Department of the Navy
Office of Naval Research
Contract NOnr 220(43)

MEASUREMENTS OF THE FREE WATER SURFACE DISPLACEMENTS CAUSED BY A HYDROFOIL OF MODERATE ASPECT RATIO

(A Supplement to Motion Picture No. 62)

By

J. Brentjes

Hydrodynamics Laboratory
Karman Laboratory of Fluid Mechanics and Jet Propulsion
California Institute of Technology
Pasadena, California

Internal Memorandum E- 110.3M
Not for General Distribution

February 1962

Copy No. 3

TABLE OF CONTENTS

LIST OF FIGURES

Purpose of Study

The purpose of this experimental study is to determine the contour of the distorted water surface behind a hydrofoil operating at shallow depths of submergence. The effects of foil depth, Froude Number, and the angle of attack were investigated for a non-cavitating hydrofoil without any flap deflections. The characteristics of the surface depression behind a foil are important when considering the applications of canard or tandem foil systems. A theoretical analysis of the same phenomena is being made by Daniel Ai and a comparison between theory and experiment will be made in the near future.

Equipment and Personnel

The investigation was made in the Free-Surface Water Tunnel of the Hydrodynamics Laboratory at the California Institute of Technology. The operator and investigator was J. Brentjes who was assisted by Carl Eastvedt in the photographic studies.

For this study, the Task Mark II Balance was replaced by a physically similar dummy balance to act as a support for the angle-changing mechanism and model. The live balance was not used because of the desire to protect it from possible wetting or overload damage. The dummy balance was mounted on the existing elevating mechanism which allowed the model to be raised and lowered to within $\pm$ 0.001 ft. from the reference depth (Fig. 1). In order to provide the model with as much clearance from this superstructure as possible, the dummy balance was rotated 180° from its usual position. By having the dummy balance point downstream in this manner, readings of the surface contour could be taken as close to the model as was desired.

To measure the surface wake profile, a Lory Type A depth pointer gage was mounted on a traversing mechanism which spanned the test section (Fig. 1). The mechanism could be positioned a maximum distance of four feet behind the model to within $\pm$ .005 of a foot. The depth gage could be read to within $\pm$.001 feet while the traversing mechanism could be set to within $\pm$.002 feet from the centerline.

Description of the Model

The model used in this investigation was an NACA 16-206 non-cavitating hydrofoil mounted on an NACA 16-006 strut. The coordinates for both the foil and the strut are presented in Table I. The rectangular foil has a chord of three inches and an aspect ratio of 1.33. The strut has a chord of 2.25 inches and a length of approximately ten inches. It was mounted with its leading edge coincident with the leading edge of the foil and with a positive rake angle of ten degrees with respect to the foil chord line. The foil tips were cut off square and had no fillets at the foil-strut intersection. The model was made of 17-4 Armco stainless steel. It is owned by the Boeing Airplane Company which cooperated in and sponsored the earlier force investigation program on this model.[1*] The photographs of the test conditions (Fig. 2 and 3) were taken during that program.

Experimental Procedure

The model with its angle of attack adjustment bracket was mounted on the dummy balance (turned end-for-end, as described earlier). Thus, as shown in Figure 1, the model was supported well aft of the elevating mechanism. By measuring the distance from the tunnel wall to the leading and trailing edges of the foil, the model was adjusted for zero yaw as accurately as possible. The roll angle was reduced to zero by bringing the trailing edge slightly above the water surface and rotating the dummy balance until the foil tips were the same distance from the water surface.

The transverse position of the centerline of the model was determined with the traversing mechanism, using the tips of the foil as reference points. With this centerline as the new reference line, the desired positions of the Lory pointer gage were marked off. It was decided that data points would be taken at 0.05, 0.1, 0.2, 0.3, 0.4, and 0.6 feet transversely from the centerline.

*Numbers refer to references at end of report

With the foil set at eight degrees angle of attack, the longitudinal positions of the pointer gage were determined for distances of $\ell = 0.5$, 1.0, 1.5, 2.0, and 2.5 feet. This was done by aligning a scribed mark on the supporting U-frame of the pointer gage with a flexible scale taped to the top of the upper working section box frame. Since the foil leading edge position varied with angle of attack, the marks for the longitudinal distance, ℓ, had to be changed for each angle. The angles of attack used in this experiment were: 8, 4, 2, and -4 degrees.

Because the effect of Froude Number on the wake profile was to be determined, four velocities were chosen which were within the practical operating range of the tunnel; namely, 10, 15, 20 and 24.5 fps. At each of these velocities the surface contour without the model was determined as a reference waterline for both the foil depth and the wake survey. The reference reading for the foil depth counter was found by lowering the model until the trailing edge of the foil barely touched the water surface and then by making the proper correction to transfer this reading to that for the leading edge. Thus the zero depth reading of the foil was determined and the settings for the three desired depths could be calculated ($h/c = 1.0$, 0.5, and 0.25). This procedure had to be repeated for each angle of attack.

Finally, with all the desired data points selected and marked off, the surface contour was surveyed, repeating the entire procedure for each velocity.

A first impression was that the strut seemed to deflect the water surface in the proximity of the model for the greater foil depths. To check this, the strut was run with the model removed. It was found, however, that the spray and surface distortion were small in comparison with that of the foil and were therefore neglected.

During the experiment it was observed that the maximum wake depth and its position behind the model were direct functions of velocity and angle of attack. Consequently, additional measurements of this maximum wake depth were made for several more foil depths, including some points where the foil was planing.

Observations

Photographs which are directly applicable to this test were taken during the force measurement program.[1] Figures 2 and 3 show the effects of depth and angle of attack at the highest velocity (24.5 fps). No photographs were taken at the lower velocities.

Because of the boundary layer and the buildup of water along the tunnel walls, the actual water surface is not very clear in these photographs. The bottom of the wake profile, however, can be seen quite well and should give a physical feeling of the maximum surface distortion.

For the case of -4 degrees angle of attack, it was observed that when the model was extremely close to the surface, a different type of upwash would occur. The foil would actually scoop up the water and throw it up into a rooster tail while underneath the foil some suction effects were observed. This total effect caused the high peak of the surface distortion in Figure 10.

Analysis of Data:

The only data reduction which was performed was the calculation of the actual wake depth with respect to the reference water line. This was done and the results were plotted to show the wake contours as affected by the various parameters. The data is presented in dimensionless form in order to make it directly applicable to other systems.

Figure 4 shows the effect of foil depth on the longitudinal profile at the centerline, and the transverse profile at the location of maximum wake depth ($\ell/c = 6.0$). All of these profiles are shown to scale. Figure 5 is a similar drawing showing the effect of angle of attack.

The effect of Froude Number and angle of attack on the longitudinal wake profiles is presented for a depth of $h/c = 0.25$ in Figure 6. For this same depth and Froude Numbers, Figure 7 shows the transverse wake profiles. These transverse profiles were taken at various distances behind the leading edge of the foil as shown in the previous figure. Figure 8 shows the transverse profiles at a full depth of half a chord.

The maximum wake depth, d', was obtained for various velocities, depths and angles of attack. Figure 9 shows this maximum wake depth as a function of foil depth for three velocities. Likewise, Figure 10 shows the effect of angle of attack. For constant foil depths it was found that the variations of d' were practically linear with Froude Number and angle of attack (Fig. 11). The longitudinal location of the maximum wake depth, ℓ, was found to vary linearly with Froude Number, but to be unaffected by foil depth or angle of attack.

REFERENCES

1. Brentjes, J., "Experimental Force Investigation of an NACA 16-206 Hydrofoil in the C.I.T. Free-Surface Water Tunnel", Document D2-11597, Boeing Company, Seattle, Washington, (July 1961).

2. Kiceniuk, T., and Hamaguchi, H., "Water Tunnel Tests of Two Hydrofoil Strut Configurations", Internal Memorandum 97392.1M, Hydrodynamics Laboratory, California Institute of Technology, Pasadena, California, (August 1961).

Measurements of the Free Watêr Surface Displacements

Caused by a Hydrofoil of Moderate Aspect Ratio

Internal Memorandum No. E-110.3M

September 1, 1961

Run Summary Sheet

Exp.	Run No.	Angle of Attack	Velocity	Foil Depth h/c	Page No.
Surface Wake Profile	1	8^o	10 fps	1.0, 0.5, 0.25	8, 9
	2	8^o	15 fps	1.0, 0.5, 0.25	10, 11
	3	8^o	20 fps	1.0, 0.5, 0.25	12, 13
	4	8^o	24.5 fps	1.0, 0.5, 0.25	14, 15
	5	4^o	24.5 fps	1.0, 0.5, 0.25	16, 17
	6	4^o	15 fps	1.0, 0.5, 0.25	18, 19
	7	2^o	15 fps	1.0, 0.5, 0.25	20, 21
Maximum Wake Profile	8	8^o	10 fps	2.0 to -.1 (14 points)	22
	9	8^o	20 fps	2.0 to -.096 (12 points)	22
	10	8^o	15 fps	1.0 to -.092 (11 points)	23
	11	2^o	15 fps	2.0 to 0 (11 points)	23
	12	4^o	15 fps	2.0 to -.02 (11 points)	23
	13	-4^o	15 fps	2.0 to 0 (12 points)	24

