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

(PART I: EXPERIMENT ON CASCADES*)

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Introduction

Though we can find a few papers which compare cascade and axial-flow compressor performances,[1][2][3] no clear answer on the relation between them has been obtained. This circumstance is produced probably by the complex phenomena accompanied by secondary flows. The authors tried to compare performances of them by the experiments which included no secondary flow controls as the most simple method. However, they intended to use almost the same size blades and the same flow velocities to eliminate the Reynolds number and Mach number effects, and made only the secondary flow effects exist. They hoped to find a key to solve the secondary flow problems together with the performance comparison between the two. The experiments were accomplished but the analyses have been progressing, and the authors intend to finish them into three reports. "Part I" consists of the intact report of cascade experiments and a few considerations.

Symbols

a: blade pitch
c: chord length
C_d: loss coefficient
$K_{\Delta p}$: pressure rise coefficient $\quad K_{\Delta p}=\dfrac{P_{S2}-P_{S1}}{1/2\,\rho V_1^2}$
l: distance from the trailing edge to the probe along stream line
P: pressure
R_e: Reynolds number
V: velocity
w: velocity component
w_{am}: mean axial velocity at inlet
α: stagger angle
α_i: attack angle
β: turning angle
Γ: blade circulation
γ: air angle from cascade axis

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* The 19th Report of the Study on Axial-flow Turbo-machines
** Engine Division, Transportation Technical Research Institute

Subscript:

1: before cascade
2: behind cascade
a: axial
S: static
T: total
t: tangential

Apparatus and Procedure

The cascade wind tunnel used was a high-speed one which belongs to the Engine Division of Transportation Technical Research Institute. The schematic drawing is illustrated in Fig. 1.

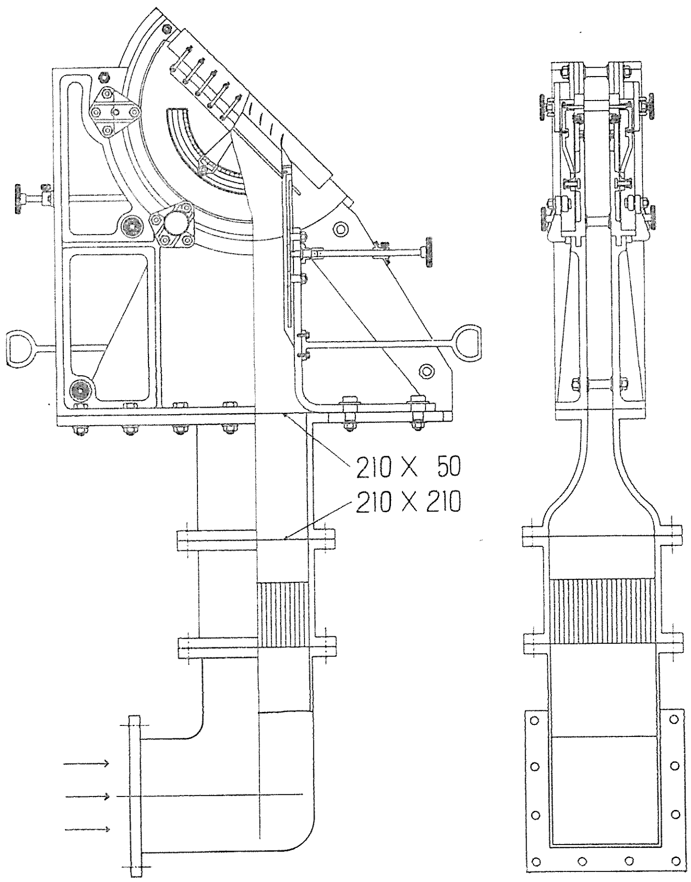
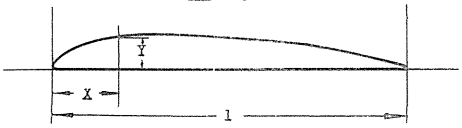


FIG. 1

The blade profile is RAF-6 of 10% thickness, and is the same as to the axial-flow compressor tested. Profile data are illustrated in Fig. 2.

Model dimensions are 24 mm in chord length, 50 mm in span and 2.08 in aspect ratio.

Symbols concerning blade arrangements are illustrated in Fig. 3.



