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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 708

# FLIGHT-TEST DATA ON THE STATIC FORE-AND-AFT STABILITY OF VARIOUS GERMAN AIRPLANES

By Walter Hübner

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# FLIGHT-TEST DATA ON THE STATIC FORE-AND-AFT STABILITY OF VARIOUS GERMAN AIRPLANES

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The static longitudinal stability of an airplane with locked elevator is usually determined by analysis; in specific cases, by model tests. The extent of agreement between analysis or model test and full-scale tests is not sufficiently known, since actual flight tests have been very meager. The present report purposes to supply the results of such measurements.

We used the same method as before (reference 1), although the accuracy in these tests was enhanced and the interpretation more complete. This method consists in recording the dynamic pressure versus elevator displacement at different center-of-gravity positions in unaccelerated flight. In order to establish definitely the operating attitude of the engine the records were made at full and closed throttle. The interpretation is limited to the flight range between $c_a \sim 0.2$ and $c_a \sim 1.0$; that is, the zone within which the lift coefficient is approximately linearly dependent on the elevator deflection.

The measurements reveal the relationship of the lift coefficient to the elevator deflection: $c_a = f\ (\beta_H)$ at different c.g. positions, so that the pitching moment coefficient versus lift coefficient can be determined: $c_m = f\ (c_a)$. The value $\partial c_{mH}/\partial c_a$ is a criterion of the static stability and is shown in figures 1-7 for the different airplanes versus the c.g. position.

As anticipated, the stability changes linearly with the c.g. position, that is, in the same ratio in all airplanes when the c.g. is expressed in percent of the mean chord. The straight lines which represent the $\partial c_{mH}/\partial c_a$ versus the c.g. position slope for all airplanes, at full

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*"Ergebnisse von Messungen der statischen Längsstabilität einiger Flugzeuge." Z.F.M., January 28, 1933, pp. 47-52.

throttle as well as by closed throttle, at

$$\frac{d}{dr}\left(\frac{\partial c_{mH}}{\partial c_a}\right) = -1.$$

By virtue of the singular relationship with the c.g. position, the stability of an airplane can, by a certain operating attitude of the engine, be numerically given for any trim; that is, for any load attitude, provided the c.g. position is known at which the airplane is neutrally stable:

$$\left(\frac{\partial c_{mH}}{\partial c_a} = 0 \quad \text{or} \quad \frac{\partial \beta_H}{\partial c_a} = 0\right)$$

Figure 8 shows this neutrally stable position of the c.g., $r_o$ of the examined airplanes for no-load engine power and for a number of models according to wind-tunnel tests versus $l_H F_H / t_m F$.* It is readily seen that the measured values lie in a zone bounded by the two lines:

$$\frac{r_o}{t_m} = 0.22 + 0.33 \frac{l_H F_H}{t_m F} \quad \text{and} \quad \frac{r_o}{t_m} = 0.30 + 0.33 \frac{l_H F_H}{t_m F}.$$

For the first approximation of the neutrally stable c.g. position of an airplane, the lower limit, that is,

$$\frac{r_o}{t_m} = 0.22 + 0.33 \frac{l_H F_H}{t_m F}{}^{**}$$

is very expedient.

The measured $\partial\beta_H/\partial c_a$ are illustrated in figures 1-7 versus the c.g. position. The static elevator effect

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*By wing area is meant the total area of the wing projected in a horizontal plane, by horizontal position of the propeller axis. The projection of the fuselage portion lying between leading and trailing edge of the center section is included in the wing area.

**According to Lapresle (reference 2), the model tests give for the neutral stability - c.g. position:

$$\frac{r_o}{t_m} = 0.225 + 0.37 \frac{l_H F_H}{t_m F}.$$

$$\frac{dc_{mH}}{d\beta_H} = \frac{\partial c_{mH}}{\partial c_a} \frac{\partial c_a}{\partial \beta_H}$$

was determined for each airplane at every operating attitude of the engine. The obtained figures reveal that

$$\frac{dc_{nH}}{d\ \beta_H} = \frac{dc_{mH}}{d\ \beta_H} \frac{F}{F_H} \frac{t_m}{l_H}$$

for the different control surfaces. The $dc_{nH}/d\beta_H$ values for throttled flight together with various wind-tunnel tests are shown in figure 9 versus the aspect ratio of the tail surfaces.

The tail surfaces show a marked difference from each other in shape and position of the elevator axis. The effect of the different division in stabilizer and elevator was minimized by converting $dc_{nH}/d\beta_H$ by multiplication with

$$[\sqrt{0.5} + (1 - 0.215 \times 0.5)] : \left[\sqrt{\frac{F_R}{F_H}} + \left(1 - 0.215\ \frac{F_R}{F_H}\right)\right]$$

to a ratio of elevator to control surface area: $\frac{F_R}{F_H} = 0.5$. According to Toussaint (reference 3), we have

$$\frac{dc_{nH}}{d\beta_H} = \frac{0.095\ \lambda_H}{\lambda_H + 1.73} \left[1.27 \sqrt{\frac{F_R}{F_H}} \left(1 - 0.215\ \frac{F_R}{F_H}\right)\right]$$

for a control group of full contour with continuous elevator. The flight tests with airplane of standard type reveal, according to the curves in figure 9, figures of from 30 to 40 percent lower than stipulated by this formula. The sole exception is the Focke-Wulf "Ente", which with $\frac{dc_{nH}}{d\beta_H} = 0.050$ approaches that of the calculated value $\frac{dc_{nH}}{d\beta_H} = 0.055$.

The marked discrepancy of $\frac{dc_{nH}}{d\beta_H}$ of the other airplanes from the theoretical figure is, in the first place, attributable to the blanketing of the control surfaces by the propeller at no-load, body effect, effect of cut-out in elevator, effect of open gap between elevator and stabilizer, and effect of form, especially where balanced elevators are used. These effects do not exist on the "Ente."

But by the usual arrangement and form of the horizontal control surfaces the loss on elevator effect must be included because of the above cited causes. This is allowed for by assuming:

$$\frac{dc_{nH}}{d\beta_H} = 0.6 \times \frac{0.095\ \lambda_H}{\lambda_H + 1.73}\left[1.27\sqrt{\frac{F_R}{F_H}}\left(1 - 0.215\ \frac{F_R}{F_H}\right)\right]$$

Owing to the lack of wind-tunnel data on all but two types, the comparison between wind-tunnel data and flight records had to be confined to these two. (See table II.)

