EXPERIMENTS ON THE COMPARISON BETWEEN CASCADE AND AXIAL-FLOW COMPRESSOR PERFORMANCES

(PART III: COMPARISON*)

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Introduction

In "Part I and II" of this report, the performances of cascade and axial-flow compressor blade were reported. This Part III deals with the comparison of both performances (performances of cascade at its mid-span position, and performances of blade elements of axial-flow compressors), and is intended to get the mutual relation between them. Because the theory of secondary flows has not yet been accomplished, the author could not establish a method to find the performance of blade element of axial-flow compressor from the performance of cascade, but he succeeded in getting qualitative comparisons of the both and an interesting quantitative relation.

Subscript

a : blade pitch
c : chord length
C_d: loss coefficient
w_a: axial velocity
α : stagger angel
β : turning angle
Γ : blade circulation
γ : air angle from cascade or compressor axis

Subscript

1: before blade row
2: behind blade row

Results and Considerations

Figures 1∼4 illustrate the performances of axial-flow compressor blade elements with those of cascades, and we can see the differences of both performances at a glance. Full lines and broken lines represent compressor and cascade performances respectively. Lines of + marks are ones for cascade performances but with insufficient accuracy which will be mentioned later. The performances of axial-flow compressores in these figures are same to the ones illustrated in "Part II" of the report, but the performances of cascades are

* The 21st Report of the Study on Axial-flow Turbo-machines

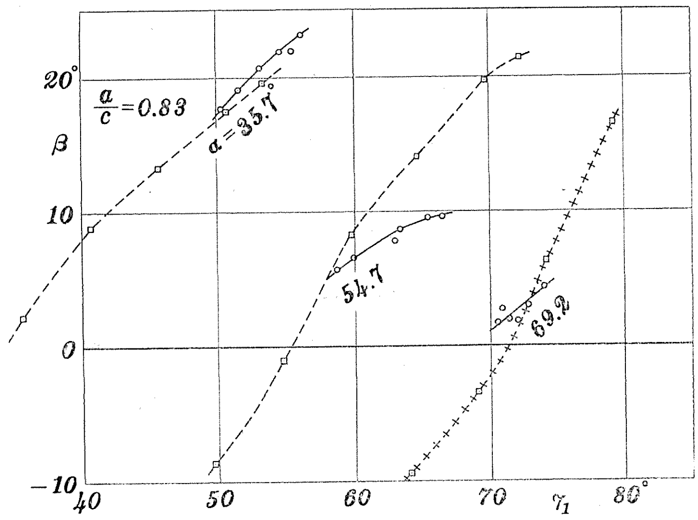

20°
β
10
0
−10
40
50
60
70
80°
γ_1
$\frac{a}{c}=0.83$
$\alpha=35.7°$
54.7
69.2

FIG. 1 (a)

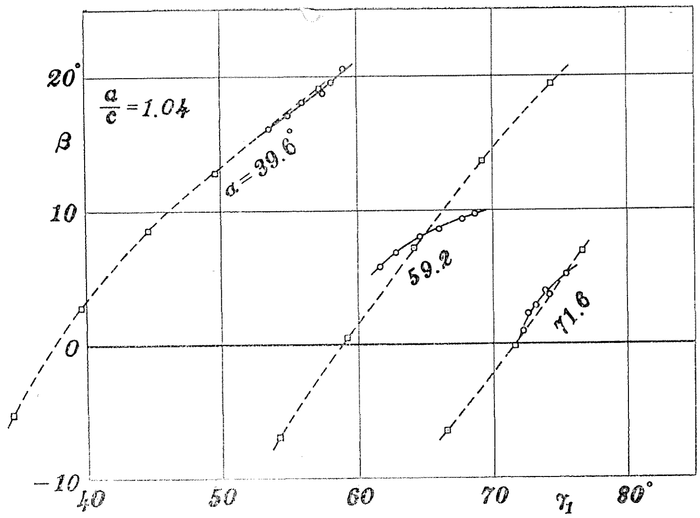

20°
β
10
0
−10
40
50
60
70
80°
γ_1
$\frac{a}{c}=1.04$
$\alpha=39.6°$
59.2
71.6

FIG. 1 (b)

