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RESEARCH MEMORANDUM

ESTIMATE OF HULL-WEIGHT CHANGE WITH VARYING LENGTH-BEAM

RATIO FOR FLYING BOATS

By

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ESTIMATE OF HULL-WEIGHT CHANGE WITH VARYING LENGTH-BEAM RATIO FOR FLYING BOATS

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SUMMARY

A study has been made of the variation of seaplane hull weight with length-beam ratio in a systematic series of hulls designed for constant gross weight and similar spray characteristics. It is found that increases in the length-beam ratio bring about small reductions in the hull weight if it is assumed that seaplanes having the same weight and bottom shape will be designed for the same load factor. A short discussion is also given to show the reduction in load factor that may occur with high length-beam ratios.

INTRODUCTION

A rough estimate has been made of the change in structural weight of the hull of a flying boat when the length-beam ratio varies from 6 to 15. The seaplane has been considered to have a gross weight of 65,000 pounds. The estimate has been prepared by considering loading conditions in landing, primarily. In preparing the weight estimate it has been assumed that the same maximum load factor would be used in the design of the seaplane for all length-beam ratios. A study is also included to show the reduction in maximum landing acceleration that occurs with increased length-beam ratio. The design is considered on the basis of the most recent Navy Department specifications.

SYMBOLS

A_h horizontal area of forebody

B beam

C_w beam loading coefficient $\left(\frac{W}{wB^3}\right)$

H height of hull

L_f length of forebody

L_a length of afterbody

L_t length of tail extension

$L = L_f + L_a$

$L' = L_f + L_a + L_t$

w unit weight of water

W gross weight of seaplane

τ trim angle

V_o velocity

$\dot{y}_o$ sinking speed

DESCRIPTION OF MODELS

Four models which were designed by the Hydrodynamics Division of the National Advisory Committee for Aeronautics have been considered. The values in the following table are in inch and pound units for a $\frac{1}{10}$-scale model. The models have been designed to have the same spray characteristics. The height of hull has been held constant. The ratio of forebody length to afterbody length is constant. The length from the step to the tail $L_a + L_t$ is held constant. The bottom shape of the models is similar so that the same dead-rise angle occurs at the same relative hull station on each model.

$\frac{L}{B}$	6	9	12	15
L_f	44.58	51.04	56.17	60.51
L_a	32.87	37.64	41.42	44.62
L_t	32.74	27.97	24.19	20.99
L	77.45	88.68	97.59	105.13
L'	110.19	116.65	121.78	126.12
B	12.91	9.85	8.13	7.01
H	20.0	20.0	20.0	20.0
L_f/L_a	1.36	1.36	1.36	1.36
W	65	65	65	65
C_w	0.82	1.85	3.29	5.22
NACA model no.	213	203	214	224

METHOD OF ESTIMATING

It has been assumed that the model having $\frac{L}{B} = 6$ corresponds to present-day practice in seaplane design. Relative values of the weights of various components have been determined for the higher values of L/B using the model with $\frac{L}{B} = 6$ as a basic standard. Ten components of the hull have been considered to show the major portion of the variation of hull weight with length-beam ratio. These components and their manner of variation with hull dimensions will be discussed individually.

In order to determine the percentage variation in structural weight for each model, it is necessary to assume specific values for the percentage of hull weight in each component for the model with $\frac{L}{B} = 6$. Specific values have been chosen for this basic model to be in agreement with the component weights of the XPBS-1 airplane.

RELATIVE COMPONENT WEIGHTS

1. Bottom plating: Since the dead-rise angle is the same at proportional stations on the models, the required bottom-plating thickness will be the same at the same relative stations. Consequently, the weight of the bottom plating will vary as the bottom area. This has been considered, for convenience, to vary as the area of the projection of the forebody of the hull on a horizontal plane.

2. Side plating: The side plating on the forebody and afterbody will vary as the length of the forebody since the height of the hull remains constant. With increase in afterbody length there will be a small decrease in side plating on the tail extension. This decrease has been disregarded and the side plating assumed to vary as L_f.

3. Deck plating: It is assumed that the thickness of the deck plating will be the same at all proportional hull stations. Thus, the weight of this plating will vary with the width of the hull and with the total length of the hull. Consequently, the deck plating is assumed to vary as the product BL'.