Data Reduction Sheets 25, 26, 27

Wake Survey Non Cavitating Hydrofoil. Aug 11, '61

B. [illegible]

V = 10 fps
$\alpha = 8^\circ$

$h_{ref} = 1.746$

page 8

Run No	l (ft)	h (ft) ind	W (ft)	d (ft) ind	h ft ind	W (ft)	d ft ind	h ft ind	w (ft)	d (ft) ind
surface contour	1.0		0	.850		0.4	.850			
	2.0			.862			.862			
	3.0			.869			.871			
		Y/c = 0			Y/c = .50			Y/c = .25		
1	1.0	1.461	0	.826	1.586	0	.786	1.648	0	.76[illegible]
			.05	.831		.05	.799		.05	.77[illegible]
dispersed plume			.10	.837		.10	.816	steep slope	.10	.797
			.20	.847		.20	.848		.20	.854
			.30	.858		.30	.867		.30	.873
			.40	.865		.40	.870		.40	.874
			.60	.867		.60	.869		.60	.874
	1.5		0	.827	rooster tail	0	.823	rooster tail	0	.814
			.05	.832		.05	.801		.05	.769
			.10	.837		.10	.816	steep slope	.10	.811
			.20	.848		.20	.843		.20	.847
			.30	.859		.30	.860		.30	.866
			.40	.866		.40	.870		.40	.877
			.60	.877		.60	.879		.60	.878
	2.0		0	.846	rooster tail	0	.868	rooster tail	0	.86[illegible]
			.05	.843		.05	.820		.05	.810
			.10	.844		.10	.823	steep slope	.10	.819
			.20	.848		.20	.841		.20	.841
			.30	.856		.30	.857		.30	.85[illegible]
			.40	.862		.40	.867		.40	.867
			.60	.874		.60	.878		.60	.879
	2.5		0	.876	high of [illegible]	0	.899		0	.89[illegible]
			.05	.856	bottom of r.t.	.05	.849		.05	.85[illegible]
			.10	.849		.10	.830	[illegible] rooster tail	.10	.837
			.20	.849		.20	.841		.20	.841
			.30	.852		.30	.848		.30	.847
			.40	.859		.40	.850		.40	.858
			.60	.869		.60	.872		.60	.87[illegible]

$V = 10$ fps
$\alpha = 8°$

Run No	ℓ	$h/c = .12$	w	d	$h/c = .5$	w	d	$h/c = .25$	w	d
1	0.5		.1	.840		.1	.823		.1	.80[illegible]
			.2	.847		.2	.847		.2	.85[illegible]
			.3	.852		.3	.859		.3	.86[illegible]
			.4	.854		.4	.860		.4	.86[illegible]
			.6	.854		.6	.855		.6	.85[illegible]

water

V = 15 fps
$\alpha = 8^\circ$

Aug. 14, '61

h_{ref} = 1.716

Run No	l ft	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} ft	w (ft)	d_{ind}
reference surface	0.5		0			0.4	.814	low [illegible]		
	1.0			.817			.819	.818		
	1.5			.818			.820	.819		
	2.0			.821			.824	.822		
	2.5			.824			.827	.825		
		h/c = 1.0			h/c = .5			h/c = .25		
2	0.5	1.431	0		1.556	0		1.619	0	[illegible]
			0.05			0.05			0.05	
			0.10	.813		0.10	.794	sharp drop	0.10	.77
			0.20	.817		0.20	.816		0.20	.82
			0.30	.821		0.30	.827		0.30	.83
			0.40	.824		0.40	.829		0.40	.83
			0.60	.830		0.60	.830		0.60	.83
	1.0	~~[illegible]~~	0	.792		0	.749		0	.72
			0.05	.800		0.05	.756		0.05	.72
			0.10	.801	steep ~~slope~~	0.1	.773	steep wall	0.1	.73
			0.2	812		0.2	.816		0.2	.82
			0.3	821		0.3	.836		0.3	.84
			0.4	828		0.4	.840		0.4	.84
			0.6	835		0.6	.843		0.6	.84
	1.5		0	.782		0	.723	deepest part of cav.	0	.69
			0.05	.787	steep slope	0.05	.737		0.05	.69
			0.1	.796		0.1	.766	steep slope	0.1	.7
			0.2	.809		0.2	.809		0.2	.82
			0.3	.825		0.3	.834		0.3	.84
			0.4	.833		0.4	.842		0.4	.84
			0.6	.841		0.6	.844		0.6	.84
	2.0		0	.780	begin. of [illegible]	0	.750		0	.6
			0.05	.787		0.05	.740	steep slope	0.05	.7
			0.1	.796		0.1	.770		0.1	.7
			0.2	.813		0.2	.810		0.2	.8
			0.3	.826		0.3	.835		0.3	.84
			0.4	.835		0.4	847		0.4	.85
			0.6	.843		0.6	.849		0.6	.85

FORM HDL4 5M 10-55 M

V = 15 fps.
α = 8°

Run No	l (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} (ft)	w (ft)	d_{ind}
2 (cont)	2.5	1.431	0	.783	1.556	0	rt. .800	1.619	0	.7
			0.05	.789	steep part slope	0.05	.753	[illegible]	0.05	.7[illegible]
			0.1	.797		0.1	.779	steep slope	0.1	.77
			0.2	.813		0.2	.808		0.2	.81
			0.3	.825		0.3	.829		0.3	.83
			0.4	.835		0.4	.842		0.4	85
			0.6	.848		0.6	851		0.6	85

FORM HDL4 5M 10-55 M

wake survey. aug 14, 61

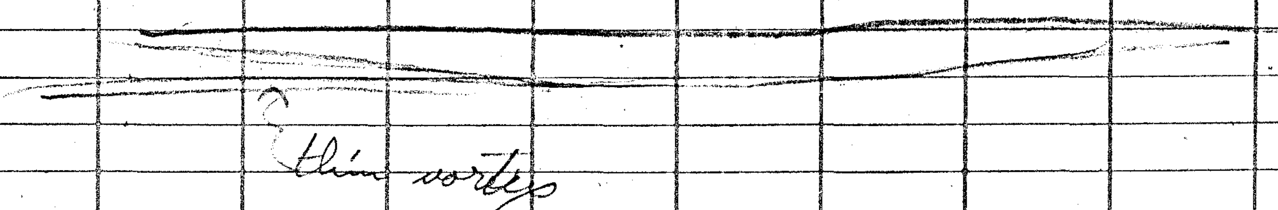
V = 20 fps.
$\alpha = 8°$

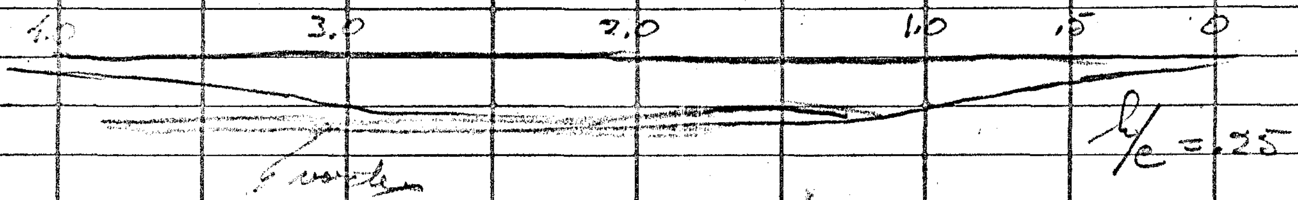
$h_{ref} = 1.715$

Run No	l (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} (ft)	w (ft)	d_{ind}
	0.5		0			0.4	.807	807		
reference surface	1.0			.810			.809	809		
	1.5			.812			812	812		
	2.0			.815			.815	815		
	2.5		~~[illegible]~~	.813			815	814		
3	0.5	1.430	0		1.555	0		1.618	0	≈.757
			0.05			0.05			0.05	
			0.1	.808		0.1	.795		0.1	.776
			0.2	.811		0.2	.816		0.2	.826
			0.3	816		0.3	.821		0.3	.830
			0.4	816		0.4	.820		0.4	.823
			0.6	.821		0.6	.820		0.6	.823
	1.0		0	.789		0	.743		0	.715
			0.05	.791		0.05	.747		0.05	.708
			0.1	.799		0.1	.776	steep slope	0.1	.743
			0.2	.809		0.2	.818		0.2	.832
			0.3	.818		0.3	.829		0.3	.844
			0.4	820		0.4	.832		0.4	.835
			0.6	829		0.6	.831		0.6	.831
	1.5		0	774		0	.705		0	.680
			0.05	782		0.05	.718		0.05	.674
			0.1	787	steep slope	0.1	.759	vertical drop	0.1	.752
			0.2	.792		0.2	816	vortices formed	0.2	837
			0.3	.813		0.3	.833		0.3	850
			0.4	.829		0.4	.840		0.4	849
			0.6	.829		0.6	.840		0.6	844
	2.0		0	.768		0	.679		0	.655
			0.05	779	steep slope	0.05	.715		0.05	693
			0.1	787		0.1	.762	steep drop	0.1	771
			0.2	804		0.2	.812		0.2	834
			0.3	820		0.3	.834		0.3	855
			0.4	832		0.4	.841		0.4	857
			0.6	.843		0.6	.849		0.6	850

V = 20 fps
$\alpha = 8^{\circ}$

Run No	l (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)
3										
	2.5	1.430	0	.767	1.555	0	678	1.618	0	649
			0.05	774		0.05	730	[illegible]	0.05	70[illegible]
			0.1	.782		0.1	769		0.1	773
			0.2	800		0.2	810		0.2	825
			0.3	819		0.3	835		0.3	847
			0.4	829		0.4	851		0.4	855
			0.6	845		0.6	854		0.6	855





FORM HDL4 5M 10-55 M

V = 24.5 fps. Wake survey.

α = 8°

$h_{ref.}$ = 1.715 ft page 14

Run	l (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} ft	w ft	d_{ind} ft	h_{ind} ft	w (ft)	d_{ind} ft
	0.5		0			0.4	805			
	1.0			809			803	806		
	1.5			809			807	808		
	2.0			812			812	812		
	2.5			813			813	813		
4	0.5	1.430	0		1.555	0		1.618	0	≈ 75[illegible]
			.05			.05			.05	
			.1	806		.1	79[illegible]		.1	770
			.2	811		.2	817	top of st. sl.	.2	826
			.3	814		.3	822		.3	827
			.4	814		.4	818		.4	819
			.6	811		.6	814		.6	814
	1.0		0	791		0	742		0	717
			0.05	792		.05	748		.05	710
			.1	792		.1	768	bottom of st. sl.	.1	731
			.2	806		.2	818		.2	835
			.3	815		.3	828		.3	843
			.4	817		.4	828		.4	835
			.6	822		.6	828		.6	828
	1.5		0	770		0	691		0	678
			.05	778		.05	713		.05	671
			.1	786	st sl	.1	761		.1	776
			.2	803		.2	816	st sl	.2	846
			.3	814		.3	834		.3	855
			.4	820		.4	834		.4	845
			.6	834		.6	834		.6	837
	2.0		0	765		0	655		0	644
			.05	773		.05	710	st sl.	.05	707
			.1	782	top of st sl	.1	761		.1	794
			.2	801		.2	819		.2	855
			.3	818		.3	836		.3	865
			.4	824		.4	841		.4	856
			.6	840		.6	848		.6	851

$V = 24.5$ fps   Wake Survey

$\alpha = 8^\circ$

J. Brazzio

h ref.