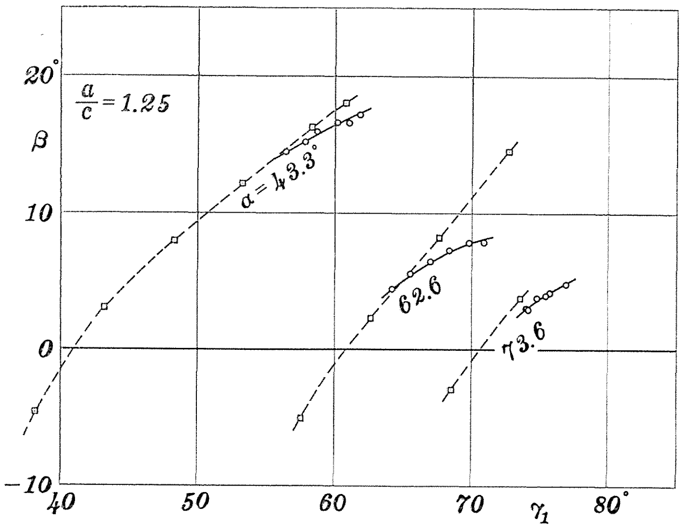

20°
$\frac{a}{c} = 1.25$
β
10
0
−10
40
50
60
70
80°
γ_1
α = 43.3°
62.6
73.6

FIG. 1 (c)

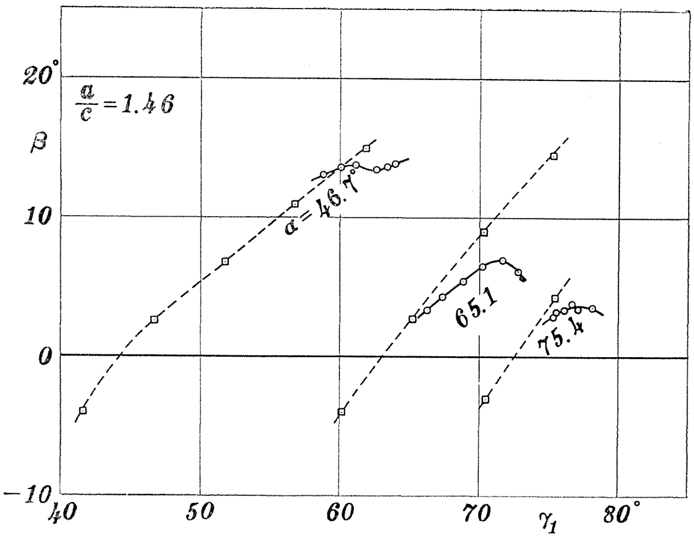
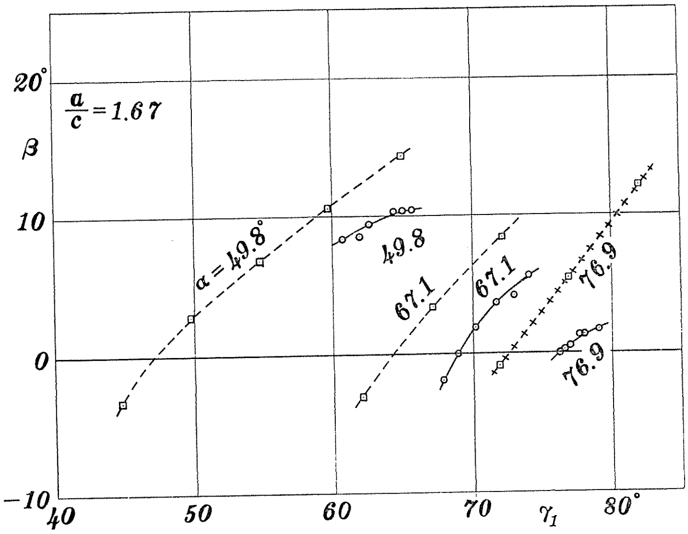
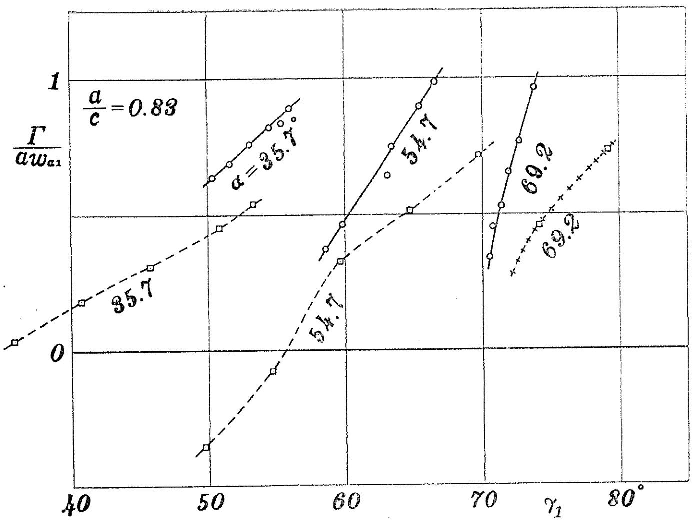

