NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
SEP 29 1926
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TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 247

# THE DRAG OF AIRSHIPS

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Washington
September, 1926

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL NOTE NO. 347.

# THE DRAG OF AIRSHIPS.

By Clinton H. Havill.

## PART I

### Summary

In order to begin research on the drag of airships it was first necessary to make a logical digest of the reported past performances and data given on deceleration tests for a large number of airships. That these data may become available for airship designers in a compact form is the purpose of this report, as well as to serve as the basis on which the author is continuing his researches, which will be given later in Part II (Technical Note No. 248).

This digest as given here in Part I was begun in September, 1923, and worked on intermittently until December, 1925.

The outstanding results are as follows:

1. In general, the maximum speed of most airships was reported about 5 per cent higher than obtained in this report.

2. Total maximum horsepower was reported in many cases higher and in a few cases lower, than obtained in this report.

3. Propulsive coefficients at maximum speeds are in general lower than the reported values. Coefficient "C" is con-

stant and the propeller efficiency "E" is reduced as at maximum speed that the propulsive coefficient "K" falls off.

4. It was further noted that several ships of widely different designs had nearly the same drag coefficient for the whole ship. However, this is looked upon as a coincidence in the cases where the type of hull, cars, and surfaces differed widely.

5. That in general an idling propeller was found to have about fifteen square feet area of drag while a stopped propeller had about six square feet area of drag. This was found by working out the area of drag from the ship's performance and comparing it with the area of drag as obtained on the deceleration test with either stopped or idling propellers as the case was reported. In some cases this difference of area worked out to be 8 or 9 square feet per propeller, but with certain types of engines it is possible that all engines were not stopped but that one or two were left idling during the deceleration tests.

Applied values of principle data and results are given in Table I and Fig. 3.

## Introduction

At the beginning of the research - "The Drag of Airships" - it was immediately discovered that there was much conflicting data on record concerning any given particular ship. Deceleration tests had been performed on some ships, yet the results of

these tests did not always agree with that held on exactly similar ships. The reported maximum speeds, propeller efficiencies, and maximum horsepower would give a drag coefficient that differed widely from that reported or found on the deceleration tests. Or, again, using the drag coefficient found on deceleration tests together with the maximum horsepower and reported maximum speed would in many cases give a propeller efficiency that was highly improbable.

A digest by Lipka's empirical method of digesting inconsistent data was applied to the following quantities: maximum speed, maximum total horsepower, propulsive coefficient at maximum speed, propeller efficiency at maximum speed, area of drag (power on), and drag coefficient for the whole ship. This was done not only for the data concerning each individual ship but taking into account the relation between ships on the two quantities of drag coefficient and propeller efficiency upon which many quantities depended. The method of how this relation was obtained is explained fully in the explanation of Lipka's method as given later in this report.

The reasons for undertaking this problem was primarily to digest the results already obtained in flight on full-sized ships so that the results could be used for further research work as will be given later in Part II (Technical Note No. 248).

The scope of the work extends over nearly all the Zeppelin ships together with five types of nonrigid airships. The method

used is Lipka's empirical method of digesting inconsistent data and is explained as follows:

The method chosen for the digestion of inconsistent data is the invention of the late Professor Joseph Lipka. It is described as the "method of selected points" in Professor Lipka's book "Graphical and Mechanical Computation." This method is frankly empirical, and has not the rigid mathematical justification of the method of least squares, but it is far less laborious, and has the great advantage for the present problem that data which is known to be especially reliable can arbitrarily be given more weight than other data of less certain accuracy.

Lipka's method does not always give results converging to consistency. If the sum of the errors is very large, each approximation shows increasing divergence from consistent values, showing that the data is too unreliable to be considered.

## Explanation of Lipka's Empirical Method for the Digest of Inconsistent Data

Lipka's empirical method of making inconsistent data consistent with the theoretical mathematical relation that exists.

As a simple example, Case 1:

A rectangle actually exists as in Fig. 1.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| An observer measures side "a" and reports | | | | | | | 5.1 |
| " | " | " | " | "b" | " | " | 3.9 |
| " | " | " | area | "A" | " | " | 20.11 |

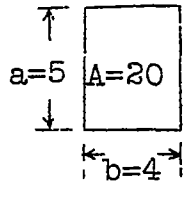

Fig.1

These reported values have been measured perhaps by different observers at different times and the accuracy of their data is not known as yet; for the purpose of research, let us therefore assume that $ab = A$ must hold true to four (4) significant figures. This is analogous to the reported data concerning a single airship. Yet with airships, the reported values of drag coefficient, horsepower, maximum speed, propeller efficiencies at maximum speed, and propulsive coefficient are interconnected by mathematical relations and would only serve to complicate the explanation of the method. The relation between different ships will be later explained analogous to using two rectangles.

| Reported values | |
|---|---|
| $a = 5.1$ | Assume A and b correct, then $a = \frac{A}{b} = 5.146$ |
| $b = 3.9$ | Assume A and a correct, then $b = \frac{A}{a} = 3.943$ |
| $A = 20.11$ | Assume a and b correct, then $A = ab = 5.1 \times 3.9 = 19.89$ |

These values of a, b, and A are the 1st approximation:

| 1st approximation: | |
|---|---|
| $a = 5.146$ | Reported $a = 5.1$ |
| $b = 3.943$ | 1st approx. $a = 5.146$ |
| $A = 19.89$ | $2: 10.246$ |
| | $5.123$ = 1st mean value of a |
| | Reported $b = 3.90$ |
| | 1st approx. $b = 3.943$ |
| | $2: 7.843$ |
| | $3.922$ = 1st mean value of b |
| | Reported $A = 20.11$ |
| | 1st approx. $A = 19.89$ |
| | $2: 40.00$ |
| | $20.00$ = 1st mean value of A |

Test for consistency $ab = 5.123 \times 3.922 = 20.092 = A$, calculated value.

1st mean value of A . . . . . $= \frac{20.00}{.092}$

Consistent to only three significant figures.

Now consider these mean values as new reported values and continue the process to the second approximation.

Similar to method of first approximation:

$$a = \frac{\text{1st mean A}}{\text{1st mean b}} = \frac{20.00}{3.922} = \text{a, 2d approx.} = 5.099$$

$$b = \frac{\text{1st mean A}}{\text{1st mean a}} = \frac{20.00}{5.123} = \text{b, 2d} \quad '' \quad = 3.903$$

$A = (\text{1st mean a})\ (\text{1st mean b}) = 5.123 \times 3.922 = 20.092 = A$, 2d approx.

(Check for consistency, $A = 5.099 \times 3.903 = 19.901$.)

| | a | b | A |
|---|---|---|---|
| Last mean value | 5.123 | 3.922 | 20.00 |
| 2d approx. " | 5.099 | 3.903 | 20.092 |
| 2d mean " | 5.111 | 3.908 | 20.046 |

$$\text{Mean value} = \frac{\text{Last mean + last approx.}}{2}$$

$$a = \frac{\text{2d mean A}}{\text{2d mean b}} = \frac{20.046}{3.908} = 5.129 = \text{a, 3d approx.}$$

$$b = \frac{\text{2d mean A}}{\text{2d mean a}} = \frac{20.046}{5.111} = 3.922 = \text{b, 3d} \quad ''$$

$A = (\text{2d mean a})\ (\text{2d mean b}) = 5.111 \times 3.908 = 19.9737 = A$, 3d approx.

| | a | b | A |
|---|---|---|---|
| Last mean value | 5.111 | 3.908 | 20.046 |
| 3d approx. " | 5.129 | 3.922 | 19.9737 |
| 3d mean " | 5.120 | 3.915 | 20.0098 |

$$a = \frac{\text{3d mean A}}{\text{3d mean b}} = \frac{20.0098}{3.915} = 5.111 = a, \text{ 4th approx.}$$

$$b = \frac{\text{3d mean A}}{\text{3d mean a}} = \frac{20.0098}{5.120} = 3.908 = b, \text{ 4th "}$$

A = (3d mean a) (3d mean b) = 5.120 × 3.915 = 20.0448 = A, 4th approx.

(Check for consistency, 5.111 × 3.908 = 19.9738.)

| | a | b | A |
|---|---|---|---|
| Last mean value | 5.120 | 3.915 | 20.0098 |
| 4th approx. " | 5.111 | 3.908 | 20.0448 |
| 4th mean " | 5.115 | 3.912 | 20.0273 |

$$a = \frac{\text{4th mean A}}{\text{4th mean b}} = \frac{20.0273}{3.912} = 5.119 = a, \text{ 5th approx.}$$

$$b = \frac{\text{4th mean A}}{\text{4th mean a}} = \frac{20.0273}{5.115} = 3.915 = a, \text{ 5th "}$$

A = (4th mean a) (4th mean b) = 5.115 × 3.912 = 20.0098 = A, 5th approx.

(Check for consistency, 5.119 × 3.915 = 20.0409.)

| | a | b | A |
|---|---|---|---|
| Last mean value | 5.115 | 3.912 | 20.0273 |
| 5th approx. " | 5.119 | 3.915 | 20.0098 |
| 5th mean " | 5.117 | 3.914 | 20.0185 |

$$a = \frac{\text{5th mean A}}{\text{5th mean b}} = \frac{20.0185}{3.914} = 5.114 = \text{6th approx., a}$$

$$b = \frac{\text{5th mean A}}{\text{5th mean a}} = \frac{20.0185}{5.117} = 3.912 = \text{6th approx., b}$$

A = (5th mean a) (5th mean b) = 5.117 × 3.914 = 20.0279 = 6th approx., A

(Check for consistency, 5.114 × 3.912 = 20.0059.)

| | a | b | A |
|---|---|---|---|
| Last mean value | 5.117 | 3.914 | 20.0185 |
| 6th approx. " | 5.114 | 3.912 | 20.0279 |
| 6th mean " | 5.1155 | 3.913 | 20.0237 |

$$a = \frac{\text{6th mean A}}{\text{6th mean b}} = \frac{20.0237}{3.913} = 5.1170 = a, \quad \text{7th approx.}$$

$$b = \frac{\text{6th mean A}}{\text{6th mean b}} = \frac{20.0237}{5.1155} = 3.9143 = b, \quad \text{7th} \quad ''$$

$$A = (\text{6th mean a})\ (\text{6th mean b}) = 5.1155 \times 3.913 = 20.0169 = A, \text{ 7th approx.}$$

(Check for consistency, $5.117 \times 3.9143 = 20.0294$.)

| | a | b | A |
|---|---|---|---|
| Last mean value | 5.1162 | 3.9136 | 20.0203 |
| 8th approx. " | 5.1155 | 3.9131 | 20.02276 |
| 8th mean " | 5.1158 | 3.9134 | 20.02153 |

$$a = \frac{\text{8th mean A}}{\text{8th mean b}} = \frac{20.02153}{3.9134} = 5.1161 = a, \quad \text{9th approx.}$$

$$b = \frac{\text{8th mean A}}{\text{8th mean a}} = \frac{20.03152}{5.1158} = 3.9136 = b, \quad \text{9th} \quad ''$$

$$A = (\text{8th mean a})\ (\text{8th mean b}) = 5.1158 \times 3.9134 = 20.02017 = A, \text{ 9th approx.}$$

(Check for consistency, $5.1161 \times 3.9136 = 20.02236$.)

Consistency exists to four (4) significant figures.

The desired values are then taken from the 9th approximation as follows: $a = 5.116$; $b = 3.914$; $A = 20.02$;

as check, $ab = A = 5.116 \times 3.914 = 20.0340$.

Case 3.

Now let us consider as example two rectangles which actually exist, as follows:

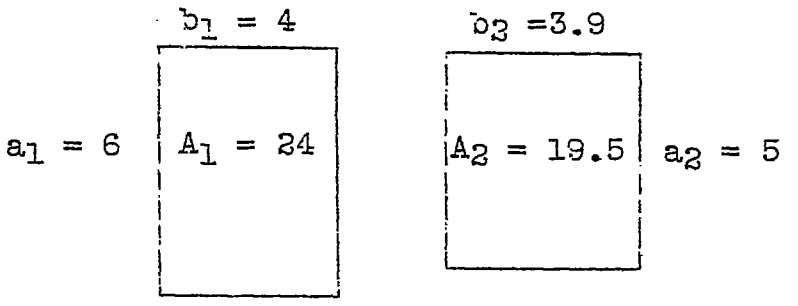


Fig.2

It is known (let us say) that human endeavor tried to make side $b_1$ = side $b_2$. This is analogous to two types of ships built say in the same year, with no apparent advancement in the art of propeller design compassed to the ships just before and just after the building of these two ships. It then is safe to say that these two ships would have as far as is known the same propeller efficiencies. On this relation that side $b_1$ = side $b_2$ the following will be worked out:

The reported values are

| 1st rectangle | 2d rectangle | Mathematical relations in this case |
|---|---|---|
| $b_1 = 3.95$ | $b_2 = 3.99$ | $a_1 b_1 = A_1$ |
| $a_1 = 6.08$ | $a_2 = 4.94$ | $a_2 b_2 = A_2$ |
| $A_1 = 24.05$ | $A_2 = 19.80$ | $b_1 = b_2$ |

Assuming consistency to three significant figures is considered sufficient. Proceed similarly to Case 1.

$$a_1 = \frac{A_1}{b_1} = \frac{24.05}{3.95} = 6.088 = a_1, \quad \text{1st approx.}$$

$$b_1 = \frac{A_1}{a_1} = \frac{24.05}{6.08} = 3.955 = b_1, \quad \text{1st} \quad ''$$

$$a_2 = \frac{A_2}{b_2} = \frac{19.80}{3.99} = 4.962 = a_2, \quad \text{1st} \quad ''$$

$$b_2 = \frac{A_2}{a_2} = \frac{19.80}{4.94} = 4.008 = b_2, \quad \text{1st} \quad ''$$

$$A_1 = a_1 b_1 = 6.08 \times 3.95 = 24.016 = A_1, \quad \text{1st approx.}$$

$$A_2 = a_2 b_2 = 4.94 \times 3.99 = 19.710 = A_2, \quad \text{1st} \quad ''$$

Now consider the relation $b_1 = b_2$ :

$b_1$, 1st approx. = 3.955

$b_2$, " " = 4.008

(mean value) cal. = 3.982 to be averaged into the mean values.