Run No	l (ft)	h_{ind} ft	w ft	d_{ind} ft	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} ft	w (ft)	d_{ind} ft
4	2.5	1.430	0	757	1.555	0	625	1.618	0	617
			.05	765	st. sl.	.05	707		.05	738
			.1	778		.1	762	st. sl.	.1	795
			.2	801		.2	811		.2	849
			.3	818		.3	839		.3	867
			.4	833		.4	848		.4	864
			.6	849		.6	858		.6	864

FORM HDL4 5M 10-55 M

page 16

V = 24.5 fps.
α = 4°

Wake Survey

Run No	ℓ (ft)	h_ind ft	w (ft)	d_ind (ft)	h_ind (ft)	w (ft)	d_ind ft	h_ind ft	w ft	d_ind ft
	0.4		0	.		0.4	804			
	1.0			808			808			
	1.5			808			808			
	2.0			811			808	810		
	2.5			811			810	810		
5	0.4	1.426	0		1.551	0	≈796	1.614	0	≈792
			.05			.05			.05	
			.1	813		.1	806		.1	818
			.2	816		.2	815		.2	818
			.3	813		.3	817		.3	818
			.4	810		.4	810		.4	812
			.6	809		.6	808		.6	807
	1.0		0	809		0	779		0	760
			.05	807		.05	780		.05	755
			.1	809		.1	792		.1	770
			.2	812		.2	817		.2	826
			.3	804		.3	824		.3	831
			.4	809		.4	820		.4	824
			.6	804		.6	820		.6	819
	1.5		0	798		0	753		0	729
			.05	798	1st sl	.05	765		.05	724
			.1	804		.1	784		.1	762
			.2	810		.2	818		.2	832
			.3	817		.3	828		.3	848
			.4	819		.4	826		.4	830
			.6	837		.6	826		.6	829

V = 24.5 fps
α = 4°

Wake Survey.

Benson

Run No	l (ft)	h ind (ft)	w (ft)	d ind (ft)	h ind (ft)	w (ft)	d ind (ft)	h ind (ft)	w (ft)	d ind (ft)
5										
	2.0	1.426	0	788	1.581	0	732	1.614	0	709
			.05	795		.05	750		.05	708
			.1	800		.1	780	st sl	.1	773
			.2	810		.2	819		.2	831
			.3	820		.3	830		.3	844
			.4	823		.4	832		.4	837
			.6	832		.6	837		.6	837
	2.5		0	781		0	725		0	698
			.05	790	st. sl	.05	743	st sl	.05	705
			.1	797		.1	780		.1	773
			.2	809		.2	816	lowest part of cav.	.2	830
			.3	821		.3	832		.3	842
			.4	827		.4	835		.4	841
			.6	839		.6	841		.6	841

FORM HDL4 5M 10-55 M

$V = 15$ fps. Wake Survey. • Aug 14, 6?

$\alpha = 4°$

Run No	l (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)
	0.4		0			0.4	814			
	1.0		816				818	817		
	1.5		817				821	819		
	2.0		819				824	821		
	2.5		822				824	823		
6	0.4	1.437	0	≈ 808	1.562	0	≈ 797	1.624	0	≈ 787
			.05			.05			.05	
			.1	815		.1	809		.1	796
			.2	816		.2	817		.2	821
			.3	818		.3	821		.3	822
			.4	818		.4	822		.4	821
			.6	824		.6	826		.6	823
	1.0		0	802		0	775		0	761
			0.05	810		.05	779		.05	760
			.1	810		.1	791	stil	.1	772
			.2	815		.2	820		.2	828
			.3	821		.3	828		.3	834
			.4	824		.4	832		.4	833
			.6	830		.6	834		.6	833
	1.5		0	796		0	760		0	743
			.05	802		.05	772		.05	751
			.1	808		.1	786	stil	.1	774
			.2	818		.2	817		.2	826
			.3	824		.3	831		.3	838
			.4	831		.4	837		.4	840
			.6	834		.6	839		.6	836

Wake survey. Aug 15, 61

V = 15 fps
$\alpha = 4^\circ$

Brantjes
page 19

Run No	l (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)
6										
	2.0	1.437	0	793	1.562	0	762	1624	0	750
			.05	799		.05	774	st sl	.05	741
			.1	805		.1	789		.1	782
			.2	816		.2	817		.2	820
			.3	824		.3	831		.3	836
			.4	832		.4	839		.4	841
			.6	837		.6	840		.6	840
	2.5		0	793		0	771		0	768
			.05	802		.05	773	st sl	.05	760
			.1	806		.1	788		.1	793
			.2	818		.2	814		.2	816
			.3	830		.3	828		.3	832
			.4	835		.4	836		.4	842
			.6	840		.6	841		.6	841

FORM HDL4 5M 10-55 M

Wake Survey

May 16, '61

V = 15 fps

α = 2°

href =

page 20

Run No	ℓ (ft)	h_{ind} (ft)	w ft	d_{ind} (ft)	h_{ind} (ft)	w (ft)	d_{ind} (ft)	h_{ind} ft	w (ft)	d_{ind} (ft)
	.4		0			0.4	.815			
	1.0			818			820	819		
	1.5			819			823	821		
	2.0			822			825	823		
	2.5			823			828	826		
7	.4	1.440	0	≈810	1.565	0	≈801	1.628	0	≈802
			.05			.05			.05	
			.1	817		.1	810		.1	805
			.2	817		.2	818		.2	820
			.3	817		.3	821		.3	820
			.4	818		.4	820		.4	821
			.6	823		.6	824		.6	826
	1.0		0	812		0	792		0	783
			.05	816		.05	798		.05	781
			.1	817		.1	802	st. l	.1	788
			.2	818		.2	821		.2	827
			.3	822		.3	827		.3	830
			.4	823		.4	830		.4	830
			.6	828		.6	831		.6	831
	1.5		0	803		0	778		0	771
			.05	810		.05	785		.05	777
			.1	814		.1	794	st. l	.1	782
			.2	820		.2	820		.2	829
			.3	826		.3	830		.3	837
			.4	831		.4	834		.4	837
			.6	833		.6	833		.6	833
			~~0~~							
			~~.05~~							
			~~.1~~							
			~~.2~~							
			~~.3~~							
			~~.4~~							
			~~.6~~							

V = 15 fps

$\alpha = 2^{0}$

$h_{ref.} = 1.690$

page 31

ℓ (ft)	h_{ind} ft	w	d_{ind} ft	h_{ind} ft	w	d_{ind} ft	h_{ind} ft	w	d_{ind} ft
2.0	1.440	0	800	1.565	0	780	1.628	0	781
		.05	808		.05	792		.05	782
		.1	810		.1	.800	st sl	.1	790
		.2	822		.2	820		.2	821
		.3	830		.3	831		.3	834
		.4	835		.4	838		.4	838
		.6	836		.6	836		.6	836
2.5		0	800		0	790	rt.	0	797
		.05	809		.05	791		.05	778
		.1	814		.1	800	st sl	.1	800
		.2	826		.2	817		.2	820
		.3	831		.3	830		.3	833
		.4	837		.4	839		.4	840
		.6	842		.6	839		.6	840

FORM HDL4 5M 10-55 M

BB. page

Maximum Wake Depth

$V = 10$ fps $\alpha = 8°$ $w = 0$ $d_{ref} = .843$ $h_{ref} = 1.710$

Run No	h_{ind} ft	l_{ind} inch	d_{max} -ind	d_{max} (ft)	l (ft)	d_{max}/c	h/c
8	1.210	45 in	≈843	0	≈1.0 ft	0	2.0
	1.335	47	≈829	.014		.056	1.5
	1.460	47	≈815	.028		.112	1.0
	1.510	48 3/4	802	.041		.164	.8
l ≈ 1.0 ft	1.560	48	785	.058		.232	.6
	1.610	48	765	.078		.312	.4
	1.660	48	754	.089		.356	.2
	1.680	48 1/8	751	.092		.368	.12
	1.690	48 1/2	754	.089		.356	.08
	1.700	48 5/8	758	.085		.340	.04
vent →	1.705	"	771	.072		.288	.02
→	1.710	"	779	.064		.256	0.00
planing	1.724	49 1/2	791	.052		.208	-.056
	1.735	49 1/2	811	.032		.128	-.1

$V = 20$ fps $\alpha = 8$ $w = 0$ $d_{ref} = .817$ ft $h_{ref} = 1.682$ ft

Run No	h_{ind} ft	l_{ind} inch	d_{max} -ind	d_{max} (ft)	l (ft)	d_{max}/c	h/c
l ≈ 2.0 ft	1.182	61"	800	.017	≈ 2.0 ft	.068	2.0
9	1.307	61"	794	.023		.092	1.5
	1.432	61"	759	.058		.232	1.0
	1.482	61"	734	.083		.332	.8
	1.532	62"	693	.124		.496	.6
≈61" = 2.0 ft	1.582	63	642	.175		.700	.4
	1.632	61 1/2	651	.166		.664	.2
	1.652	62	665	.152		.608	.12
incip.	1.667	62	678	.139		.546	.06
ventil. →	1.672	62	690	.127		.508	.04
planing	1.699	62	740	.077		.308	-.068
	1.706	62	761	.056		.224	-.096

	h	h/c
V = 10 fps	1.652	.232
15 fps	1.570	.444
20 fps	1.530	.608

} points of incip. tip ventilation.