20°
$\frac{a}{c} = 1.46$
β
10
0
−10
40
50
60
70
80°
γ_1
α = 46.7°
65.1
75.4

FIG. 1 (d)



20°
$\frac{a}{c}=1.67$
β
10
0
−10
40
50
60
70
γ_1
80°
α = 49.8°
49.8
67.1
67.1
76.9
76.9

FIG. 1 (e)



1
$\frac{a}{c}=0.83$
$\frac{\Gamma}{aw_{a1}}$
0
40
50
60
70
γ_1
80°
α = 35.7°
35.7
54.7
54.7
69.2
69.2

FIG. 2 (a)

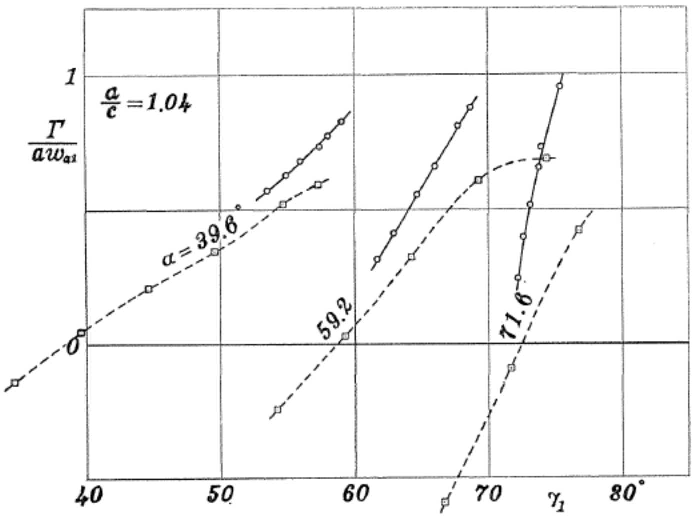

1
$\frac{a}{c}=1.04$
$\frac{\Gamma}{aw_{a1}}$
0
$\alpha=39.6$
59.2
71.6
40
50
60
70
γ_1
80°

FIG. 2 (b)

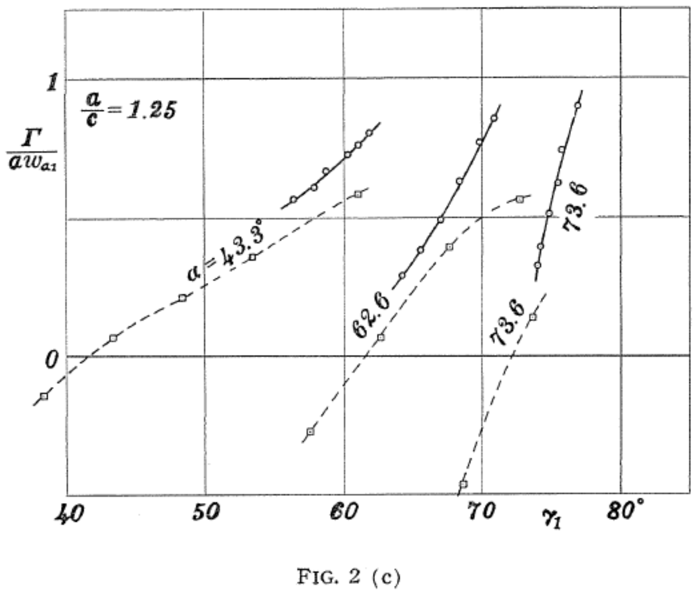

1
$\frac{a}{c}=1.25$
$\frac{\Gamma}{aw_{a1}}$
0
$\alpha=43.3°$
62.6
73.6
73.6
40
50
60
70
γ_1
80°

FIG. 2 (c)