4. Bottom stringers: The stress in the bottom stringers is due to both axial forces and bending moments. The axial force in a stringer is due to bending of the hull. It is found in the analysis of flying-boat hulls that these axial forces are very small, while the bending moments due to transverse loading are large. Consequently, it may be assumed for weight-estimating purposes that the design of the stringer is determined solely by the bending loads. In the present

paper it is assumed that all frames are placed at the same spacing in all models. The transverse loading at a proportional hull station will be the same on all models. Consequently, the size of the stringers will be the same at a proportional station on all models. The stringers are assumed to have the same spacing on all models. Thus, the stringer weight will vary with the number of stringers which, in turn, will vary with the hull width. The weight of the stringers will also vary with the forebody length. Consequently, the weight of the stringers has been assumed to vary with the horizontal area of the forebody of the hull.

5. Side stringers: The weight of side stringers has been assumed to vary inversely as the width of the hull in order to preserve equal lateral bending strength of the hull. The weight of these stringers will also vary directly with their length. Hence, the variation factor for these stringers is given by the ratio L'/B.

6. Longerons and deck stringers: The stress in the longerons and deck stringers is primarily due to positive bending of the hull. The bending moments at various hull stations should vary approximately as the forebody length. Thus, the cross-sectional area of the longerons and stringers should also vary as the forebody length. The weight of these members will also vary as the total length of the hull. Thus, the variation factor for these members is given by the product $L'L_f$.

7. Keel and chine: It is assumed that the keel and chine will be the same on all models. Consequently, the weight will vary as the sum of the length of the forebody and the length of the afterbody. The length of the forebody may thus be used as a variation factor.

8. Frames: It is assumed that 40 percent of the weight of a frame is contained in its vertical members. The remaining 60 percent is contained in the top and bottom horizontal members. It is assumed that the vertical members of a frame on all models will be identical. It is also assumed that they are placed at the same spacing on all models. Thus, the weight of the vertical members will vary as the total length of the hull. It is assumed that the horizontal members are designed partially by shear and partially by bending moments. In order to allow for the possible use of deeper members on longer spans, it is assumed that the weight will vary as the square of the span. The weight of horizontal members will also vary as the total length of the hull. A variation factor for the frames may then be written in the following form:

$$0.4L' + 0.6L'\left(\frac{B}{B_6}\right)^2$$

where B_6 is the width of model having $\frac{L}{B} = 6$.

9. Bulkheads: It is assumed that there will be the same number of bulkheads in each model. The weight of the bulkheads should vary approximately as the width of the hull.

10. Flooring: It is assumed that the flooring will be designed for bending moment due to transverse loading. The span of the flooring will be the same at proportional stations in all models. Consequently, the weight of the flooring should vary approximately as the product $L'B$.

SUMMARY OF COMPONENT WEIGHTS

The variation factors that have been described in the previous section are summarized in the following table:

No.	Components	Variation factor
1	Bottom plating	A_h
2	Side plating	L_f
3	Deck plating	BL'
4	Bottom stringers	A_h
5	Side stringers	L'/B
6	Longerons and deck stringers	L'/L_f
7	Keel and chine	L_f
8	Frames	$0.4L' + 0.6L' \left(\frac{B}{B6}\right)^2$
9	Bulkheads	B
10	Flooring	$L'B$

By using these factors, relative values of the weights of these components have been computed. These values are shown in the following table:

No. \ L/B	6	9	12	15
1	1	0.873	0.794	0.735
2	1	1.142	1.260	1.356
3	1	.807	.695	.620
4	1	.873	.794	.735
5	1	1.390	1.758	2.11
6	1	1.211	1.396	1.553
7	1	1.142	1.260	1.356
8	1	.791	.704	.660
9	1	.762	.629	.543
10	1	.807	.695	.620

The percentage of hull weight represented by each component has been assumed to be approximately equal to the values of these quantities of the XPBS-1 model airplane. These percentages of weight are assumed to be applicable to the model having $\frac{L}{B} = 6$. These values are shown in the second column of the following table:

No. \ L/B	6 (percent)	9 (percent)	12 (percent)	15 (percent)
1	6.6	5.76	5.24	4.85
2	7.3	8.33	9.20	9.89
3	2.4	1.94	1.67	1.49
4	4.5	3.93	3.57	3.31
5	2.9	4.03	5.10	6.12
6	3.7	4.48	5.16	5.74
7	1.7	1.94	2.14	2.30
8	15.6	12.33	10.98	10.30
9	12.5	9.52	7.86	6.79
10	5.3	4.28	3.68	3.28
Total	62.5	56.54	54.60	54.07

By means of the relative weight factors, the percentage of hull weight in the various components has been computed to be as shown in the remaining columns of the foregoing table. The sum of the second column of the foregoing table indicates that the 10 components being considered represent 62.5 percent of the total structural weight of the hull. The differences between the total values shown represent percentage hull-weight changes.