Last mean (in this case reported data):

| | $a_1$ | $b_1$ | $A_1$ | $a_2$ | $b_2$ | $A_2$ |
|---|---|---|---|---|---|---|
| Last mean | 6.08 | 3.95 | 24.05 | 4.94 | 3.99 | 19.80 |
| 1st approx. | 6.088 | 3.955 | 24.016 | 4.962 | 4.008 | 19.710 |
| (mean value)cal. | | 3.982 | | | 3.982 | |
| 1st mean value | 6.084 | 3.962 | 24.033 | 4.951 | 3.993 | 19.755 |

It is to be noted that the assumption that $b_1 = b_2$ based on human endeavor is given equal weight with reported data and hence enters the mean value only once, having thus one-third effect on the mean values of $b_1$ and $b_2$. However, if (in the case

of ships) a certain data, say as obtained from deceleration tests is assumed to be highly correct, this can be given greater weight by averaging it on a weighted mean principle. On ships where the deceleration data looked reasonable it was given three times the weight of other reported values and was averaged in on each approximation, thereby forcing the dependent variables to closely conform to the actual deceleration test. To continue the case at hand -

Check for consistency:

$(a_1$, 1st approx.$)(b_1$, 1st approx.$) = 6.038 \times 3.955 = 24.078$

$(a_2$, " " $)(b_2$, " " $) = 4.962 \times 4.008 = 19.887$

Compared against the mean values of

$A_1 = 24.033$

$A_2 = 19.755$

$$a_1 = \frac{\text{1st mean } A_1}{\text{1st mean } b_1} = \frac{24.033}{3.962} = 6.065 = a_1, \quad \text{2d approx.}$$

$$b_1 = \frac{\text{1st mean } A_1}{\text{1st mean } a_1} = \frac{24.033}{6.084} = 3.950 = b_1, \quad \text{2d "}$$

$$A_1 = (\text{1st mean } a_1)(\text{1st mean } b_1) = 6.084 \times 3.962 = 24.1048 = A_1, \text{ 2d approx.}$$

$$a_2 = \frac{\text{1st mean } A_2}{\text{1st mean } b_2} = \frac{19.755}{3.993} = 4.947 = a_2, \quad \text{2d approx.}$$

$$b_2 = \frac{\text{1st mean } A_2}{\text{1st mean } a_2} = \frac{19.755}{4.951} = 3.990 = b_2, \quad \text{2d "}$$

$$A_2 = (\text{1st mean } a_2)(\text{1st mean } b_2) = 4.951 \times 3.993 = 19.7693 = A_2, \text{ 2d approx.}$$

Check for consistency:

($a_1$, 2d approx.)($b_1$, 2d approx.) = $A_1$=6.065 × 3.950=23.9567

($a_2$, 2d " )($b_2$, 2d " ) = $A_2$=4.947 × 3.990=19.738 =

as compared against $A_1$ = 24.1048 $b_1$, 2d approx. = 3.950

$A_2$ = 19.7693 $b_2$, 2d " = 3.990

mean = 3.970

| | $a_1$ | $b_1$ | $A_1$ | $a_2$ | $b_2$ | $A_2$ |
|---|---|---|---|---|---|---|
| Last mean | 6.084 | 3.962 | 24.033 | 4.951 | 3.993 | 19.755 |
| 2d approx. | 6.065 | 3.950 | 24.1048 | 4.947 | 3.990 | 19.7693 |
| Mean value of $b_1$ & $b_2$ | | 3.970 | | | 3.970 | |
| 2d mean | 6.074 | 3.961 | 24.0689 | 4.949 | 3.984 | 19.7622 |

$$a_1 = \frac{\text{3d mean } A_1}{\text{2d mean } a_1} = \frac{24.0689}{3.961} = 6.0764 = a_1, \quad \text{3d approx.}$$

$$b_1 = \frac{\text{2d mean } A_1}{\text{3d mean } a_1} = \frac{24.0689}{6.074} = 3.9626 = b_1, \quad \text{3d "}$$

$$A_1 = (\text{2d mean } a_1)(\text{2d mean } b_1) = 6.074 \times 3.961 = 24.0591 = A_1, \text{ 3d approx.}$$

$$a_2 = \frac{\text{3d mean } A_2}{\text{2d mean } b_2} = \frac{19.7622}{3.984} = 4.9603 = a_2, \quad \text{3d approx.}$$

$$b_2 = \frac{\text{2d mean } A_2}{\text{2d mean } a_2} = \frac{19.7622}{4.949} = 3.9931 = b_2, \quad \text{3d "}$$

$$A = (\text{2d mean } a_2)(\text{2d mean } b_2) = 4.949 \times 3.984 = 19.7168 = A_2, \text{ 3d approx.}$$

Check for consistency:

($a_1$, 3d approx.)($b_1$, 3d approx.)= $A_1$=6.0764×3.9626=24.0783

($a_2$, " " )($b_2$, " " )= $A_2$=4.9603×3.9931=19.8069

as compared against

$A_1 = 24.0591$

$A_2 = 19.7168$

$b_1$, 2d approx. = 3.9626

$b_2$, " " = 3.9931

mean = 3.9778

| | $a_1$ | $b_1$ | $A_1$ | $a_2$ | $b_2$ | $A_2$ |
|---|---|---|---|---|---|---|
| Last mean | 6.074 | 3.961 | 24.0689 | 4.949 | 3.984 | 19.7622 |
| 3d approx. | 6.0764 | 3.9626 | 24.0591 | 4.9603 | 3.993 | 19.7168 |
| mean value $b_1$ & $b_2$ | | 3.9778 | | | 3.9778 | |
| 3d mean | 6.0752 | 3.9671 | 24.0640 | 4.9546 | 3.9849 | 19.7395 |

$$a_1 = \frac{\text{3d mean } A_1}{\text{3d mean } b_1} = \frac{24.0640}{3.9671} = 6.0658 = a_1, \quad \text{4th approx.}$$

$$b_1 = \frac{\text{3d mean } A_1}{\text{3d mean } a_1} = \frac{24.0640}{6.0752} = 3.9610 = b_1, \quad \text{4th} \quad ''$$

$$A_1 = (\text{3d mean } a_1)(\text{3d mean } b_1) = 6.0752 \times 3.9671 = 24.1009 = A_1, \text{ 4th approx.}$$

$$a_2 = \frac{\text{3d mean } A_2}{\text{3d mean } b_2} = \frac{19.7395}{3.9849} = 4.9535 = a_2, \quad \text{4th approx.}$$

$$b_2 = \frac{\text{3d mean } A_2}{\text{3d mean } a_2} = \frac{19.7395}{4.9546} = 3.9840 = b_2, \quad \text{4th} \quad ''$$

$$A_2 = (\text{3d mean } a_2)(\text{3d mean } b_2) = 4.9546 \times 3.9849 = 19.7436 = A_2, \text{ 4th approx.}$$

Check for consistency:

$(a_1$, 4th approx.$)(b_1$, 4th approx.$) = A_1 = 6.0658 \times 3.9610 = 24.0266$

$(a_2$, " " $)(b_2$, " " $) = A_2 = 4.9535 \times 3.9840 = 19.7347$

as against

$A_1 = 24.1009$

$A_2 = 19.7436$

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It is seen that rectangle No. 2 has reached consistency to three significant figures as specified, which are for engineering purposes.

$a_2 = 4.95$ b 3.98 $A_2$ 19.7

For check $4.95 \times 3.98 = 19.7010$

Thus the value of $b_2 = 3.98$ can be averaged into the next approximation, the same as the mean of $b_1$ and $b_2$ was formerly. The next approximation need only be carried out on rectangle No. 1 -

Thus:

| | | | |
|---|---|---|---|
| Last mean | = 6.0752 | 3.9671 | 24.0640 |
| 4th approx. | = 6.0658 | 3.9610 | 24.1009 |
| $b_2$ | = | 3.98 | |
| 4th mean | = 6.0705 | 3.9649 | 24.0825 |

$$a_1 = \frac{A \text{ 4th mean}}{b \text{ 4th mean}} = \frac{24.0825}{3.9694} = 6.0670 = a_1, \quad \text{5th approx.}$$

$$b_1 = \frac{A \text{ 4th mean}}{a \text{ 4th mean}} = \frac{24.0825}{6.0705} = 3.9671 = b_1, \quad \text{5th} \quad ''$$

$A_1$ = (4th mean $a_1$)(4th mean $b_1$) = $6.0705 \times 3.9694 = 24.0962 = A_1$, 5th approx.

Check for consistency ($a_1$, 5th approx.)($b_1$, 5th approx.) = $6.067 \times 3.9671 = 24.068$.

It is seen that rectangle No. 1 has reached consistency to three significant figures as specified which are for engineering purposes.

$a_1 = 6.07$ $b_1 = 3.97$ $A_1 = 24.09$ or 24.1 for 3 figures

Check $6.07 \times 3.97 = 24.0979$.

It is here well to note that although human endeavor tried to make $b_1 = b_2$ it was so tempered by the reported values of $b_1$ and $b_2$ that they never did quite equal each other. Thus final values $b_1 = 3.97$ and $b_2 = 3.98$.

So it can be seen that even though an assumption was made that the propeller efficiency of one ship is equal to that of another, they do not necessarily in the final values equal each other unless the reported data agrees close enough to make it so.

The interconnecting quantities between ships where no data were available were propeller efficiencies and drag coefficients.

The data obtained by direct observation are maximum speed and horsepower; drag coefficient (with dead or idling propellers as was the case at the given deceleration test).

The data calculated from observed data are drag coefficient with engines having no propeller drag, propeller efficiency, maximum speed and propulsive coefficient.

The data obtained where no deceleration test had been run were to consider as reported data a drag coefficient that lay between the ships built just before and after with due regard to fineness ratio, type of cars and surfaces, contours of hull, etc. This assumed drag coefficient was forced by Lipka's method to vary if necessary to accommodate the drag coefficient as calculated from maximum speed, horsepower and propeller efficiency or from area of drag. Likewise, in ships where propeller effici-

ency was not known by any data, it was assumed as between the ships on either side of it. This could not be much in error as propeller efficiency at maximum speed was almost a continuous function. Then again the area of drag as found for ships on which deceleration test had been run, was seen to be nearly a continuous function from one design to another. So where reported data were missing (two cases only) these assumptions were made.

Great weight was given to the drag coefficients and propeller efficiencies as obtained from an actual known deceleration test. This was done by averaging this observed data in on each successive mean value; thereby forcing the conflicting reported data to conform to the deceleration test data. In some cases two deceleration tests of the same ship were found and they differed in drag coefficient and propeller efficiencies. In such cases an average value was used for the initial reported data. After the fifth approximation the relative value of each quantity compared to the same value of ships on each side of it was maintained by averaging in this interpolated value of drag coefficient and propeller efficiency. These two quantities determined all the rest for each individual ship so gave twice the number of calculated values for quantities. Thus, on a particular ship a value of drag coefficient would be arrived at from the data pertaining to that particular ship and another value of its drag coefficient would be arrived at by its relation to the ship's

"items" on each side of it, which amounts to this: digest all reported observed data (giving great weight to deceleration tests) for five approximations, then calculate the relative values of similar quantities between each item in succession. Then on each successive approximation, average in to its mean the interpolated values of drag coefficients and propeller efficiencies. Thus the relative values of quantities would have nearly the same relation between ships as found to exist on the fifth approximation and would be found to exist in the final analysis.

## Body of Report

Preliminary calculations of data, and empirical digest of reported and deceleration test data to obtain consistent values of all necessary quantities.

Lipka's empirical method was used. This method, as explained in the introduction, gives consistent results by changing values that lie off the mean by arbitrarily moving (by averaging) them half way to that mean and then calculating the dependent variables. This was done for six dependent quantities: maximum air speed, horsepower at maximum speed, propulsive coefficient at maximum speed, propeller efficiency at maximum speed, area of drag, and whole ship's drag coefficient.

It was found that the data thought reliable often moved slightly as it was not always consistent.

Preliminary approximate calculations were made on the relative total drag of each ship, its approximate skin friction, resistance of the bare hull, etc. This was done purely to get a convenient arrangement of the ships, and not intended to be the basis for the subdivision of a ship's drag into its component parts, as bare hull resistance and skin friction are only very approximate. Part II (Technical Note No. 248) deals entirely with the subdivision of the drag of airships.

The quantity S = "characteristic length" with power on and power off, was carried along through three approximations primarily to give a more accurate start to the system of approximations.

Consistent results were obtained in eleven approximations when most quantities showed a rapidly converging series of their differences with the previous approximation, and the differences yet to be so small as to show such a small numerical change in the dependent quantities that the limits of these series were taken as the final consistent values. The final values were then checked against each other by the formulas of their relations (See Tables I to VIII given at the end of report).

## Assumptions

The justification for the relations between ships is based on these assumptions. The art of propeller design for airships showed nearly a continuous function over the time. The propel-

ler efficiencies gave several points on this function. It then was safe to assume that the propeller efficiency of a ship on which no deceleration data could be found was between that obtained on the ships before and the ships after. This assumed propeller efficiency was given equal weight with reported (not deceleration test data) data on the first approximation. The same was done for whole ship's drag coefficient on the ships where no deceleration tests had been run, taking into account type of hull, volume, type of cars, surfaces, etc., and so, in fact, it became an interpolated value of the drag coefficient for use on the first approximation.

Each ship's data were then run independently of other ships for five approximations, giving greater weight to deceleration test data where available. At the end of the fifth approximation the values of C and E were compared to the items on each side of it and this relative position was kept by averaging in these new interpolated values on all the approximations that follow.

## Symbols and Definitions Used in Part I

$L$ = Length of ship in feet.

$D$ = Maximum diameter of hull in feet.

$v$ = Air speed in ft./sec.

$v_{max.}$ = Air speed at full throttle all engines.

$\frac{L}{D}$ = Fineness ratio.

$A$ = Maximum cross sectional area in sq.ft.

$V$ or Vol. = Air volume of hull in cu.ft.

$\frac{V}{AL}$ = Cylindrical coefficient.

$X$ = Distance from nose to maximum diameter in feet.

$X$ Also used to indicate type of series as in $X, \frac{X}{2}, \frac{X}{4} \ldots\ldots 0$.

$r$ = Maximum radius of hull in feet.

$e$ = Eccentricity of nose ellipse.

$A_S$ = Total surface area of hull in sq.ft.

S.F. = Skin friction.

$K_P$ = Approx. drag coef. due to pressure difference.
$K_S$ = " " " " " skin friction.
$K$ = " " " " " hull.
} Used only in first approximations.

$K$ = Propulsive coefficient in last approximations and final summaries.

$P_0$ = Full rated horsepower.

$HP_{max.}$ = Full developed horsepower at full throttle all engines.

$\eta$ = A term that approaches propeller efficiency $E$.

$E$ = Propeller efficiency for whole ship.

$E_{max.}$ = Propeller efficiency with $v_{max.}$ and $HP_{max.}$

$\rho$ = Density of the air; consistently used as a constant of .00237 slugs/cu.ft.

$V_M$ = Virtual volume in cu.ft.

$S$ = Characteristic length in feet.

$S_P$ = " " with power on in feet.

$A$ = Area of drag in sq.ft.

$A_P$ = " " " with power on in feet.

$C$ = Drag, coefficient of whole ship in absolute units.

Note.- Subscript numerals denote the number of the approximation.

Primes (as K', K", K"')" " " " " "

in the first few approximations.

Where there are any approximations on a sheet, the whole sheet is labeled "Preliminary Calculations." This is to prevent misuse of this article.

Final results of Part I are summarized on Page 3.

## Formulas

$$HP\cdot_{available} = C \times \frac{\rho}{2} \times \frac{Vol.^{2/3}\ v^3}{550\ E}$$

$HP\cdot_r$ = Horsepower useful in line of flight.

$$E = \frac{HP\cdot_r}{HP\cdot_{available}} = \frac{D\ v}{550\ HP\cdot_{available}}$$

$$K = \text{Propulsive coeff.} = \frac{2E}{C} = \frac{2E(Vol.)^{2/3}}{A_P} = \frac{\rho\ v^3(Vol.)^{2/3}}{550\ HP\cdot_r}$$

$A_\rho$ = Area of drag with power on (sq.ft.).

$$A_P = \frac{\text{Drag in pounds}}{\frac{\rho\ v^2}{2}}$$

$\rho$ = slugs/cu.ft.
$v$ = ft./sec.
$A_P$ = sq.ft.

$C$ = Drag coefficient (absolute units).

$$C = \frac{\text{Drag in pounds}}{\frac{\rho}{2}\ v^2(Vol.)^{2/3}} = \frac{2E}{K}$$

$$C = \frac{A_P}{(Vol.)^{2/3}} \quad \text{(absolute units).}$$

$$K = \frac{2E(Vol.)^{2/3}}{A_P} = \frac{2E}{C} = \frac{\rho\ v^3(Vol.)^{2/3}}{550\ HP.}$$

$$A_P = \frac{2V_M}{S_P}$$

$V_M$ = virtual volume in cu.ft. = Vol. + $\frac{\pi r^3}{3}$
($r$ = max. radius of cross section).
$S_P$ = characteristic length, power on (ft.).

$$A_{power\ off} = \frac{2V_M}{S_{power\ off}}$$ $S_{power\ off}$ found from deceleration curve.

$A_P - A_{power\ off}$ = Area of drag, due to idle propellers.

$\rho$ = .00237 slugs/cu.ft. (All foregoing data based on the standard density of air.)

Formulas (Cont.)