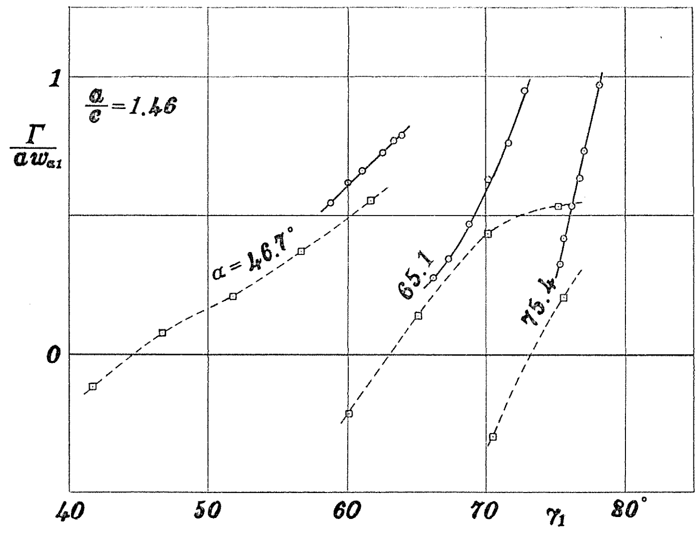

1
0
$\frac{a}{c}=1.46$
$\frac{\Gamma}{aw_{a1}}$
$\alpha=46.7°$
65.1
75.4
40
50
60
70
γ_1
80°

FIG. 2 (d)

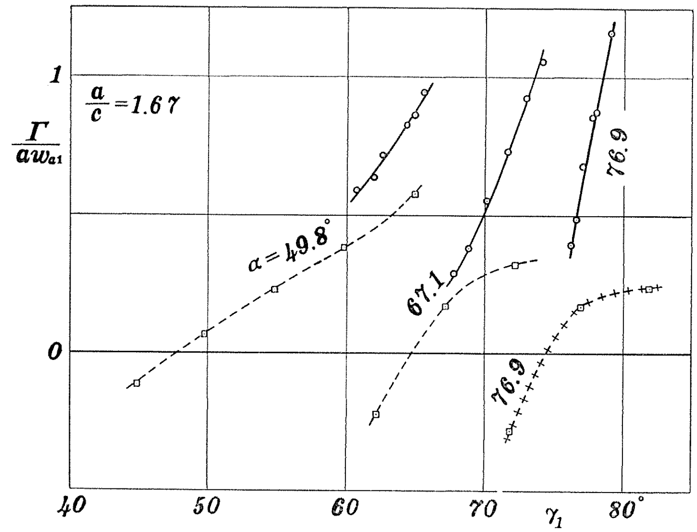

1
0
$\frac{a}{c}=1.67$
$\frac{\Gamma}{aw_{a1}}$
$\alpha=49.8°$
67.1
76.9
76.9
40
50
60
70
γ_1
80°

FIG. 2 (e)

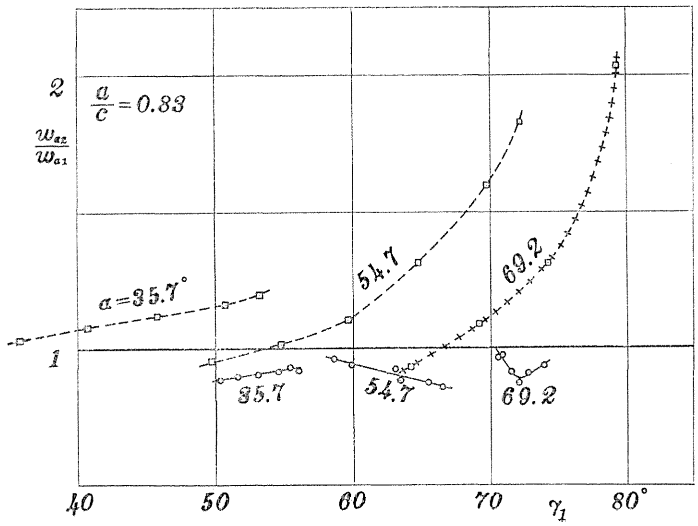

2
$\frac{a}{c}=0.83$
$\frac{w_{a2}}{w_{a1}}$
1
$a=35.7°$
54.7
69.2
35.7
54.7
69.2
40
50
60
70
γ_1
80°

FIG. 3 (a)