WEIGHT REDUCTIONS

It is also of some interest to determine the percentage reduction in airplane structural weight and the percentage reduction in gross weight brought about by using high length-beam ratios. The ratio of hull weight to gross weight for five flying boats is shown in the following table:

Flying boat	$\frac{\text{Hull weight}}{\text{Gross weight}}$	$\frac{\text{Structural weight}}{\text{Gross weight}}$
PBY-5	0.095	0.292
PB2Y	.107	.318
XPBS-1	.130	.318
Lerwick	.126	.325
Sunderland	.153	.349
Average	.122	.320

There is also shown the ratio of structural weight to gross weight. The average values of these ratios are also shown. From these values it is seen that the hull weight represents an average of 38 percent of the structural weight. From these average values the reduction in hull weight may be converted to reduction in structural weight of the airplane or reduction in gross weight. The reductions in weight are summarized in the following table:

L/B \ No.	Hull weight (percent)	Structural weight (percent)	Gross weight (percent)
6	0	0	0
9	6.0	2.3	.73
12	7.9	3.0	.96
15	8.4	3.2	1.03

A graph showing the variation with L/B of the percentage reduction in hull weight is shown in figure 1.

LOAD-FACTOR REDUCTION

The weight reduction that has been previously computed has assumed that all models would be designed for the same load factor. The most recent Navy specifications do not take account of the fact that there will be some reduction in maximum impact acceleration with high length-beam ratios. However, this matter is of considerable importance. Some values of load-factor reduction will be illustrated to show the effect of high beam loading (high length-beam ratios). In the current designs of seaplane hulls the maximum acceleration of the impact will generally be reached before the chines of the hull submerge. If narrow hulls are used, the chines will submerge before the maximum acceleration has been reached. Theoretical solutions of this problem have been recently developed by W. L. Mayo of the impact basin of the NACA. There is, however, no experimental evidence to verify the theory.

An example has been computed for a flying boat weighing 65,000 pounds and having a stalling speed of 75 miles per hour. This speed is approximately the same as that of the PBM-3. The landing has been assumed to occur at a trim angle of 6°. The sinking speed has been assumed to be 17 feet per second in order to give a maximum acceleration of 4g. This gives a load factor of 5g. The percentage reduction in maximum acceleration for narrow hulls is indicated by curve A in figure 2. There is a critical length-beam ratio below which no reduction in acceleration would occur. The percent reductions indicated in this figure are very large.

In order to indicate the trend for future seaplanes with higher landing speeds, a second example has been computed. In this case the seaplane again weighs 65,000 pounds and is assumed to land at a trim angle of 6°. The sinking speed is assumed to be 16.2 feet per second in order to give a value of 5g for the maximum acceleration. The resulting reduction in acceleration is shown by curve B of figure 2.

PLANING-TAIL HULLS

Several models have also been considered in which the afterbody extends completely to the tail surface. The tail extension part of the hull is completely eliminated. These models are numbers 203, 221A, 221B, and 221E. Each of these models has dimensions that are very similar to those of the model previously investigated which has $\frac{L}{B} = 9$. It is probable that a good estimate of the weight reduction in these planing-tail hulls can be made by assuming it to be the same as for the model having $\frac{L}{B} = 9$. A peculiarity of these hulls lies in the fact that they have pointed steps. There is at present no theoretical solution for the maximum acceleration that would occur with a pointed step in a landing impact. (Both theoretical and experimental research is needed on this problem.)

CONCLUSIONS

From the studies that have been made it appears reasonable to believe that there will be a noticeable reduction in the structural weight of a hull when high length-beam ratios are used. The largest part of this benefit may be realized by increasing the value of L/B from 6 to 9. There should be a further gain in the over-all serviceability of a hull with high length-beam ratio, due to the fact that lesser accelerations will be experienced in the landing. These benefits become more noticeable at very high values of L/B.