Maximum Wake Depth Aug 15, '61

page 33

$V = 15$ fps $\alpha = 8°$ $\omega = 0$ $d_{ref} = .818$ $h_{ref} = 1.681$

Run No	h_{ind} ft	h_{ind} inch	$d_{max\ ind}$ (ft)	d_{max}	ℓ	d_{max}/c	h/c			
10	1.431	53 ⅞	.783	.035	1.5 ft	.140	1.0			
	1.481	"	.764	.054		.206	.8			
	1.531	54 ½	.738	.080		.320	.6			
	1.581	54 ⅞	.703	.115		.460	.4			
	1.631	54 ⅞	.689	.129		.516	.2			
	1.651	55	.692	.126		.504	.12			
	1.661	55	.698	.120		.480	.08			
	1.671	55	.705	.113		.452	.04			
	1.676	55	.711	.107		.428	.02			
point of support →	1.681	55	.720	.098		.392	0			
planing →	1.704	55	.761	.057		.228	-.092			
									Aug 18, '61	
	$V = 15$ fps	$\alpha = 2°$	$\omega = 0$ $d_{ref} = 819$		$h_{ref} = 1690$					
11	1.190	1.5 ft	803	.016	$\ell = 1.5$ ft	.064	2.0			
	1.440		795	.024		.096	1.0			
	1.490		789	.030		.120	.8			
	1.540		778	.041		.164	.6			
	1.590		768	.051		.204	.4			
	1.640		765	.054		.216	.2			
	1.660		771	.048		.192	.12			
	1.670		778	.041		.164	.08			
	1.680		791	.028		.112	.04			
	1.685		809	.010		.040	.02			
	1.690		818	.001		.004	0			
	$\alpha = 4°$	$V = 15$ fps	$d_{ref} = 818$		$h_{ref} =$	1.688	781			
12	1.188	1.5 ft	800	.018	1.5 ft	.072	2.0			
	1.438		785	.033		.132	1.0			
	1.488		777	.041		.164	.8			
	1.538		757	.061		.244	.6			
	1.588		745	.073		.292	.4			
	1.638		740	.078		.312	.2			
	1.658		745	.073		.292	.12			
	1.668		750	.068		.272	.08			
	1.678		763	.055		.220	.04			
	1.683		771	.047		.188	.02			
	1.698		804	.014		.056	-.02			

FORM HDL4 5M 10-58

V = 15 fps ℓ = 1.5 h_{ref} = 1.683
α = -4° d_{ref} = 820

page 24

Run No	h_{ind} ft	d_{ind} (ft)	d_{max} (ft)	d_{max}/c	h/c
13	1.183	828	-.008	-.032	2.0
	1.308	831	-.011	-.044	1.5
	1.433	835	-.015	-.060	1.0
	1.483	838	-.018	-.072	.8
	1.533	843	-.023	-.092	.6
	1.583	847	-.027	-.108	.4
	1.633	860	-.040	-.160	.2
	1.653	874	-.054	-.216	.12
	1.663	888	-.064	-.256	.08
	1.673	939	-.119	-.476	.04
	1.678	932	-.112	-.448	.02
	1.683	—	0	0	0

$\alpha = 8°$

red = − values

		V = 10 fps			V = 15 fps			V = 20 fps		
		h/c = 1.0	.5	.25	h/c = 1.0	.5	.25	h/c = 1.0	.5	.25
ℓ ft	W ft	d (ft)	d ft	d (ft)	d	d	d	d	d	d
.5	0				$= d_{ind} - d_{ow}$					
	.05									
	.1	.004	.021	.040	.001	.020	.038	.001	.012	.031
	.2	-.003	-.003	-.010	-.003	-.002	-.014	-.004	-.009	-.019
	.3	-.009	-.015	-.020	-.007	-.013	-.021	-.009	-.014	-.023
	.4	-.010	-.016	-.016	-.010	-.015	-.018	-.009	-.013	-.016
	.6	-.010	-.011	-.008	-.016	-.016	-.017	-.014	-.013	-.016
1.0	0	.024	.064	.087	.026	.069	.094	.020	.066	.094
	.05	.019	.051	.078	.018	.062	.097	.018	.062	.101
	.1	.013	.034	.053	.017	.045	.083	.010	.033	.066
	.2	.003	.002	-.004	.006	.002	-.011	0	-.009	-.023
	.3	-.008	-.017	-.023	-.003	-.018	-.026	-.009	-.020	-.035
	.4	-.015	-.020	-.024	-.010	-.022	-.028	-.011	-.023	-.026
	.6	-.017	-.019	-.024	-.017	-.025	-.025	-.020	-.022	-.022
1.5	0	.029	.033	.042	.037	.096	.127	.033	.107	.132
	.05	.024	.055	.087	.032	.082	.121	.030	.094	.138
	.1	.019	.040	.045	.023	.053	.064	.025	.053	.060
	.2	.008	.013	.009	.010	.010	-.005	.020	-.004	-.025
	.3	-.003	-.004	-.010	-.006	-.015	-.027	-.001	-.021	-.038
	.4	-.010	-.014	-.021	-.014	-.023	-.029	-.017	-.028	-.037
	.6	-.021	-.023	-.022	-.022	-.025	-.025	-.017	-.028	-.032
2.0	0	.016	.006	.000	.042	.072	.126	.047	.136	.160
	.05	.019	.042	.052	.035	.082	.122	.036	.100	.122
	.1	.018	.039	.043	.026	.052	.060	.028	.053	.044
	.2	.014	.021	.021	.009	.012	.007	.011	0	-.019 815
	.3	.006	.005	.009	-.004	-.013	-.018	-.005	-.019	-.040
	.4	.000	-.005	-.005	-.013	-.025	-.029	-.017	-.026	-.042
	.6	-.012	-.016	-.017	-.034	-.027	-.028	-.028	-.034	-.035
2.5	0	-.010	-.033	-.025	.042	.025	.070	.047	.136	.165
	.05	.010	.017	.007	.036	.072	.084	.035	.084	.114
	.1	.017	.036	.029	.028	.046	.046	.032	.045	.041
	.2	.017	.025	.025	.012	.017	.011	.014	.004	-.011
	.3	.014	.018	.019	0	-.004	-.012	-.005	-.021	-.033
	.4	.007	.016	.008	-.010	-.017	-.025	-.015	-.037	-.041
	.6	-.003	-.006	-.013	-.023	-.026	-.030	-.031	-.040	-.041

FSWT 26

		V = 24.5 fps, α = 8°			V = 15 fps, α = 4°			24.5 fps, α = 4°		
		h/c = 1.0	.5	.25	h/c = 1.0	.5	.25	h/c = 1.0	.5	.25
l	w (ft)	d (ft)	d (ft)	d (ft)	d	d	d	d	d	d
.5	0				l = .4			l = .4		
	.05									
	.1	-.001	.014	.035	-.001	.005	.018	-.009	-.002	-.014
	.2	-.006	-.012	-.021	-.002	-.003	-.007	-.012	-.011	-.014
	.3	-.009	-.017	-.022	-.004	-.007	-.008	-.009	-.013	-.014
	4	-.009	-.013	-.014	-.004	-.008	-.007	-.006	-.006	-.008
	6	-.006	-.009	-.009	-.010	-.012	-.009	-.005	-.004	-.003
1.0	0	.015	.064	.089	.015	.042	.056	-.001	.029	.048
	.05	.014	.058	.096	.007	.038	.057	.001	.028	.053
	.1	.014	.038	.075	.007	.026	.045	-.001	.016	.038
	.2	0	-.012	-.029	.002	-.003	-.008	-.004	-.009	-.018
	.3	-.009	-.022	-.037	-.004	-.011	-.017	.004	-.016	-.023
	.4	-.011	-.022	-.029	-.007	-.015	-.016	.004	-.012	-.016
	.6	-.016	-.022	-.022	-.013	-.017	-.016	.004	-.012	-.011
1.5	0	.038	.117	.130	.023	.059	.076	.010	.055	.079
	.05	.030	.095	.137	.017	.047	.068	.010	.043	.084
	.1	.022	.047	.032	.011	.033	.045	.004	.024	.046
	.2	.005	-.008	-.034	.001	.002	-.007	-.002	-.010	-.024
	.3	-.006	-.026	-.047	-.005	-.012	-.019	-.009	-.020	-.040
	.4	-.012	-.026	-.037	-.012	-.018	-.021	-.011	-.018	-.022
	.6	-.026	-.026	-.029	-.015	-.020	-.017	-.029	-.018	-.021
2.0	0	.047	.157	.168	.028	.059	.071	.022	.078	.101
	.05	.039	.102	.105	.022	.047	.080	.015	.060	.102
	.1	.030	.051	.018	.016	.032	.039	.010	.030	.037 810
	.2	.011	-.007	-.043	.005	.004	.001	0	-.009	-.021
	.3	-.006	-.024	-.053	-.003	-.010	-.015	-.010	-.020	-.034
	.4	-.012	-.029	-.044	-.011	-.018	-.020	-.013	-.022	-.027
	.6	-.028	-.036	-.039	-.016	-.019	-.019	-.022	-.027	-.027
2.5	0	.056	.188	.196	.030	.052	.074	.029	.085	.112
	.05	.048	.106	.075	.021	.050	.063	.020	.067	.105
	.1	.035	.051	.018	.017	.035	.030	.013	.030	.037
	.2	.012	.002	-.036	.005	.009	.007	.001	-.006	-.020
	.3	-.005	-.026	-.054	-.007	-.005	.009	-.011	-.022	-.032
	.4	-.020	-.035	-.051	-.012	-.013	-.019	-.017	-.025	-.031
	.6	-.036	-.045	-.051	-.017	-.018	-.018	-.029	-.031	-.031

Wake Survey (Data Reduction)

