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RESISTANCE OF SHIPS IN CANAL LOCKS.

U.S. Experimental Model Basin,
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1. The tests of deMas (1895), Engels and Gebers (1907), and model tests at the E.M.B. support the formula

$$\frac{R}{R_o} = 1 + kn^2,$$

in which R and R_0 are the resistances of a given ship in the canal and in open water, n is the ratio of the sectional area of the ship to the remaining area between ship and canal boundary, and k is a number whose value is about 11.

Each term in this formula is dimensionless; the tests cover lengths from 4 feet to 125 feet without systematic variation of k with length (except at 4 feet). The formula is, therefore, assumed applicable to full sized vessels. An increase of k with speed is indicated, but does not greatly affect results at low speeds. It is estimated that the error of resistances calculated by the formula will not exceed ± 25% at speeds not exceeding 3 knots in ships of 600 feet length and over.

2. A considerable amount of study has elsewhere been given the problem of resistance in restricted channels, but in no known previous tests has n been carried to values exceeding 0.4. The values of n in the new tests at the E.M.B. range from 0.4 up to 2.8. The tests were made with models of two sectional forms, one broad and shallow and the other narrow and deep. There is no difference between these two cases within the rather wide limits of error of the tests. It is therefore considered that the formula offers the best data available for rough estimate of resistance in very narrow and shallow channels.

3. Estimated resistances at uniform speed of the three ships named are as follows:

	n	1 kt.	2 kts.	3 kts.	
TEXAS (with blister)	1.89	20,000	75,000	155,000	lbs.
NEVADA	2.04	22,000	80,000	165,000	lbs.
LEXINGTON	2.19	39,000	135,000	290,000	lbs.

4. The main features of motion of the water about the ship are as follows:

(a) The water moves forward of the ship and the level there rises over a distance equal to two or more lengths.

(b) Abreast the ship the water moves aft and the level is depressed.

(c) Aft there is a following wake, strongly turbulent, with recovery of water level which nearly but not quite reaches that of the undisturbed water by the time the stern is reached.

Frictional resistance at a given speed is increased due to increased speed of water past the surface of the ship. The mean speed of the water, u_o , taken over the section available for flow, is equal to n times the speed of the ship, v, though the maximum value u is greater, as a considerable part of the section is occupied by water flowing forward instead of aft; thus $u = k_1 n v$.
The ratio n has a maximum value at the midship section, and its

mean value taken over the length of the ship is therefore less; but we may reasonably take the value amidship as our parameter and account for the departure of mean from maximum value by means of a coefficient, determined by test.

The residuary resistance is due to the pressure of the water which stands at a higher level forward than aft. The rise of water level forward is due to the fact that the water cannot flow aft against the frictional resistance until a pressure gradient is built up to push it. The amount of the pressure gradient depends on the frictional resistance which is, in first approximation, proportional to u^2.

5. In symbols, let R_1 be the increase in frictional, and R_2 the residuary resistance in the lock. R_0 at the speeds in question is entirely frictional. The total resistance is thus made up of three terms:

$$R = R_0 + R_1 + R_2 .$$

The frictional terms give us

$$\frac{R_0 + R_1}{R_0} = \frac{u^2}{v^2} = k_1^2 n^2 .$$

The residuary term

$$R_2 = k_2 n^2 v^2 .$$

Thus

$$\frac{R_2}{R_0} = k_2' n^2 .$$

Observations give us a rough indication of the relative values of R_1 and R_2. The depression amidship, by Bernoulli's equation, is $\frac{u^2}{2g}$. Then v = 0.31 knots, or .52 feet per second, and n = 2.8, the depression is observed to be about one inch. Thus

$$u_0 = nv = 1.5 \text{ ft/sec.},$$

$$u = \sqrt{\frac{2g}{12}} = 2.3 \text{ ft/sec.},$$

so that

$$\frac{R_1}{R_0} = \frac{u^2}{v^2} - 1 = 5.2 .$$

At the same time the rise in water level forward was observed to be about 1/2 inch. Area of midship section being about 0.8 square feet, the head resistance was

$$R_2 = \frac{0.5 \times 62.4}{12} \times 0.8 = 2.1 \text{ lb.}$$

Since

$$R_0 = .029^{\#},$$

$$R_1 = 5.2 \times .029 = 0.15 \text{ lb.},$$

and

$$R = 2.28 \text{ lb.},$$

which is in reasonable agreement with the observed resistance of 2.5 lbs.

The small value of R_0 and R_1 in comparison with R_2 permits us to write

$$\frac{R_0 + R_1}{R_0} = k_1^2 n^2 \doteq \frac{R_1}{R_0},$$

and we thus roughly justify the formula

$$\frac{R}{R_0} = 1 + k_1^2 n^2 + k_2' n^2 = 1 + kn^2$$

which was found approximately to fit observed resistances.

