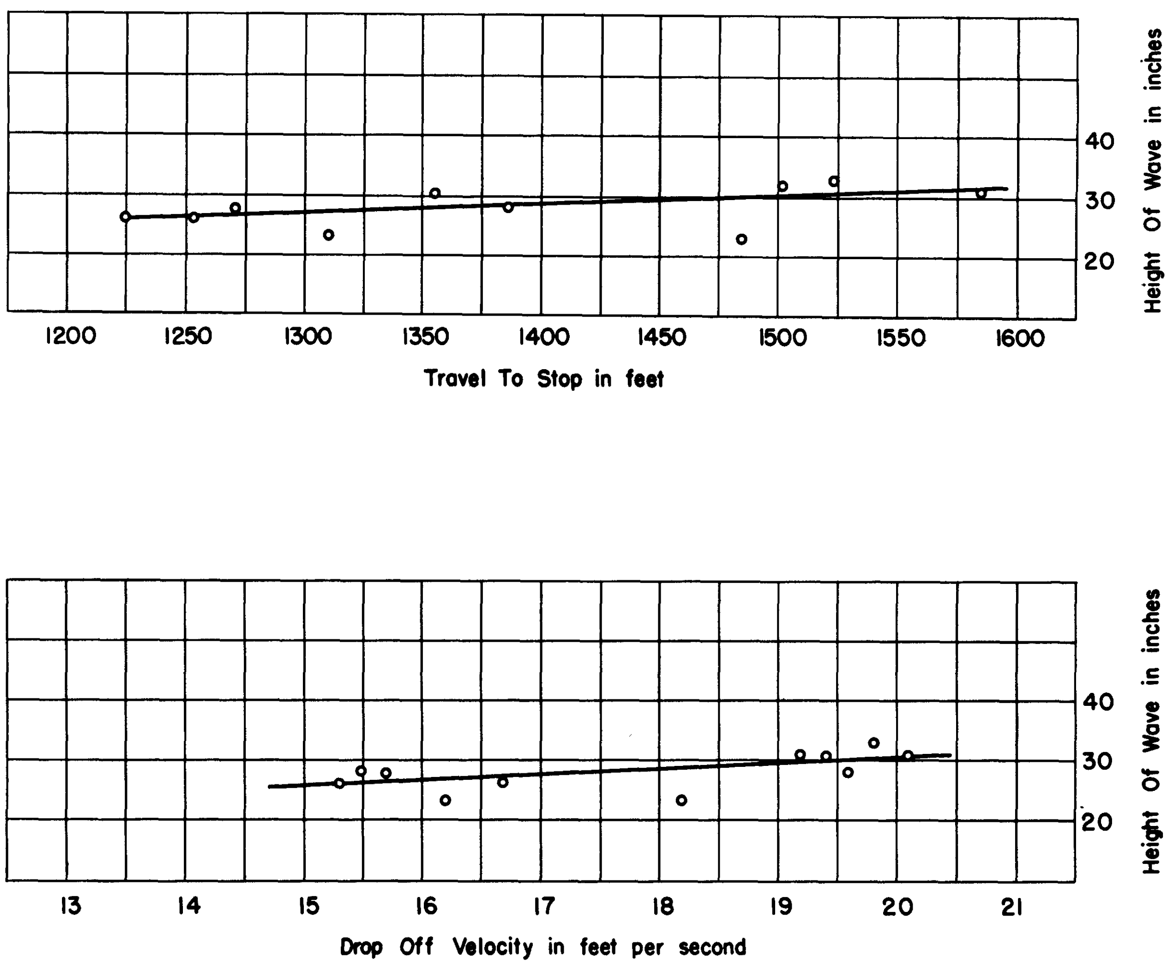


Figure 32 - Height of Wave at Opposite Shore

The variations in wave height at the opposite shore are shown in relation to the speed of the ship at drop-off and to the distance traveled before coming to rest.