TABLE II. COMPARISON OF WIND-TUNNEL DATA TO FLIGHT RECORDS

| Type | Neutrally stable position of c.g. : $r_0$ | | $\frac{dc_{nH}}{d\beta_H}$ | |
|---|---|---|---|---|
| | Flight | Wind tunnel | Flight | Wind tunnel |
| Junkers A 35 | 42.2% $t_m$ | 44.0% $t_m$ | 0.030 | 0.0299 |
| Focke-Wulf "Ente" | -16.3% $t_m$ | -16.6% $t_m$ | | |

The agreement is better with the "Ente" than with the Junkers; probably because the slipstream effect in the former is less owing to the location of the horizontal tail surfaces and of the fuselage.

The approximate limits of the range of the c.g. positions due to load changes in practical service are shown in figures 1-7. These limits are very nearly the same as those set up in the type tests as limits of unobjectionable service qualities;* right-hand limit of the shown range which gives the maximum permissible rearward position of the c.g. is of particular significance, for it corresponds to the c.g. position at which an airplane with released elevator and at cruising speed (i.e., about 60 to 80 percent of the full horsepower), is just sufficiently stable about the lateral axis. It is seen from the figures that the limit of stability with elevator released is, in all airplanes, with the exception of the "Ente," only reached by rear c.g. position, at which instability already pre-

*Design specifications for airplanes, No. 4515.

vails with locked elevator and the same running attitude of the engine.

The range of stability with released elevator in consequence extends up to greater c.g. positions than with locked elevator (reference 4).

Current practice demands that every airplane should be stable with elevator released. For the stability with elevator released determines the direction of the elevator forces, which is decisive from the point of view of flight attitude and of landing the airplane in flight. The question of whether an airplane should also be stable with elevator locked, however, still remains to be answered.

The existence of stability with elevator released, even if very slight, is readily and accurately determinable by the pilot from the elevator forces. The decision as to whether an airplane with locked elevator is stable or not, especially by small absolute stability figures and pronounced elevator effect, demands pilots particularly trained for this work, unless instruments are used. The conclusion lies close that the stability with locked elevator is not only of less significance for the airplane pilot than that with elevator released, but that it is altogether unnecessary.

In measurements such as these the airplane is flown under varying degrees of stability. The changes in behavior due to the degree of stability are especially plainly visible when a stated dynamic pressure must be held.

By instability with elevator locked it is very difficult to maintain even an approximately constant dynamic pressure for any length of time; even in calm weather it requires continuous up and down movements of the elevator. By stability with elevator locked it is only necessary to hold the elevator at its exact setting; the airplane then maintains the dynamic pressure for this deflection by itself.* Stability with elevator locked therefore facilitates in maintaining a certain flight attitude, but these

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*By high stability with elevator locked the dynamic pressure recorder can be exchanged for an elevator displacement recorder, because of the singular relationship between elevator displacement and dynamic pressure, for a certain engine load and a stated stabilizer setting.

advantages become especially noticeable at landing, since it requires only a steady pull on the elevator without up and down movement. Handling an airplane at landing is much more simple by stability with elevator locked than by instability, provided, of course, the elevator effect is sufficient.

For that reason, airplanes should be stable with elevator released as well as with elevator locked, except those used primarily for acrobatic purposes.

## SUMMARY

1. Stability with elevator locked: $\frac{\partial c_{mH}}{\partial c_a}$ changes linearly with the c.g. position in every airplane tested, that is,

$$\frac{d}{dr}\left(\frac{\partial c_{mH}}{\partial c_a}\right) = -1$$

2. The neutrally stable position of the c.g. for throttled flight can be estimated conformable to

$$\frac{r_o}{t_m} = 0.22 + 0.33\,\frac{l_H\,F_H}{t_m\,F} \quad \text{and}$$

3. $\frac{dc_{nH}}{d\beta_H}$ (for the conventional tail surface designs and arrangements) according to:

$$\frac{dc_{nH}}{d\beta_H} = 0.6 \times \frac{0.095\,\lambda_H}{\lambda_H + 1.73}\left[1.27\sqrt{\frac{F_R}{F_H}}\left(1 - 0.215\,\frac{F_R}{F_H}\right)\right].$$

4. The agreement for $r_o$ and $\frac{dc_{nH}}{d\beta_H}$ between wind tunnel and flight test is satisfactory.

5. Every one of the examined airplanes of standard design is still stable with elevator released at c.g. positions at which it is already unstable when the elevator is locked.

6. From the point of view of landing in flight, every airplane, unless primarily intended for acrobatic purposes, should be stable with released as well as with locked elevator.

REFERENCES

1. V. Heidelberg: Measurements of Rudder Moments on an Airplane in Flight. T.N. No. 38, N.A.C.A., 1921.

Hübner, W.: Messung der Höhensteuerkräfte und der Langsstabilität eines Flugzeuges vom Muster Junkers F 13 ge. W.G.L. Jahrbuch 1929, pp. 158-164; and D.V.L. Jahrbuch 1930, pp. 638-644.

Blenk, H.: Flight Tests for the Determination of Static Longitudinal Stability. T.M. 584, N.A.C.A., 1930.

Hübner, W.: Ergebnisse von Messungen der Stabilität um die Querachse. D.V.L. Jahrbuch 1931, pp. 684-690.

2. Lapresle, A.: The Aerodynamic Wind Vane and the Inherent Stability of Airplanes. T.M. No. 607, N.A.C.A., 1931.

3. Haus, Fr. Ch.: Stabilité et Maniabilité des Avions. Paris, 1930, p. 61.

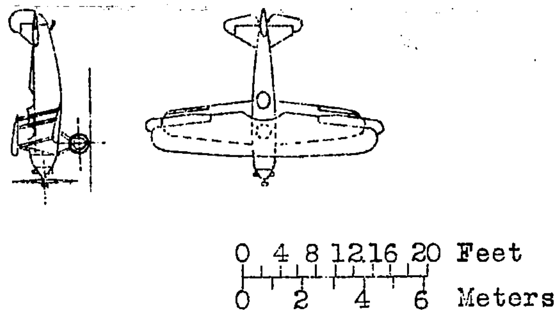
Toussaint: L'Aviation Actuelle, Paris, 1928, p. 140.

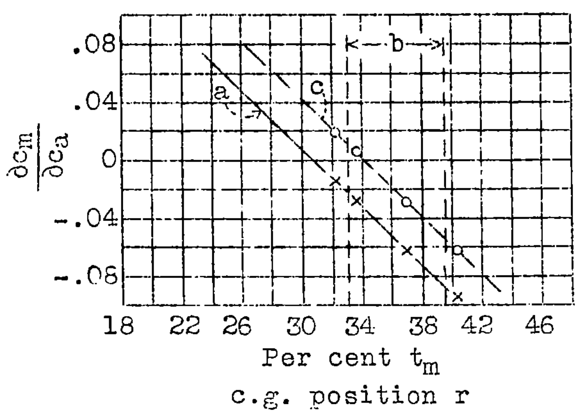
4. Blenk, H.: Uber die Längsstabilität eines Flugzeuges mit losgelassenem Höhensteuer. Z.F.M., Vol. 21, No. 8, 1930, pp. 189-196; and D.V.L. Jahrbuch 1930, pp. 61-68.