$v_{max.}$ = Velocity; air speed in ft./sec.

$$v_{max.} = \sqrt[3]{\frac{HP. \times 2 \times 550 \times E}{C \frac{\rho}{2} (Vol.)^{2/3}}}$$

(HP. = Max. HP. available.)
(E = Prop. Eff. at $v_{max.}$ and $HP._{max.}$)

$$v = \sqrt[3]{\frac{HP. \times 2 \times 550 \times E}{C \frac{\rho}{2} (Vol.)^{2/3}}}$$

(HP. = any available HP.)
(E = Prop. Eff. at $v$ and HP.)

$$D = C \frac{\rho}{2} v^2 (Vol.)^{2/3} = \text{Drag in pounds.}$$

$$= \rho V_M \frac{dv}{dt} = A_P \frac{\rho v^2}{2}$$

$$HP._r = \frac{D v}{550}$$

$v$ = ft./sec.
D = pounds

$$\frac{dt}{dv} = \frac{S}{v^2}$$

(S = characteristic length);

$$S_{power\ off} = \frac{t}{\frac{1}{v_0} - \frac{1}{v}}$$

(From slope of $\frac{1}{v}$ plotted against t during deceleration test.)

## Conclusion

1. The consistent values obtained in the body of this report and given again in the Summary must be used in the light of the method by which they were obtained. Thus, it must be realized that the net errors on reported data compared to what actually exists, are pro-rated around and that errors in deceleration test data are likewise pro-rated around until consistency is obtained. It can then be said that the values herein obtained are the probable relative values and thus for design and research purposes can be considered as a digest of past performance and deceleration data.

2. Part II (T.N. No. 248) deals with the subdivision of the Drag of Airships and this work presents (by the author) the point of preliminary calculations and a first VL curve for full size bare airship hulls.

3. The range of application of the data obtained in Part I can not logically be applied to new designs that are not nearly similar to airships from which these data were obtained. However, on the judgment of the designer, certain quantities such as drag coefficient and propeller efficiency may be used for ships of larger volumes, the accuracy of the results will largely depend on the assumptions made. Part II (T.N. No. 248) endeavors to devise a method of calculating quantities concerning a new design.

References

N.A.C.A. Technical Memorandum No. 237 - "Rigid Airships" by Friedrich Stahl, November, 1923.

N.A.C.A. Technical Report No. 117 - "The Drag of Zeppelin Airships" by Max M. Munk, 1921.

N.A.C.A. Technical Report No. 184 - "The Aerodynamic Forces in Airship Hulls" by Max M. Munk, 1924.

N.A.C.A. Technical Note No. 194 - "A Method of Determining the Dimensions and Horsepower of an Airship for any Given Performance" by C. P. Burgess, 1924.

Bureau of Aeronautics (U.S. Navy) Design Memos Nos. 30, 41, 43, 44 and 47, by C. P. Burgess.

Various Papers by Prandtl, Furman, Blasius and Stanton.

U.S. Navy Bu. C. & R. Bulletin No. 101, Dec. 1919.

"The Rigid Airship, ZR-3" by C. P. Burgess, published in Journal A.S.N.E., November, 1924.

Reports on Airship Models, by Eiffel, 1918.

Classroom Notes from Professors E. P. Warner and Lipka, Mass. Institute of Technology.

In addition to data and formulas taken from the above, the following data obtained from German sources are considered. (Where data for more than one ship in an item was given, the average is tabulated here.)

Additional Reported Data

| Item | Air Volume cu.ft. | Dist.max. Ord.from Nose % length | Prop. Coef. K | Prop. Eff. at $v_{max.}$ E | Drag Coef. C* | Remarks |
|---|---|---|---|---|---|---|
| 8 | | 17.50 | 16 | 36 | | |
| 9 | 573000 | 25.80 | 10 | 28 | .056 | Formula $C = \frac{2E}{K}$ does not always hold true with this data. |
| 10 | | 23.63 | 16 | 33 | .044 | |
| 11 | | 25.00 | 19 | 66 | .071 | |
| 12 | | 24.61 | 26 | 59 | .052 | |
| 13 | | 22.40 | 19 | 57 | .048 | |
| 14 | 858000 | 22.19 | 24 | 55 | .055 | |
| 15 | | 21.62 | 32 | 56 | .035 | |
| 16 | | 21.40 | 32 | 58 | .032 | |
| 17 | | 19.62 | 36 | 54 | .030 | |
| 18 | 2149000 | 30.80 | 39 | 56 | .029 | |
| 19 | | 30.80 | 47 | 61 | .021 | |
| 20 | | 30.80 | 56 | 61 | .020 | |
| 21 | | 30.80 | 57 | 62 | .020 | On this item, data states skin friction = 82% hull drag. |
| 22 | 2640000 | 24.40 | 58 | 64 | .020 | |
| 23 | | 24.40 | 59 | 65 | .019 | |
| 24 | | 30.80 | 59 | 65 | .020 | |
| 25 | 2400000 | 24.40 | 56 | 65 | .020 | |

In general this data conflicts with that given in the references. It is thus considered as reported data.

A statement in the above reported data, that skin friction = constant $\times V^{-.047}$ = % of hull drag (where V = volume of hull) is not consistent with data reported for item 22.

*For whole ship.

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[illegible] RESULTS

[illegible] PURPOSES

| $A_P$ Drag Area Power On | C Drag Coeff. (Whole Ship) |
|---|---|
| 87.40 | .047582 |
| 127.40 | .039962 |
| 131.49 | .039807 |
| 78.00 | .037161 |
| 79.01 | .037945 |
| 170.01 | .019[illegible] |
| 396.99 | .018[illegible] |
| | |
| | |
| 251.00 | .046234 |
| 383.01 | .055578 |
| 374.00 | .045973 |
| 563.00 | .071371 |
| 412.00 | .050191 |
| 482.00 | .056547 |
| 409.00 | .054298 |
| 333.98 | .036262 |
| 393.00 | .034422 |
| 369.47 | .030068 |
| 474.00 | .028540 |
| 423.00 | .025505 |
| 372.00 | .022402 |
| 371.00 | .022340 |
| 419.00 | .021935 |
| 424.[illegible] | .022198 |
| [illegible] | .022400 |
| [illegible] | .022538 |
| [illegible] | .0[illegible]3172 |

— FORMULAE —

$HP_{AVAILABLE} = C \times \frac{R}{P} = \frac{Vol^{\frac{2}{3}} U^3}{550 E}$

$HP_T$ = HORSE POWER USEFUL IN LINE OF FLIGHT

$E = \frac{HP_T}{HP_{AVAILABLE}} = \frac{DU}{550\ HP_{AVAILABLE}}$

$K$ = PROPULSIVE COEFF. $= \frac{2E}{C} = \frac{2E(Vol)^{\frac{2}{3}}}{A_P} = \frac{\frac{\rho}{2} U^2 (Vol)^{\frac{2}{3}}}{550\ HP_T}$

$A_P$ = AREA OF DRAG WITH POWER ON (FOR IS)

$A_P = \frac{\text{DRAG IN POUNDS}}{\frac{\rho}{2} U^2}$ [illegible]

$C$ = DRAG COEFF. (ABSOLUTE UNITS)

$C = \frac{\text{DRAG IN POUNDS}}{\frac{\rho}{2} U^2 (Vol)^{\frac{2}{3}}} = \frac{2E}{K}$

$C = \frac{A_P}{(Vol)^{\frac{2}{3}}}$ (ABS UNITS

$K = \frac{2E(Vol)^{\frac{2}{3}}}{A_P} = \frac{2E}{C} = \frac{\rho U^3 (Vol)^{\frac{2}{3}}}{550\ HP_T}$

$A_P = \frac{2 V_M}{S_P}$ $V_M$ = VIRTUAL VOLUME IN CU. FT. $= Vol + \frac{\pi T^3}{3}$ ($T$ = [illegible] RADIUS OF CROSS SECTION)

$S_P$ = CHARACTERISTIC LENGTH, POWER ON, [illegible]

$A_{POWER\ OFF} = \frac{2 V_M}{S_{POWER\ OFF}}$ $S_{POWER\ OFF}$ FOUND FROM DECELERATION [illegible]

$A_P - A_{POWER\ OFF}$ = AREA OF DRAG DUE TO IDLE PROPELLERS

$\rho = .00237$ SLUGS/[illegible] (ALL FOREGOING DATA BASED ON THIS STANDARD [illegible] OF AIR)

$U_{MAX}$ = VELOCITY, AIR SPEED [illegible]

$U_{MAX} = \sqrt[3]{\frac{HP \times 2 \times 550 E}{C \frac{\rho}{2} (Vol)^{\frac{2}{3}}}}$ [illegible]

$U = \sqrt[3]{\frac{HP \times 2 \times 550 E}{C \frac{\rho}{2} (Vol)^{\frac{2}{3}}}}$ [illegible]

$D = \frac{\rho}{2} U^2 (Vol)^{\frac{2}{3}}$ = DRAG IN POUNDS [illegible]

$HP_T = \frac{DU}{[illegible]}$ [illegible]

[illegible]

[illegible]

TABLE VII

PRELIMINARY CALCULATIONS

FIGURES ON THIS SHEET ARE ONLY APPROXIMATE.

| ITEM | Convergent Series of $\Delta A_p$ | | | | $A_p$ Limit Drag/Area Power On Sq. Ft. | $A_p = \frac{(V_{Rel})^2 2E_{lim}}{K_{lim}}$ Check for $A_p$ Limit. | Check or Error | $C_{calculated}$ $\left(\frac{A_p \text{ Limit}}{Vol^{\frac{2}{3}}}\right)$ Used Five Place Logs. | $HP_{calculated}$ $C_{lim}\frac{E(V_{Rel})^3 10^3}{E_{556}\,E_{lim}}$ Check Top HP Limit | Check or Error | Summary Relative Values Of | | Constants Min Tail D. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1st Term $\Delta A_{p1}$ | 2nd Term $\Delta A_{p2}$ | 3rd Term $\Delta A_{p3}$ | 4th Limit 0.00 | | | | | | | $U_{max}$ Ft/Sec | $HP_{max}$ | K (Prop. Const.) | E Prop. Eff. |
| 1 | | | | | 87.40 | 87.40 | Check | .045582 | 99.46 | Check | 69.00 | 99.46 | 27.63 | .622 |
| 2 | | | | | 127.40 | 127.40 | " | .039962 | 296.42 | " | 88.00 | 296.42 | 31.59 | .631 |
| 3 | - .63 | - .31 | - .16 | 0.00 | 131.49 | 149.50 | " | .039789 | 250.00 | " | 83.11 | 250.00 | 32.78 | .650 |
| 4 | | | | | 78.00 | 78.00 | " | .097464 | 153.10 | " | 82.20 | 153.10 | 32.35 | .610 |
| 5 | + .13 | + .07 | + .03 | 0.00 | 79.01 | 79.00 | " | .037946 | 126.80 | " | 77.30 | 126.80 | 32.68 | .620 |
| 6 | + .83 | - .44 | + .22 | 0.00 | 170.01 | 170.00 | " | .019776 | 958.90 | " | 119.99 | 958.89 | 66.76 | .660 |
| 7 | - .5 | .32 | - .19 | 0.00 | 356.99 | 357.00 | " | .018125 | 2017.00 | " | 115.00 | 2017.00 | 64.23 | .580 |
| 8 | - .50 | - .25 | - .13 | 0.00 | 251.00 | 251.02 | Check | .046233 | 27.64 | Check | 26.40 | 27.63 | 15.58 | .360 |
| 9 | -3.50 | - 1.75 | - .87 | 0.00 | 383.01 | 383.00 | " | .055580 | 202.90 | " | 41.00 | 202.93 | 10.08 | .280 |
| 10 | | | | | 374.00 | 374.00 | " | .045963 | 343.34 | " | 51.98 | 343.34 | 14.36 | .330 |
| 11 | | | | | 563.00 | 563.00 | " | .071371 | 447.91 | " | 62.40 | 347.88 | 18.44 | .658 |
| 12 | | | | | 412.00 | 412.00 | " | .050189 | 478.90 | " | 67.50 | 479.89 | 24.45 | .570 |
| 13 | | | | | 487.00 | 482.00 | " | .056547 | 592.70 | " | 66.69 | 592.71 | 18.42 | .520 |
| 14 | | | | | 409.00 | 409.00 | " | .045298 | 592.71 | " | 70.89 | 592.68 | 23.40 | .530 |
| 15 | | | | | 333.93 | 333.98 | " | .036261 | 592.37 | " | 77.09 | 591.40 | 30.51 | .540 |
| 16 | | | | | 393.00 | 393.00 | " | .034423 | 836.49 | " | 81.61 | 836.58 | 31.96 | .550 |
| 17 | - .13 | .01 | - .03 | 0.00 | 369.49 | 369.50 | " | .030079 | 959.40 | " | 86.00 | 959.39 | 35.25 | .530 |
| 18 | | | | | 474.00 | 474.00 | " | .028544 | 1465.80 | " | 97.40 | 1465.80 | 38.52 | .550 |
| 19 | | | | | 423.00 | 423.00 | " | .025473 | 1215.80 | " | 92.41 | 1215.81 | 46.65 | .594 |
| 20 | | | | | 372.00 | 372.00 | " | .022401 | 1187.30 | " | 94.19 | 1189.30 | 53.57 | .600 |
| 21 | | | | | 371.00 | 371.00 | " | .027340 | 1191.30 | " | 97.40 | 1191.80 | 55.51 | .620 |
| 22 | | | | | 419.00 | 419.00 | " | .021936 | 1201.60 | " | 94.29 | 1201.60 | 57.44 | .630 |
| 23 | | | | | 426.00 | 426.00 | " | .022[illegible] | 1193.70 | " | 94.19 | 1193.71 | 51.66 | .640 |
| 24 | | | | | 372.00 | 372.00 | " | .022400 | 1341.60 | " | 104.81 | 1341.39 | 57.74 | .640 |
| 25 | | | | | 404.00 | 404.00 | " | .022539 | 1998.80 | " | 113.12 | 1998.81 | 55.91 | .630 |
| 26 | + .38 | + .19 | + .09 | 0.00 | 407.51 | 407.51 | " | .023170 | 1559.50 | " | 91.00 | 1559.11 | 36.34 | .475 |
| | $\Delta_1$ | $\Delta_2$ | $\Delta_3$ | $\Delta_4$ | | | | * | | | | | | |

NOTE: * — THIS COLUMN CHECKS WITH $2E_{556}$.

AND IN THE FOURTH COLUMN OF 5 ITEMS WITH CLOSE SET TWIN TAIL BOOMS IS CONSIDERED CHECKED.

$\Delta_1$, $\Delta_2$, $\Delta_3$ SHOW TYPE OF SERIES.