X	Y
0.025	0.041
0.050	0.059
0.100	0.079
0.200	0.095
0.300	0.100
0.400	0.099
0.500	0.095
0.600	0.087
0.700	0.074
0.800	0.056
0.900	0.035
leading edge radius	0.010
trailing edge radius	0.0077

FIG. 2

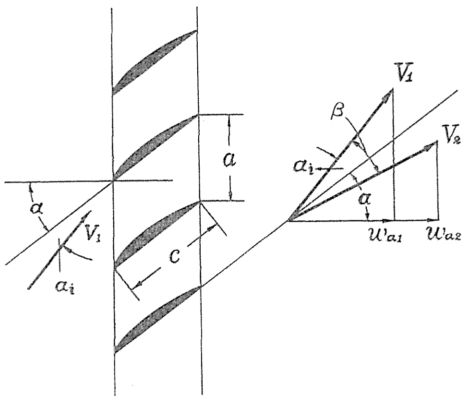


FIG. 3

Scopes of experiments are as follows:

$$a = 20,\ 25,\ 30,\ 35,\ 40\ \text{mm}$$
$$(a/c = 0.83,\ 1.04,\ 1.25,\ 1.46,\ 1.67)$$
$$\alpha = 30^\circ,\ (35),\ 40,\ (45),\ 50,\ (55),\ 60,\ (65),\ 70^\circ$$
$$\alpha_i = -5^\circ,\ 0,\ 5,\ 10,\ 15,\ (17.5),\ 20,\ (22.5^\circ)$$

Because of the limitations of equipments, there are some cases omitted out.

As large number of blades as permitted by the equipments were used. 7, 9 blades were used for the most part and 11 for some part. Confirmations were obtained about practically sufficient uniformness of the flow along the cascade direction by the yaw measurement of exit flow along the full length of cascade in every experiment.

Measurements carried out are as follows; spanwise traverse of air velocity at two chords upstream of the cascade, then air direction measurement along the cascade at midspan and one chord downstream position of the cascade were done. After that, velocity measurement of exit flow was done with the pitot tube directed to the mean flow direction at the same position. The position of measurements in the downstream was examined by varying the distance from cascade to the probe, and it was confirmed that one chord downstream was sufficient to get stable value as shown in Fig. 4.

Measuring probes were made by copper tube of 1 mm in diameter, and it was

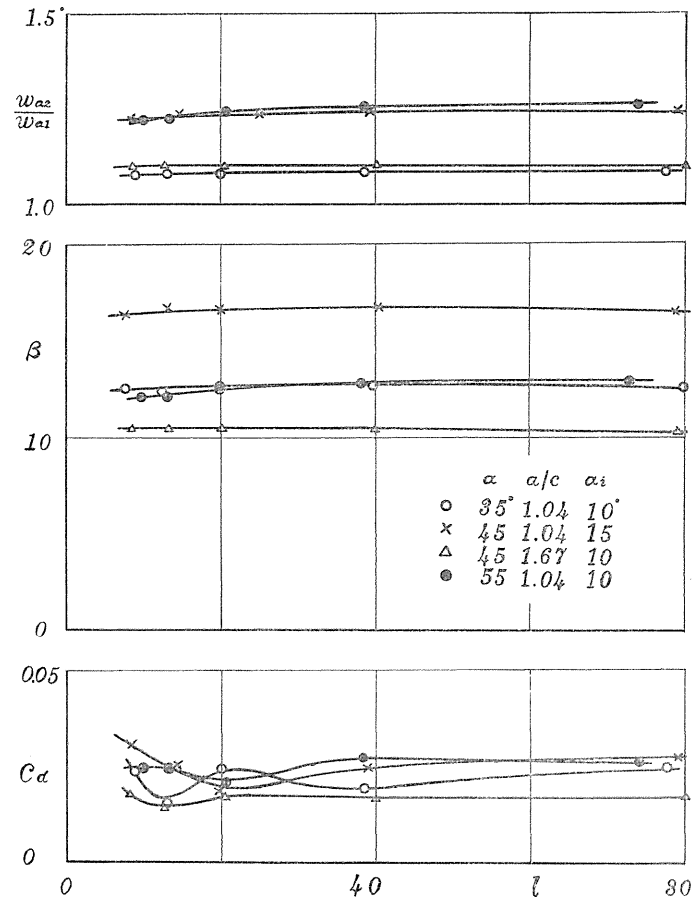


FIG. 4

confirmed that their presence had negligible effect to the flow.

The effect of the Reynolds number (velocity) was examined by changing the air velocity. When it exceeds 70~80 m/s, we can get settled results as shown in Fig. 5, and the experiments were done at the velocity about 80 m/s. ($Re \fallingdotseq 1.3 \times 10^5$)

