Friction and Resistance Coefficients by End Launching

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ABSTRACT: The paper deals with the use of records of ship end launching in order to calibrate the coefficients of sliding friction and water resistance for future applications. The paper at the beginning describes the problem and summarizes the theoretical background of end launching calculations. Next it presents a case-study of end launching and compares the theoretic results with the real time record of launching made by video cameras. At the end the paper presents the calibrated coefficients of sliding friction and water resistance.

1 INTRODUCTION

Launching is commonly a routine operation in shipyards which use sliding ways. However, from time to time new types of objects of unusual shape or size have to be launched. In such situations the shipyard management needs a confirmation of safe launching operation and may require precaution studies. The paper provides an analysis of a realistic launching record and suggests re-calibration of primarily assumed sliding friction and resistance coefficients.

Shipyard Leda in Korčula (www.shipyard-leda.hr) (Fig. 1) was ready to launch a ship which exceeds in size and mass all the formerly built and launched ships. Therefore a feasibility study was requested.

Figure 1. Shipyard Leda, island of Korčula, Croatia

For this reason a detailed launching calculation was performed in a short available time in order to confirm the possibility of safe launching operation.

Although it was not planned in advance, several amateur videos of the launching offered an opportunity to compare the calculated values of launching characteristics based on assumed parameters with those which are reconstructed from the recorded values in a backward launching calculation procedure.

2 THE LAUNCHING CALCULATION MODEL

Launching calculations had been intensively developing before appearance of dry dock shipbuilding technologies. At the beginning of this paper the calculation of end launching is resumed following Keith (1949), Rob (1952), Rawson & Tupper (1968), Andrews (1968), Uršić (1991) and Ziha(1997).

2.1 *The quasi-static calculation method*

In each instant of reasonably slow travel down the sliding ways, the checking of hydrostatic balance between ship's weight and buoyancy provides moments, contact pressures, reactions, buoyancy distribution and position of the ship on the sliding ways.

2.2 *The energy conservation method*

The data used in the dynamic launching calculations are ship's mass M, sliding friction coefficient μ, resistance coefficient k, angle of sliding ways ψ, distance of travel s, velocity v and acceleration a.

The loss of potential energy during travel s at declivity ψ of sliding ways before immersion of the hull into the sea is as follows:

$$E_p = s \cdot M \cdot \sin\psi \qquad (1)$$

The loss of energy due to friction also accounting for change of buoyancy U during hull immersion relative to the mass of the ship M is as follows:

$$E_t = s \cdot M \cdot \mu \cdot (1 - U / M) \cdot \cos\psi \qquad (2)$$

The work done by the average water resistance R defined as R=kv^2 during the travel s is as shown:

$$E_w = s \cdot k \cdot (v_2^2 + v_1^2)/2 = M \cdot T_r \cdot (v_2^2 + v_1^2)/2 \qquad (3)$$

The water resistance coefficient $k(s)$ during immersion of the hull depends on the distance of travel s due to changes of the immersed shape of the hull.

The gain in kinetic energy available at the segment of travel s due to changes of the velocity v is:

$$E_k = M \cdot (v_2^2 - v_1^2) / 2 \quad (4)$$

The energy conservation principle is expressed by the next equilibrium equation:

$$E_t + E_w + E_k = E_p \quad (5)$$

Analytic solution of the energy conservation equation (5) provides the velocity v_2 at the end of travel segment depending on the velocity v_1 at the beginning of the travel in the following term:

$$v_2 = \sqrt{\frac{T_f}{(1+T_r)} + \frac{(1-T_r)}{(1+T_r)} \cdot v_1^2} \quad (6)$$