TABLE I. AERODYNAMIC CHARACTERISTICS AND TEST DATA OF THE INVESTIGATED AIRPLANES

*Upper wing.
**With special control surfaces.

| | | | Raka KL Ic | Heinkel HD 32 | Udet U 12 a | Junkers F 13 ge | Junkers A 35 | Albatros L 75** | Focke-Wulf F 19a |
|---|---|---|---|---|---|---|---|---|---|
| Wing area | $F$ | ($m^2$) | 18.3 | 24.8 | 25.1 | 44.4 | 30.1 | 30.1 | 29.5 |
| Span | $b$ | (m) | 7.99 | 10.45 | 10.0 | 17.75 | 15.94 | 12.5 | 14.0 |
| Mean chord (chord at $2b/3\pi$ from wing center) | $t_m$ | (m) | 1.34 | 1.35 | 1.36 | 2.62 | 2.02 | 1.52 | 2.5 |
| Position of the leading edge of the mean wing chord back of the leading edge of the center section of the wing | $a$ | (m) | 0.183* | 0.33* | 0.23* | 0.158 | 0.115 | 0.18* | 0.08 |
| Area of horizontal tail surfaces | $F_H$ | (m) | 2.3 | 3.4 | 3.3 | 7.0 | 4.9 | 4.4 | 6.2 |
| Span of horizontal tail surfaces | $b_H$ | (m) | 2.8 | 3.6 | 3.2 | 5.6 | 4.21 | 4.0 | 5.2 |
| Width of fuselage at leading edge of stabilizer | $\Delta_H$ | (m) | 0.38 | 0.4 | 0.32 | 0.4 | 0.42 | (0.42) | - |
| Free span of horizontal tail surfaces | $b_H-\Delta_H$ | (m) | 2.42 | 3.2 | 2.88 | 5.2 | 3.9 | (3.58) | 5.2 |
| Aspect ratio of horizontal tail surfaces | $\lambda_H=b_H^2/F_H$ | | 3.4 | 3.8 | 3.07 | 4.5 | 3.65 | 3.65 | 4.35 |
| " " " " " " | $\lambda_H=(b_H-\Delta_H)^2/F_H$ | | 2.55 | 3.0 | 2.49 | 3.9 | 2.95 | (3.2) | 4.35 |
| Area of stabilizer | $F_F$ | ($m^2$) | 1.1 | 1.4 | 2.2 | 3.65 | 2.8 | 1.8 | 4.8 |
| Area of elevator | $F_R$ | ($m^2$) | 1.2 | 2.0 | 1.3 | 3.3 | 2.05 | 2.6 | 1.7 |
| Relative elevator area | $F_R/F_H$ | | 0.52 | 0.59 | 0.4 | 0.475 | 0.42 | 0.59 | 0.275 |
| Distance of elevator axis from c.g. of airplane | $l_H$ | (m) | 3.76 | 4.45 | 4.55 | 6.7 | 5.42 | 6.08 | 4.7 |
| | $F t_m / l_H F_H$ | | 1.34 | 2.21 | 1.36 | 2.48 | 2.31 | 1.52 | 2.5 |
| Dead weight | $G_R$ | (kg) | 530 | 590 | 545 | 1440 | 1100 | 1300 | 1235 |
| Total weight | $G$ | (kg) | 800 | 850 | 800 | 2300 | 1600 | 1835 | 1650 |
| Engine type | | | Siemens SH 12 | Siemens SH 12 | Siemens SH 11 | Junkers L 5 | Junkers L 5 | BMW Va | 2xSiemens SH 14 |
| Horsepower | $N$ | (hp) | 112 | 112 | 86 | 300 | 300 | 320 | 200 |
| Operation - c.g. position range | | % $t_m$ | ~ 33.1 ...39.5 | ~ 27.4 ...36.4 | ~ 27.4 ...35.4 | ~ 27.8 ...39.1 | ~ 30.9 ...35.9 | ~ 16.9 ...23.0 | ~ -28.5 ...-23.2 |
| Neutrally stable position of c.g. | | | | | | | | | |
| by full throttle | $r_{OV}$ | % $t_m$ | 30.8 | 28.6 | 33.35 | 36.5 | 33.0 | - | -16.3 |
| by closed throttle | $r_{OL}$ | % $t_m$ | 34.2 | 36.9 | 37.3 | 39.0 | 42.2 | 44.1 | - |
| Static controllability | | | | | | | | | |
| at full throttle | $\left(\frac{dc_m}{d\beta}\right)_V$ | | 0.0155 | 0.0325 | 0.016 | 0.020 | 0.0155 | - | 0.0155 |
| at closed throttle | $\left(\frac{dc_m}{d\beta}\right)_L$ | | 0.010 | 0.0145 | 0.011 | 0.014 | 0.013 | 0.018 | - |
| Rise of normal force coefficient of longitudinal tail surfaces with elevator displacement | | | | | | | | | |
| in full throttle flight ......................... | $\left(\frac{dc_n}{d\beta}\right)_V$ | | 0.044 | 0.0755 | 0.036 | 0.050 | 0.036 | - | 0.039 |
| in closed throttle flight ...................... | $\left(\frac{dc_n}{d\beta}\right)_L$ | | 0.028 | 0.0335 | 0.0245 | 0.035 | 0.0295 | 0.038 | - |

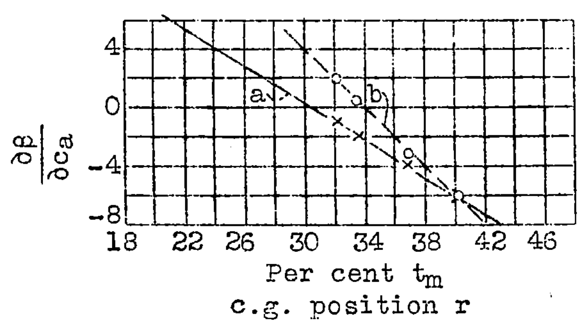



a, Full throttle

b, Approximate operating range.

c, ~~No load~~ Closed throttle




a. Full throttle

b. No load

Figure 1.-Two-view drawings of Raab-Katzenstein KL.Ic "swallow" and test data on static stability with elevator locked.