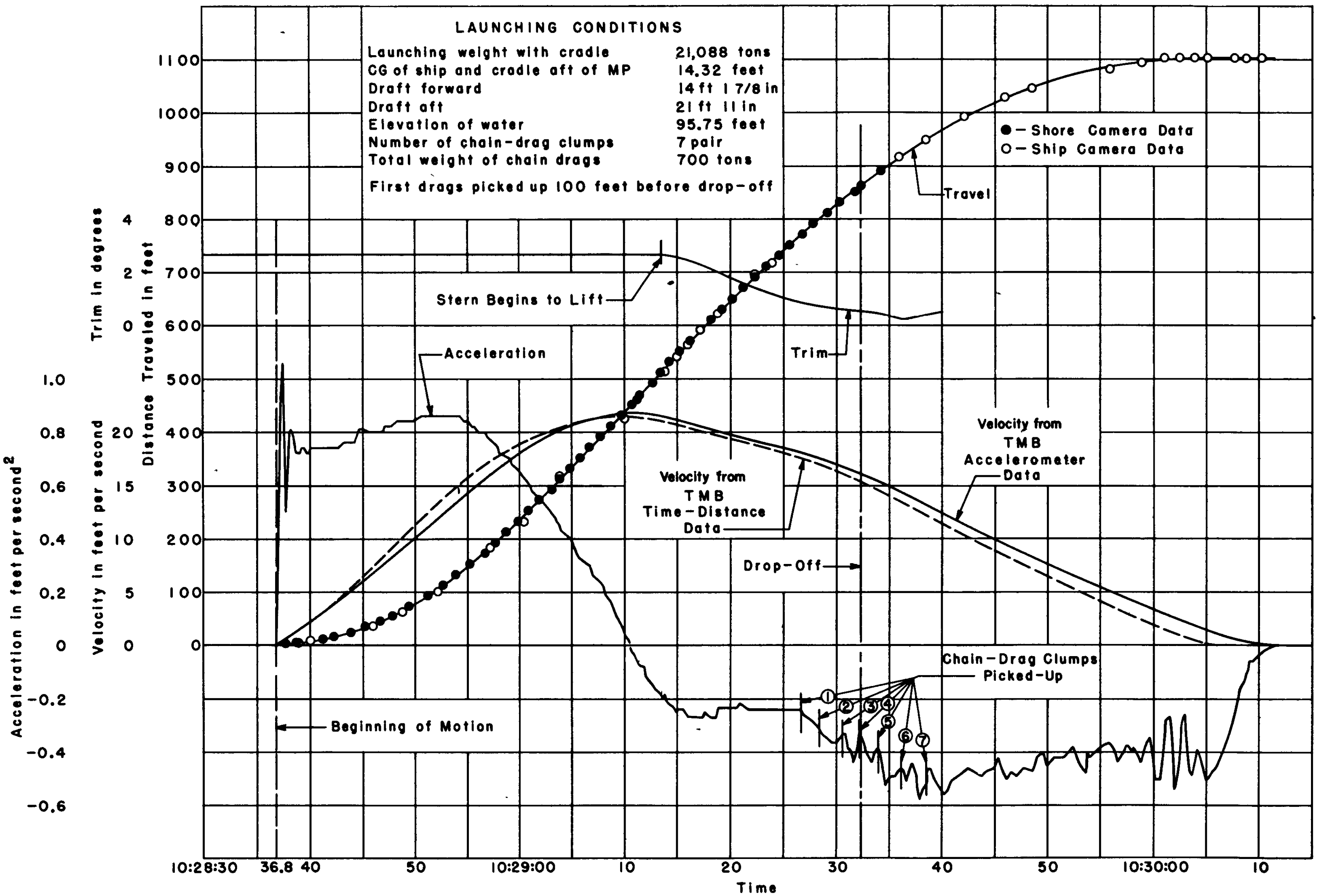


Figure 33 - Full-Scale Accelerometer and Motion-Picture Camera Data

The acceleration curve is from the Gyro-Accelerometer record, and the velocity curve is a mechanical integration of the acceleration curve. The points showing the distance traveled are from the shore camera data and from the ship camera triangulation data.