The quantities T_f and T_r in (6) depend on travel s as put down below:

$$T_f(s) = s \cdot 2 \cdot \cos\psi \cdot [\tan\psi - \mu \cdot (1 - U / M)] \quad (7)$$

$$T_r(s) = s \frac{k}{M} \quad (8)$$

For dry sliding before immersion of the hull is T_r=0 and the velocity v_2 at the end of the travel s is:

$$v_2 = \sqrt{T_f + v_1^2} \quad (9)$$

For float off is T_f=0 (7) and E_w+E_k=0 in (5)and it is:

$$v_2 = v_1 \cdot \sqrt{\frac{(1-T_r)}{(1+T_r)}} \quad (10)$$

For T_r=1 in (10) is v_2=0 and the average water resistance coefficient is $k=M/s_s$. The theoretical stopping distance s_s is then calculated as follows:

$$s_s = M/k \quad (11)$$

The energy conservation method (1-10) is applied in recursive mode from segment to segment.

2.3 *Kinematics of launching operation*

The paper takes on two modes for launching kinematics. First, supposing constant acceleration at segment Δs as $a = (v2 - v1)/\Delta s = const$ the velocity is $v(\Delta s) = v_1 + a \cdot \Delta s$. Time increment is then $\Delta t = \Delta s \cdot \ln(v2/v1)/(v_2 - v_1)$. Second, supposing uniform velocity $v(\Delta s) = (v_2 + v_1)/2 = \text{const}$ at segment Δs, the time increment is $\Delta t = 2 \cdot \Delta s \cdot /(v_2 + v_1)$.

2.4 *The resistance coefficients during launching*

The resistance coefficients by launching are less known empirical data for ships and objects of diferent shapes. The common formulation of resistance coefficient k is a function of buoyancy U due to immersion of hull during travel s. According to Andrews (1960) the resistance coefficient is

$$k[U(s)] = c \cdot [U(s)/M]^{2/3} \quad (12)$$

where c in (12) is a parameter depending on the hydrodynamic characteristics of the immersed hull.

A simple proposal by Rob (1952) reads:

$$c = 0.0929 \cdot M^{2/3} \quad (13)$$

An alternative expression for the resistance coefficient was given by F. W. Benson in Henry and Keith (1949) as follows:

$$c = C_c \cdot A_c + C_w \cdot A_w \quad (14)$$

A_c and A_w in (14) are the lateral area and the wetted area of the immersed hull. The reported empirical coefficients are C_c=0.3246 and C_w=0.00206.

3 THE LAUNCHING CALCULATION

Here the results of the primary launching calculation of the case study are shortly presented (Fig. 2).

3.1 *The characteristics of the sliding ways*

Length of sliding ways	119.3 m
Underwater length	59.4 m
Declivity of sliding ways	3° 42' 31.5''
Mass of packing	70 t

3.2 *The characteristics of the ship*

The length of ship	117.9 m
The breadth of ship	13.35 m
The draft of ship for/aft	1.27 / 0.89 m
The mass of ship	1283 t

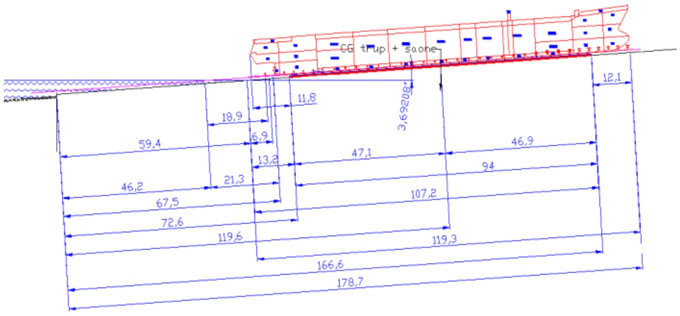
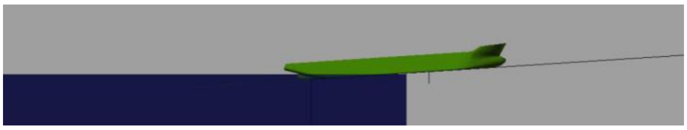


Figure 2. The geometry of sliding way and ship

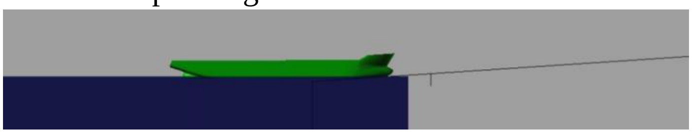
Four particular positions of ship relative to sliding-ways were set as checking points for comparison of theoretical results and launching records (Fig. 3).

