NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

REPORT No. 264

DIFFERENTIAL PRESSURES ON A PITOT-VENTURI AND A PITOT-STATIC NOZZLE OVER 360° PITCH AND YAW

By R. M. BEAR

REPRINT OF REPORT No. 264, ORIGINALLY PUBLISHED JULY, 1927

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AERONAUTICAL SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Symbol	Unit	Symbol
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	sec	second (or hour)	sec. (or hr.)
Force	F	weight of one kilogram	kg	weight of one pound	lb.
Power	P	kg/m/sec		horsepower	HP.
Speed		km/hr		mi./hr	M. P. H.
		m/sec		ft./sec	f. p. s.

2. GENERAL SYMBOLS, ETC.

W, Weight, $=mg$

g, Standard acceleration of gravity $=9.80665$ m/sec.$^2=32.1740$ ft./sec.^{2}

m, Mass, $=\frac{W}{g}$

ρ, Density (mass per unit volume).

Standard density of dry air, 0.12497 (kg-m^{-4} sec.^{2}) at 15° C and 760 mm $=0.002378$ (lb.-ft.$^{-4}$ sec.^{2}).

Specific weight of "standard" air, 1.2255 kg/m$^3=0.07651$ lb./ft.^{3}

mk^2, Moment of inertia (indicate axis of the radius of gyration, k, by proper subscript).

S, Area.

S_w, Wing area, etc.

G, Gap.

b, Span.

c, Chord length.

b/c, Aspect ratio.

f, Distance from $c.\ g.$ to elevator hinge.

μ, Coefficient of viscosity.

3. AERODYNAMICAL SYMBOLS

V, True air speed.

q, Dynamic (or impact) pressure $=\frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L=\frac{L}{qS}$

D, Drag, absolute coefficient $C_D=\frac{D}{qS}$

C, Cross-wind force, absolute coefficient $C_C=\frac{C}{qS}$

R, Resultant force. (Note that these coefficients are twice as large as the old coefficients L_C, D_C.)

i_w Angle of setting of wings (relative to thrust line).

i_t, Angle of stabilizer setting with reference to thrust line.

γ, Dihedral angle.

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension.

e. g., for a model airfoil 3 in. chord, 100 mi./hr. normal pressure, 0° C: 255,000 and at 15° C., 230,000;

or for a model of 10 cm chord 40 m/sec, corresponding numbers are 299,000 and 270,000.

C_p, Center of pressure coefficient (ratio of distance of $C.\ P.$ from leading edge to chord length).

β, Angle of stabilizer setting with reference to lower wing, $=(i_t-i_w)$.

α, Angle of attack.

ϵ, Angle of downwash.

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SUMMARY

Measurements of the differential pressures on two Navy air-speed nozzles, consisting of a Zahm type Pitot-Venturi tube and a SQ–16 two-pronged Pitot-static tube, in a tunnel air stream of fixed speed at various angles of pitch and yaw between 0° and ±180°, show for a range over −20° to +20° pitch and yaw, indicated air speeds varying very slightly over 2 per cent for the Zahm type and a maximum of about 5 per cent for the SQ–16 type from the calibrated speed at 0°.

For both types of air-speed nozzle the indicated air speed increases slightly as the tubes are pitched or yawed several degrees from their normal 0° attitude, attains a maximum around ±15° to 25°, declines rapidly therefrom as ±40° is passed, to zero in the vicinity of ±70° to 100°, and thence fluctuates irregularly from thereabouts to ±180°. The complete variation in indicated air speed for the two tubes over 360° pitch and yaw is graphically portrayed in Figures 9 and 10.

For the same air speed and 0° pitch and yaw the differential pressure of the Zahm type Pitot-Venturi nozzle is about seven times that of the SQ–16 type two-pronged Pitot-static nozzle.

INTRODUCTION

The data presented in this report were obtained in tests made for the Navy Bureau of Aeronautics at different times on a Zahm type and a SQ–16 type of air-speed nozzle in the 4 by 4 foot wind tunnel of the Bureau of Construction and Repair, Washington Navy Yard.

The present text and figures, submitted for publication to the National Advisory Committee for Aeronautics, November 29, 1926, have been compiled with some revision from C. & R. Aeronautical Reports Nos. 295 and 300 prepared by the aeronautics staff for the Bureau of Aeronautics.

Other N. A. C. A. reports on air-speed nozzles are Nos. 31, 110, 127, and 156. (References 1–4.)