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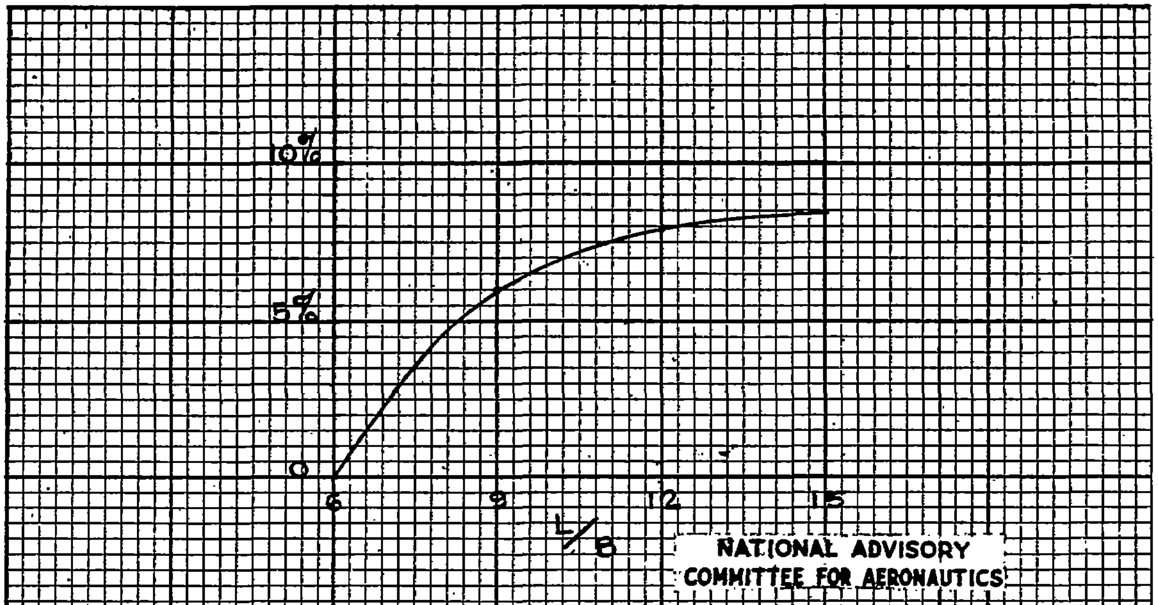

FIG. 1 - PERCENT REDUCTION OF HULL WEIGHT

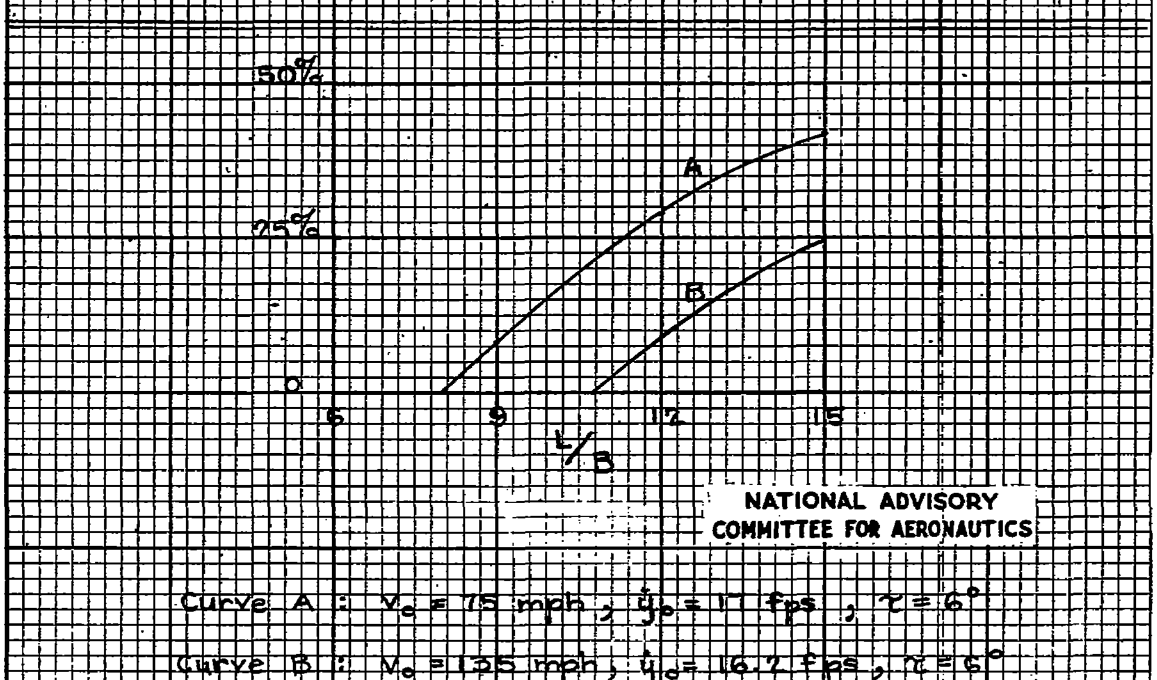

FIG. 2 - PERCENT REDUCTION OF MAXIMUM ACCELERATION