** THIS COLUMN GIVES PROPELLER DATA.

| ...RGING SERIES OF ΔK: 2ND TERM $K_{10}-K_9$ | 3RD TERM $K_{11}-K_{10}$ | ΔK LIMIT ... 0 | K LIMIT (PROP. COEFF.) $K_{11}+(K_{11}-K_{10})$ | $E_9$ LIMIT EXCEPT 2R-1 WHERE $E_{11}$ IS LIMITING | C (DRAG COEFF.) 11TH APP. | ΔC $(C_{11}-C_{10})10^4$ | CONVERGING SERIES ON ΔC: 1ST T. $(C_9-C_8)10^4$ | 2ND T. $(C_{10}-C_9)10^4$ | 3RD T. $(C_{11}-C_{10})10^4$ | ΔC LIM. ... 0.00 | DRAG COEFFICIENT: C LIMIT $C_{11}+(C_{11}-C_{10})$ | C CALCULATED $\frac{2E_{LIMIT}}{K_{LIMIT}}$ CHECK AGAINST C LIMIT. (5 PLACE LOGS) | $C_{LIM}-C_{CALC.}$ CHECK OR ERROR. | $A_P$ DRAG AREA POWER ON SQ FT. 11TH APP. EXCEPT WHERE $A_{10}-A_9=0$ | $\Delta A_P$ $A_{P11}-A_{P10}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| +.06 | +.03 | 0.00 | 27.63 | .622 | .045583 | -.01 | -.05 | -.02 | -.01 | 0.00 | .045582 | .045582 | CHECK | | |
| +.01 | +.01 | 0.00 | 31.59 | .631 | .039762 | 0.00 | | | | | .039962 | .039962 | " | | |
| -.04 | -.02 | 0.00 | 32.78 | .650 | .039780 | +.27 | +1.04 | +.54 | +.27 | 0.00 | .039807 | .039789 | +.000018 | 131.65 | -.16 |
| -.10 | -.05 | 0.00 | 32.55 | .610 | .037564 | -.03 | -.10 | -.05 | -.03 | 0.00 | .037561 | .037464 | +.000097 | | |
| -.07 | -.03 | 0.00 | 32.68 | .620 | .037911 | +.34 | +1.36 | +.68 | +.34 | 0.00 | .037945 | .037946 | CHECK. | 78.98 | +.03 |
| -.33 | -.16 | 0.00 | 66.76 | .660 | .019752 | +.24 | +.97 | +.48 | +.24 | 0.00 | .019776 | .019776 | " | 169.79 | +.22 |
| +.07 | +.04 | 0.00 | 64.03 | .580 | .018736 | -.11 | -.44 | -.22 | -.11 | 0.00 | .018125 | .018125 | " | 357.18 | -.19 |
| +.03 | +.01 | 0.00 | 15.58 | .360 | .046263 | -.29 | -1.16 | -.58 | -.29 | 0.00 | .046234 | .046233 | CHECK. | 251.13 | -.13 |
| -.03 | -.01 | 0.00 | 10.08 | .280 | .055505 | +.73 | +2.95 | +1.47 | +.73 | 0.00 | .055578 | .055580 | " | 383.88 | -.87 |
| +.02 | +.01 | 0.00 | 14.36 | .330 | .046004 | -.31 | -1.36 | -.62 | -.31 | 0.00 | .045973 | .045963 | +.000010 | | |
| | | | 18.44 | .658 | .071379 | -.08 | -.32 | -.16 | -.08 | 0.00 | .071371 | .071371 | CHECK | | |
| +.32 | +.16 | 0.00 | 24.45 | .570 | .050291 | -1.00 | -4.03 | -2.01 | -1.00 | 0.00 | .050191 | .050189 | " | | |
| +.07 | +.04 | 0.00 | 18.42 | .520 | .056644 | -.97 | -3.89 | -1.94 | -.97 | 0.00 | .056547 | .056547 | " | | |
| +.10 | +.05 | 0.00 | 23.40 | .530 | .054329 | -.31 | -1.26 | -.63 | -.31 | 0.00 | .054298 | .054298 | " | | |
| +.10 | +.06 | 0.00 | 30.51 | .540 | .036270 | -.08 | -.35 | -.17 | -.08 | 0.00 | .036262 | .036261 | " | | |
| | | | 31.96 | .550 | .034427 | -.05 | -.20 | -.10 | -.05 | 0.00 | .034422 | .034423 | " | | |
| -1.07 | -.53 | 0.00 | 35.25 | .530 | .029706 | +3.62 | +14.70 | +7.35 | +3.62 | 0.00 | .030068 | .030079 | -.000011 | 369.52 | -.03 |
| -.11 | .06 | 0.00 | 38.52 | .550 | .028532 | +.08 | +.36 | +.16 | +.08 | 0.00 | .028540 | .028544 | CHECK. | | |
| -.04 | -.02 | 0.00 | 46.65 | .594 | .025489 | +.16 | +.66 | +.33 | +.16 | 0.00 | .025505 | .025473 | +.000032 | | |
| -.03 | -.01 | 0.00 | 53.57 | .600 | .022395 | +.07 | +.25 | +.13 | +.07 | 0.00 | .022402 | .022401 | CHECK. | | |
| -.15 | -.07 | 0.00 | 55.51 | .620 | .022306 | +.34 | +1.35 | +.67 | +.34 | 0.00 | .022340 | .022340 | " | | |
| -.02 | -.01 | 0.00 | 57.44 | .630 | .021933 | +.02 | +.09 | +.04 | +.02 | 0.00 | .021935 | .021936 | " | | |
| | | | 57.66 | .640 | .022198 | 0.00 | | | | | .022198 | .022198 | " | | |
| | | | 57.14 | .640 | .022400 | 0.00 | | | | | .022400 | .022400 | " | | |
| +.01 | +.01 | 0.00 | 55.91 | .630 | .022542 | -.04 | -.15 | -.08 | -.04 | 0.00 | .022538 | .022539 | " | | |
| | | | 36.34 | .425 | .023161 | +.11 | +.43 | +.22 | +.11 | 0.00 | .023172 | .023170 | " | 402.42 | +.09 |

OF ACCURACY ± .01
$\frac{x}{2}$ 1 $\frac{x}{4}$ ... 0

CALCULATIONS BY CLINTON H. HAVILL
LIEUT., U.S. NAVY.

# TABLE VII

## PRELIMINARY CALCULATIONS

FIGURES ON THIS SHEET ARE ONLY APPROXIMATE

| ITEM | Converging Series of ΔU: 1st Term $U_9 - U_8$ | 2nd Term $U_{10} - U_9$ | 3rd Term $U_{11} - U_{10}$ | ΔU Limit ---0 | U Limit. $U_{MAX} = U_{11} + (U_{10} - U_9)$ Ft./Sec. | $HP_{MAX}$. 11th Approx. | ΔHP. $HP_{11} - HP_{10}$ | Converging Series of ΔHP: 1st Term $HP_9 - HP_8$ | 2nd Term $HP_{10} - HP_9$ | 3rd Term $HP_{11} - HP_{10}$ | ΔHP Limit -- 0 | HP Limit $HP_{MAX}$ $HP_{11} + (HP_{11} - HP_{10})$ | K (Prop. Coeff) 11th App. | ΔK $K_{11} - K_{10}$ | Conv. 1st Term $K_9 - K_8$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | 69.00 | 99.49 | -0.03 | - 0.14 | - 0.07 | -0.03 | 0.00 | 99.46 | 27.60 | + .03 | + .11 |
| 2 | | | | | 88.00 | 296.65 | -0.23 | - 0.89 | - 0.45 | -0.23 | 0.00 | 296.42 | 31.58 | + .01 | + .02 |
| 3 | - .57 | - .29 | - .14 | 0.00 | 83.11 | 250.00 | 0.00 | | | | | 250.00 | 32.80 | - .02 | -.08 |
| 4 | | | | | 82.20 | 152.91 | +0.19 | + 0.78 | +0.39 | +0.19 | 0.00 | 153.10 | 32.60 | - .05 | -.19 |
| 5 | | | | | 77.30 | 126.69 | +0.11 | + 0.45 | +0.23 | +0.11 | 0.00 | 126.80 | 32.71 | - .03 | -.14 |
| 6 | - .03 | - .01 | - .01 | 0.00 | 119.99 | 958.96 | -0.07 | - 0.28 | -0.14 | -0.07 | 0.00 | 958.89 | 66.92 | - .16 | -.66 |
| 7 | | | | | 115.00 | 2017.81 | -0.81 | - 3.25 | -1.63 | -0.81 | 0.00 | 2017.00 | 63.99 | + .04 | +.13 |
| 8 | | | | | 26.40 | 27.72 | -0.09 | - 0.34 | -0.17 | -0.09 | 0.00 | 27.63 | 15.57 | + .01 | +.05 |
| 9 | | | | | 41.00 | 202.74 | +0.19 | +0.73 | +0.37 | +0.19 | 0.00 | 202.93 | 10.09 | - .01 | -.06 |
| 10 | - .12 | - .07 | - .04 | 0.00 | 51.98 | 344.38 | -1.04 | -4.17 | - 2.08 | -1.04 | 0.00 | 343.34 | 14.35 | + .01 | +.04 |
| 11 | | | | | 67.40 | 448.02 | -0.14 | -0.53 | -0.27 | -0.14 | 0.00 | 347.88 | 18.44 | .00 | |
| 12 | - .13 | - .06 | -.03 | 0.00 | 67.50 | 481.21 | -1.32 | -5.28 | - 2.64 | -1.32 | 0.00 | 479.89 | 24.29 | +.16 | +.64 |
| 13 | - .08 | - .04 | -.02 | 0.00 | 66.69 | 588.79 | +3.92 | -15.68 | - 7.84 | -3.92 | 0.00 | 592.71 | 18.38 | +.04 | +.13 |
| 14 | -.15 | -.08 | - .04 | 0.00 | 70.89 | 595.02 | -2.34 | - 9.33 | -4.67 | -2.34 | 0.00 | 592.68 | 23.35 | +.05 | +.20 |
| 15 | -.13 | -.07 | -.03 | 0.00 | 77.09 | 594.05 | -2.15 | - 8.61 | -4.31 | -2.15 | 0.00 | 591.40 | 30.45 | +.06 | +.20 |
| 16 | -.10 | -.05 | -.02 | 0.00 | 81.61 | 837.40 | -0.82 | - 3.38 | -1.64 | -0.82 | 0.00 | 836.58 | 31.96 | .00 | |
| 17 | +1.00 | +.50 | +.25 | 0.00 | 86.00 | 955.68 | -0.29 | -1.15 | -0.58 | -0.29 | 0.00 | 959.39 | 35.78 | -.53 | -2.14 |
| 18 | + .93 | +.46 | +.23 | 0.00 | 92.40 | 1464.19 | +1.61 | +6.45 | +3.23 | +1.61 | 0.00 | 1465.80 | 38.58 | -.06 | -.22 |
| 19 | + .95 | +.38 | +.19 | 0.00 | 92.41 | 1214.82 | +0.99 | +3.95 | +1.98 | +0.99 | 0.00 | 1215.81 | 46.67 | -.02 | -.09 |
| 20 | -.15 | -.08 | -.04 | 0.00 | 96.19 | 1189.97 | -0.67 | -2.67 | -1.34 | -0.67 | 0.00 | 1189.30 | 53.58 | -.01 | -.06 |
| 21 | -.25 | -.13 | -.06 | 0.00 | 97.40 | 1191.84 | -0.54 | -2.15 | -1.09 | -0.54 | 0.00 | 1191.30 | 55.58 | -.07 | -.30 |
| 22 | -.03 | -.01 | -.01 | 0.00 | 94.29 | 1201.50 | +0.10 | +0.40 | +0.20 | +0.10 | 0.00 | 1201.60 | 57.45 | -.01 | -.04 |
| 23 | -.03 | -.01 | -.01 | 0.00 | 94.19 | 1193.63 | -0.42 | -1.70 | -0.85 | -0.42 | 0.00 | 1193.21 | 57.66 | .00 | |
| 24 | -.05 | -.02 | -.01 | 0.00 | 104.81 | 1441.93 | -0.54 | -2.16 | -1.08 | -0.54 | 0.00 | 1441.39 | 57.14 | .00 | |
| 25 | +.03 | -.02 | -.01 | 0.00 | 113.12 | 1998.88 | -0.07 | -0.30 | -0.15 | -0.07 | 0.00 | 1998.81 | 55.90 | +.01 | +.03 |
| 26 | -.25 | -.13 | -.06 | 0.00 | 91.00 | 1567.84 | -3.13 | -12.52 | -6.26 | -3.13 | 0.00 | 1559.71 | 36.34 | .00 | |
| | Limits of Accuracy -±.01 | | | | | | | Limits of Accuracy -±.01 | | | | | | | Limit |
| | X | $\frac{X}{2}$ | $\frac{X}{4}$ | ±0 | | | | X | $\frac{X}{2}$ | $\frac{X}{4}$ | ±0 | | | | X |

Note: Expressions $\frac{X}{2}$ & $\frac{X}{4}$ show the type of series.

| | ΔE $E_9 - E_8$ | $A_P$ Power ON 9TH App. | Δ $A_P$ $A_{P9} - A_{P8}$ | $v_{MAX}$ Ft./Sec. 10TH App | Δ $v_{MAX}$ $v_{10} - v_9$ | $HP_{MAX.}$ 10TH App. | Δ HP $HP_{10} - HP_9$ | K (Prop Coeff) 10TH App. | ΔK $K_{10} - K_9$ | C (Drag Coeff) 10TH Approx. | ΔC $C_{10} - C_9$ | $A_P$ (Power ON) 10TH App | Δ A $A_{10} - A_9$ | $v_{MAX.}$ Ft./Sec. 11TH App. | Δ $v_{MAX.}$ $v_{11} - v_{10}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| App. | | | | | | | | | | | | | | | |
| 22 | .000 | 87.40 | 0.00 | 69.00 | 0.00 | 99.52 | -0.07 | 27.57 | +0.06 | .045984 | -.000002 | 87.40 | 0.00 | 69.00 | 0.00 |
| 31 | " | 127.40 | 0.00 | 88.00 | 0.00 | 296.88 | -0.45 | 31.57 | +0.01 | .039962 | .000000 | 127.40 | 0.00 | 88.00 | 0.00 |
| 50 | " | 132.12 | -0.63 | 83.39 | -0.29 | 250.00 | 0.00 | 32.82 | -0.04 | .039753 | +.000054 | 131.81 | -0.31 | 83.25 | -0.14 |
| 10 | " | 78.00 | 0.00 | 82.20 | 0.00 | 152.72 | +0.39 | 32.65 | -0.10 | .037567 | -.000005 | 78.00 | 0.00 | 82.20 | 0.00 |
| 20 | " | 78.88 | +0.13 | 77.30 | 0.00 | 126.58 | +0.23 | 32.74 | -0.07 | .037877 | +.000068 | 78.95 | +0.07 | 77.30 | 0.00 |
| 0 | " | 169.13 | +0.88 | 120.01 | -0.01 | 959.03 | -0.14 | 67.08 | -0.33 | .019728 | +.000048 | 169.57 | +0.44 | 120.00 | -0.01 |
| 0 | " | 357.75 | -0.75 | 115.00 | 0.00 | 2018.62 | -1.63 | 63.95 | +0.07 | .018147 | -.000022 | 357.37 | -0.38 | 115.00 | 0.00 |
| 60 | .000 | 251.51 | -0.50 | 26.40 | 0.00 | 27.81 | -0.17 | 15.56 | +0.03 | .046292 | -.000058 | 251.26 | -0.25 | 26.40 | 0.00 |
| 80 | " | 386.50 | -3.50 | 41.00 | 0.00 | 202.55 | +0.37 | 10.10 | -0.03 | .055432 | +.000147 | 384.75 | -1.75 | 41.00 | 0.00 |
| 30 | " | 374.00 | 0.00 | 52.06 | -0.07 | 345.42 | -2.08 | 14.34 | +0.02 | .046035 | -.000062 | 374.00 | 0.00 | 52.02 | -0.04 |
| 58 | " | 563.00 | 0.00 | 62.40 | 0.00 | 448.16 | -0.27 | 18.44 | +0.01 | .071387 | -.000016 | 563.00 | 0.00 | 62.40 | 0.00 |
| 70 | " | 412.00 | 0.00 | 67.56 | -0.06 | 482.53 | -2.64 | 24.13 | +0.32 | .050391 | -.000201 | 412.00 | 0.00 | 67.53 | -0.03 |
| 20 | " | 482.00 | 0.00 | 66.73 | -0.04 | 584.87 | +7.84 | 18.34 | +0.07 | .056741 | -.000194 | 482.00 | 0.00 | 66.71 | -0.02 |
| 30 | " | 409.00 | 0.00 | 70.97 | -0.08 | 597.36 | -4.67 | 23.30 | +0.10 | .054360 | -.000063 | 409.00 | 0.00 | 70.93 | -0.04 |
| 40 | " | 333.98 | -0.01 | 77.15 | -0.07 | 596.20 | -4.31 | 30.39 | +0.10 | .036278 | -.000017 | 333.98 | 0.00 | 77.12 | -0.03 |
| 50 | " | 393.00 | 0.00 | 81.65 | -0.05 | 838.22 | -1.64 | 31.96 | +0.01 | .034432 | -.000010 | 393.00 | 0.00 | 81.63 | -0.02 |
| 30 | " | 369.62 | -0.13 | 85.50 | +0.50 | 955.97 | -0.58 | 36.31 | -1.07 | .029344 | +.000735 | 369.55 | -0.07 | 85.75 | +0.25 |
| 50 | " | 474.00 | 0.00 | 91.94 | +0.46 | 1462.58 | +3.23 | 38.64 | -0.11 | .028524 | +.000016 | 474.00 | 0.00 | 92.17 | +0.23 |
| 94 | " | 423.00 | 0.00 | 92.03 | +0.38 | 1213.83 | +1.98 | 46.69 | -0.04 | .025473 | +.000033 | 423.00 | 0.00 | 92.22 | +0.19 |
| 0 | " | 372.00 | 0.00 | 96.27 | -0.08 | 1190.64 | -1.34 | 53.59 | -0.03 | .022388 | +.000013 | 372.00 | 0.00 | 96.23 | -0.04 |
| 20 | " | 371.00 | 0.00 | 97.52 | -0.13 | 1192.38 | -1.09 | 55.65 | -0.15 | .022272 | +.000067 | 371.00 | 0.00 | 97.46 | -0.06 |
| 30 | " | 419.00 | 0.00 | 94.31 | -0.01 | 1201.40 | +0.20 | 57.46 | -0.02 | .021931 | +.000004 | 419.00 | 0.00 | 94.30 | -0.01 |
| 40 | " | 424.00 | 0.00 | 94.21 | -0.01 | 1194.05 | -0.85 | 57.66 | +0.01 | .022198 | .000000 | 424.00 | 0.00 | 94.20 | -0.01 |
| 40 | " | 372.00 | 0.00 | 104.83 | -0.02 | 1442.47 | -1.08 | 77.14 | +0.01 | .022400 | .000000 | 372.00 | 0.00 | 104.82 | -0.01 |
| 30 | " | 404.00 | 0.00 | 113.10 | +0.02 | 1998.95 | -0.15 | 55.89 | +0.01 | .022546 | -.000008 | 404.00 | 0.00 | 113.11 | +0.01 |
| .39 | -0.14 | 402.14 | +0.38 | 91.12 | -0.13 | 1565.97 | -6.26 | 36.34 | +0.01 | .023150 | +.000022 | 402.33 | +0.19 | 91.06 | -0.06 |

CALCULATIONS BY CLINTON H. HAVILL
LIEUT., U.S. NAVY.