Results and Considerations

From the results of experiments, we can deduce turning angle β, circulation Γ, loss coefficient C_d and axial velocity ratio as illustrated in figures. In each case α was taken as parameter and γ_1 in abscissa.
Of course, we have

$$\gamma_1 = \alpha + \alpha_i \tag{1}$$

The definition of C_d is

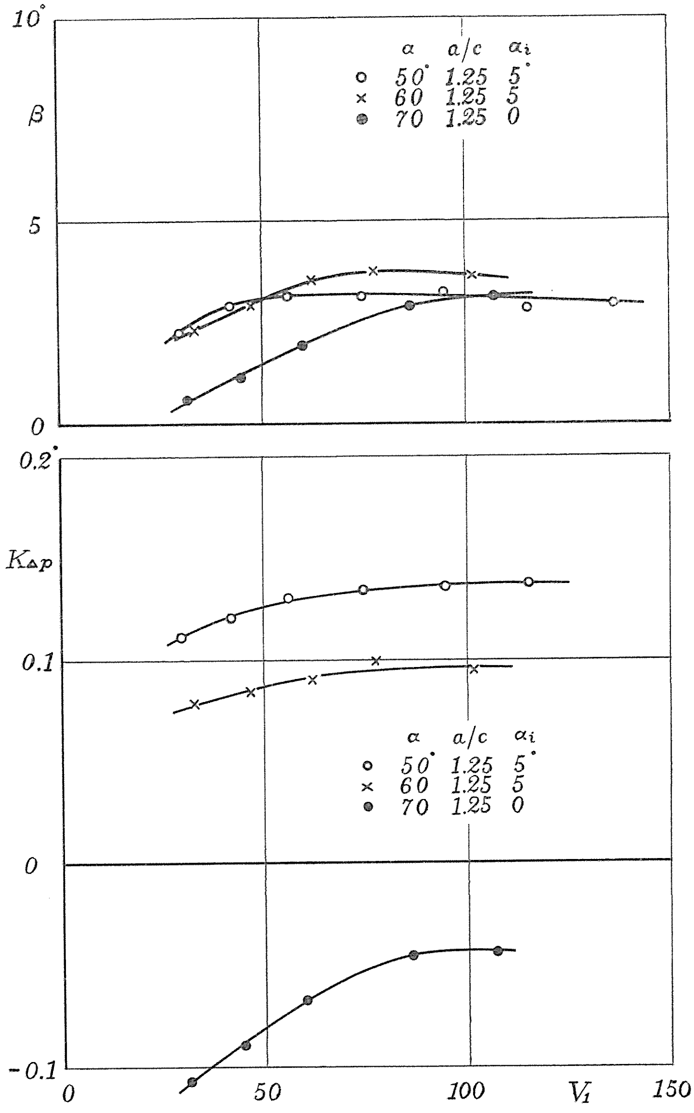


FIG. 5

$$C_d = \frac{P_{T1} - \bar{P}_{T2}}{1/2\,\rho V_1^2} \tag{2}$$

$\bar{P}_{T2}$ is a mean value of P_{T2} in cascade direction at midspan position.

Fig. 6 represents curves of β and Γ/aw_{a1}, and Fig. 7 represents w_{a2}/w_{a1} and C_d. Curves of the ratio of velocity at midspan to mean velocity in the upstream are shown in Fig. 8.

At large γ_1 we see the trends of β curves like stalling, but in Γ curves they are still increasing, therefore it is doubtful to consider them as stalling.