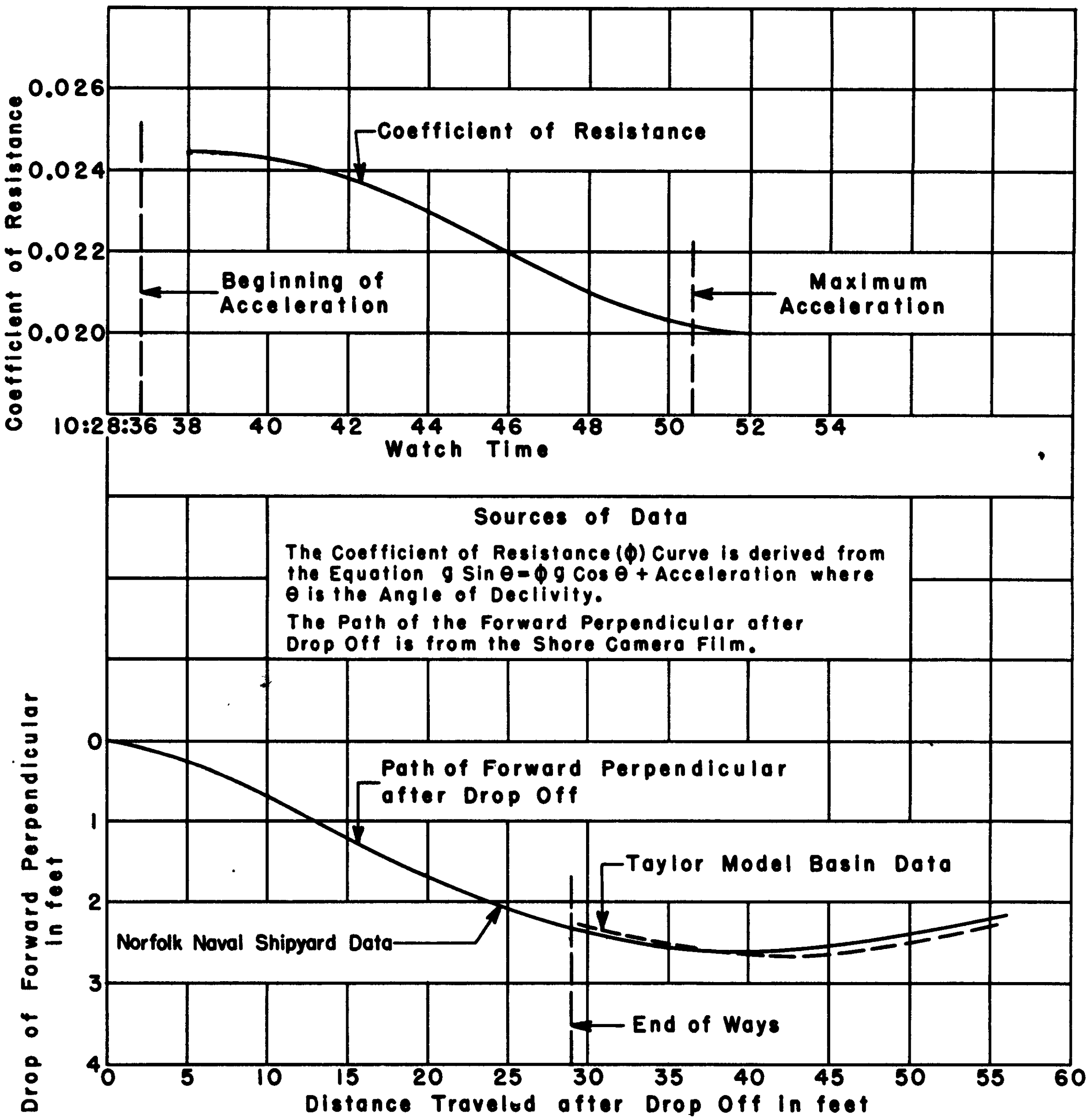


Figure 34 - Data From Full-Scale Observations Showing the Coefficient of Total Resistance and the Path of the Bow After Drop-Off

The coefficient of total resistance is shown for the first 100 feet of the ship's travel; and the path of the bow is shown as it was recorded by motion-picture cameras.

PNNC-6077-6-11-48-100