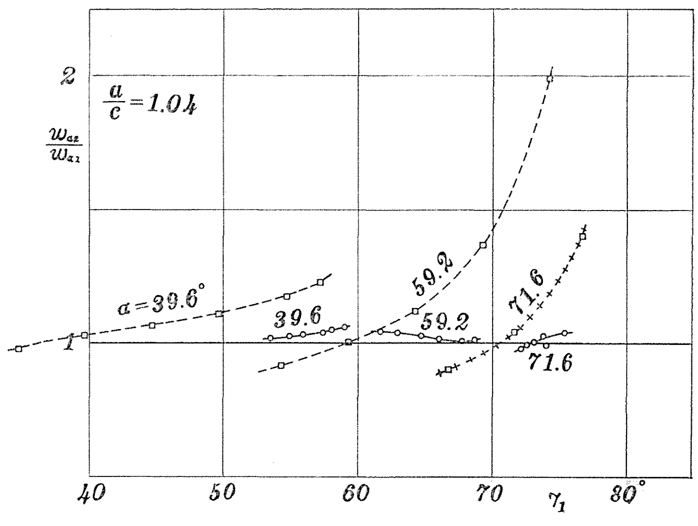
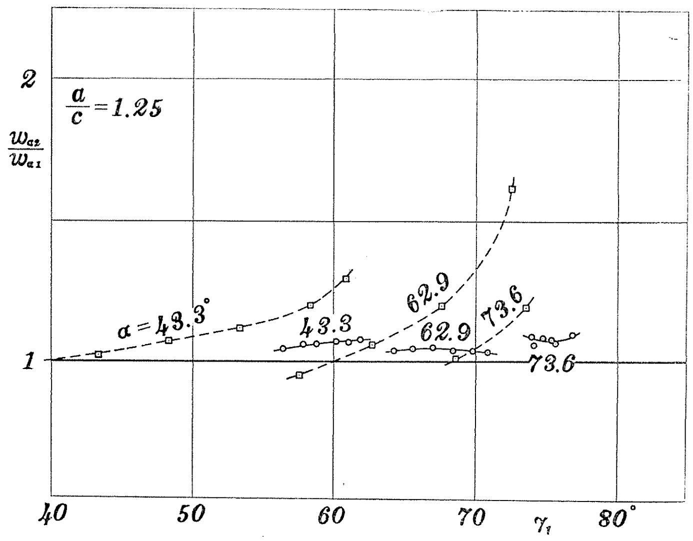
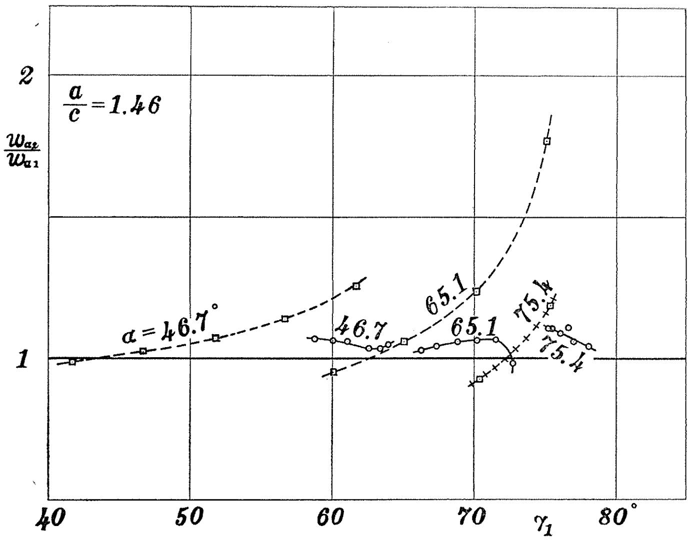

2
$\frac{a}{c}=1.04$
$\frac{w_{a2}}{w_{a1}}$
1
$a=39.6°$
39.6
59.2
59.2
71.6
71.6
40
50
60
70
γ_1
80°

FIG. 3 (b)



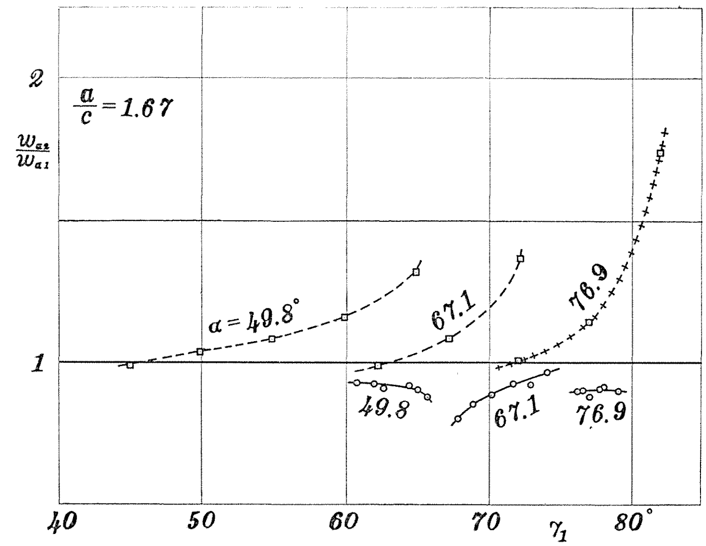
a/c = 1.25
2
1
w_a2/w_a1
a = 43.3°
43.3
62.9
62.9
73.6
73.6
40
50
60
70
γ_1
80°