The start of launching s=0 m; t=0 s

The start of hull immersion s=24 m s; t=16 s



The start of pivoting s=72 m t=25 s



The start of float off s=132 m, t=30 s

Figure 3. Position of ship on sliding ways during launching

The quasy-static calculation provided the distribution of buoyancy U/M along the travel path (Fig. 4).

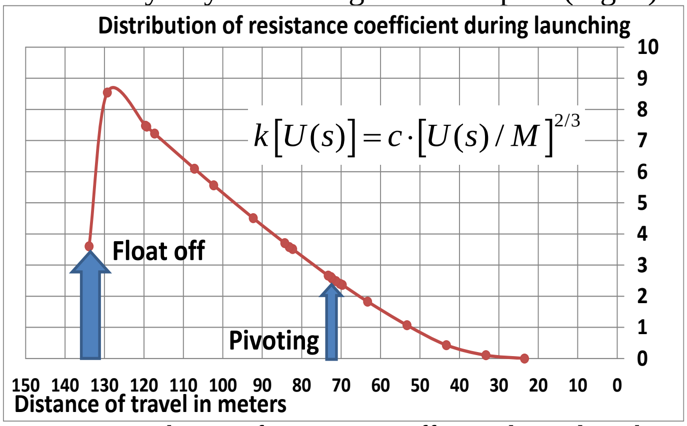


Figure 4. Distribution of resistance coefficient during launching

The primary average coefficient of resistance c=11 in (12) is considered constant during the launching and is firstly estimated from (13) during float off for the mass of the ship with mass of packing of M=1353 t. Secondly it is estimated as c=11 from (14) for lateral and wetted surfaces A_c=20 m^2 and A_w=2000 m^2. The average friction coefficient is taken constant from catalogues of lubricant manufacturers as μ=0.03. Thus, the primal dynamic calculation is performed for μ=0.03 and c=11 (Table 1, Fig. 4 and Figs. 8-10).

Table 1. Launching record analysis

Setting	Calculated	Measured	Corrected
Friction coeff. μ	0.030		0.025
Res. coeff. c at float off	11		3.60
Velocity at float off	13 m/s	Chek points	15 m/s
Time to immersion T_m	18 s	15 s	16 s
Time to pivoting T_p	26 s	25 s	25 s
Time to float off T_f	32 s	30 s	30 s
Time to stop T_s	120 s	180 s	180 s
Travel to stop Ss	210 m	265 m	264 m

4 THE LAUNCHING RECORDS ANALYSIS

The launching took place at shipyard Leda having restrictions on float off of about 800 meters (Fig. 5) with respect to the neighboring island.

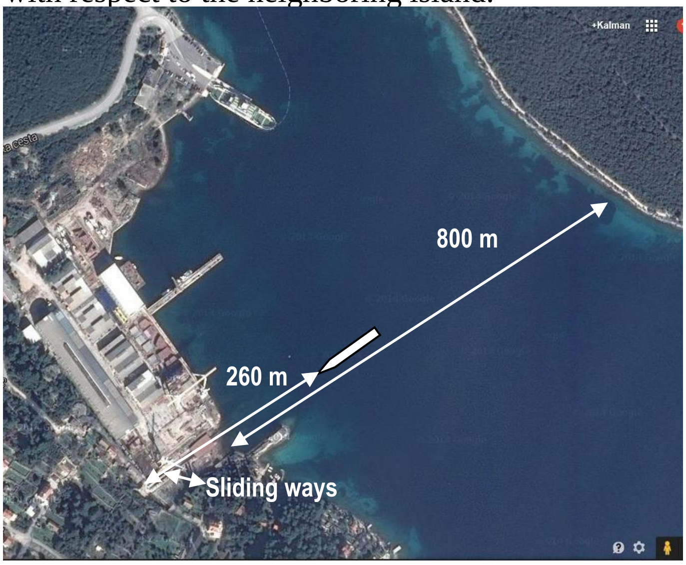


Figure 5. The launching area in Korčula (From Google Maps)