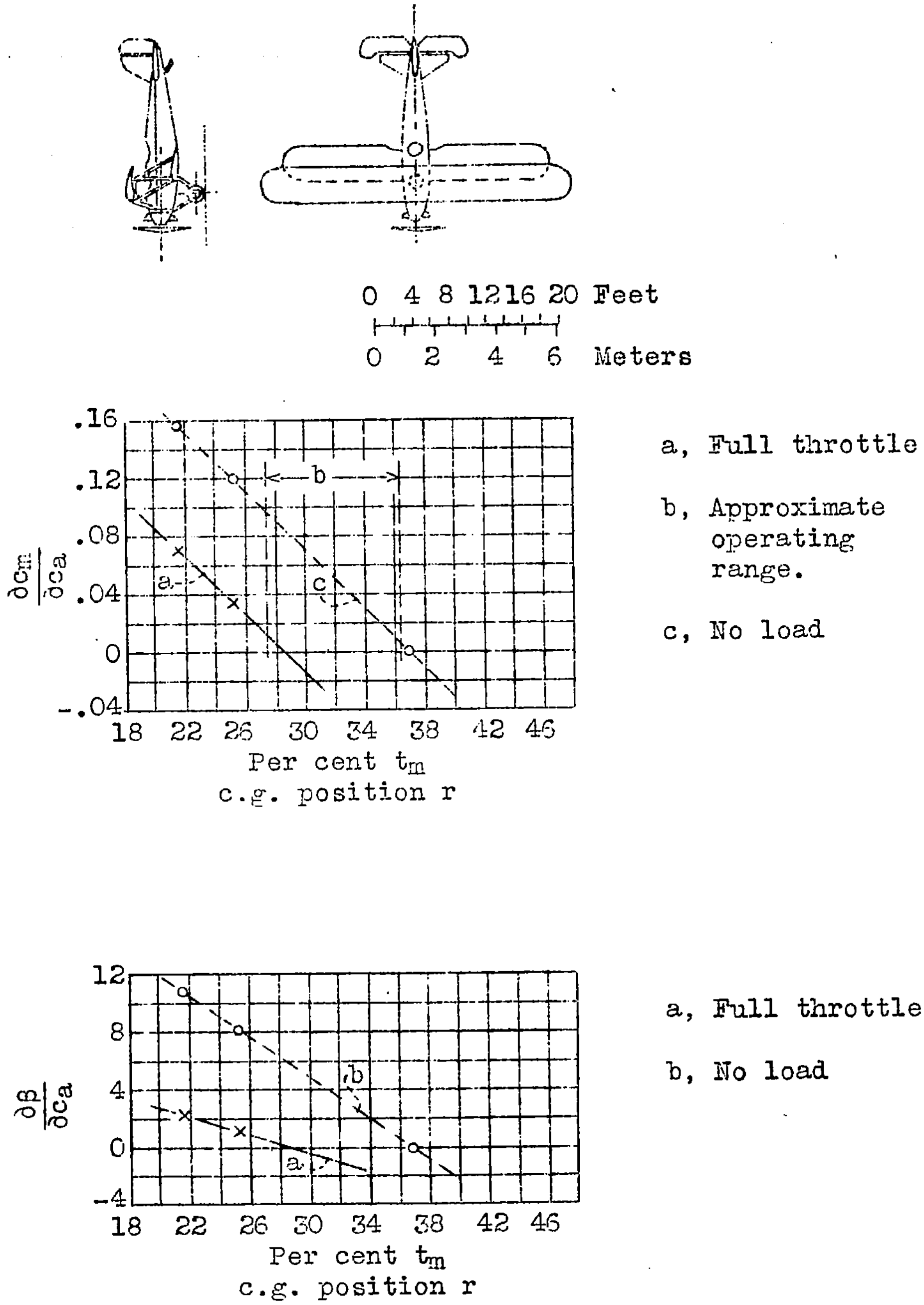
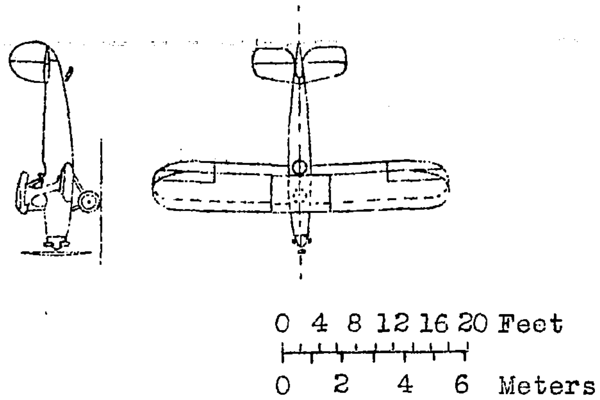
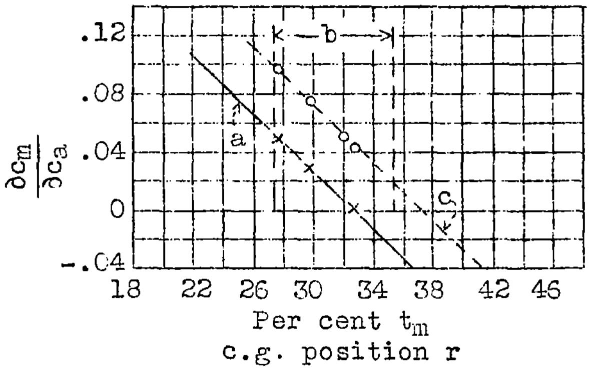



Figure 2.-Two-view drawings of Heinkel HD 32 and test data on static stability with elevator locked.



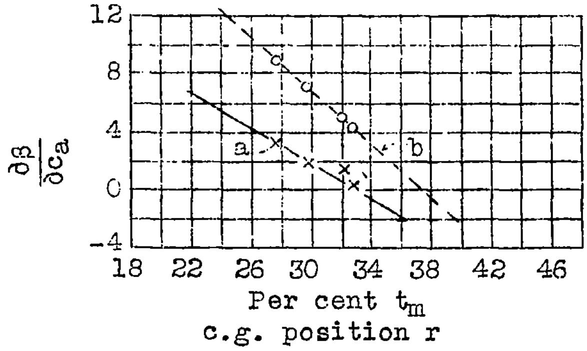
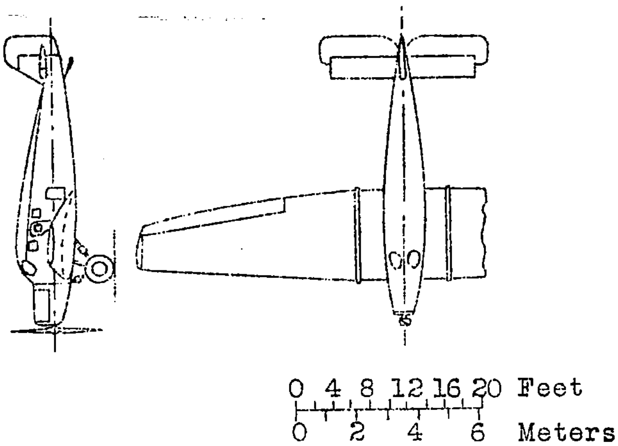
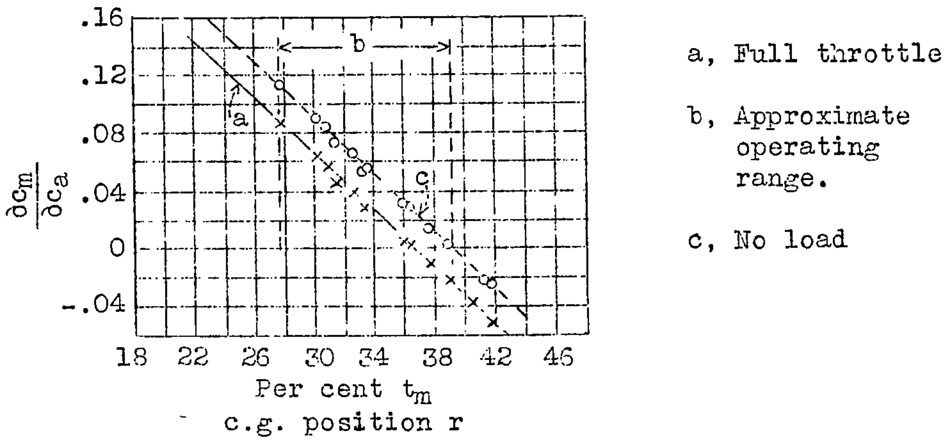