Aug 15, '61 FSWT

V = 15 fps, α = 2°

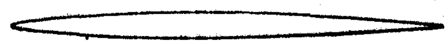
l	w(ft)	h/c = 1.0 d(ft)	.5 d(ft)	.25 d(ft)
.4	0	.005	.014	.013
	.05			
	.1	-.002	.005	.010
	.2	-.002	-.003	-.005
	.3	-.002	-.006	-.005
	.4	-.003	-.005	-.006
	.6	-.008	-.009	-.011
1.0	0	.007	.027	.036
	.05	.003	.021	.038
	.1	.002	.017	.031
	.2	.001	-.002	-.006
	.3	-.003	-.008	-.009
	.4	-.004	-.011	-.009
	.6	-.009	-.012	-.010
1.5	0	.018	.043	.050
	.05	.011	.036	.044
	.1	.007	.027	.039
	.2	.001	.001	-.008
	.3	-.005	-.009	-.016
	.4	-.010	-.015	-.016
	6	-.012	-.012	-.012
2.0	0	.023	.043	.042
	.05	.015	.031	.041
	.1	.013	.023	.033
	.2	.001	.003	.002
	.3	-.007	-.008	-.011
	.4	-.012	-.015	-.015
	6	-.013	-.013	-.013
2.5	0	.026	.036	.029
	.05	.017	.035	.048
	.1	.012	.026	.026
	.2	0	.009	.006
	.3	-.005	-.004	-.007
	.4	-.011	-.013	-.014
	.6	-.016	-.013	-.014

FORM HDL-A-5M-10-55-M

HYDROFOIL AND STRUT COORDINATES

Table I

NACA 16-206



NACA 16-006

NACA 16-206				NACA 16-006	
HYDROFOIL				STRUT	
X_u	Y_u	X_l	Y_l	X	Y_u , Y_l
0.	0.	0.	0.	0.	0.
0.0362	0.0225	0.0383	0.01611	0.0281	0.0145
0.0734	0.0326	0.0766	0.0215	0.0563	0.0203
0.1482	0.0467	0.1518	0.0286	0.1125	0.0282
0.2232	0.0582	0.2268	0.0327	0.1683	0.0341
0.2920	0.0674	0.3018	0.0363	0.2250	0.0389
0.4483	0.0822	0.4517	0.0418	0.3375	0.0465
0.5984	0.0938	0.6016	0.0461	0.4500	0.0535
0.8989	0.1104	0.9011	0.0521	0.6750	0.0610
1.1994	0.1199	1.2006	0.0557	0.5000	0.0659
1.5000	0.1231	1.5000	0.0569	1.1250	0.0675
1.8006	0.1196	1.7994	0.0554	1.3500	0.0656
2.1010	0.1082	2.0990	0.0499	1.5750	0.0593
2.4014	0.0868	2.3986	0.0391	1.8000	0.0472
2.7013	0.0532	2.6587	0.0222	2.0250	0.0283
2.8510	0.0307	2.8499	0.0117	2.1375	0.0159
3.000	0.	3.0000	0.	2.2500	0.0014
L.E. RADIUS = 0.00176" SLOPE OF RADIUS THROUGH L.E. = .0824				L.E. RADIUS = .00396"	

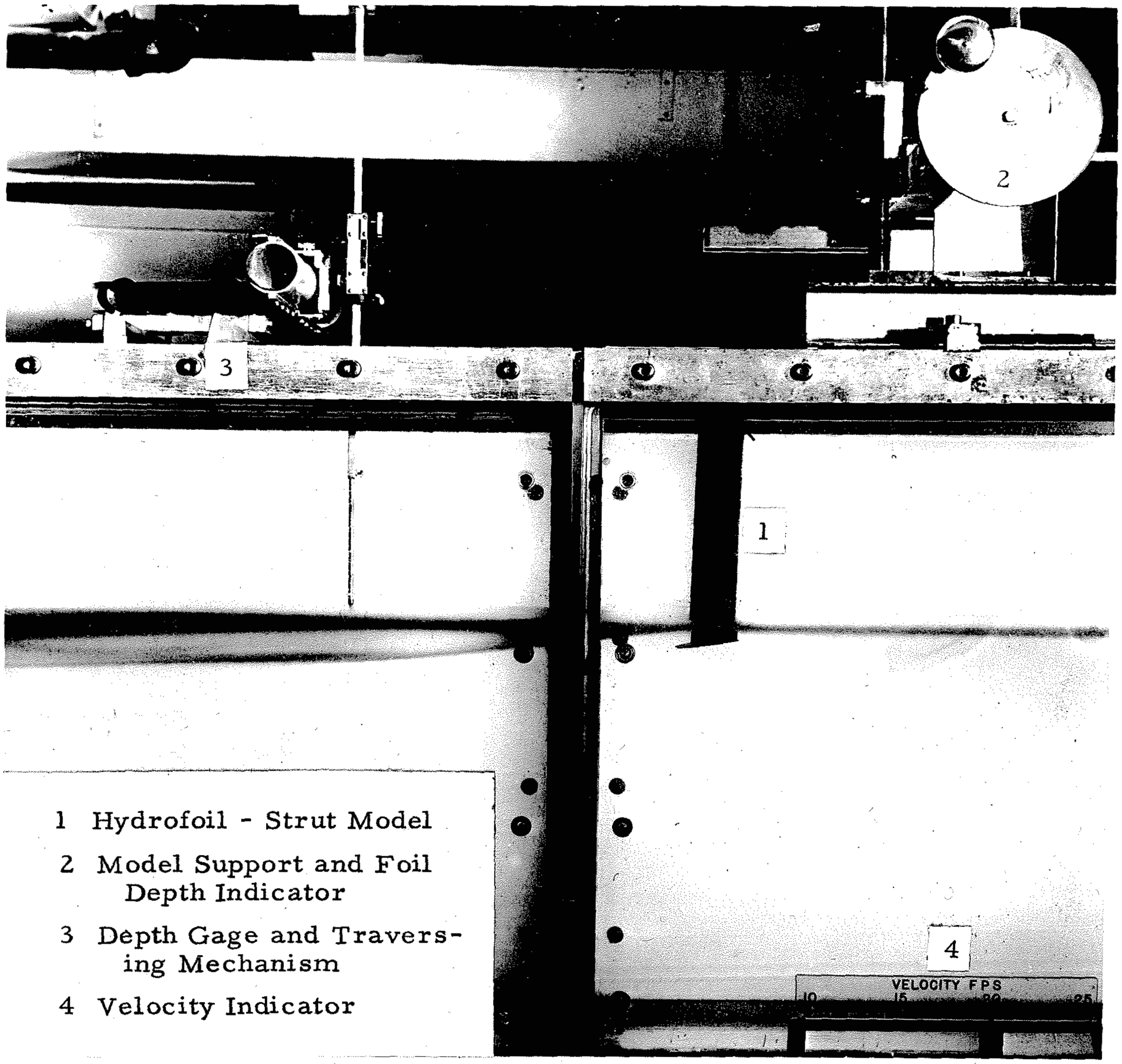
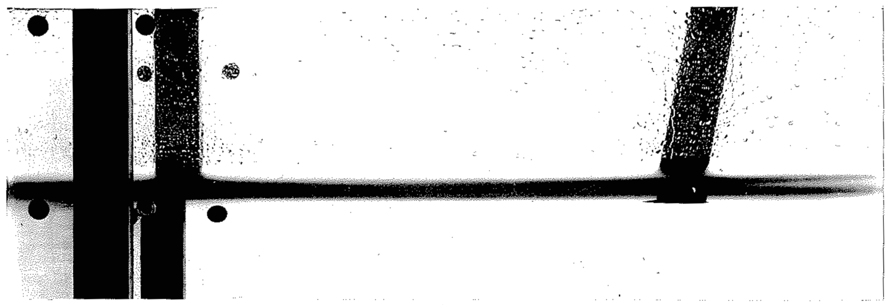
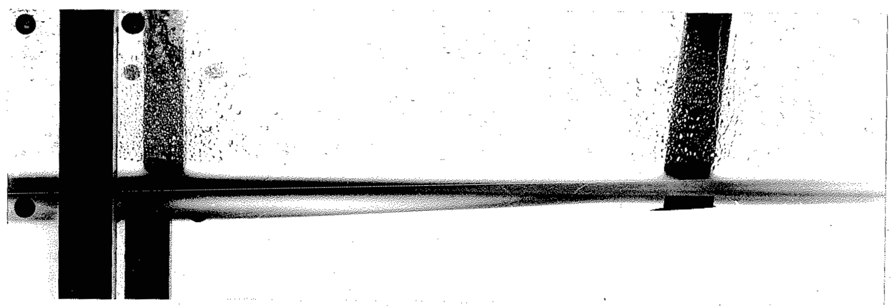


Figure 1 -- Free-Surface Water Tunnel Working Section

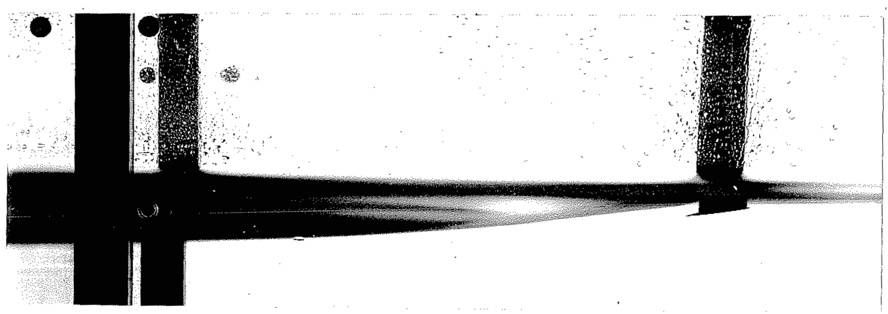
Conditions as shown: Velocity = 20 fps
Angle of Attack = 8^{o}
Foil Depth, h/c = .25