FIG. 3 (c)



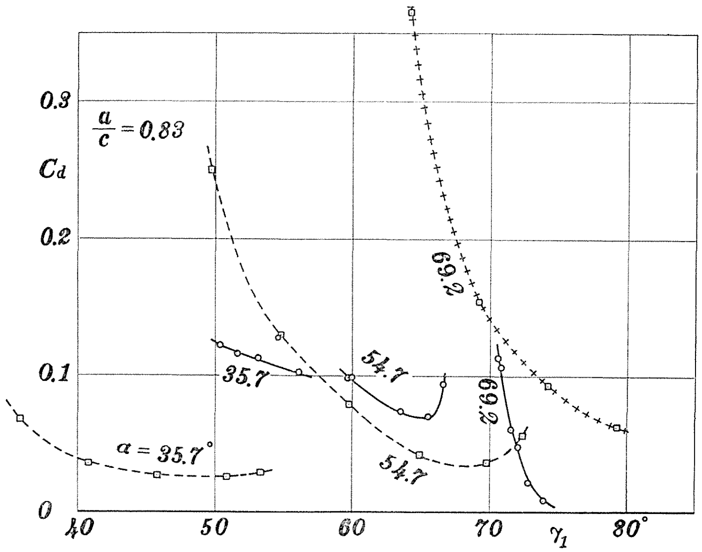
a/c = 1.46
2
1
w_a2/w_a1
a = 46.7°
46.7
65.1
65.1
75.4
75.4
40
50
60
70
γ_1
80°

FIG. 3 (d)



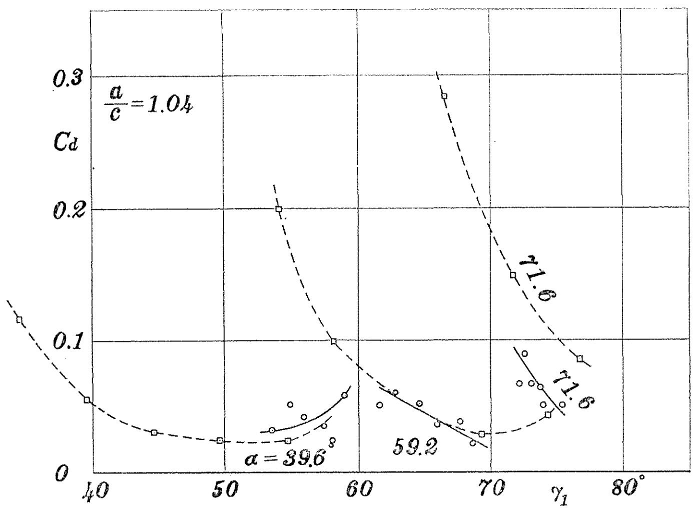
2
a/c = 1.67
w_a2/w_a1
1
α = 49.8°
67.1
76.9
49.8
67.1
76.9
40
50
60
70
γ1
80°

FIG. 3 (e)



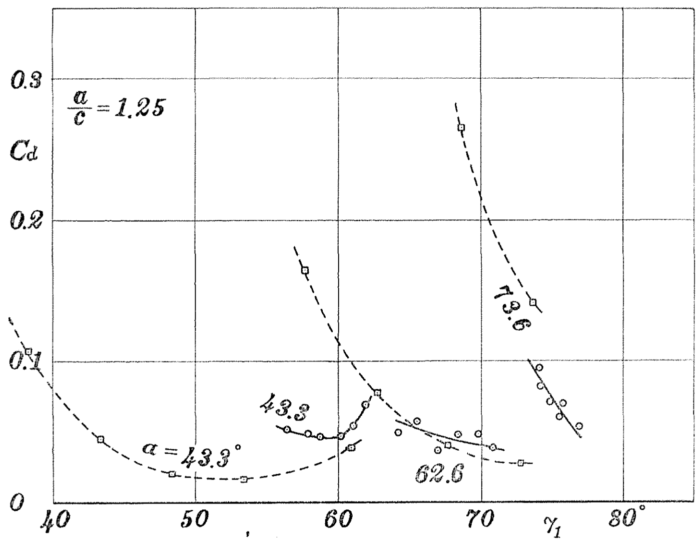
0.3
a/c = 0.83
Cd
0.2
0.1
0
69.2
54.7
35.7
69.2
α = 35.7°
54.7
40
50
60
70
γ1
80°

FIG. 4 (a)