We can understand as a matter of course that w_{a2}/w_{a1} curves are increasing

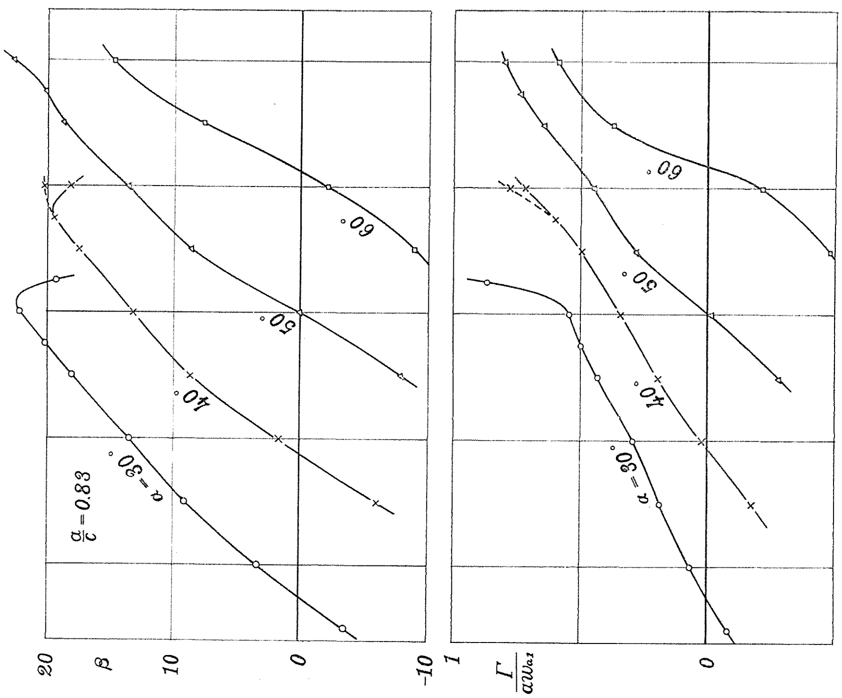

a/c = 0.83
α = 30°
40°
50°
60°
β
20
10
0
-10
1
Γ/aw_a1
0
30
40
50
60
70
γ1

FIG. 6-1

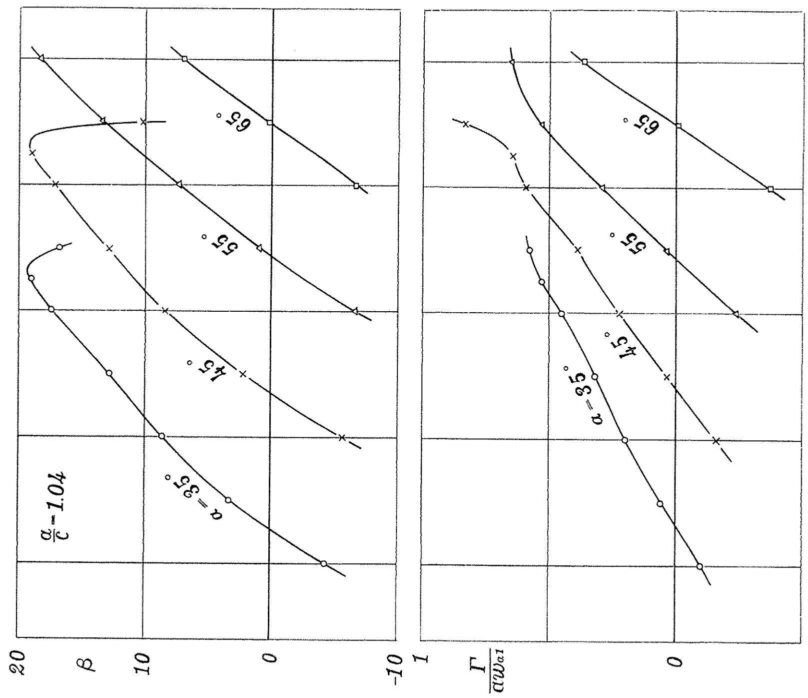

a/c = 1.04
α = 35°
45°
55°
65°
β
20
10
0
-10
1
Γ/aw_a1
0
30
40
50
60
70
γ1

FIG. 6-2

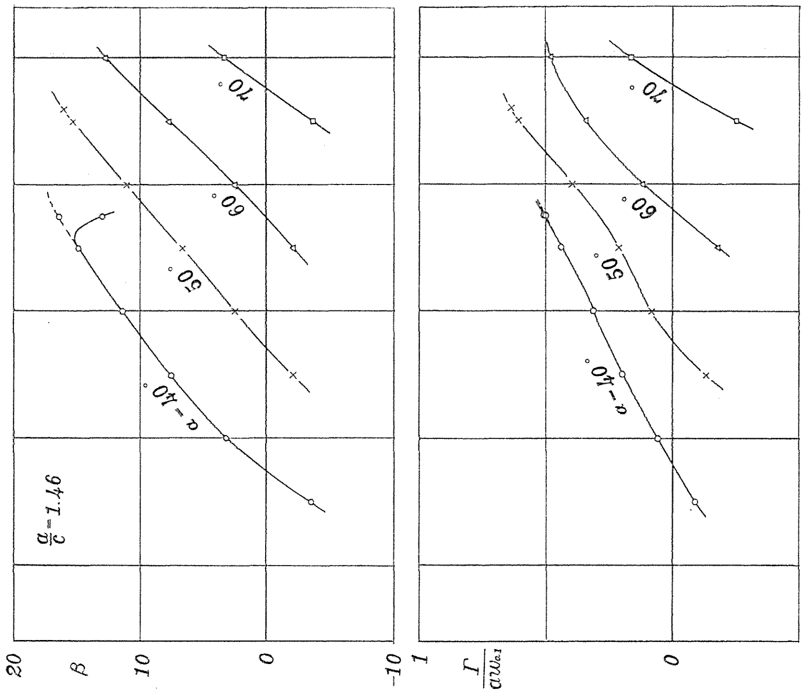