Angle of Attack = 0°



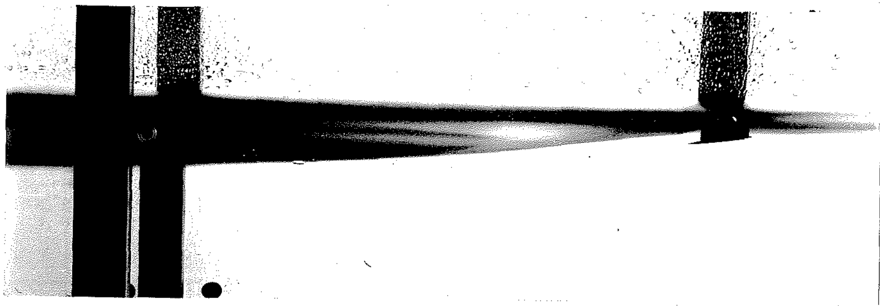
Angle of Attack = 4°



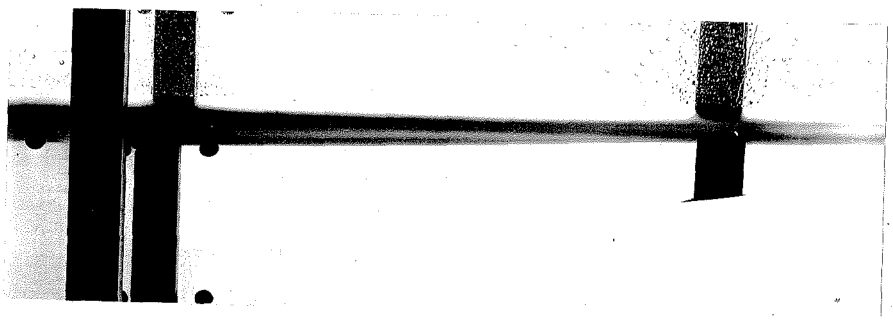
Angle of Attack = 8°

Velocity = 24.5 fps. h/c = .236

Figure 2. Effect of Angle of Attack on the Water Surface Distortion



h/c = .236



h/c = .98

Velocity = 24.5 fps.   Angle of Attack = 8°

Figure 3. Effect of Foil Depth on the Water Surface Distortion

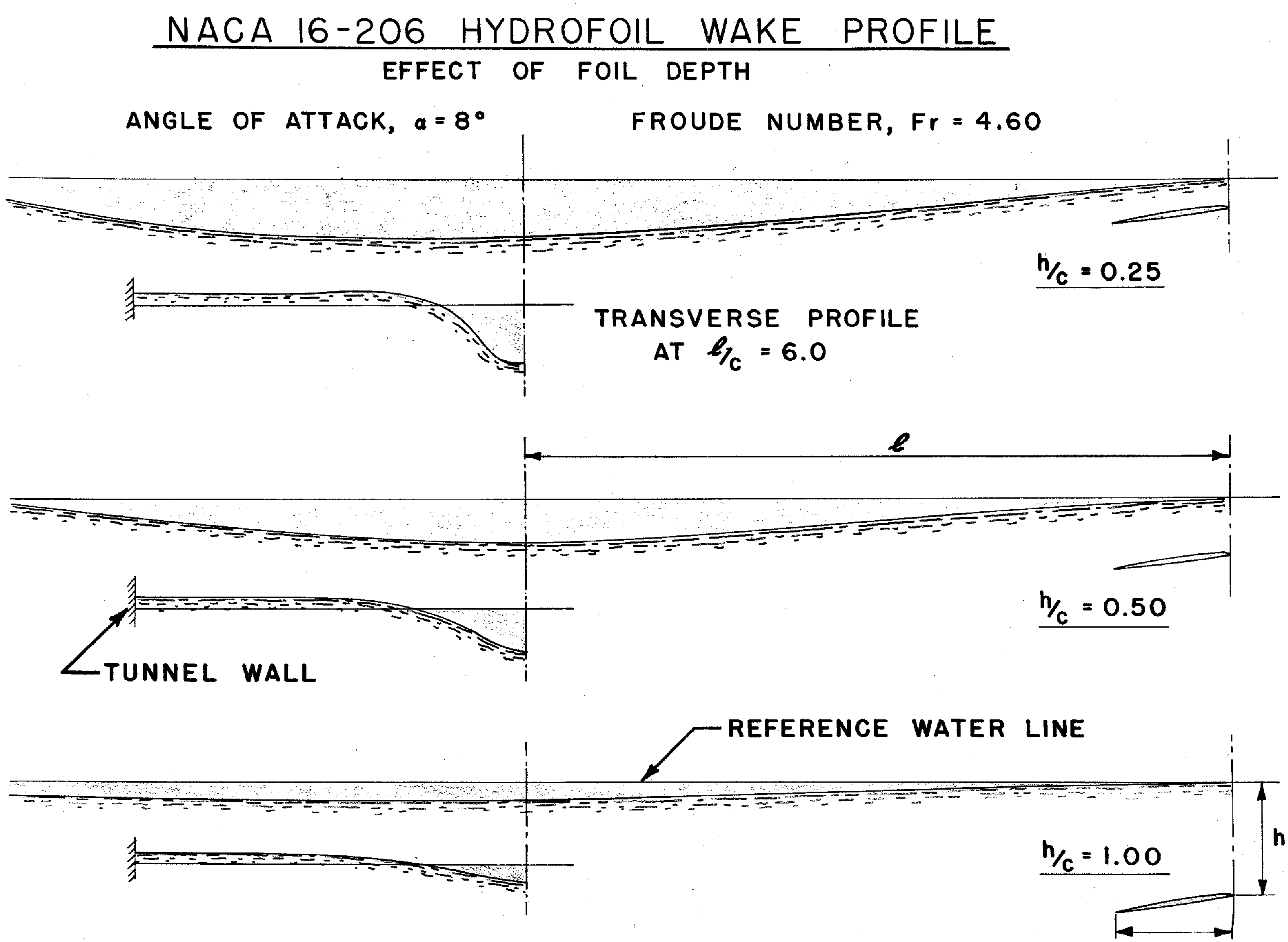

NACA 16-206 HYDROFOIL WAKE PROFILE
EFFECT OF FOIL DEPTH
ANGLE OF ATTACK, α = 8°
FROUDE NUMBER, Fr = 4.60
h/c = 0.25
TRANSVERSE PROFILE
AT ℓ/c = 6.0
ℓ
h/c = 0.50
TUNNEL WALL
REFERENCE WATER LINE
h
h/c = 1.00
c

Figure 4

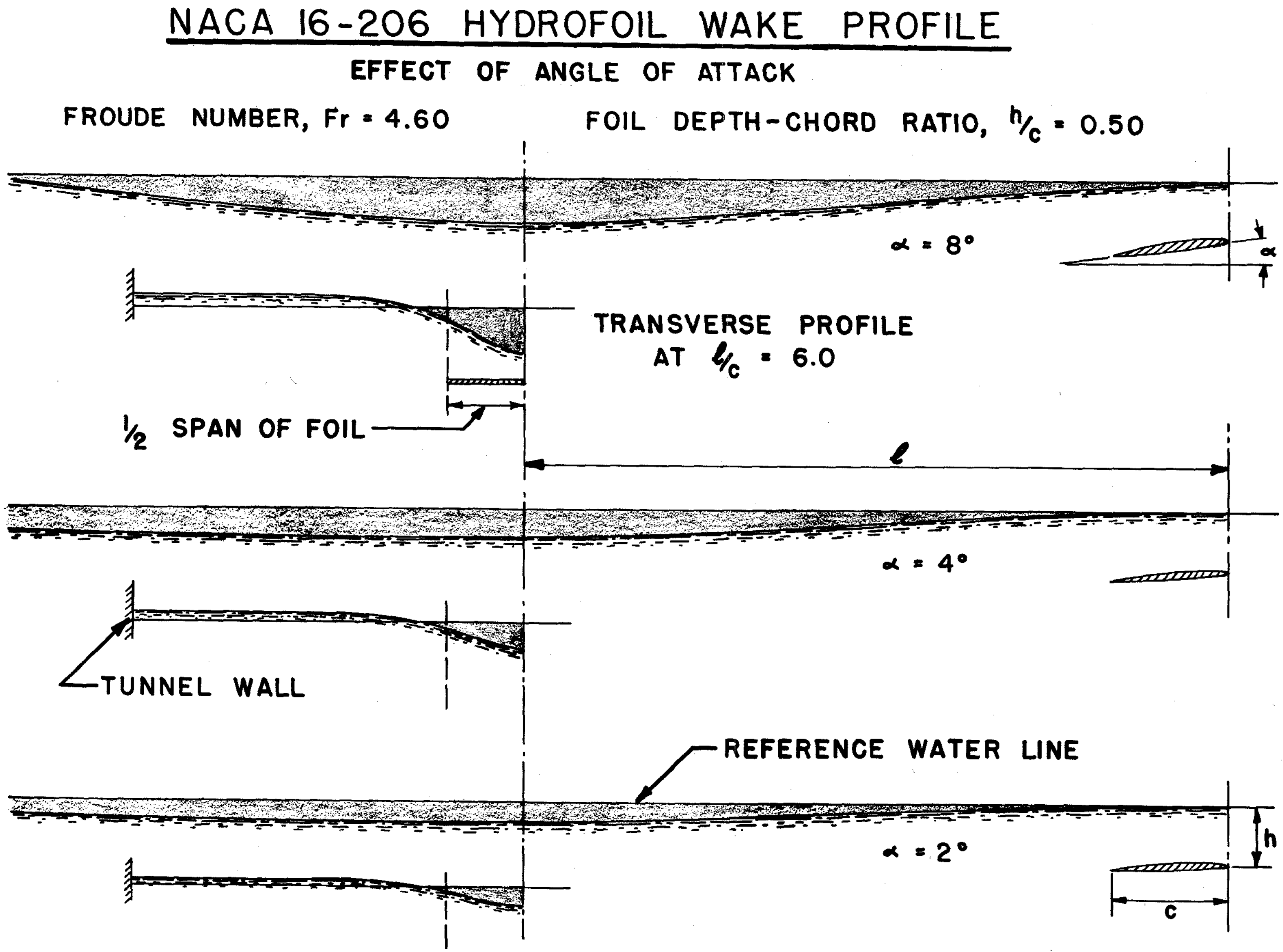

NACA 16-206 HYDROFOIL WAKE PROFILE
EFFECT OF ANGLE OF ATTACK
FROUDE NUMBER, Fr = 4.60
FOIL DEPTH-CHORD RATIO, h/c = 0.50
α = 8°
α
TRANSVERSE PROFILE
AT ℓ/c = 6.0
1/2 SPAN OF FOIL
ℓ
α = 4°
TUNNEL WALL
REFERENCE WATER LINE
α = 2°
h
c