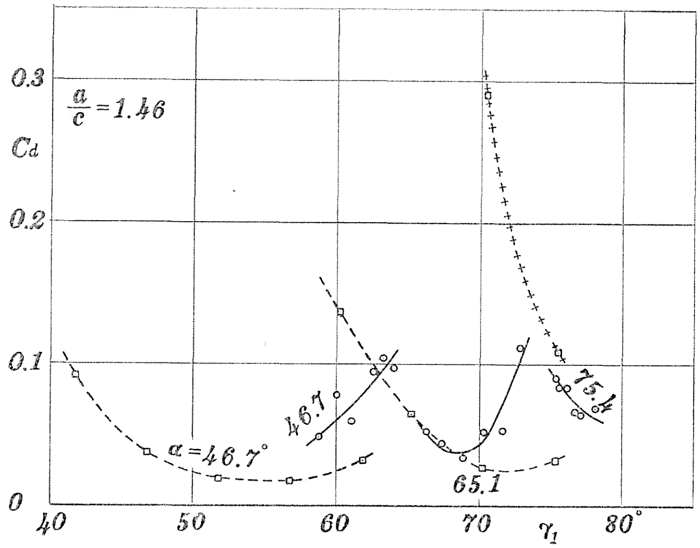
0.3
$\frac{a}{c}=1.04$
Cd
0.2
0.1
0
40
50
60
70
80°
γ_1
$\alpha=39.6°$
59.2
71.6
71.6

FIG. 4 (b)



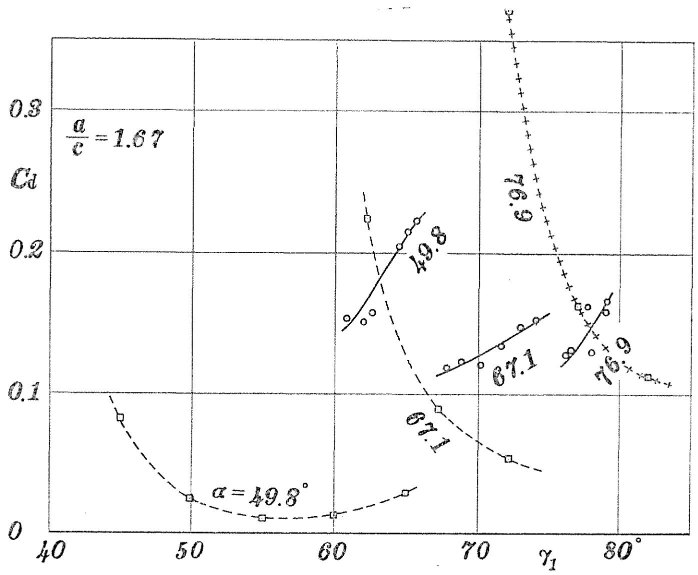
0.3
$\frac{a}{c}=1.25$
Cd
0.2
0.1
0
40
50
60
70
80°
γ_1
$\alpha=43.3°$
43.3
62.6
73.6

FIG. 4 (c)



0.3
$\frac{a}{c}=1.46$
Cd
0.2
0.1
0
40
50
60
70
80°
γ_1
α=46.7°
46.7
65.1
75.4

FIG. 4 (d)



0.3
$\frac{a}{c}=1.67$
Cd
0.2
0.1
0
40
50
60
70
80°
γ_1
α=49.8°
49.8
67.1
67.1
76.9
76.9

FIG. 4 (e)

the interpolations or exterpolations from "Part I" to get the data with same parameter α as the former. The accuracy of these latter curves, therefore, may be insufficient in some cases and these inaccurate curves are distinguished by marks.

Figures 1 (a)~(e) illustrate the relation between inflow angle γ_1 and turning angle β. The difference of both curves is pretty large, and especially large in the boundary layer ($a/c=1.67$ and 0.83). Maximum values of both βs at small stagger angle α are close to each other, but we can recognize that β of cascade has much higher maximum value than compressor's at large stagger angle. The author could not get the lower part of β curves of compressors because of the experimental equipment.

In contrast with the fact that the relations of $\beta-\gamma_1$ curves indicate no clear trend, the relations of $\Gamma-\gamma_1$ curves illustrated in figures 2 (a)~(e) are interesting. Disregarding the inflection (deviation) of curves at high attack angle (high γ_1) on cascade (this inflection may be caused by the change of condition in boundary layer), we may be able to say that the curve of cascade can be connected smoothly to the curve of compressor. It is also interesting that the compressor has larger Γ than the cascade in contrast with the case of $\beta-\gamma_1$. This may be caused by the Coriolis force acting on the particle in boundary layer just as there exists pressure drop. This was pointed out by Schlichting[3].