Figure 3.-Two-view drawings of Udet U 12a "Flamingo" and test data on static stability with elevator locked.



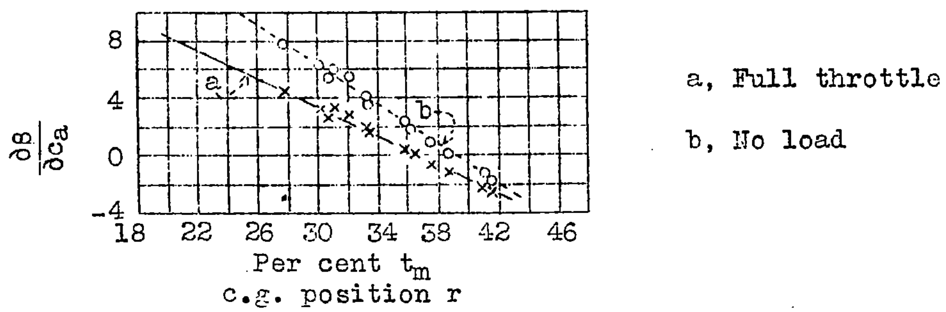
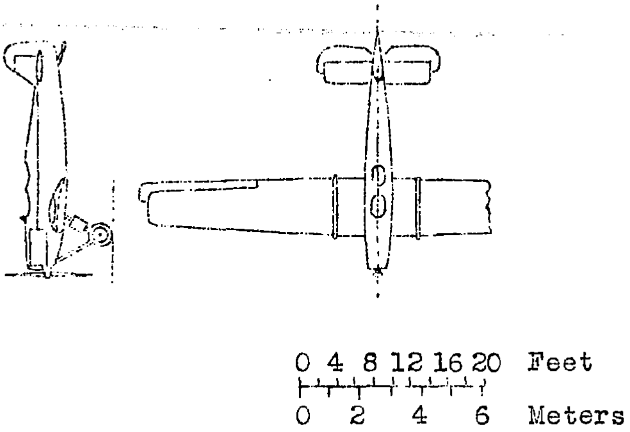
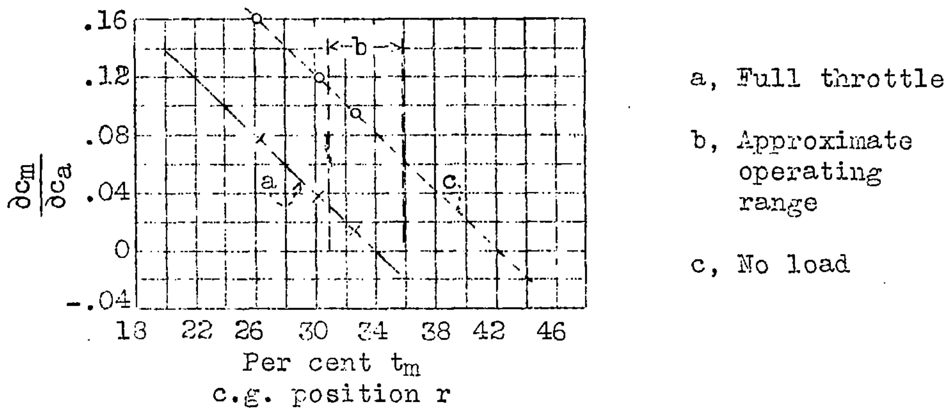




Figure 4.-Two-view drawings of Junkers F 13ge and test data on static stability with elevator locked.



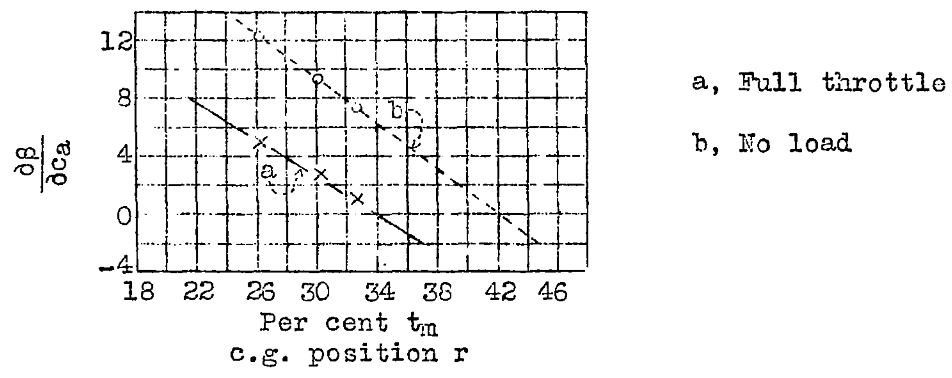




Figure 5.-Two-view drawings of Junkers A 35 and test data on static stability with elevator locked.