# TABLE VI

## PRELIMINARY CALCULATIONS

FIGURES ON THIS SHEET ARE ONLY APPROXIMATE.

| ITEM | $H.P._{MAX.}$ 8TH APPROX. | K (PROP. COEFF) 8TH APP. | C (DRAG COEFF) 8TH APPROX. | E (PROP. EFF) 8TH APP | $A_P$ AREA OF DRAG POWER ON SQ. FT. 8TH APP. | $V_{MAX.}$ FT./SEC 9TH APP. | $\Delta V_{MAX}$ $(v_9 - v_8)$ FT./SEC. | $H.P._{MAX.}$ 9TH APPROX. | $\Delta H.P.$ $HP_9 - HP_8$ | K (PROP. COEFF) 9TH APP | $\Delta K$ $K_9 - K_8$ | C (DRAG COEFF) 9TH APPROX. | $\Delta C$ $(C_9 - C_8)$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 99.73 | 27.40 | .045591 | .622 | 87.40 | 69.00 | 0.00 | 99.59 | -0.14 | 27.51 | +0.11 | .045586 | -.000005 |
| 2 | 298.22 | 31.54 | .040031 | .631 | 127.40 | 88.00 | 0.00 | 297.33 | -0.89 | 31.56 | +0.02 | .039962 | -.000069 |
| 3 | 250.00 | 32.94 | .039595 | .650 | 132.75 | 83.68 | -0.57 | 250.00 | 0.00 | 32.86 | -0.08 | .039699 | +.000104 |
| 4 | 151.55 | 32.94 | .037582 | .610 | 78.00 | 82.20 | 0.00 | 152.33 | +0.78 | 32.75 | -0.19 | .037572 | -.000010 |
| 5 | 125.90 | 32.95 | .037673 | .620 | 78.75 | 77.30 | 0.00 | 126.35 | +0.45 | 32.81 | -0.14 | .037809 | +.000136 |
| 6 | 959.45 | 68.07 | .019583 | .660 | 168.25 | 120.02 | -0.03 | 959.17 | -0.28 | 67.41 | -0.66 | .019680 | +.000097 |
| 7 | 2023.50 | 63.75 | .018213 | .580 | 358.50 | 115.00 | 0.00 | 2020.25 | -3.25 | 63.88 | +0.13 | .018169 | -.000044 |
| 8 | 28.32 | 15.48 | .046466 | .360 | 252.01 | 26.40 | 0.00 | 27.98 | -0.34 | 15.53 | +0.05 | .046350 | -.000116 |
| 9 | 201.45 | 10.19 | .054990 | .280 | 390.00 | 41.00 | 0.00 | 202.18 | +0.73 | 10.13 | -0.06 | .055285 | +.000295 |
| 10 | 351.67 | 14.28 | .046232 | .330 | 374.00 | 52.13 | -0.12 | 347.50 | -4.17 | 14.32 | +0.04 | .046097 | -.000135 |
| 11 | 448.96 | 18.42 | .071435 | .678 | 563.00 | 62.40 | 0.00 | 448.43 | -0.53 | 18.43 | +0.01 | .071403 | -.000032 |
| 12 | 489.45 | 23.27 | .050995 | .570 | 412.00 | 67.62 | -0.13 | 484.17 | -5.28 | 23.81 | +0.64 | .050592 | -.000403 |
| 13 | 561.35 | 18.14 | .057324 | .520 | 482.00 | 66.77 | -0.08 | 577.03 | +15.68 | 18.27 | +0.13 | .056935 | -.000389 |
| 14 | 611.36 | 23.00 | .045549 | .530 | 409.00 | 71.05 | -0.15 | 602.03 | -9.33 | 23.20 | +0.20 | .045423 | -.000126 |
| 15 | 608.67 | 30.09 | .036330 | .540 | 333.99 | 77.22 | -0.13 | 600.51 | -8.61 | 30.29 | +0.20 | .036295 | -.000035 |
| 16 | 843.24 | 31.93 | .034467 | .550 | 393.00 | 81.70 | -0.10 | 839.86 | -3.38 | 31.95 | +0.02 | .034442 | -.000020 |
| 17 | 957.70 | 39.52 | .027139 | .530 | 369.75 | 85.00 | +1.00 | 956.55 | -1.15 | 37.38 | -2.14 | .028609 | +.001470 |
| 18 | 1452.90 | 38.97 | .028472 | .550 | 474.00 | 91.48 | +0.93 | 1459.35 | +6.45 | 38.75 | -0.22 | .028508 | +.000036 |
| 19 | 1207.90 | 46.82 | .025386 | .574 | 423.00 | 91.65 | +0.95 | 1211.85 | +3.95 | 46.73 | -0.09 | .025440 | +.000066 |
| 20 | 1194.65 | 53.68 | .022350 | .600 | 372.00 | 96.35 | -0.15 | 1191.98 | -2.67 | 56.32 | -0.06 | .022375 | +.000025 |
| 21 | 1195.65 | 56.10 | .022070 | .620 | 371.00 | 97.65 | -0.25 | 1193.47 | -2.18 | 55.80 | -0.30 | .022205 | +.000135 |
| 22 | 1200.80 | 57.52 | .021918 | .630 | 419.00 | 94.32 | 0.03 | 1201.20 | +0.40 | 57.48 | -0.04 | .021927 | +.000009 |
| 23 | 1196.60 | 57.63 | .022199 | .640 | 424.00 | 94.22 | -0.03 | 1194.90 | -1.70 | 57.65 | +0.02 | .022198 | -.000001 |
| 24 | 1445.70 | 57.12 | .022400 | .640 | 372.00 | 104.85 | -0.05 | 1443.55 | -2.15 | 57.13 | +0.01 | .022400 | .000000 |
| 25 | 1999.40 | 55.85 | .022569 | .630 | 404.00 | 113.08 | +0.03 | 1999.10 | -0.30 | 55.88 | +0.03 | .022554 | -.000015 |
| 26 | 1584.75 | 36.32 | .023085 | .453 | 401.76 | 91.25 | -0.25 | 1572.23 | -12.52 | 36.33 | +0.01 | .023128 | +.000043 |

| AL ES | $A + A_{P_1} - \frac{2V_M}{S}$ $S_1 = \frac{2V_M}{A + A_P}$ (ft) | $S_{P_1} = \frac{2V_M}{A_{P_1}}$ (ft) | $S - S_P$ $\Delta S$ Due to Drag of Stopped Propeller $\tau_{(ft)}$ | $\Delta S$ No Eng. $\Delta S$ Per Eng. | Av $\Delta S$ x No Engs 129 x No Eng. | $S_1 + \Delta S_1 = S_{P_2}$ | $S_P - \Delta S_1$ $S_2$ | $S_1 + S_2 = S_3$ | $S_{P_1} + S_{P_2} = S_{P_3}$ | Area of Drag $A_s$ $\frac{2V_M}{S_3}$ Sq Ft | Area of Drag $A_{P_3}$ $\frac{2V_M}{S_{P_3}}$ Sq Ft | Area of Drag Avg Power Off A | Area of Drag Avg Power On $A_P$ | Average Points (Comp Plot.) | Area of Drag $A_P$ Power On Take Off | Area of Drag A Power Off Take Off | Drag Avg. Ft. Sec. (Approx) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 80 | 1931 | 2068 | 137 | 137 | 12.9 | 2060 | 1931 | 1934 | 2064 | 93.4 | 87.4 | 93.4 | 87.4 | 87 | 87.4 | 94 | 69.00 |
| 10 | 2810 | 2961 | 151 | 15.5 | 258 | 3068 | 2703 | 2786 | 2984 | 136 | 127 | 138 | 177.4 | | 127.4 | 141 | 88.00 |
| 10 | 2790 | 3047 | 257 | 128.5 | 258 | 3048 | 2789 | 2799 | 3047 | 148 | 135 | 145 | 133 | 130 | 131.5 | 146 | 84.0: |
| 20 | 2360 | 2540 | 180 | 180 | 129 | 2489 | 2411 | 2385 | 2514 | 83.6 | 79.6 | 84 | 78 | | 78 | 84.5 | 82.20 |
| 20 | 2380 | 2560 | 180 | 180 | 129 | 2509 | 2431 | 2405 | 2534 | 83.1 | 79.9 | 83.5 | 78.5 | | 79 | 85.5 | 77.30 |
| 20 | 8700 | 9840 | 1140 | 285 | 516 | 9216 | 9324 | 9012 | 9528 | 184 | 174 | 187 | 170 | | 170 | 200 | 120.05 |
| 61 | 14700 | 15900 | 1200 | 250 | 645 | 15345 | 15255 | 14977 | 15622 | 383 | 366 | 387 | 363 | 353 | 357 | 389 | 115.00 |
| 10 | 3070 | 3220 | 150 | 75 | 258 | 3328 | 2942 | 3016 | 3274 | 272 | 249 | 268 | 251 | | 251 | 268 | 26.40 |
| 00 | 3000 | 3100 | 100 | 50 | 258 | 3258 | 2842 | 2921 | 3179 | 398 | 292 | 392 | 383 | | 383 | 397 | 4 .00 |
| 70 | 3762 | 3941 | 179 | 59.6 | 377 | 4139 | 3564 | 3663 | 4040 | 407 | 370 | 401 | 374 | | 374 | 394 | 52.25 |
| 30 | 1887 | 2280 | 393 | 131 | 377 | 2264 | 1903 | 1900 | 2272 | 676 | 566 | 679 | 567 | 565 | 563 | 583 | 62.40 |
| 10 | 3580 | 3660 | 120 | 40 | 377 | 3957 | 3283 | 3431 | 3908 | 446 | 399 | 445 | 412 | | 412 | 433 | 67.75 |
| 10 | 3199 | 3241 | 42 | 14 | 377 | 3576 | 2864 | 3031 | 3408 | 528 | 470 | 520 | 482 | | 482 | 905 | 66.85 |
| 10 | 4050 | 4220 | 170 | 56.7 | 377 | 4427 | 3343 | 3946 | 4323 | 442 | 404 | 437 | 409 | | 409 | 430 | 71.20 |
| 40 | 5110 | 5390 | 280 | 93 | 377 | 5487 | 5013 | 5112 | 5436 | 353 | 332 | 353 | 334 | | 334 | 353 | 77.35 |
| 00 | 5960 | 6360 | 400 | 100 | 516 | 6476 | 5844 | 5952 | 6418 | 420 | 391 | 419 | 393 | | 393 | 419 | 81.80 |
| 00 | 8660 | 9360 | 700 | 175 | 516 | 9176 | 8844 | 8752 | 9268 | 318 | 361 | 380 | 369 | | 370 | 399 | 84.00 |
| 20 | 8660 | 9360 | 700 | 116.6 | 714 | 8434 | 8536 | 8623 | 8897 | 513 | 496 | 511 | 484 | 464 | 474 | 512 | 90.5 |
| 20 | 9760 | 10040 | 280 | 56 | 645 | 10405 | 9395 | 9577 | 10222 | 451 | 431 | 451 | 426 | 420 | 423 | 455 | 96.10 |
| 20 | 11100 | 11910 | 810 | 162 | 645 | 11745 | 11265 | 11182 | 11827 | 393 | 373 | 397 | 372 | | 372 | 403 | 96.50 |
| 20 | 11240 | 12210 | 970 | 195 | 645 | 11885 | 11565 | 11402 | 11547 | 386 | 361 | 387 | 371 | | 371 | 403 | 97.97 |
| 20 | 12200 | 12900 | 700 | 140 | 645 | 12845 | 12255 | 12227 | 12872 | 440 | 420 | 444 | 417 | 418 | 417 | 452 | 94.3 |
| 20 | 11920 | 12710 | 790 | 158 | 645 | 12565 | 12065 | 11992 | 12637 | 451 | 427 | 453 | 423 | 425 | 424 | 457 | 94.25 |
| 20 | 11200 | 11820 | 620 | 124 | 645 | 11845 | 11175 | 11187 | 11872 | 397 | 372 | 399 | 372 | | 372 | 403 | 104.9 |
| 20 | 11610 | 12300 | 690 | 138 | 645 | 12255 | 11655 | 11632 | 12277 | 414 | 402 | 424 | 403 | 405 | 404 | 435 | 1.3.05 |
| 81 | 10920 | 11720 | 800 | 160 | 645 | 11565 | 10975 | 10992 | 11642 | 428 | 434 | 430 | [illegible] | 401 | 401 | 434 | 91.50 |
| | Power Off. | Power On. | | | | Power On | Power Off. | Power Off. | Power On | Power Off. | Power On | | | | | | |

CALCULATIONS BY CLINTON H. HAWKES
LT, U.S. NAVY.