As aforesaid, the expression of the performance of blade element by Γ will not only make it easier to get the physical explanation but be convenient to have the relation between compressor and cascade, and this idea will be again discussed later.

$w_{a2}/w_{a1}-\gamma_1$ curves indicate marked differences between cascades and compressor blade elements. Not only the values are different but inclinations are quite different. The author cannot explain this situation but suppose that this is caused by complex secondary flows and cannot be explained by the present theory of secondary flows which has not yet been fully developed.

$C_d-\gamma_1$ curves are comparatively similar to each other except in boundary layers ($a/c=1.67$, 0.83). The reason why values in boundary layers are quite different may be that the low energy flow of the wall boundary layer is mixed to the exit flow of blade by the secondary flow.

As aforesaid, we have been able to get the qualitative comparison of performances between cascades and compressor blade elements, but there remains a question if we can find the quantitative relation between the two. The author tried to do it by taking the difference of the both, *i.e.*

$$\Delta = (\text{compressor blade element performance}) - (\text{cascade performance})$$

and he got the following conclusions,

a) no simple relation was recognized between $\Delta\beta$ and ΔC_d.

b) same as above between $\Delta\frac{\Gamma}{a w_{a1}}$ and ΔC_d.

c) same as above between $\Delta\frac{w_{a2}}{w_{a1}}$ and ΔC_d.

d) there exists a relation between $\Delta\beta$ and $\Delta\frac{w_{a2}}{w_{a1}}$

which can be got on one curve, but the scatter of points in the positive region of $\Delta\beta$ is recognized. This is illustrated in the figure 5.

e) the relation between $\Delta \frac{\Gamma}{a w_{a1}}$ and $\Delta \frac{w_{a2}}{w_{a1}}$ can be got on to one curve pretty well, as illustrated in the figure 6. The scatter of points is less than the above (d). The author thinks, therefore, that it is better and more convenient to use circulation Γ rather than turning angle β when we say about the performance of cascades or blade elements.

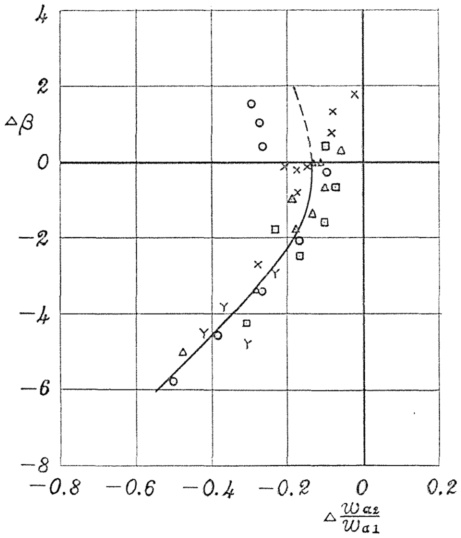


FIG. 5

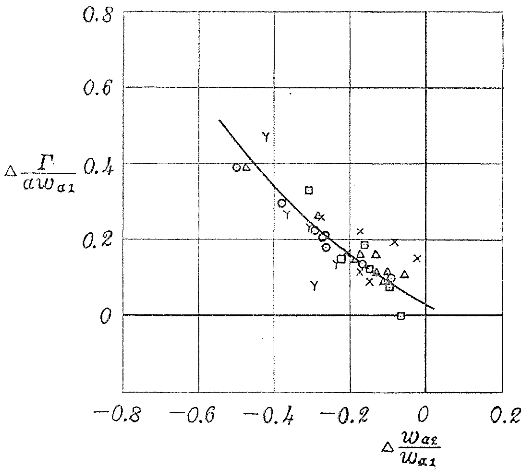


FIG. 6

References

1) Otsuka and Sato: Experiments on the Comparison between Cascade and Axial-Flow Compressor Performances (Part I: Experiment on Cascades), Memoirs of the Faculty of Engineering, Nagoya Univ., Vol. **14**, No. 1-2, Nov. 1962.
2) Otsuka and Hiki: Same Title as above (Part II: Experiment on Axial-Flow Compressor), in the same Memoir as above.
3) Schlichting: Three-Dimensinal Boundary Layer Flow, DFL-Bericht, Nr. 195, 1962.

Errata

Part I, title: EXPERIMENTS ON TNE COMPARISON ··· ⟶ EXPERIMENT ON THE COMPARISON ···

Part II, Fig. 13 (e): α=46.7° ⟶ α=49.8°