Launching was recorded by two amateur video cameras. Four easily assessable check-points are taken from the record (Table 1 and Figs. 6-7) regarding immersion, pivoting, float off and stopping.


Figure 6. Recorded start of the launching closing to immersion


Figure 7. Float off after pivoting from the record

4.1 *The calibration of launching parameters*

The launching parameters, c and μ, are calibrated with respect to recorded five check-points: time to immersion T_m, time to pivoting T_p, time to float off T_f and time to stop T_s (Table 1, Fig. 3, Figs. 6-7 and Figs 8-10) assessed form the record as shown.

The calibration is achieved by minimization of differences among theoretical values of t_m, t_p, t_f , t_s defined by the mathematical model (1-10) and check-points of T_m, T_p, T_f , T_s (Table 1) as follows:

$$d = (T_m - t_m)^2 + (T_p - t_p)^2 + (T_f - t_f)^2 + (T_s - t_s)^2 \qquad (15)$$

The minimization is performed by using General Reduced Gradient (GRG) method and evolutionary algorithm on the basis of the following program:

Find free variables t_m, t_p, t_f , t_s in model (1-10) by finding Min(d) (15) changing parameters c and μ.

4.2 *The discussion of results*

The launching record analysis indicated that the sliding till the hull immersion was too slow what for the sliding friction coefficient is to be slightly reduced (Figs. 8-10).

The float off was significantly slower of expected what for the resistance coefficient has to be taken lower than it was primarily estimated (Figs. 8-10). The repeated launching calculation with corrected launching parameters provides almost coinciding results with the recorded data (Table 1, Figs. 8-10).

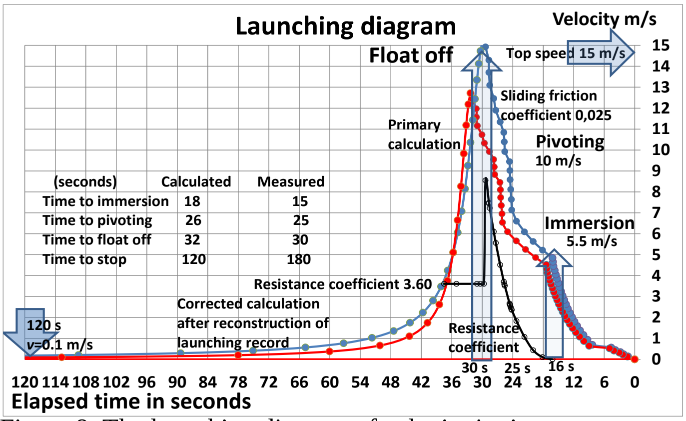


Figure 8. The launching diagram of velocity in time

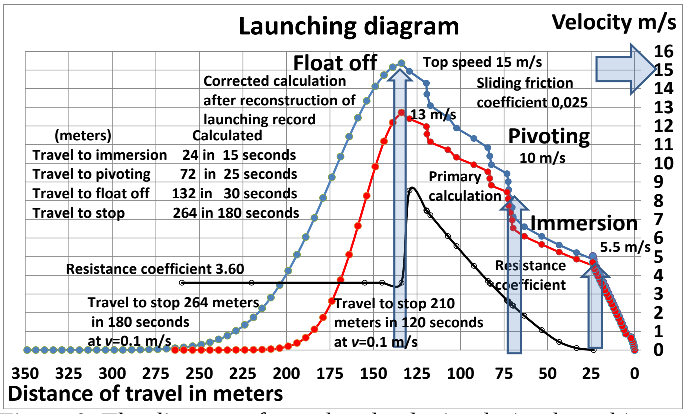


Figure 9. The distance of travel and velocity during launching

The stopping distance $s_s=M/k=1353/3.60=376$m defined theoretically (13) is hardly attainable in reality. For this reason the stopping criteria is related in this paper to some selected small velocity of 0.1 m/s.