| $(v)^3$ Poly 550 K (Lat) η .62 | $v'$ Ft. Sec η .62 2nd Appr. | $v_{max}$ (Lat) Ft. Sec | $K'''$ Approx Drag Coeff | $\eta'$ Approx Over Eff (Approx) B | $v''$ Ft. Sec 3rd Appr. | H.P. Full Rated H.P. Element | $(v'')^3$ Poly 550 K (Lat) | $v'$ Ft. Sec 4th Appr. | H.P. 4th Appr. | $v_{max}'''$ Ft. Sec 4th Appr. | $K''$ 4th Appr. | $\eta'''$ 4th Appr. | $K'$ Approx 5th Appr. | H.P. 5th Appr. | $v'$ Ft. Sec 5th Appr. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 374000 | 68.9 | 69.0 | .0232 | .67 | 69.0 | 100 | 374000 | 68.9 | 100 | 69.0 | .02785 | .62 | .0457 | 100 | 69.0 |
| 423000 | 75.1 | 88.0 | .0280 | .67 | 80.5 | 300 | 523000 | 80.6 | 300 | 80.6 | .0280 | .67 | .0560 | 300 | 88.0 |
| 376000 | 72.2 | 85.1 | .0279 | .67 | 75.1 | 250 | 422000 | 75.1 | 250 | 75.1 | .0271 | .67 | .0554 | 250 | 85.1 |
| 422000 | 75.1 | 82.2 | .0236 | .64 | 76.8 | 150 | 452000 | 76.8 | 150 | 76.8 | .0236 | .64 | .0412 | 150 | 82.2 |
| 298000 | 66.9 | 77.3 | .0246 | .62 | 70.9 | 125 | 352000 | 70.6 | 125 | 70.9 | .0246 | .62 | .0492 | 125 | 77.3 |
| 974000 | 99.2 | 121.5 | .0172 | .68 | 107.4 | 980 | 1270000 | 107.8 | 980 | 107.8 | .0146 | .68 | .0200 | 960 | 121.0 |
| 887000 | 96.3 | 110.0 | .0165 | .69 | 105.1 | 2050 | 1015000 | 100.2 | 2050 | 105.1 | .0166 | .69 | .0180 | 2030 | 115.0 |
| | | | | | | | | | | | | | | | |
| 16400 | 25.7 | 26.4 | .0405 | .60 | 26.2 | 29 | 14400 | 26.3 | 29 | 26.3 | .0405 | .59 | .0462 | 29 | 26.4 |
| 504000 | 79.1 | 41.0 | .0419 | .58 | 43.0 | 170 | 79600 | 43.1 | 170 | 43.1 | .0406 | .58 | .0460 | 200 | 41.0 |
| 924000 | 91.3 | 52.5 | .0490 | .60 | 52.5 | 360 | 126000 | 50.1 | 360 | 50.1 | .0492 | .60 | .0450 | 360 | 52.5 |
| 177000 | 56.2 | 62.3 | .0690 | .67 | 62.3 | 464 | 133000 | 51.1 | 475 | 51.5 | .0690 | .67 | .0715 | 450 | 62.4 |
| 208200 | 59.1 | 67.9 | .0440 | .65 | 65.0 | 510 | 213200 | 59.9 | 520 | 61.7 | .0410 | .65 | .0430 | 500 | 67.9 |
| 301800 | 67.1 | 67.0 | .0292 | .62 | 63.0 | 530 | 307000 | 67.1 | 530 | 67.1 | .0302 | .62 | .0330 | 530 | 67.0 |
| 447000 | 76.8 | 71.5 | .0303 | .58 | 71.0 | 635 | 314000 | 68.0 | 635 | 68.0 | .03047 | .58 | .0310 | 630 | 71.5 |
| 323400 | 68.9 | 77.6 | .0290 | .62 | 76.0 | 635 | 342000 | 69.9 | 640 | 72.3 | .0290 | .62 | .0280 | 625 | 77.6 |
| 395900 | 73.9 | 82.0 | .0260 | .58 | 82.0 | 860 | 392000 | 74.0 | 860 | 75.1 | .0290 | .60 | .0260 | 850 | 82.0 |
| 416000 | 74.5 | 82.0 | .0270 | .59 | 82.0 | 960 | 396000 | 74.1 | 960 | 75.1 | .0260 | .61 | .0269 | 960 | 82.0 |
| 676000 | 85.3 | 88.7 | .0200 | .63 | 86.0 | 1440 | 635000 | 85.9 | 1440 | 87.0 | .0280 | .63 | .0274 | 1440 | 88.7 |
| 348000 | 70.1 | 88.8 | .0240 | .57 | 78.0 | 1230 | 405000 | 74.3 | 1260 | 74.4 | .0240 | .57 | .0312 | 1270 | 88.8 |
| 463000 | 77.6 | 96.8 | .0230 | .64 | 94.0 | 1200 | 467000 | 71.5 | 1260 | 86.0 | .0220 | .64 | .0243 | 1200 | 96.8 |
| 473000 | 77.9 | 98.4 | .0210 | .67 | 900 | 1320 | 588000 | 83.4 | 1360 | 84.7 | .0210 | .67 | .0232 | 1200 | 98.4 |
| 410100 | 74.2 | 94.4 | .0220 | .67 | 94.4 | 1320 | 502000 | 79.2 | 1360 | 80.7 | .0220 | .65 | .0229 | 1200 | 94.4 |
| 427000 | 75.1 | 94.3 | .0210 | .66 | 94.3 | 1320 | [illegible] | 79.4 | 1360 | 81.1 | .0210 | .68 | .0222 | 1200 | 94.3 |
| 478000 | 78.1 | 105.0 | .0200 | .66 | 105.0 | 1460 | 62[illegible]000 | 85.5 | 1490 | 92.6 | .0200 | .67 | .0224 | 1450 | 105.0 |
| 817000 | 93.1 | 113.2 | .0200 | .65 | 113.2 | 2140 | 70[illegible]000 | 76.8 | 2150 | 77.5 | .0200 | .67 | .0226 | 2000 | 113.0 |
| 759000 | 91.2 | 97.0 | .0207 | .64 | 97.0 | 1[illegible] | 6[illegible]1000 | 86.7 | 1580 | 85.[illegible] | .0210 | .62 | .0230 | 1610 | 92.0 |

CALCULATIONS BY CLINTON H. HAVILL
LIEUT, U.S. NAVY.

PR[illegible] CALCULATIONS

FIGURE [illegible] SECTOR ONLY APPLICABLE

| ITEM | [illegible] Due To Envel. (%) | [illegible] To 88° Sec (LBS) | To A. Of [illegible] @ 88° Sec (LBS) | [illegible] 88° Sec (LBS) | K' [illegible] | HP₀ ÷ 550 62' | KC(Vol.) (C .0237) [illegible]/FT. | U' [illegible] / KC(Vol.) | U Ideal (Calc) ÷ .62 FT/Sec 1ST App. | [illegible] /Sec | [illegible] Calc − Prop F/Sec | U' (Assume Adj. From Model Ation Where Possible) | [illegible] X K K | KC(Vol.) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 37.1 | 7.98 | 718 | 502 | .0428 | 24100 | .0648 | 526000 | 80.7 | 69.0 | +11.1 | .0232 | .633 | .1052 |
| 2 | 38.4 | 11.56 | 1158 | 713 | [illegible] | 102300 | .1495 | 686000 | 88.2 | 88.0 | 0.2 | .0322 | 1.633 | .2430 |
| 3 | 43.2 | 10.72 | 1012 | 608 | .01770 | 85250 | .138[illegible] | 614000 | 85.0 | 85.1 | −0.1 | .0289 | 1.633 | .2262 |
| 4 | 64.5 | 5.76 | 516 | 176 | .01510 | 51150 | .0747 | 686000 | 88.2 | 82.2 | +6.0 | .0246 | 1.633 | .1216 |
| 5 | 58.3 | 6.87 | 681 | 287 | .01110 | 42600 | .0816 | 486000 | 78.6 | 77.3 | +1.3 | .0289 | 1.633 | .1430 |
| 6 | 92.06 | 14.3 | 1430 | 120 | .00910 | 321360 | .1849 | 1736000 | 120.1 | 121.5 | −1.4 | .0149 | 1.633 | .3300 |
| 7 | 69.5 | 37.9 | 3790 | 1120 | .01090 | 682000 | .489 | 1395000 | 111.9 | 110.0 | +1.9 | .0165 | 1.570 | .7690 |
| 8 | 19.6 | 3.41 | 3410 | 2742 | .03420 | 9880 | .441 | 22380 | 28.1 | 26.4 | +1.7 | .0468 | 1.372 | .6020 |
| 9 | 12.0 | 76.6 | 7660 | 6140 | .06075 | 68200 | .991 | 68800 | 41.1 | 41.0 | −0.1 | .0834 | 1.372 | 1.3520 |
| 10 | 14.1 | 74.4 | 7440 | 6381 | .04970 | 12280 | .958 | 128700 | 50.7 | 52.5 | −1.8 | .0690 | 1.372 | 1.3300 |
| 11 | 21.2 | 48.4 | 4840 | 3818 | .03342 | 151200 | .624 | 243000 | 62.8 | 62.3 | +0.5 | .0459 | 1.374 | .8560 |
| 12 | 24.1 | 45.3 | 4530 | 3440 | .03018 | 168000 | .587 | 286200 | 65.9 | 67.9 | −2.0 | .0414 | 1.374 | .8060 |
| 13 | 36.5 | 32.1 | 3210 | 2040 | .02053 | 177900 | .283 | 367900 | 71.5 | 67.0 | +4.5 | .0292 | 1.374 | .5400 |
| 14 | 24.7 | 48.4 | 4840 | 3647 | .01928 | 214200 | .626 | 343000 | 70.0 | 71.5 | −1.5 | .0403 | 1.374 | .8610 |
| 15 | 36.7 | 36.7 | 3670 | 2368 | .02180 | 212000 | .477 | 444000 | 76.2 | 77.6 | −1.4 | .0300 | 1.374 | .6555 |
| 16 | 37.6 | 40.7 | 4070 | 2540 | .01960 | 287000 | [illegible] | 562000 | 82.4 | 82.0 | +0.4 | .0267 | 1.374 | .7230 |
| 17 | 37.8 | 44.2 | 4470 | 2750 | .01959 | 327000 | [illegible] | 576000 | 83.2 | 82.0 | +1.2 | .0270 | 1.376 | .7860 |
| 18 | 41.9 | 54.8 | 5480 | 3192 | .01799 | 471040 | .708 | 670000 | 86.8 | 88.7 | −0.1 | .0200 | 1.120 | .1880 |
| 19 | 50.6 | 45.0 | 4500 | 2720 | .01462 | 409700 | .583 | 703000 | 88.9 | 88.8 | +0.1 | .0299 | 2.021 | 1.1780 |
| 20 | 65.8 | 34.7 | 3470 | 1170 | .01135 | 409700 | [illegible] | [illegible]000 | 97.1 | 96.8 | +0.3 | .0276 | 2.021 | .8800 |
| 21 | 68.5 | 33.3 | 3330 | 1[illegible] | .01088 | 409700 | .427 | 957000 | 98.3 | 98.4 | −0.1 | .0220 | 2.021 | .8650 |
| 22 | 66.7 | 37.6 | 3760 | 1[illegible] | .01074 | 409700 | .467 | 837000 | 94.1 | 94.4 | −0.3 | .0220 | 2.030 | .9960 |
| 23 | 66.1 | 37.9 | 3790 | 1288 | .01061 | 409700 | [illegible] | 834900 | 94.1 | 94.3 | −0.2 | .0210 | 1.940 | .9520 |
| 24 | 69.0 | 33.1 | 3310 | 1030 | .01082 | 494250 | [illegible] | 861000 | 95.2 | 105.0 | −9.8 | .0217 | 2.030 | .8550 |
| 25 | 61.1 | 41.8 | 4180 | 1620 | .01267 | 692230 | .53[illegible] | 1271000 | 108.8 | 113.2 | −4.4 | .0200 | 1.582 | .8280 |
| 26 | 57.6 | 41.6 | 4160 | 1762 | .01310 | 646500 | [illegible] | 1201000 | 106.7 | 97.0 | +9.7 | .0207 | 1.580 | .8510 |
| | | | $K_{sr}$ | $K_{sr}$ [illegible] | $K_{sr}$ (Volume) .00237 0.88 | | | | | | | | | |

| S.F. @ 88 Ft/Sec (Lbs) .03385 $A_2^{3/2}$ | .00166 ℓ Emp. Const. For Effect 1st Approx. | .0000476 $\ell \times \frac{V^x}{AL} \times \frac{L}{D}$ 1st Approx. | Approximate Drag Coefficient Due To: Pressure Diff. $K_p$ | Skin Friction $K_s$ | Hull $K$ | % Drag Due To S.F. (%) | Drag Of Hull At 88 Ft/Sec (Lbs) | Max. Vel. Reported Ft/Sec (U) | $U^2$ | Drag At Rep. U Max. Lbs (Hull Only) | Thrust = HP × .62 (.62 Assumed) | Thrust At Rep U Max .62 HP 550 / U Max. | Drag Due To Cars, Fins Etc (Lbs.) | % Total Drag Due To Cars Etc % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| .242 | .00158 | -.0001055 | .001475 | .00693 | .008405 | 82.4 | 296 | 69.0 | 4761 | 184 | 62 | 495 | 311 | 62.9 |
| 361 | .00155 | -.0001360 | .001414 | .00618 | .007594 | 81.6 | 445 | 88.0 | 7774 | 445 | 186 | 1161 | 716 | 61.6 |
| 380 | .00155 | -.0001616 | .001388 | .00625 | .007638 | 81.9 | 464 | 85.1 | 7242 | 432 | 155 | 1002 | 570 | 56.8 |
| 345 | .00159 | -.0001473 | .001453 | .00903 | .010483 | 86.2 | 400 | 88.2 | 7779 | 403 | 93 | 580 | 177 | 30.5 |
| 345 | .00159 | -.0001473 | .001453 | .00903 | .010483 | 86.2 | 400 | 77.3 | 5975 | 309 | 77.5 | 551 | 242 | 41.7 |
| 1086 | .00161 | -.0001920 | .001418 | .00689 | .008308 | 82.8 | 1310 | 121.5 | 14762 | 2495 | 595.2 | 2710 | 215 | 7.94 |
| 2162 | .00162 | -.0002190 | .001401 | .00601 | .007411 | 81.2 | 2670 | 110.0 | 12100 | 4170 | 1240 | 6200 | 2030 | 30.5 |
| 694 | .00161 | -.0003421 | .001268 | .00698 | .008248 | 84.7 | 668 | 26.4 | 697 | 73.8 | 18 | 374 | 300 | 80.4 |
| 768 | .00163 | -.0004380 | .001192 | .00608 | .007272 | 83.6 | 920 | 41.0 | 1681 | 199.5 | 124 | 1662 | 1462 | 88.0 |
| 884 | .00163 | -.0004640 | .001164 | .00593 | .007094 | 83.7 | 1059 | 52.5 | 2756 | 376 | 223.2 | 2340 | 1964 | 83.9 |
| 844 | .00162 | -.0003870 | .001243 | .00583 | .007073 | 82.6 | 1022 | 62.3 | 3881 | 514 | 275.3 | 2430 | 1916 | 78.8 |
| 905 | .00162 | -.0003860 | .001234 | .00601 | .007244 | 83.1 | 1090 | 67.9 | 4610 | 650 | 306.9 | 2490 | 1840 | 73.9 |
| 978 | .00162 | -.0004020 | .001218 | .00626 | .007478 | 83.7 | 1170 | 67.0 | 4489 | 677 | 325 | 1850 | 1173 | 63.5 |
| 999 | .00161 | -.0004380 | .001182 | .00604 | .007222 | 83.7 | 1198 | 71.5 | 5112 | 740 | 390 | 3000 | 2260 | 75.3 |
| 1089 | .00160 | -.0003590 | .001241 | .00643 | .007671 | 83.8 | 1322 | 77.6 | 6022 | 1010 | 385.6 | 2730 | 1720 | 63.1 |
| 1262 | .00159 | -.0003022 | .001288 | .00603 | .007318 | 82.4 | 1530 | 82.0 | 6724 | 1332 | 527 | 3540 | 2208 | 62.4 |
| 1388 | .00159 | -.0003342 | .001256 | .00616 | .007416 | 83.2 | 1670 | 82.0 | 6724 | 1510 | 595.2 | 3980 | 2470 | 62.2 |
| 1866 | .00162 | -.0002640 | .001356 | .00612 | .007476 | 81.9 | 2288 | 88.7 | 7867 | 2320 | 892.8 | 5530 | 3210 | 58.1 |
| 1870 | .00162 | -.0002621 | .001358 | .00613 | .007486 | 82.0 | 2280 | 88.8 | 7885 | 2324 | 744 | 4600 | 2276 | 49.4 |
| 1870 | .00162 | -.0002621 | .001358 | .00613 | .007488 | 82.0 | 2280 | 96.8 | 9370 | 2781 | 744 | 4230 | 1449 | 34.2 |
| 1872 | .00162 | -.0002624 | .001358 | .00612 | .007478 | 81.9 | 2280 | 98.4 | 9682 | 2850 | 744 | 4160 | 1310 | 31.5 |
| 2036 | .00162 | .0002800 | .001340 | .00580 | .007140 | 81.3 | 2502 | 94.4 | 8911 | 2890 | 744 | 4330 | 1440 | 33.3 |
| 2036 | .00162 | -.0002800 | .001340 | .00580 | .007140 | 81.3 | 2502 | 94.3 | 8892 | 2870 | 744 | 4340 | 1470 | 33.9 |
| 1870 | .00162 | -.0002621 | .001358 | .00613 | .007488 | 81.7 | 2280 | 105.0 | 11025 | 3242 | 899 | 4700 | 1458 | 31.0 |
| 2124 | .00162 | -.0003038 | .001316 | .00646 | .007776 | 82.9 | 2560 | 113.2 | 12814 | 3740 | 1258.6 | 6120 | 2380 | 38.9 |
| 1970 | .00162 | .0002779 | .001342 | .00614 | .007532 | 82.2 | 2398 | 97.0 | 9409 | 3040 | 930 | 5280 | 2240 | 42.4 |
| .03385 $A_2^{3/2}$ | .00166 ℓ | | Approaches True Coeff. | | | | $KCU^2(V)^3$ C=.00237 | | | $KCU^2(V)^3$ C=.00237 | | | At U Max. Approx. | |

Calculations by Clinton H. Havill
Lieut., U. S. Navy.