6. It is very likely that more precise study would show the formula to be inadequate for closer approximation to actual resistances. In particular it is noted that k tends to rise with increasing speeds. This is believed to be due to appearance of resistance terms depending on $\frac{v}{\sqrt{L}}$, and therefore to be of no significance in estimating resistances at ship speeds below 3 knots. If more accurate estimates are desired, it is requested that the rather extensive work required be separately authorized. Observation of actual speeds and towline resistances at Panama would be of value.

7. The formula suggests the possibility of obtaining data on friction in open water by measuring towline resistance of a ship when passing through the locks. Assuming that an increase over of 5% could be allowed for with sufficient accuracy by application of this formula, so as to leave errors from that source not exceeding 1%, it is noted that this method might be used for ships whose sectional area did not exceed 300 square feet. The length of run and the towing appliances available are better than any known to exist elsewhere.

8. Data are summarized in the table appended. References on this subject are as follows:

Johow-Foerster's Hilfssbuch, 4th edition,
pp 327 - 340.
Baker, Ship Form Resistance, 1920,
Chapter XV.
Engels & Gebers, SBTG, 1907
pp 389-416.

SUMMARY OF DATA ON RESISTANCE IN VERY RESTRICTED CHANNELS.

SHIP	LENGTH	SPEED	n	$\frac{R}{R_o} - 1$	k
Flute	123 feet	see note	.37	1.24	9.05
"	" "	" "	.286	0.74	9.03
"	" "	" "	.204	0.38	9.05
Peniche	125 feet	" "	.37	0.89	6.5
Tone	118.4 "	" "	.37	1.77	12.8
"	118.4 "	" "	.272	1.00	13.7
Jeanne(light)	99 Feet	" "	.357	0.88	6.8
" "	99 "	" "	.278	0.70	8.9
" "	99 Feet	" "	.208	0.56	12.7
Jeanne(Medium)	99 Feet	" "	.385	1.41	9.5
" "	99 "	" "	.286	1.08	13.2
" "	99 "	" "	.185	0.33	9.7
Jeanne(heavy)	99 "	" "	.37	2.00	14.6
" "	99 "	" "	.238	0.71	12.2
Engels and	23 "	.39 Ft.	.377	1.67	11.7
Gebbers	23 "	.58 "	.377	1.72	12.1
Spoon	23 "	.78 "	.377	2.07	14.5
Form	23 "	.97 "	.377	2.67	18.8
"	23 "	1.16 "	.377	3.8	26.8
Form	23 "	1.36 "	.377	7.6	54.
Sharp	23 "	.39 "	.377	1.0	7.0
Form	23 "	.58 "	.377	1.1	7.7
"	23 "	.78 "	.377	1.38	9.7
"	23 "	.97 "	.377	1.85	13.0
"	23 "	1.16 "	.377	2.85	20.
"	23 "	1.36 "	.377	6.6	46.