Figure 5

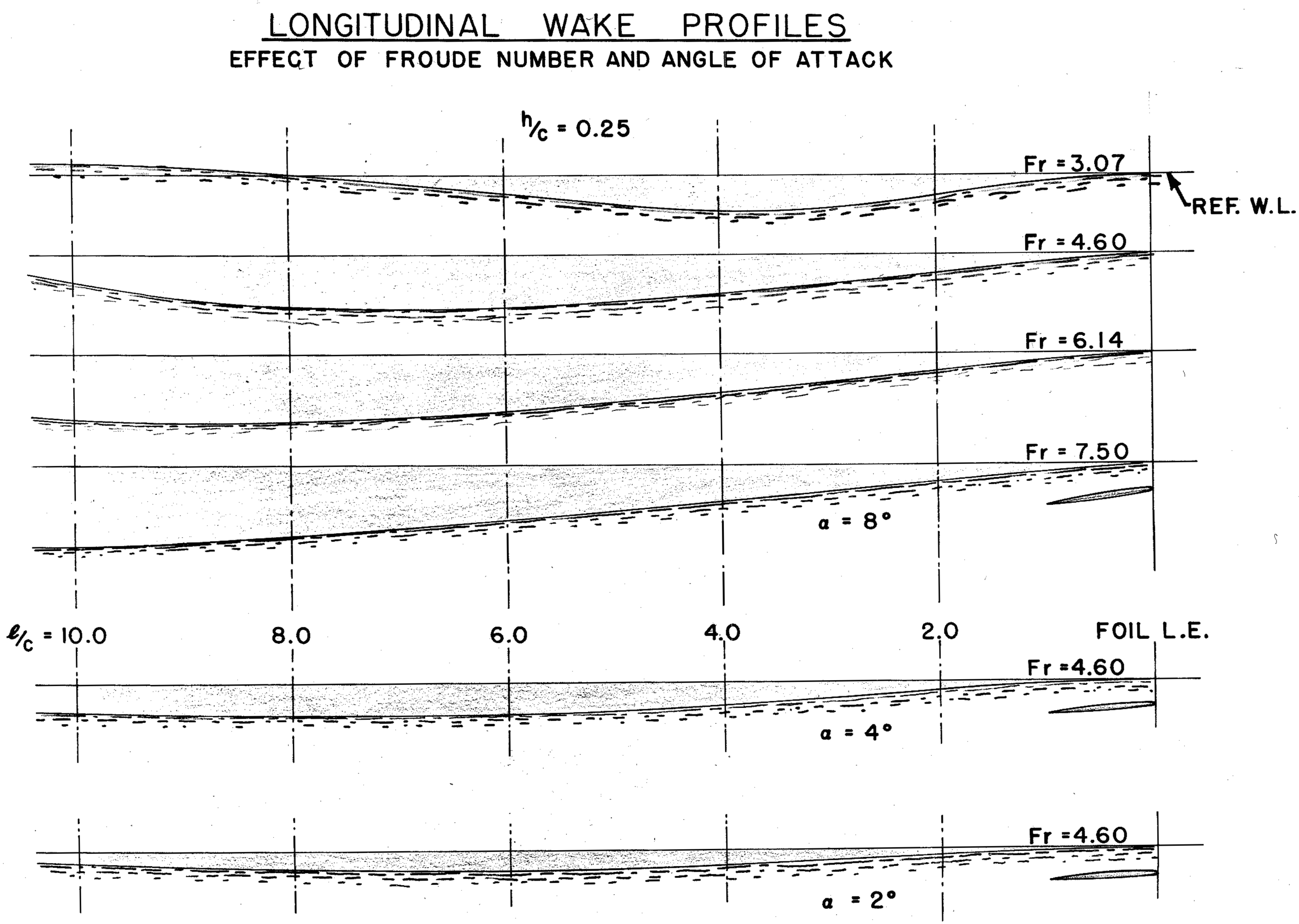

LONGITUDINAL WAKE PROFILES
EFFECT OF FROUDE NUMBER AND ANGLE OF ATTACK
h/c = 0.25
Fr = 3.07
REF. W.L.
Fr = 4.60
Fr = 6.14
Fr = 7.50
a = 8°
ℓ/c = 10.0
8.0
6.0
4.0
2.0
FOIL L.E.
Fr = 4.60
a = 4°
Fr = 4.60
a = 2°

Figure 6

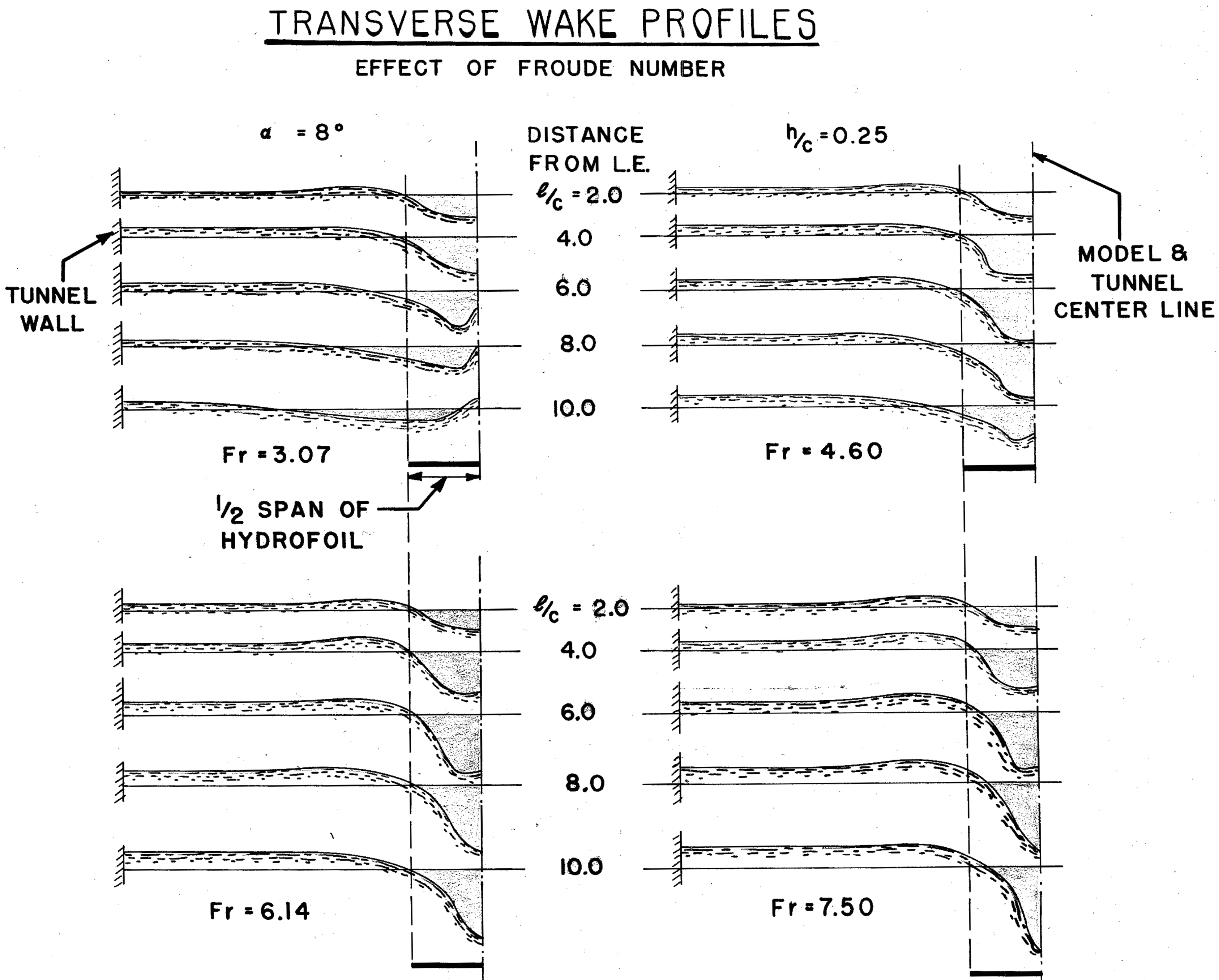

TRANSVERSE WAKE PROFILES
EFFECT OF FROUDE NUMBER
α = 8°
DISTANCE FROM L.E.
h/c = 0.25
ℓ/c = 2.0
4.0
6.0
8.0
10.0
TUNNEL WALL
MODEL & TUNNEL CENTER LINE
Fr = 3.07
Fr = 4.60
1/2 SPAN OF HYDROFOIL
ℓ/c = 2.0
4.0
6.0
8.0
10.0
Fr = 6.14
Fr = 7.50