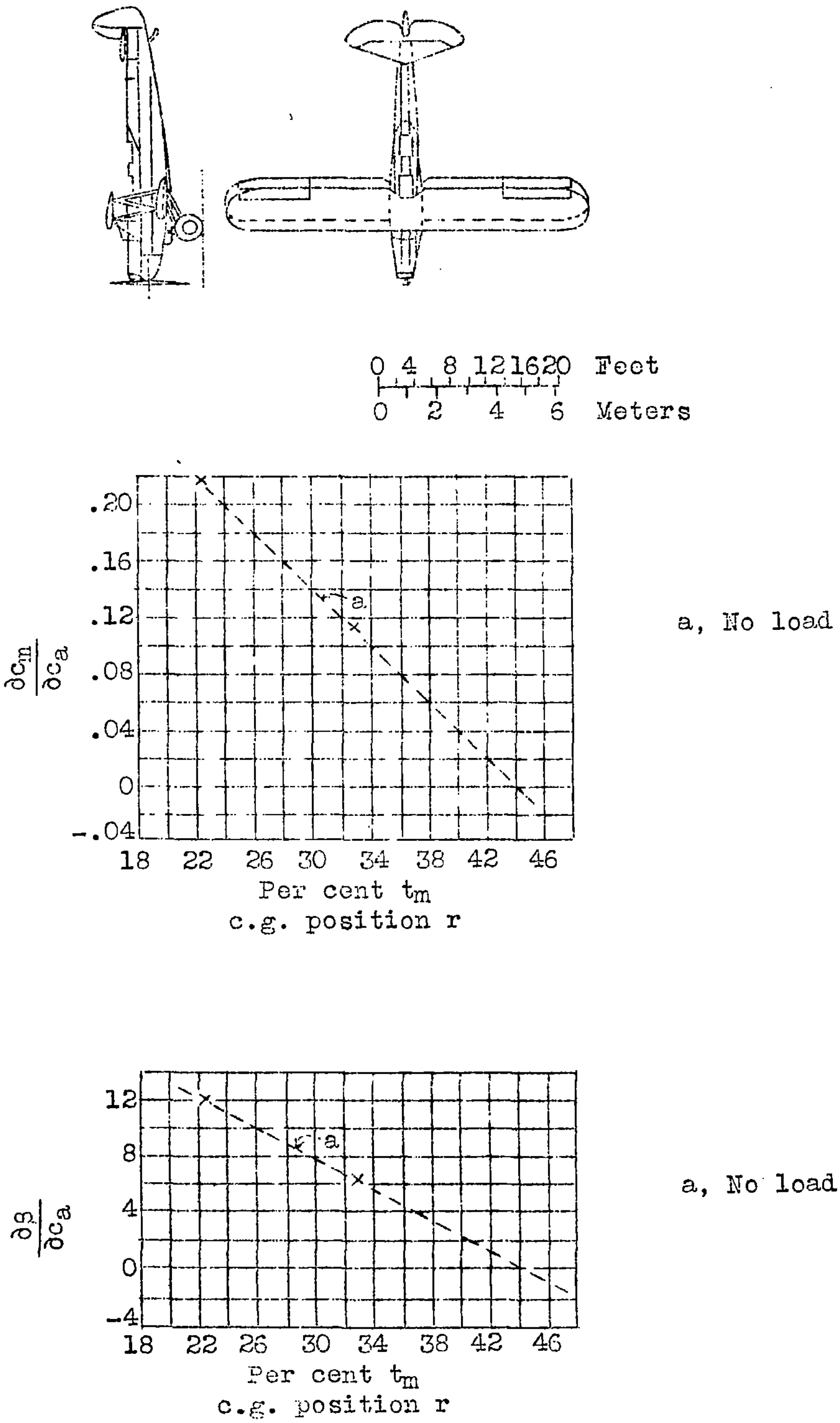



Figure 6.-Albatros L 75 "Ass", with special horizontal tail surfaces, and test data on static stability with elevator locked.

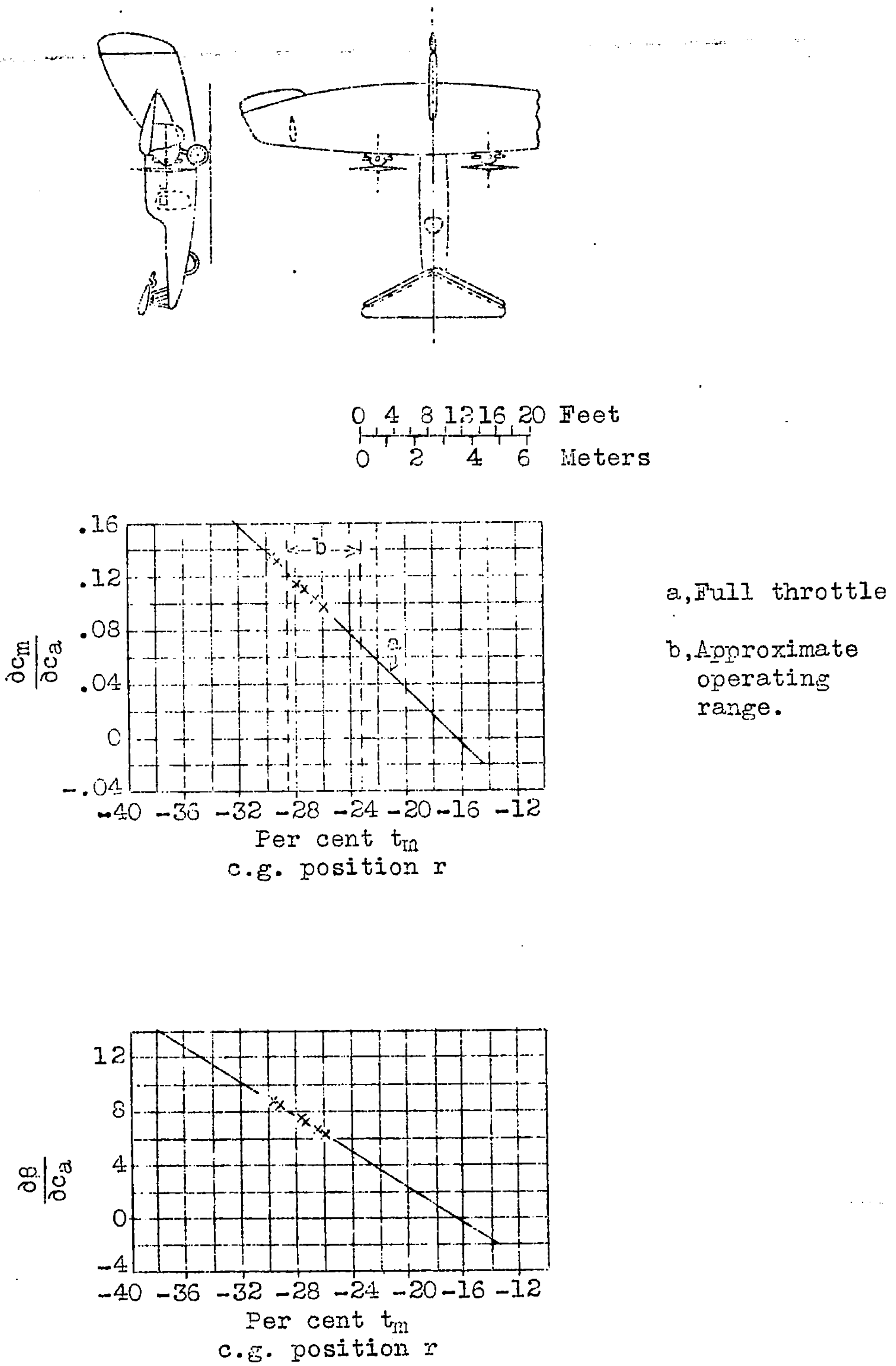



Figure 7.-Two-view drawings of FockeWulf F 19a "Ente" and test data on static stability with elevator locked.