a/c = 1.46
α = 40°
50°
60°
70°
β
Γ/aw_a1
γ1
20
10
0
-10
1
0
30
40
50
60
70

FIG. 6-4

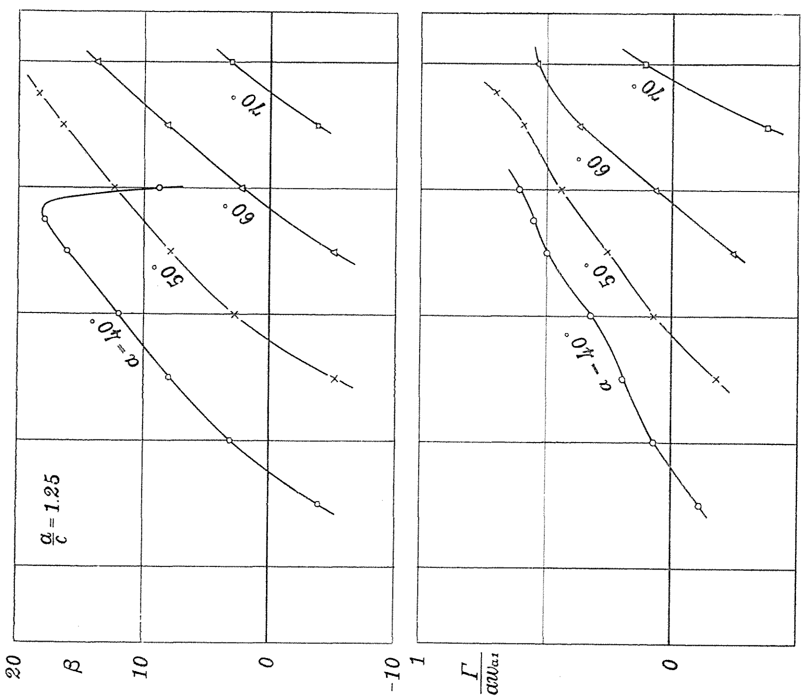

a/c = 1.25
α = 40°
50°
60°
70°
β
Γ/aw_a1
γ1
20
10
0
-10
1
0
30
40
50
60
70

FIG. 6-3

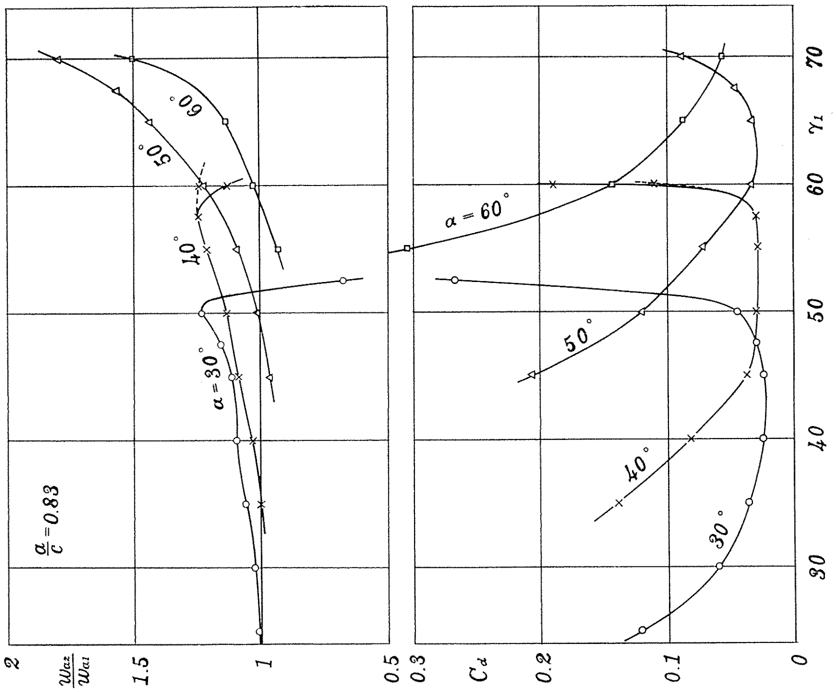

a/c = 0.83
w_a2/w_a1
C_d
α = 30°
40°
50°
60°
α = 60°
γ1
2
1.5
1
0.5
0.3
0.2
0.1
0
30
40
50
60
70