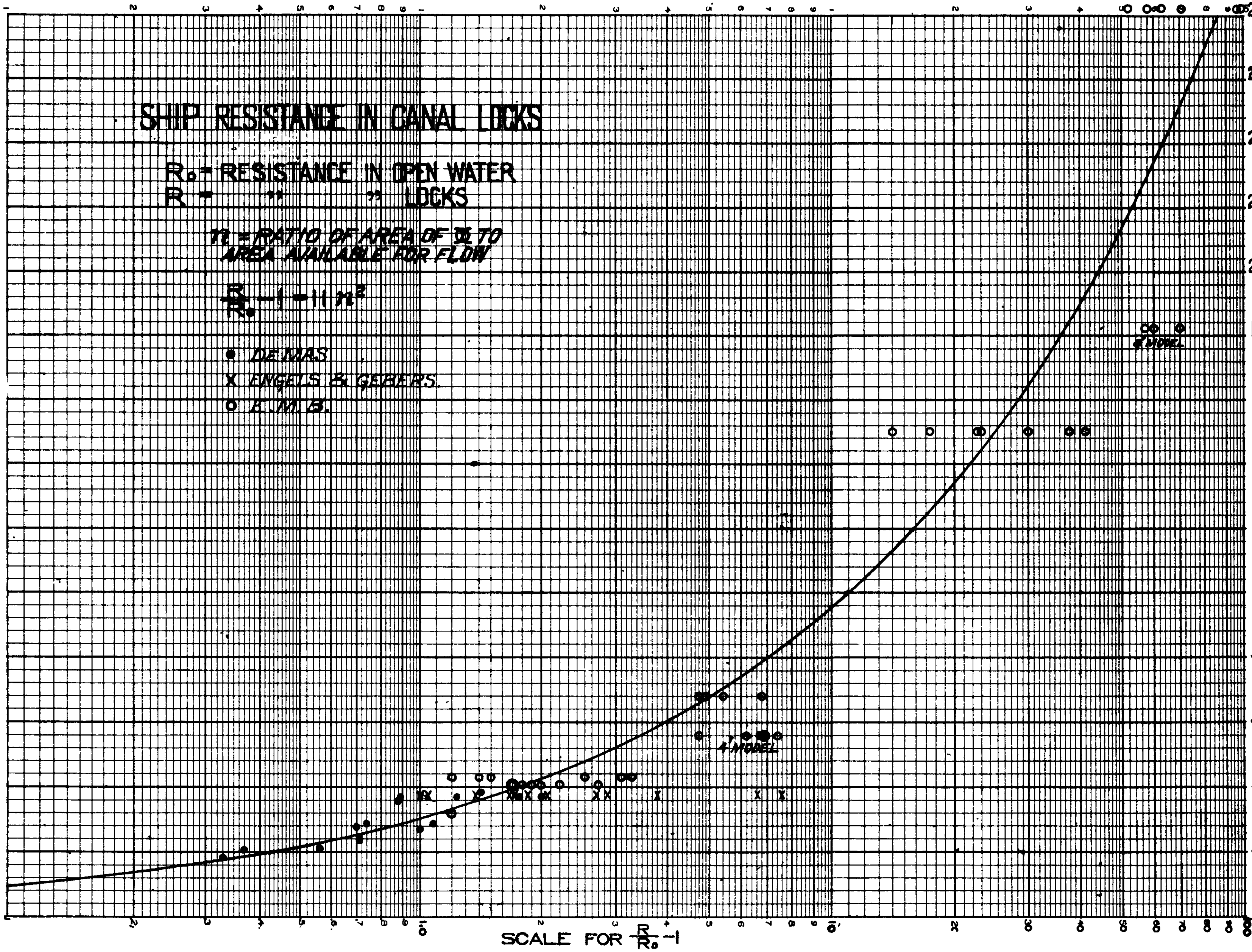
SUMMARY OF DATA (completed)

SHIP	LENGTH	SPEED	n	$\frac{R}{R_o} - 1$	k
EMB MODEL #2541	4 feet	.098 kt.	.56	6.7	21.4
"	4 "	.141	.43	3.3	17.9
"	4 "	.21	.56	4.7	15.0
"	4 "	.286	.43	2.5	13.5
"	4 "	.392	.32	1.2	11.7
New Mexico	4 "	.05	1.82	57	17.2
" "	4 "	.10	1.82	60	18.1
" "	4 "	.20	1.82	70	21.1
" "	4 "	.05	0.56	7.4	23.6
" "	4 "	.10	0.56	6.9	22.0
" "	4 "	.20	0.56	6.2	19.8
" "	4 "	.26	0.56	6.9	22.0
Model #2510	10 "	.388	0.43	1.5	8.2
"	10 "	.510	0.43	3.1	16.7
"	10 "	.642	0.43	1.4	7.6
"	10 "	.760	0.43	1.2	6.5
New Mexico	10 "	.234	0.68	4.7	10.2
" "	10 "	.409	0.68	6.8	14.7
" "	10 "	.56	0.68	5.4	11.7
" "	10 "	.67	0.68	4.9	10.6
" "	10 "	.36	0.405	2.2	13.4
" "	10 "	.49	0.405	2.7	16.5
" "	10 "	.624	0.405	1.7	10.4
" "	10 "	.76	0.405	1.7	10.4
" "	10 "	.83	0.405	1.8	11.0
" "	10"	.88	0.405	1.9	11.6

SUMMARY OF DATA (continued)

SHIP	LENGTH	SPEED	n	$\frac{R}{R_o}-1$	k
New Mexico	10 feet	.93 kt.	0.405	2.0	12.2
" "	10 "	.19 "	1.5	14	6.2
" "	10 "	.24 "	1.5	17.4	7.7
New Mexico	10 "	.29	1.5	22/6	10.1
" "	10 "	.345	1.5	23.	10.2
" "	10 "	.39	1.5	30.	13.3
" "	10 "	.43	1.5	38.	16.9
" "	10 "	.46	1.5	41.	18.2
" "	10 "	.095	2.82	52	6.5
" "	10 "	.13	2.82	58	7.2
" "	10 "	.19	2.82	63	7.9
" "	10 "	.23	2.82	71	8.9
" "	10 "	.26	2.82	99	12.4
" "	10 "	.31	2.82	96	12.0

Note:- Speeds up to 2.3 M.P.H. above which resistance increases.



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