# TABLE III

## PRELIMINARY CALCULATIONS

FIGURES ON THIS SHEET ARE ONLY APPROXIMATE.

| ITEM | Ecc × Cyl Coeff. | % Of Hull Drag Due To Skin Friction (Approximate Empirical) | Ecc. × Cyl Coeff × $\frac{L}{D}$ | Drag Coeff Due To S. F 1st Approx. | $\sqrt{VL}$ (Sq. Ft) | Total Surface Area (Sq. Ft) | $\frac{V}{D}$ (Sq Ft) | $5.94\sqrt{VL}$ | $-3.49\frac{V}{D}$ | $A_s^{.93}$ | $88^{1.86}$ (60 M/H = 88 Ft/Sec) | .000008193 × $88^{1.86}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | .458 | .58675 | 2.21 | .00446 | 3700.4 | 13950 | 2301 | 21980 | − 8030 | 7152 | 4137.4 | .03385 |
| 2 | .621 | .56629 | 2.86 | .00430 | 5939.7 | 21424 | 4286 | 35382 | − 14958 | 10660 | " | " |
| 3 | .647 | .56481 | 3.40 | .00429 | 6133.6 | 23061 | 4524 | 36434 | − 15788 | 11415 | " | " |
| 4 | .637 | .58362 | 3.10 | .00443 | 3923.0 | 20404 | 2836 | 23303 | − 9898 | 10187 | " | " |
| 5 | .637 | .58362 | 3.10 | .00443 | 3923.0 | 20404 | 2836 | 23303 | − 9898 | 10187 | " | " |
| 6 | .604 | .52800 | 4.04 | .00401 | 18448.0 | 69990 | 11427 | 109800 | − 39810 | 32055 | " | " |
| 7 | .636 | .48669 | 4.61 | .00371 | 42660.0 | 147027 | 30483 | 253413 | −106386 | 63915 | " | " |
| 8 | .705 | .54538 | 7.20 | .00414 | 13084 | 41100 | 10471 | 77610 | − 36510 | 20459 | 4137.4 | .03385 |
| 9 | .879 | .53629 | 9.21 | .00408 | 15973 | 48180 | 13396 | 98430 | − 46650 | 22650 | " | " |
| 10 | .901 | .53004 | 9.76 | .00403 | 18888 | 56300 | 15991 | 112100 | − 55800 | 26180 | " | " |
| 11 | .814 | .53385 | 8.14 | .00406 | 17037 | 53400 | 13748 | 101300 | − 47900 | 24924 | " | " |
| 12 | .839 | .52971 | 8.12 | .00402 | 18620 | 57600 | 15246 | 110800 | − 53200 | 26742 | " | " |
| 13 | .807 | .52831 | 8.45 | .00402 | 20084 | 62650 | 16127 | 119000 | − 56350 | 28916 | " | " |
| 14 | .870 | .52625 | 9.21 | .00400 | 21103 | 64000 | 17681 | 125300 | − 61300 | 29495 | " | " |
| 15 | .749 | .52447 | 7.55 | .00399 | 21645 | 70300 | 16806 | 128900 | − 58600 | 32186 | " | " |
| 16 | .734 | .51745 | 6.36 | .00393 | 25572 | 82400 | 19741 | 151300 | − 68900 | 37309 | " | " |
| 17 | .741 | .51485 | 7.05 | .00391 | 28262 | 91000 | 22055 | 167900 | − 76900 | 40916 | " | " |
| 18 | .674 | .50394 | 5.55 | .00383 | 37230 | 125200 | 27446 | 221000 | − 95800 | 55051 | " | " |
| 19 | .671 | .50401 | 5.52 | .00383 | 37148 | 125430 | 27331 | 220736 | − 95200 | 55149 | " | " |
| 20 | .671 | .50401 | 5.52 | .00383 | 37148 | 125436 | 27331 | 220736 | − 95200 | 55149 | " | " |
| 21 | .672 | .50400 | 5.53 | .00383 | 37161 | 125500 | 27344 | 220800 | − 95300 | 55174 | " | " |
| 22 | .619 | .49910 | 5.89 | .00379 | 44349 | 146200 | 33716 | 263800 | −117600 | 61010 | " | " |
| 23 | .619 | .49910 | 5.89 | .00379 | 44349 | 146200 | 33716 | 263800 | −117600 | 61010 | " | " |
| 24 | .672 | .50400 | 5.53 | .00383 | 37161 | 125436 | 27344 | 220736 | − 95300 | 55149 | " | " |
| 25 | .671 | .50134 | 6.38 | .00381 | 42285 | 144173 | 30651 | 261173 | −107000 | 62784 | " | " |
| 26 | .676 | .50244 | 5.84 | .00382 | 39465 | 132889 | 29096 | 234422 | −101535 | 58187 | " | " |
| | $\frac{V}{AL}$ | $V^{.047}$ | | $.0076V^{.047}$ | $\sqrt{VL}$ | $A_s$ | $\frac{V}{D}$ | $5.94\sqrt{VL}$ | $-3.49\frac{V}{D}$ | $A_s^{.93}$ | $88^{1.86}$ | |

| $(\text{Air Volume})^{\frac{2}{3}}$ Sq. Ft. | No. Eng's | No. Gas Cells | Fineness Ratio | Max Cross Section Area Sq. Ft. | Volume of Circ. Cylinder Cu. Ft. | Cyl. Coeff. | Distance From Nose To Max. Ord. % L | Distance From Nose To Max. Ord. Ft. (x) | Max. Radius Ft. (r) | $x^2$ | $r^2$ | $x^2-r^2$ | $\sqrt{x^2-r^2}$ | Ecc. of Nose Ellipse $\frac{\sqrt{x^2-r^2}}{x}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1918 | 1 | N.R. | 4.46 | 1046 | 170900 | .482 | 37.00 | 60.4 | 18.25 | 3648.16 | 333.06 | 3315.1 | 57.58 | .954 |
| 3188 | 2 | N.R | 4.62 | 1385 | 271900 | .664 | 30.00 | 58.8 | 21.00 | 3457.44 | 441.00 | 3016.4 | 54.91 | 935 |
| 3305 | 2 | N.R | 4.72 | 1385 | 274100 | .693 | 29.70 | 58.8 | 21.00 | 3457.44 | 441.00 | 3016.4 | 54.91 | .935 |
| 2082 | 1 | N.R | 4.84 | 881 | 142500 | .667 | 36.25 | 58.7 | 16.75 | 3445.61 | 280.56 | 3165.3 | 56.27 | 956 |
| 2082 | 1 | N.R | 4.84 | 881 | 142500 | .667 | 36.25 | 58.7 | 16.75 | 3445.64 | 280.56 | 3165.3 | 56.27 | 956 |
| 8596 | 4 | | 6.70 | 2999 | 1280000 | .622 | 30.75 | 131.2 | 30.90 | 17213.44 | 954.81 | 16258.6 | 127.61 | 972 |
| 19697 | 5 | 14 | 7.25 | 6461 | 4253276 | .650 | 38.50 | 236.2 | 45.35 | 55790.44 | 2068.62 | 53721.8 | 231.78 | 978 |
| 5429 | 2 | 17 | 10.21 | 1146 | 552000 | .726 | 17.50 | 75.2 | 18.10 | 5655.04 | 327.61 | 5327.4 | 72.99 | .971 |
| 6891 | 2 | 18 | 10.50 | 1432 | 639900 | .893 | 25.80 | 114.8 | 21.35 | 13179.04 | 455.82 | 12723.2 | 112.99 | .984 |
| 8137 | 3 | 18 | 10.60 | 1655 | 804000 | .914 | 23.62 | 114.8 | 22.95 | 13179.04 | 526.70 | 12652.3 | 112.81 | .983 |
| 7888 | 3 | 17 | 10.00 | 1655 | 761300 | .829 | 25.00 | 114.8 | 22.95 | 13179.04 | 526.70 | 12652.3 | 112.81 | .983 |
| 8209 | 3 | 16 | 9.55 | 1870 | 870000 | .856 | 24.61 | 114.8 | 24.40 | 13179.04 | 595.36 | 12583.7 | 112.29 | .979 |
| 8524 | 3 | 18 | 10.48 | 1870 | 956000 | .823 | 22.40 | 114.8 | 24.40 | 13179.04 | 595.36 | 12583.7 | 112.29 | .979 |
| 9029 | 3 | 18 | 10.61 | 1870 | 969000 | .886 | 22.19 | 114.8 | 24.40 | 13179.04 | 595.36 | 12583.7 | 112.29 | .980 |
| 9211 | 3 | 15 | 10.08 | 2173 | 1148000 | .770 | 21.62 | 114.8 | 26.30 | 13179.04 | 691.69 | 12487.4 | 111.63 | .972 |
| 11417 | 4 | 16 | 8.68 | 2999 | 1600000 | .762 | 21.40 | 114.8 | 30.90 | 13179.04 | 954.81 | 12224.2 | 110.44 | .963 |
| 12284 | 4 | 18 | 9.50 | 2999 | 1750000 | .770 | 19.62 | 114.8 | 30.90 | 13179.04 | 954.81 | 12224.2 | 110.44 | .963 |
| 16652 | 6 | 19 | 8.24 | 4815 | 3105797 | .691 | 30.80 | 180.5 | 39.15 | 32580.25 | 1532.72 | 31047.5 | 176.10 | .976 |
| 16606 | 5 | 18 | 8.24 | 4815 | 3105797 | .688 | 30.80 | 180.5 | 39.15 | 32580.25 | 1532.72 | 31047.5 | 176.10 | .976 |
| 16606 | 5 | 18 | 8.24 | 4815 | 3105797 | .688 | 30.80 | 180.5 | 39.15 | 32580.25 | 1532.72 | 31047.5 | 176.10 | .976 |
| 16607 | 5 | 14 | 8.24 | 4815 | 3105797 | .689 | 30.80 | 180.5 | 39.15 | 32580.25 | 1532.72 | 31047.5 | 176.10 | .976 |
| 19101 | 5 | 16 | 9.52 | 4815 | 3587316 | .737 | 24.40 | 180.5 | 39.15 | 32580.25 | 1532.72 | 31047.5 | 176.10 | .976 |
| 19101 | 5 | 16 | 9.52 | 4815 | 3587316 | .737 | 24.40 | 180.5 | 39.15 | 32580.25 | 1532.72 | 31047.5 | 176.10 | .976 |
| 16607 | 5 | 14 | 8.24 | 4815 | 3105797 | .689 | 30.80 | 180.5 | 39.15 | 32580.25 | 1532.72 | 31047.5 | 176.10 | .976 |
| 17925 | 5 | 15 | 9.52 | 4815 | 3587316 | .688 | 24.40 | 180.5 | 39.15 | 32580.25 | 1532.72 | 31047.5 | 176.10 | .976 |
| 17372 | 5 | 20 | 8.64 | 4864 | 3308492 | .694 | 28.20 | 180.5 | 39.35 | 32580.25 | 1548.42 | 31031.8 | 176.09 | .976 |
| $V^{\frac{2}{3}}$ | | N.R. = Non Rigid. | $\frac{L}{D}$ | A | A × L | $\frac{V}{AL}$ | | x | $r = \frac{D}{2}$ | $x^2$ | $r^2$ | $x^2-r^2$ | $\sqrt{x^2-r^2}$ | $\frac{\sqrt{x^2-r^2}}{x}$ |

CALCULATIONS BY CLINTON H. HAVILL
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# TABLE II

## PRELIMINARY CALCULATIONS

FIGURES ON THIS SHEET ARE ONLY APPROXIMATE.

| ITEM | SHIP BUILDERS NUMBERS | GAS VOLUME CU FT. | LENGTH FT (L) | MAX. DIAM. FT (D) | MAX. SPEED REPORTED AV. OF DIFF. REPORTS MI/HR. | KNOTS | FT/SEC. | FULL RATED HORSE POWER | AIR VOLUME OF HULL CU. FT. |
|---|---|---|---|---|---|---|---|---|---|
| | CONTINUOUS CURVATURE SERIES | | | | | | | | |
| 1 | U.S.N. "B" | 84000 | 163 | 36.5 | 47 | 40.8 | 69 | 100 | 84000 |
| 2 | U.S.N. "C" | 180000 | 196 | 42 | 60 | 52 | 88 | 300 | 180000 |
| 3 | U.S.N. "D" | 190000 | 198 | 42 | 58 | 50.2 | 85.1 | 250 | 190000 |
| 4 | U.S.N. "E" | 95000 | 162 | 33.5 | 56 | 48.6 | 82.2 | 150 | 95000 |
| 5 | U.S.N "F" | 95000 | 162 | 33.5 | 52 | 45.1 | 77.3 | 125 | 95000 |
| 6 | LZ-120 & 121 BODENSEE (AFTER LENGTHENING) NORDSTERN | 706200 | 427 | 61.8 | 83 | 72 | 121.5 | 960 | 797000 |
| 7 | LZ-126 U.S.S. LOS ANGELES (NO WATER RECOVERY) | 2599110 | 658.3 | 90.7 | 75 | 65.1 | 110 | 2000 | 2764461 |
| | PARALLEL SECTION SERIES | | | | | | | | |
| 8 | LZ-1 | 375000 | 428 | 38.2 | 18 | 15.6 | 26.4 | 29 | 400000 |
| 9 | LZ-4 & 5 | 530000 | 446 | 42.7 | 27.9 | 24.2 | 41 | 200 | 572000 |
| 10 | LZ-7 & 8 | 680200 | 486 | 45.9 | 35.7 | 31. | 52.5 | 360 | 734000 |
| 11 | LZ-10 & 12 | 592000 | 460 | 45.9 | 42.5 | 36.8 | 62.3 | 444 | 631000 |
| 12 | LZ-15 & 16 | 688000 | 466 | 48.8 | 46.3 | 40.3 | 67.9 | 495 | 744000 |
| 13 | LZ-22 & 23 | 728000 | 512 | 48.8 | 45.6 | 39.6 | 67 | 525 | 787000 |
| 14 | LZ-24 & 25 & 27 To 35 | 794000 | 519 | 48.8 | 48.7 | 42.7 | 71.5 | 630 | 858000 |
| 15 | LZ-36 | 830000 | 530 | 52.6 | 53.0 | 46. | 77.6 | 622 | 884000 |
| 16 | LZ-42 To 50 | 1130000 | 536 | 61.8 | 55.9 | 48.6 | 82 | 850 | 1220000 |
| 17 | LZ-59 To 61; 64 To 71 EXCEPT 60 & 70. | 1262000 | 586 | 61.8 | 55.9 | 48.6 | 82 | 960 | 1363000 |
| 18 | LZ-72 To 90 EXCEPT 73, 77 & 81. | 1945000 | 645 | 78.3 | 60.4 | 52.9 | 88.7 | 1440 | 2149000 |
| 19 | LZ-91 To 94 | 1965298 | 645 | 78.3 | 60.5 | 52.9 | 88.8 | 1200 | 2140000 |
| 20 | LZ-95 To 99 | 1970000 | 645 | 78.3 | 65.9 | 57.2 | 96.8 | 1200 | 2140000 |
| 21 | LZ-100 & 101 | 1972000 | 645 | 78.3 | 67.1 | 58.3 | 98.4 | 1200 | 2141000 |
| 22 | LZ-102 | 2420000 | 745 | 78.3 | 64.5 | 55.9 | 94.4 | 1200 | 2640000 |
| 23 | LZ-104 (CALLED L-59 AFRICAN SHIP) | 2427000 | 745 | 78.3 | 64.4 | 55.9 | 94.3 | 1200 | 2640000 |
| 24 | LZ-106 To 111 | 1972000 | 645 | 78.3 | 71.5 | 62.1 | 105.0 | 1450 | 2141000 |
| 25 | LZ-112 To 114 | 2190000 | 745 | 78.3 | 77.3 | 67.1 | 113.2 | 2030 | 2400000 |
| 26 | ZR-1 U.S.S. SHENANDOAH (NO WATER RECOVERY 5 ENGINES) | 2151174 | 680.2 | 78.7 | 66.2 | 57.5 | 97.0 | 1500 | 2289864 |
| | | | L | D | | | U | HP | V |