FIG. 7-1

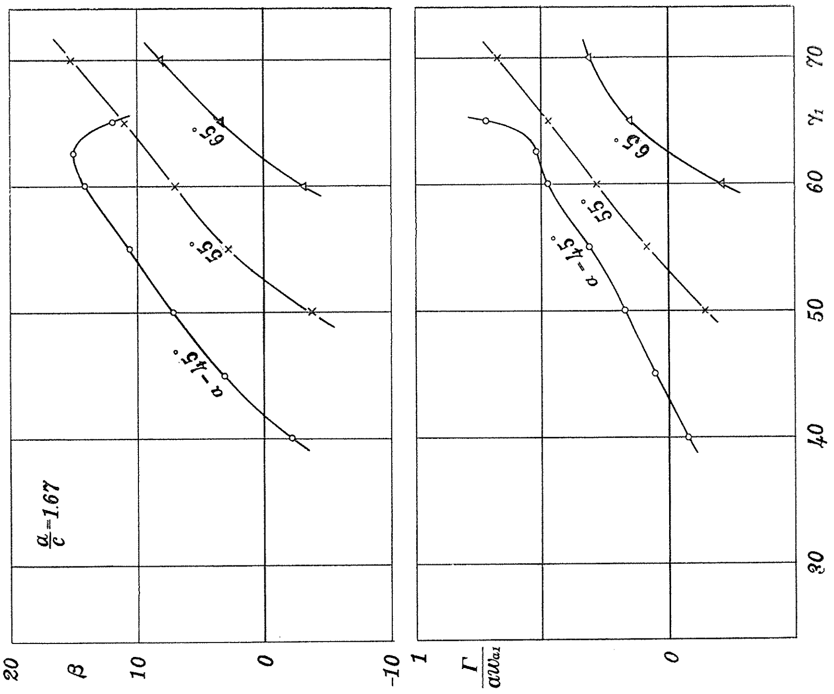
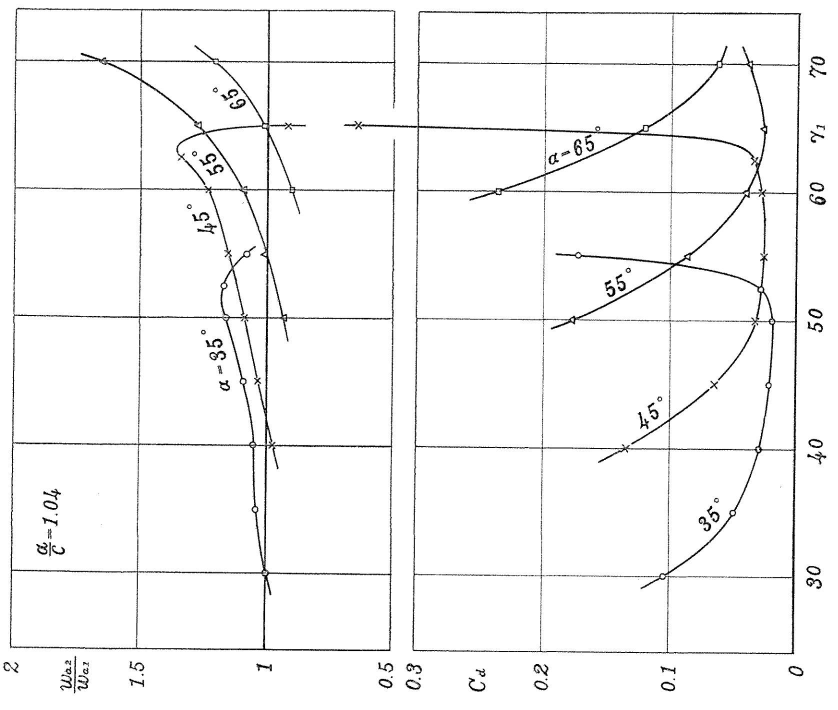
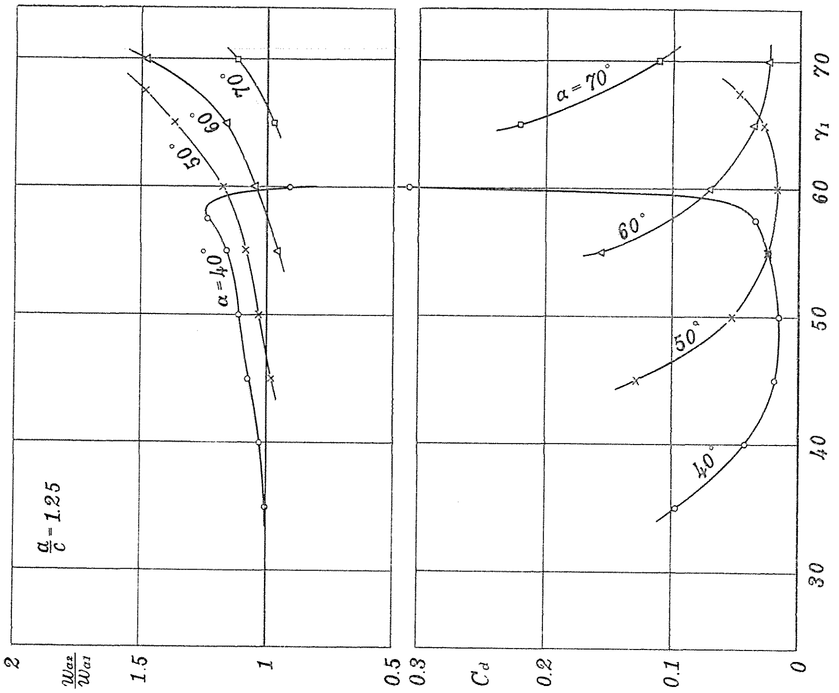