Figure 7

TRANSVERSE WAKE PROFILES

EFFECT OF FROUDE NUMBER

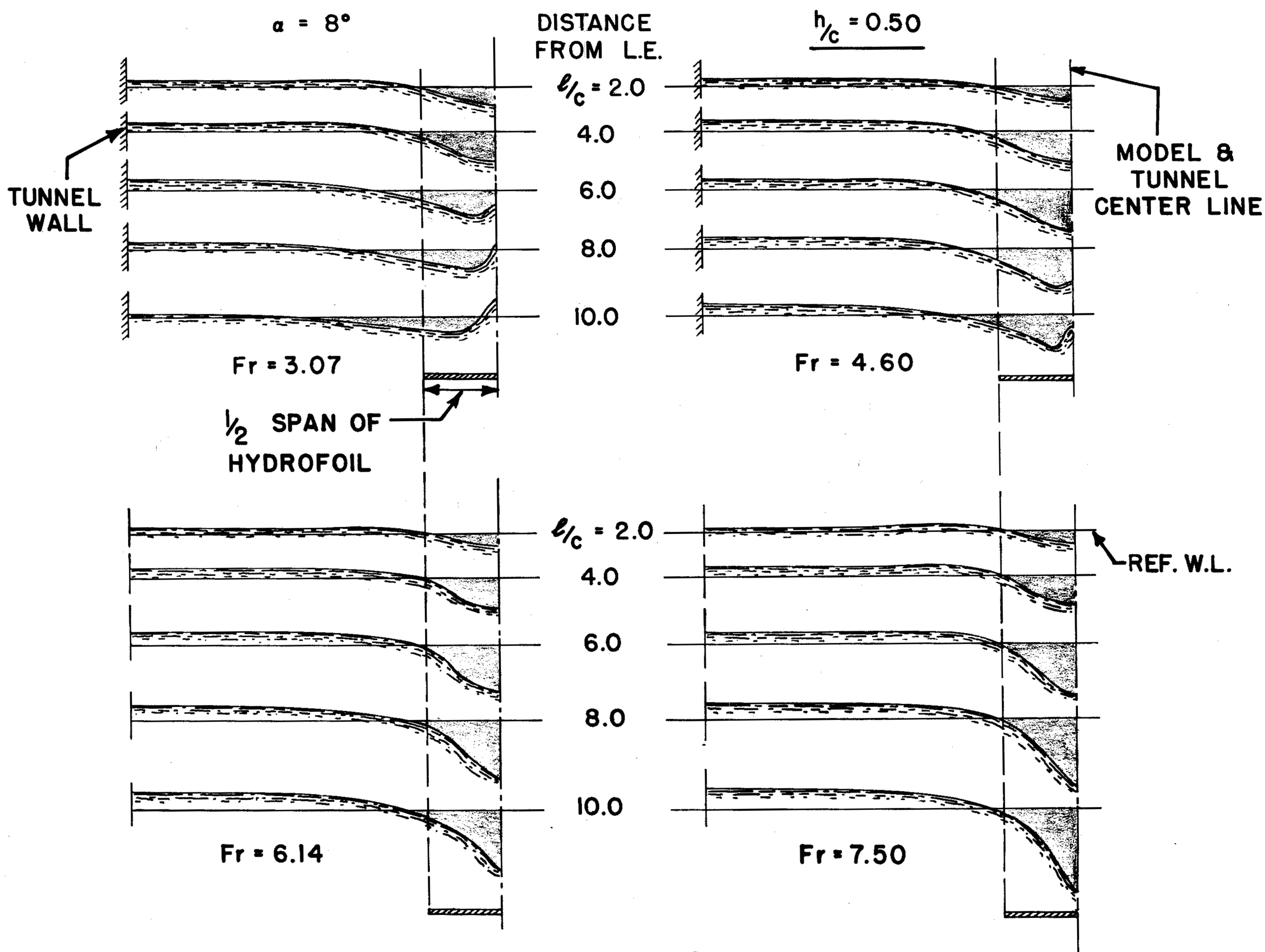


Figure 8

MAXIMUM WAKE DEPTH, d'

EFFECT OF FROUDE NUMBER, Fr

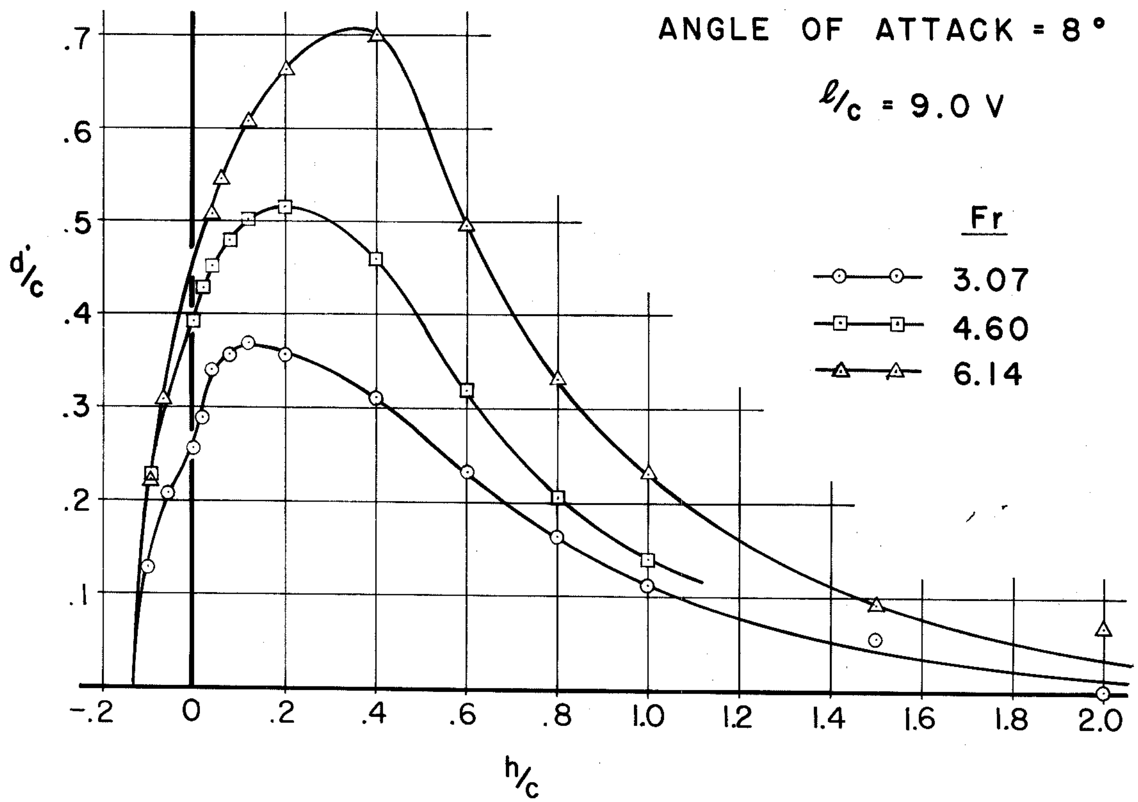


Figure 9

MAXIMUM WAKE DEPTH, d'

EFFECT OF ANGLE OF ATTACK, α

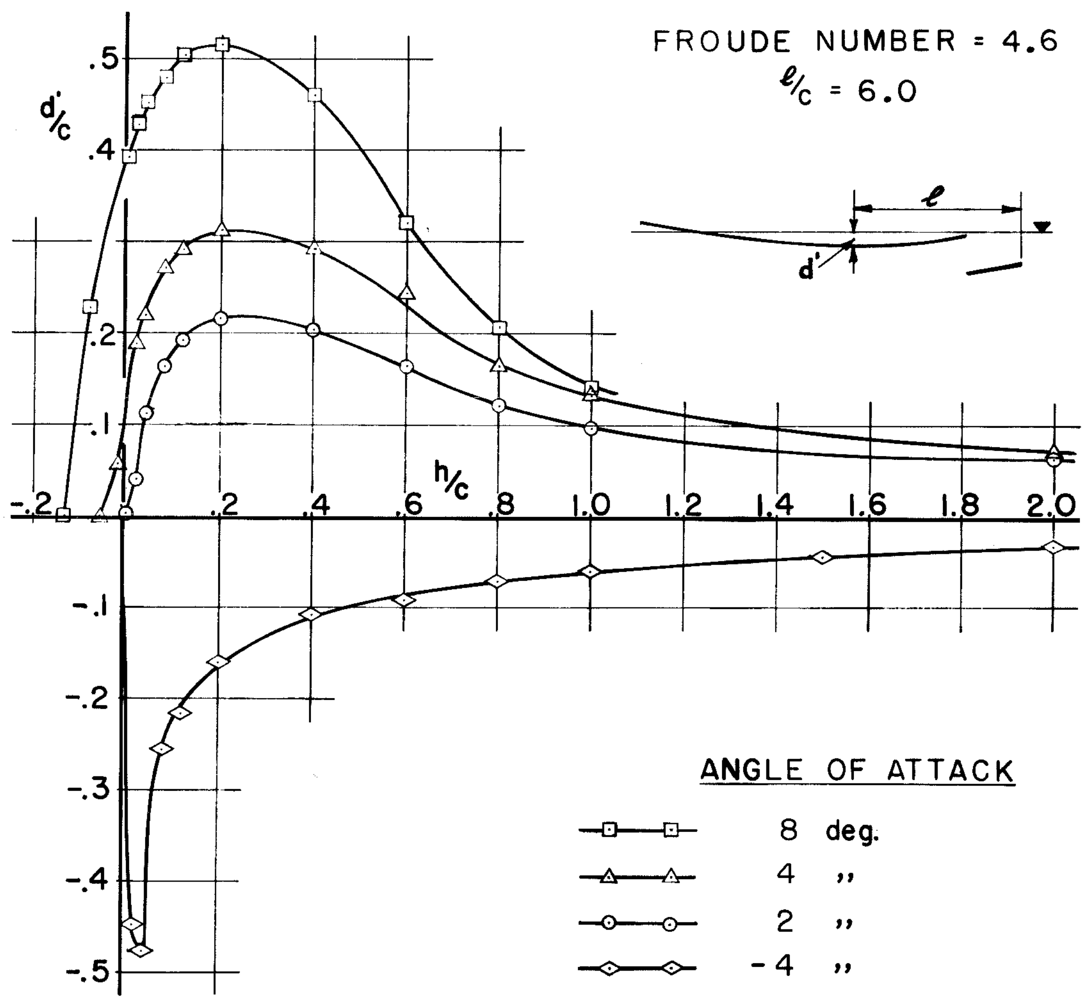


Figure 10

DISTRIBUTION LIST

Copy No. 1	-	Original Copy - Tunnel Operations Office
2	-	Hydrodynamics Laboratory Office File Copy
3	-	Library Copy
4	-	Working Copy - Tunnel Operations Office
5	-	)
6	-	) Supernumerary Copies
7	-	)