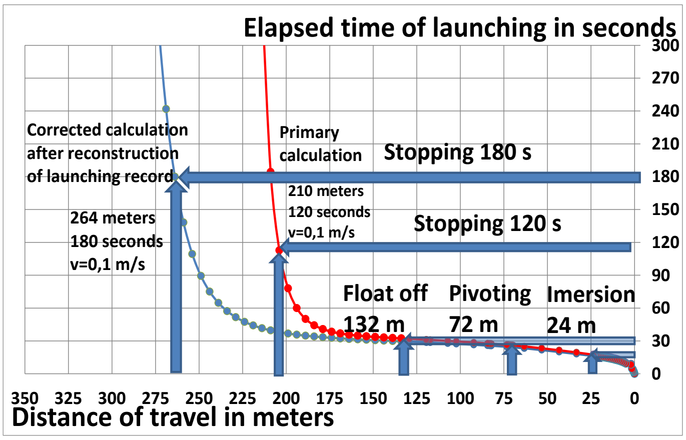


Figure 10. The distance of travel and velocity during launching

The launching record analysis resulted in proposal for changing of the sliding friction coefficients for future launchings from μ=0.03 to μ=0.025.

The launching record analysis also resulted in proposal for changing of the resistance coefficients to c=3.6 instead of primarily assumed c=11.

The value of the resistance coefficients following Rob (1952) is changed from $c=0.093\ M^{2/3}$ to $c=0.0305\ M^{2/3}$.The values of the resistance coefficients following F. W. Benson in Henry and Keith (1949) are changed from C_c=0.3246 and C_w=0.00206 to C_c=0.1062 and C_w=0.000674.

4.3 *Sensitivity to launching parameters*

It is worth noting different sensitivities of launching parameters depending on launching phases.

Sensitivity of the float off distance s_f to ±1% resistance coefficient c at c=3.74 is $\Delta s_f/\Delta c\sim$ -1 m.

Sensitivity of the time to immersion t_i to ±1% to sliding friction μ at μ =0.025 is $\Delta t_i/\Delta\mu\sim$ 0.1 s.

Sensitivity of the velocity v_i at immersion to ±1% sliding friction μ at μ =0.025 is $\Delta v_i/\Delta\mu\sim$ 0.04 m/s.

Sensitivity of the velocity v_f of float off to ±1% resistance coefficient c at c=3.74 is $\Delta v_f/\Delta c\sim$ 0.02 m/s.

5 CONCLUSION

There are many uncertainties regarding the launching operation affecting the accuracy of launching calculations such as wind, currents, tide, appendages, quality of lubricant, resistance coefficients for backward motion of the ship, ship's mass, balancing of buoyancy during launching and the mathematical model of launching. All uncertainties require wary checking by experiments or real time recording.

The first observation of the launching indicated that the travel of ship down the sliding ways and the free float off was faster than it was predicted by primal calculations. This impression motivated the recalculation of the launching procedure based on launching records and the following conclusions are gained.

Firstly, the launching record analysis in this paper confirmed the appropriateness of the analytic launching model for practical applications based on energy conservation principle.

Secondly, the comparison with the launching record indicated the need for re-calibration of primarily assumed sliding friction and resistance coefficients values.

And finally, the shipyard is now more prepared for launching of even bigger ships in the future using the experiences from the presented analysis of launching calculation and launching records.

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The launching records are available on following web sites:
https://www.youtube.com/watch?v=NkLOaTUv_cc
https://www.youtube.com/watch?v=MpMlxyu_O7A