a/c = 1.67
β
Γ/aw_a1
α = 45°
55°
65°
γ1
20
10
0
-10
1
30
40
50
60
70

FIG. 6-5



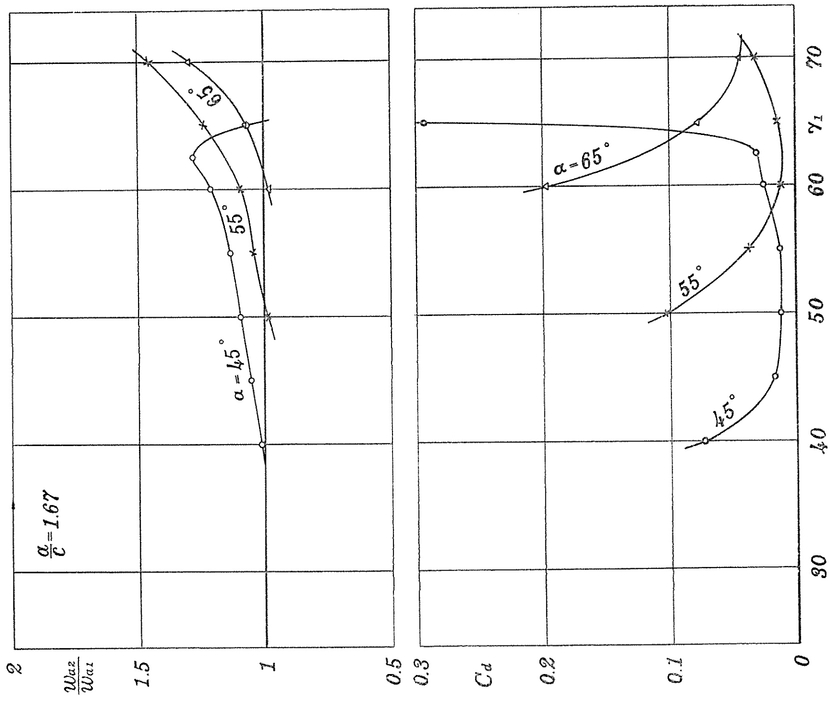
a/C = 1.04
α = 35°
45°
55°
65°
α = 65°
35°
Wa2/Wa1
Cd
γ1
2
1.5
1
0.5
0.3
0.2
0.1
0
30
40
50
60
70

FIG. 7-2



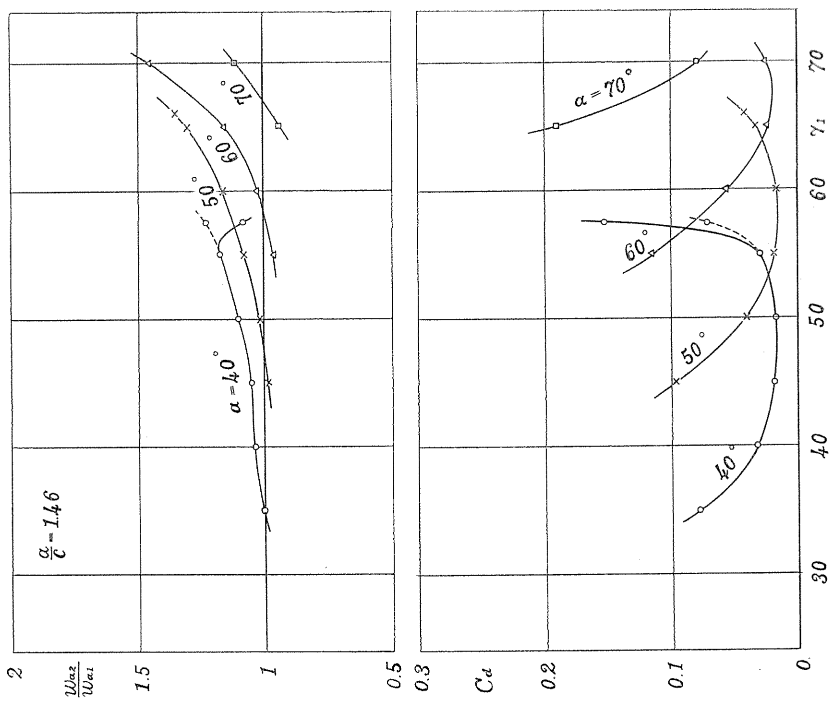
a/C = 1.25
α = 40°
50°
60°
70°
α = 70°
40°
Wa2/Wa1
Cd
γ1
2
1.5
1
0.5
0.3
0.2
0.1
0
30
40
50
60
70

FIG. 7-3



a/c = 1.67
Wa2/Wa1
Cd
γ1
2
1.5
1
0.5
0.3
0.2
0.1
0
30
40
50
60
70
α = 45°
55°
65°
α = 65°
55°
45°

FIG. 7-5



a/c = 1.46
Wa2/Wa1
Cd
γ1
2
1.5
1
0.5
0.3
0.2
0.1
0
30
40
50
60
70
α = 40°
50°
60°
70°
α = 70°
60°
50°
40°