FIGURE 8.- Neutrally stable position of the c.g., according to flight and model tests versus $l_H F_H/t_m F$.

| Mark | Type | Test | $\frac{l_H F_H}{t_m F}$ | $r_o$ in % $t_m$ | Reference |
|---|---|---|---|---|---|
| ◿ | Raka Kl Ic | flight | 0.35 | 34.2 | |
| ◺ | Heinkel HD 32 | " | 0.45 | 36.9 | |
| ◸ | Udet U 12 a | " | 0.44 | 37.3 | This report |
| ◹ | Junkers F 13 ge | " | 0.40 | 39.1 | |
| -o | Junkers A 35 | " | 0.43 | 42.2 | |
| ♀ | Albatros L 75 | " | 0.48 | 44.1 | |
| ȯ | Junkers A 35 | model | 0.43 | 44.0 | DVL Jahrb. 1930, Ber. 155 |
| + | "Vampyr" (glider) | " | 0.265 | 39.0 | Göttinger Ber. III |
| × | "Greif" (glider) | " | 0.25 | 36.5 | Göttinger Ber. III |
| △ | Rohrbach | " | 0.47 | 45.0 | Göttinger Ber. III |
| ▽ | Focke-Wulf A 16 (landplane) | " | 0.44 | 39.5 | Göttinger Ber. III |
| ◇ | DFW C V | " | 0.27 | 35.0 | T.B. III |
| □ | Morano | " | 0.205 | 29.0 | Bull. Tech. No. 66 |
| | " | " | 0.305 | 33.0 | " |
| | " | " | 0.442 | 37.0 | " |
| | " | " | 0.67 | 48.0 | " |
| | " | " | 0.00 | 22.5 | " |
| ◁ | Romano | " | 0.205 | 31.0 | " |
| | " | " | 0.305 | 36.5 | " |
| | " | " | 0.442 | 41.5 | " |
| | " | " | 0.67 | 48.5 | " |
| | " | " | 0.00 | 23.5 | " |
| ▷ | A 47 | " | 0.205 | 29.5 | " |
| | " | " | 0.305 | 32.5 | " |
| | " | " | 0.442 | 38.0 | " |
| | " | " | 0.67 | 45.0 | " |
| | " | " | 0.00 | 25.0 | " |
| ○ | 425 | " | 0.00 | 24.0 | Göttinger Ber. II |
| • | 482 | " | 0.00 | 28.0 | Göttinger Ber. III |

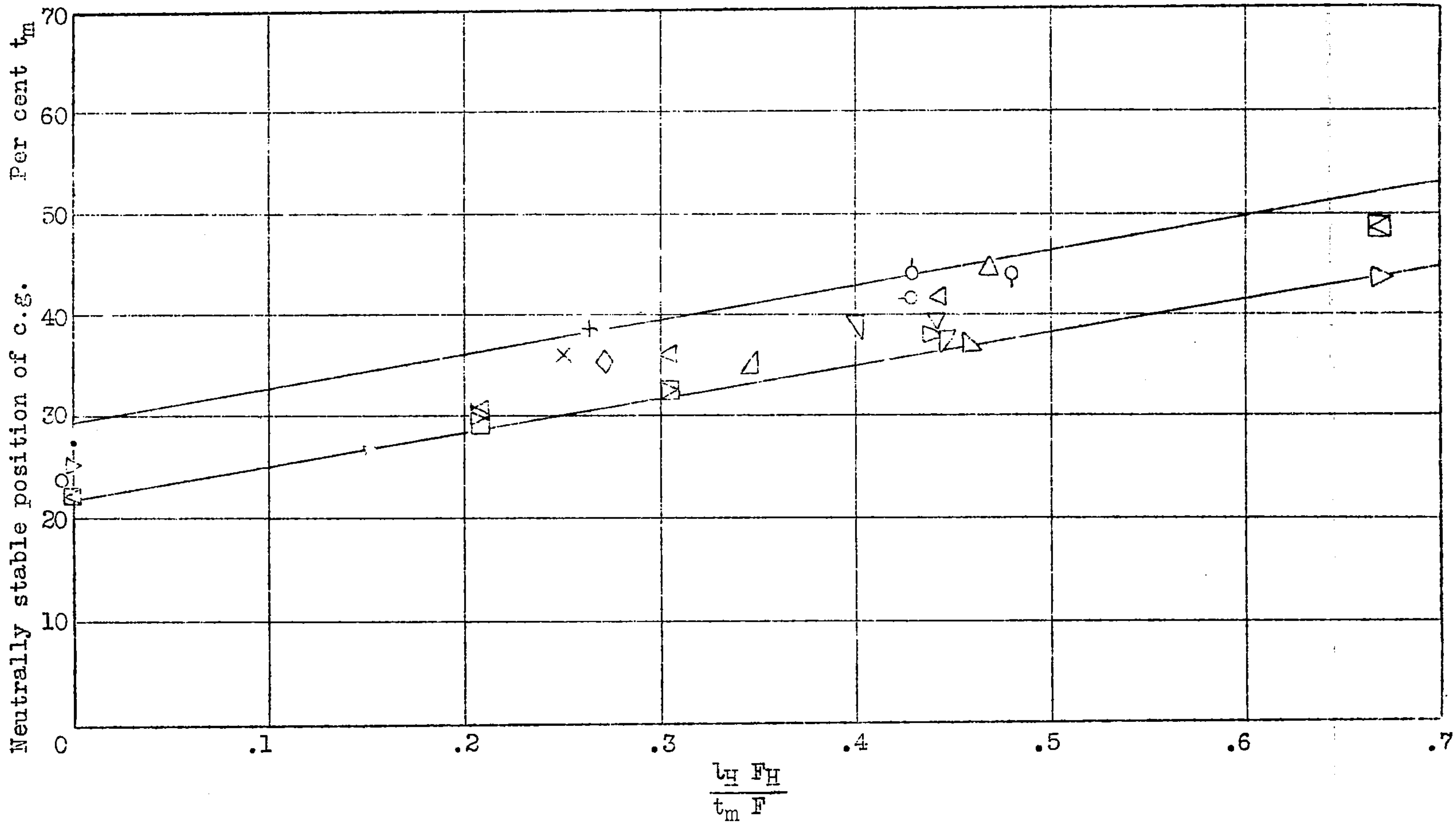



Figure 8.-Neutrally stable position of the c.g. according to flight and model tests versus $\frac{l_H F_H}{t_m F}$.