| | PRINCIPAL DATA | | | | | | | CONSISTENT RESULTS OF PART I | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gas Volume Cu. Ft. | Length Ft. | Max. Diam. of Hull In. | Air Volume of Hull Cu. Ft. | Engines | Fineness Ratio | Total Surface Area of Hull Sq. Ft. | Maximum Speed Ft./Sec. | Mi./Hr. | Kts./Hr. | H.P.$_{max}$ | K* Prop Coeff. | F* Prop Eff. | $A_p$* Disk Area Engine On | C* (Whole Ship) |
| | 84000 | 185 | 36.5 | 84000 | 1 | 5.06 | 13750 | 69.00 | 47.04 | 40.86 | [illegible].46 | 27.63 | .622 | 87.40 | .045582 |
| | 180000 | 196 | [illegible] | 180000 | 2 | 4.62 | 21474 | 88.00 | 60.00 | [illegible] | 296.42 | 31.59 | .631 | 127.40 | .031962 |
| | 190000 | 198 | 47 | 190000 | 2 | 4.72 | [illegible] | 83.11 | 56.66 | 49.21 | 290.00 | 32.78 | .650 | 131.49 | .039801 |
| | 95000 | 167 | 33.5 | 95000 | 1 | 4.84 | [illegible] | 82.20 | 56.04 | 48.67 | [illegible] | 32.55 | .610 | 78.00 | .037761 |
| | 95000 | 162 | 33.5 | 95000 | 1 | 4.84 | 20404 | 77.30 | 52.70 | 45.11 | 226.80 | 32.68 | .620 | 19.01 | .037945 |
| | 706200 | 427 | 61.8 | 197000 | 4 | 6.70 | 69790 | 119.99 | 81.81 | 71.05 | 958.89 | 66.76 | .660 | 170.01 | .019776 |
| | 2599110 | 698.1 | 90.7 | 2764461 | 5 | 1.25 | 141071 | 115.00 | 78.41 | 68.09 | 2017.00 | 64.03 | .580 | 356.99 | .018125 |
| | 375000 | 428 | 38.2 | 400000 | 2 | 10.21 | 41100 | 26.40 | 18.00 | 15.63 | 27.63 | 15.78 | .360 | 251.00 | .046234 |
| | 530000 | 446 | 47.7 | 512000 | 2 | 10.50 | 48180 | 41.00 | 27.95 | 24.28 | 202.93 | 10.08 | .280 | 383.01 | .055578 |
| | 680200 | 486 | 49.9 | 734000 | 3 | 10.60 | 52300 | 51.98 | 35.44 | 30.78 | 343.34 | [illegible] | .330 | 374.00 | .045973 |
| | 592000 | 460 | 45.9 | 631000 | 3 | 10.00 | 53400 | 62.40 | 42.54 | 36.95 | 347.88 | [illegible] | .658 | 368.00 | .071371 |
| | 688000 | 466 | 48.8 | 744000 | 3 | 9.55 | 57600 | 67.50 | 46.02 | 39.97 | 419.89 | [illegible] | .570 | 412.00 | .050191 |
| | 728000 | 512 | 48.8 | 787000 | 3 | 10.48 | [illegible] | [illegible] | 45.47 | 39.49 | [illegible] | [illegible] | .520 | 482.00 | .056547 |
| | 794000 | 519 | 48.8 | 858000 | 3 | 10.61 | [illegible] | [illegible].89 | 43.33 | 41.97 | 592.68 | 23.10 | .530 | 409.00 | .054798 |
| | 800000 | 530 | 52.6 | 884000 | 3 | 10.08 | 70[illegible] | [illegible]7.09 | 52.56 | 45.65 | 591.10 | 30.51 | .540 | 333.98 | .026762 |
| LZ | 1130000 | 536 | [illegible] | 1220000 | 4 | 8.68 | 82[illegible] | [illegible] | 55.64 | 48.32 | 836.58 | 31.96 | .590 | 393.00 | .054222 |
| NAVY | 1267000 | 586 | [illegible] | 1363000 | 4 | 9.50 | 91000 | 86.00 | 58.64 | 50.92 | 959.39 | 35.25 | .530 | 367.47 | .030068 |
| 145. | 1945000 | 645 | 78.3 | 2149000 | 6 | 8.24 | 125200 | [illegible] | 63.00 | 54.71 | 1467.00 | 38.57 | .550 | 474.00 | .028540 |
| 120. | 1965298 | 645 | 78.3 | 2140000 | 5 | 8.24 | 125430 | 92.41 | 63.01 | 54.72 | 1215.81 | 46.65 | .594 | 423.00 | .025909 |
| | 1970000 | 645 | 78.3 | 2140000 | 5 | 8.24 | 125436 | 96.19 | 65.58 | 56.96 | 1189.30 | 53.97 | .600 | 372.00 | .022402 |
| | 1971000 | 645 | 78.3 | 2141000 | 5 | 8.24 | 125900 | 97.40 | 66.41 | 57.67 | 1191.30 | [illegible] | .620 | 371.00 | .022300 |
| | 2420000 | 645 | 78.3 | [illegible] | [illegible] | 9.57 | 146200 | [illegible] | 64.29 | 55.83 | 1201.00 | 57.44 | .630 | 419.00 | .021935 |
| | 2471000 | 745 | 78.3 | 2640000 | 5 | 9.52 | 146200 | [illegible] | 64.22 | 55.77 | 1193.21 | 57.66 | .640 | 424.00 | .022198 |
| | 1977000 | 645 | 78.3 | 2141000 | 5 | 8.24 | 125436 | 104.81 | 71.46 | 62.06 | 1441.39 | 57.14 | [illegible] | 372.00 | .022400 |
| | 2190000 | 745 | 78.3 | 2400000 | 5 | 9.52 | 144173 | [illegible] | 77.13 | 66.98 | 1993.81 | 55.91 | .630 | 404.00 | .022538 |
| | 2151174 | 680.2 | 78[illegible] | [illegible]59861 | 5 | 8.64 | 132889 | [illegible]00 | 62.04 | 53.88 | 1559.71 | 36.34 | .425 | 402.51 | .023172 |

EN ONE FOR THE OTHER. THIS IS DUE TO
NAVY "L", AND THE GERMAN ARMY "LZ".
ETTERS.

* AT $D_{max}$ & H.P.$_{max}$

CALCULATIONS BY CLINTON H. HAVILL
LIEUT., U.S. NAVY

## [illegible] I

## GENERAL DATA AND FINAL SUMMARY OF PART I

| ITEM | SHIP. BUILDER'S NUMBERS. | BUILDERS | OWNERS | NAMED BY OWNERS. (SEE NOTE) |
|---|---|---|---|---|
| | CONTINUOUS CURVATURE SERIES. | | | |
| 1 | U.S.N. "B" | U.S. MFRS. | U.S. NAVY & ARMY. | U.S. NAVY "B" & U.S. ARMY "B" |
| 2 | U.S.N. "C" | " | " " | " "C" " "C" |
| 3 | U.S.N. "D" | " | " " | " "D" " "D" |
| 4 | U.S.N. "E" | " | " " | " "E" " "E" |
| 5 | U.S.N. "F" | " | " " | " "F" " "F" |
| 6 | LZ-120 & 121 BODENSEE (AFTER [illegible]) NORDSTERN. | ZEPPELIN | GERMAN [illegible] NAVY CO. | BODENSEE & NORDSTERN. |
| 7 | LZ-126 U.S.S. LOS ANGELES (AFTER [illegible]) | " | U.S. NAVY. | U.S.S. LOS ANGELES [illegible] |
| | PARALLEL SECTION SERIES. | | | |
| 8 | LZ-1 | ZEPPELIN | ZEPPELIN | LZ-1 |
| 9 | LZ-4 & 5 | " | & GERMAN ARMY | LZ 4 & ARMY Z II |
| 10 | LZ-7 & 8 | " | GER [illegible] | DEUTSCHLAND & ERSATZ. |
| 11 | LZ-10 & 14 | " | & GER ARM | [illegible] & ARMY Z III |
| 12 | LZ-15 & 16 | " | GERMAN ARMY. | ERSATZ Z I & ARMY Z IV |
| 13 | LZ-22 & 23 | " | | ARMY Z VII & Z VIII |
| 14 | LZ-24 TO 35 (EXCEPT 34) | " | & NAVY. | [illegible] 8-8 AND ARMY Z [illegible] |
| 15 | LZ-36 | " | NAVY | NAVY L9 |
| 16 | LZ-47 TO 50 | " | " & ARMY | NAVY LZ 72, [illegible] 74, [illegible] 77 & [illegible] 79 AND NAVY [illegible] |
| 17 | LZ-59 TO 61 & 64 TO [illegible] (EXCEPT 60 & 70) | " | " " | ARMY LZ 88, [illegible] 92, [illegible] 97, [illegible] A & LZ 101 A[illegible] |
| 18 | LZ-72 TO 80 (EXCEPT 73, 77 & 81) | " | " " | [illegible] 72, L73 & L24. [illegible] 37, L38, [illegible] 32, L34, L35, L36, L38 [illegible] 40 & L50 AND ARMY [illegible] 103, LZ 113 & L[illegible] |
| 19 | LZ-91 TO 94 | " | " " | NAVY L42, L43, L44 & L46. |
| 20 | LZ-95 TO 99 | " | " " | L48, L49, L51, L52 & L54. |
| 21 | LZ-100 & 101 | " | " " | L53 & L55. |
| 22 | LZ-102 | " | " " | L57. |
| 23 | LZ-104 | " | " " | L59 |
| 24 | LZ-106 TO 111 | " | " " | L61, L62, L60, L64, L63 & L65. |
| 25 | LZ-112 TO 114 | " | " " | L70 & L71 |
| 26 | ZR-1 U.S.S. SHENANDOAH | U.S. NAVY | U.S. NAVY | U.S.S. SHENANDOAH, [illegible] |

NOTE:— IN THE CASE OF GERMAN BUILT SHIPS, THE BUILDERS AND OWNER'S NUMBERS ARE APT TO BE MISTA[illegible] THE FACT THAT, THE ZEPPELIN COMPANY USES THE DESIGNATING LETTERS "LZ", THE GERMAN [illegible] HOWEVER EACH OF THE ORGANIZATIONS USES DIFFERENT NUMBERS AFTER THE DESIGNATING

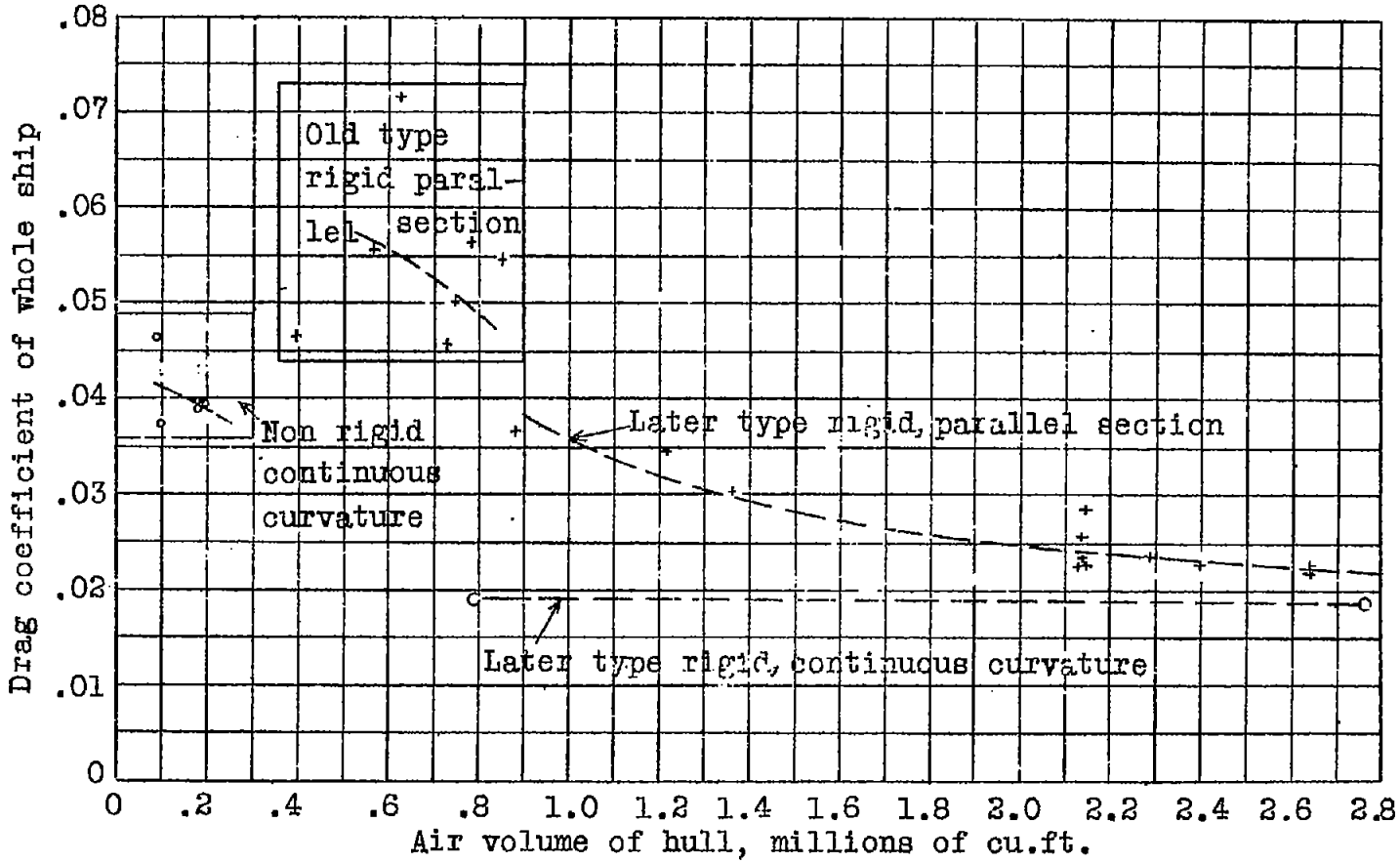


Fig.3 Plot of design history of American & German airships. Drag Coefficient of whole ship vs. air volume of hull. Data from results of part I. (Each plotted point is the plot of an item).