FIG. 7-4

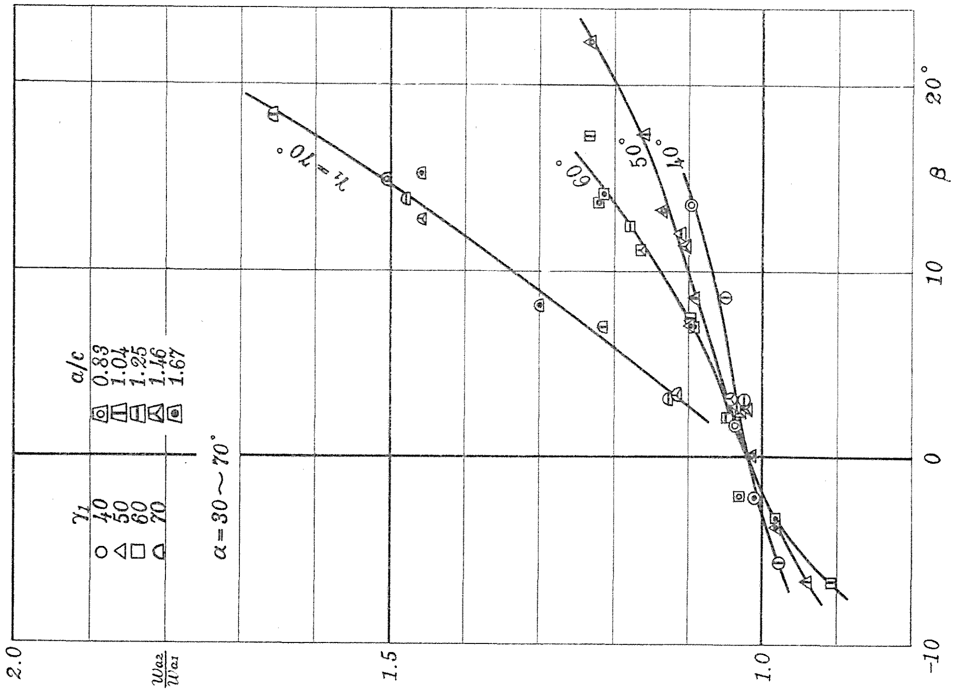

2.0
1.5
1.0
−10
0
10
20°
β
γ_1
40
50
60
70
a/c
0.83
1.04
1.25
1.46
1.67
α = 30 ∼ 70°
γ_1 = 70°
60°
50°
40°
$\frac{w_{a2}}{w_{a1}}$

FIG. 9

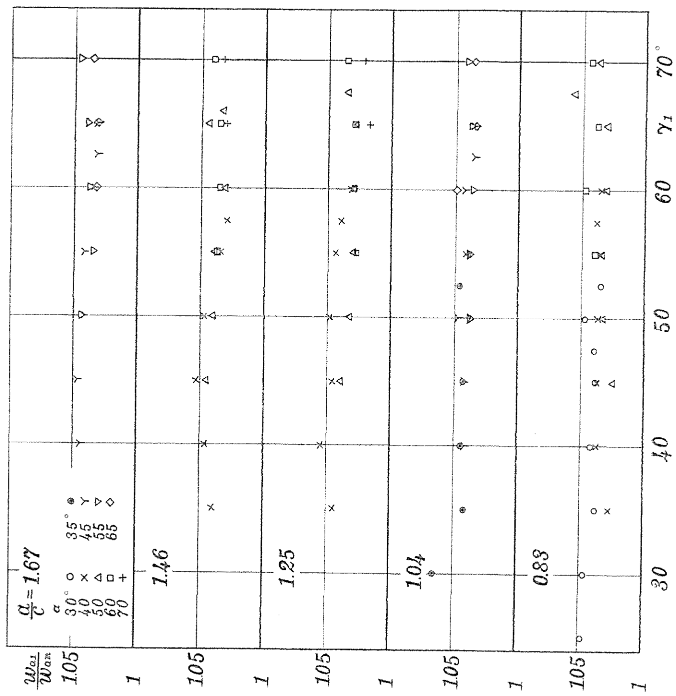

$\frac{a}{c}$ = 1.67
1.46
1.25
1.04
0.83
1.05
1
30
40
50
60
70°
γ_1
$\frac{w_{a1}}{w_{an}}$

FIG. 8

in right direction, but there are some cases that the curves decrease from the halfway. Therefore, much more earnest explanations will be needed for this phenomenon from the standpoint of secondary flow, together with the problem of stalling above-mentioned.

Fig. 9 is a diagram drawn to find any relation between axial velocity ratio w_{a2}/w_{a1} and turning angle β, and it is very interesting to find that in spite of many kind of a/c and α, w_{a2}/w_{a1} is always on one curve provided γ_1 is constant. This fact will become good data for the discussion about the relation between axial velocity ratio and turning angle.[4) 5)] But, to our disappointment we can say nothing about the situation caused by the variation of boundary layers. It was ascertained that changes in aspect ratio cause the change in trend of the curves.

References

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2) Westphal, Godwin: Comparison of NACA 65-series Compressor-blade Pressure Distributions and Performance in a Rotor and in Cascade. NACA TN 3806, 1957.

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