FIGURE 9a.- $dc_n/d\beta$ versus aspect ratio of tail unit.

FIGURE 9b.- $dc_n/d\beta$ for $F_R/F_H = 0.5$ versus aspect ratio of tail group.

$$\text{I for } \frac{dc_{nH}}{d\beta_H} = 0.7 \frac{0.095\ \lambda_H}{\lambda_H + 1.73}\left[1.27 \sqrt{\frac{F_R}{F_H}}\left(1 - 0.215\ \frac{F_R}{F_H}\right)\right]$$

$$\text{II for } \frac{dc_{nH}}{d\beta_H} = 0.6 \frac{0.095\ \lambda_H}{\lambda_H + 1.73}\left[1.27 \sqrt{\frac{F_R}{F_H}}\left(1 - 0.215\ \frac{F_R}{F_H}\right)\right]$$

| Mark | Type | Test | $\lambda_H$ | $\frac{F_R}{F_H}$ | $\frac{dc_n}{d\beta_H}$ | $\frac{dc_n}{d\beta_H}$ for $\frac{F_R}{F_H} = 0.5$ | Reference |
|---|---|---|---|---|---|---|---|
| ⊿ | Raka Kl Ic | flight | 2.55 | 0.52 | 0.028 | 0.0275 | This report |
| ◺ | Heinkel HD 32 | " | 3.0 | 0.58 | 0.034 | 0.032 | |
| ◸ | Udet U 12a | " | 2.45 | 0.40 | 0.0245 | 0.0265 | |
| ◹ | Junkers F 13 ge | " | 3.9 | 0.475 | 0.035 | 0.0355 | |
| ὀ | Junkers A 35 | " | 2.95 | 0.42 | 0.030 | 0.032 | |
| ⊙ | Junkers A 35 | " | 2.95 | 0.42 | 0.027 | 0.029 | DVL Jahrb. 1930 Ber. 174 |
| -o | Junkers A 35 | Model | 2.95 | 0.42 | 0.0299 | 0.032 | DVL Jahrb. 1930 Ber. 155 |
| ♀ | Albatros L 75 | flight | 3.65 | 0.59 | 0.038 | 0.036 | This report |
| ▽ | Focke-Wulf "Ente" | " | 4.35 | 0.275 | 0.039 | 0.050 | |
| o | Gött. 409 | model | 4.3 | 0.45 | 0.037 | 0.0385 | Gött. Ber. III, p. 102 |
| △ | Gött. 646 | " | 3.0 | 0.25 | 0.028 | 0.0375 | T.B. I, No. 6 |

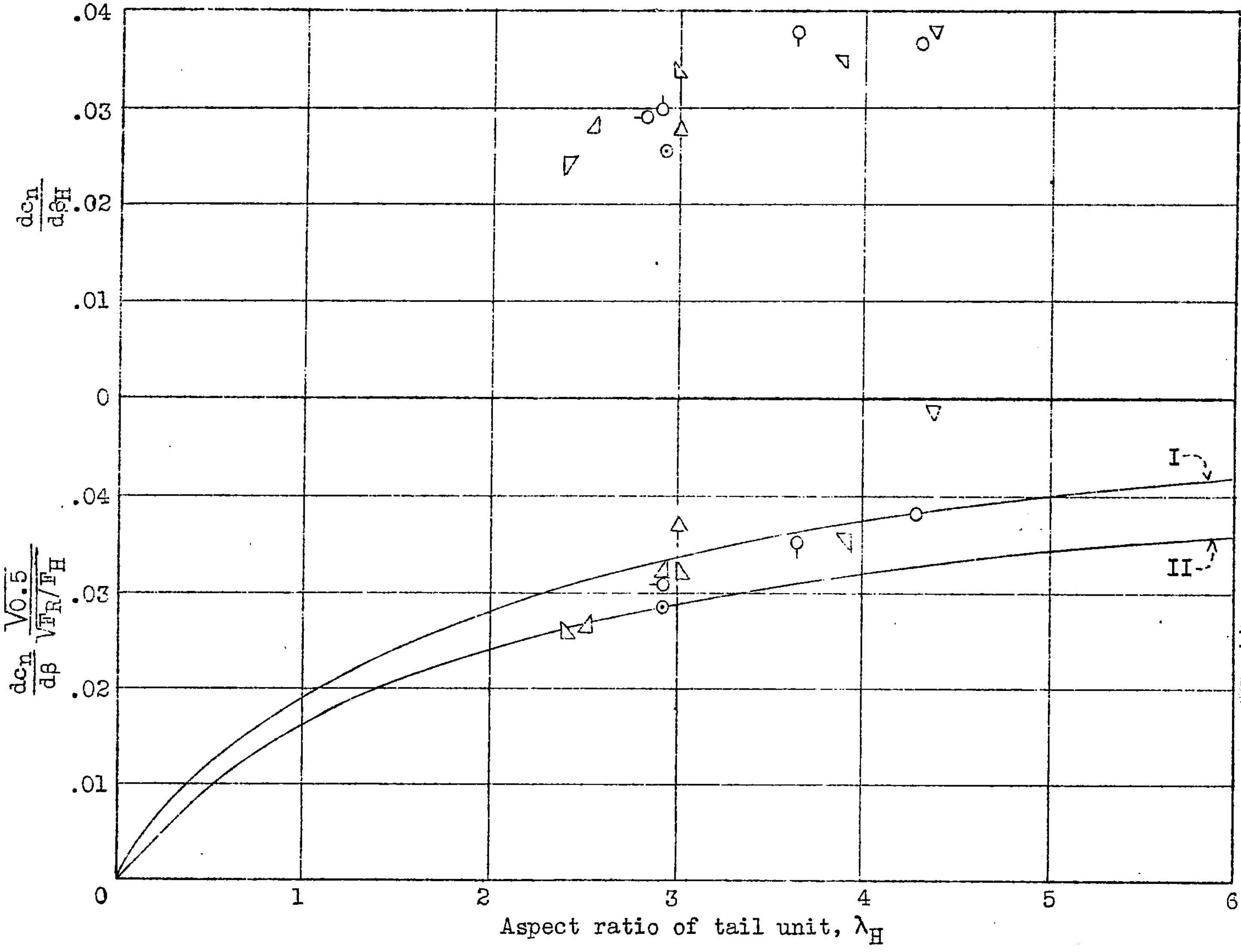



Figure 9a

Figure 9b.