DESCRIPTION OF NOZZLES

Photographs of the Zahm and SQ–16 air-speed nozzles mounted in the tunnel for testing constitute Figures 1, 2, 3, and 4, and drawings of the two nozzles with their chief dimensions are presented in Figures 5 and 6.

The Zahm Pitot-Venturi nozzles are manufactured by the American Instrument Company, of Washington, D. C.; the SQ–16 two-pronged Pitot-static nozzles, by the Pioneer Instrument Company, of Brooklyn, N. Y.

The two sample nozzles tested were stamped with the factory serial Nos. 1041 and 066239, respectively.

The Venturi of the Zahm type nozzle is made and assembled in three parts; namely, a short forward cone, a long trailing cone with spun trumpet flare, and an accurately reamed short cylinder connecting the two cones and forming the Venturi throat. The small boss visible

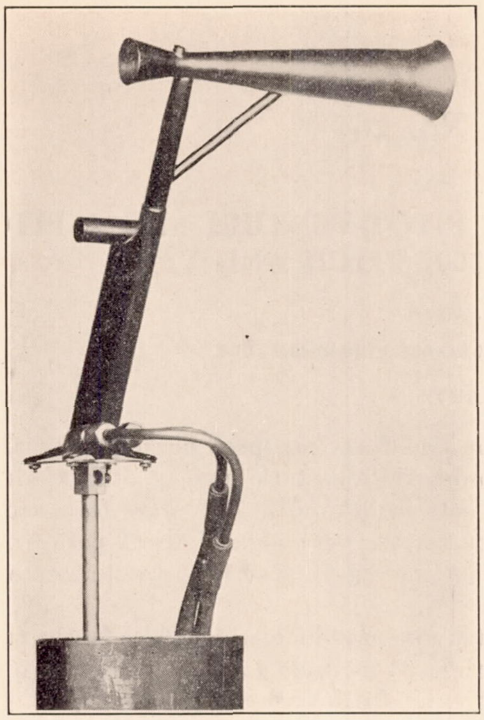

FIG. 1.—Zahm nozzle. Pitch mounting

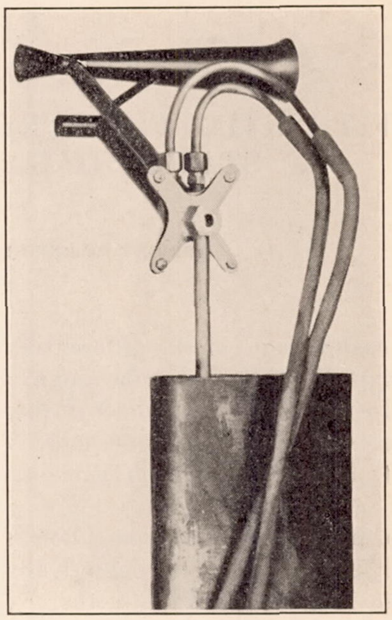

FIG. 2.—Zahm nozzle. Yaw mounting

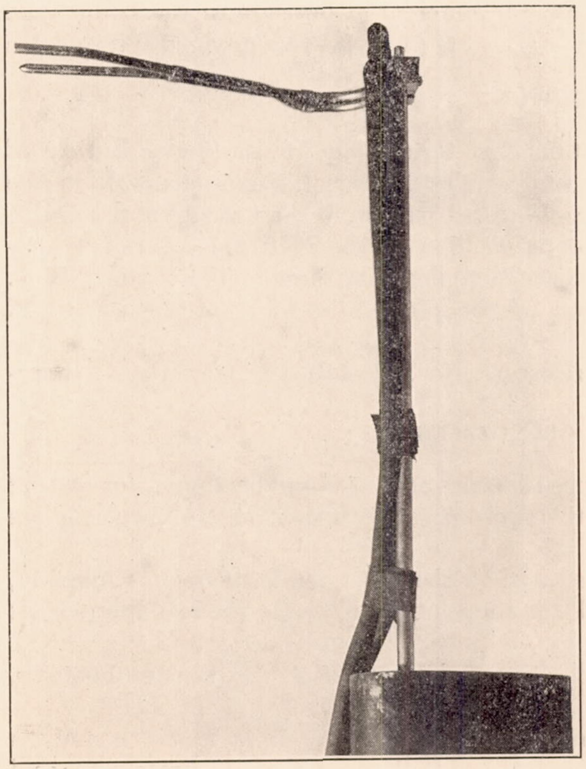

FIG. 3.—SQ-16 nozzle. Pitch mounting

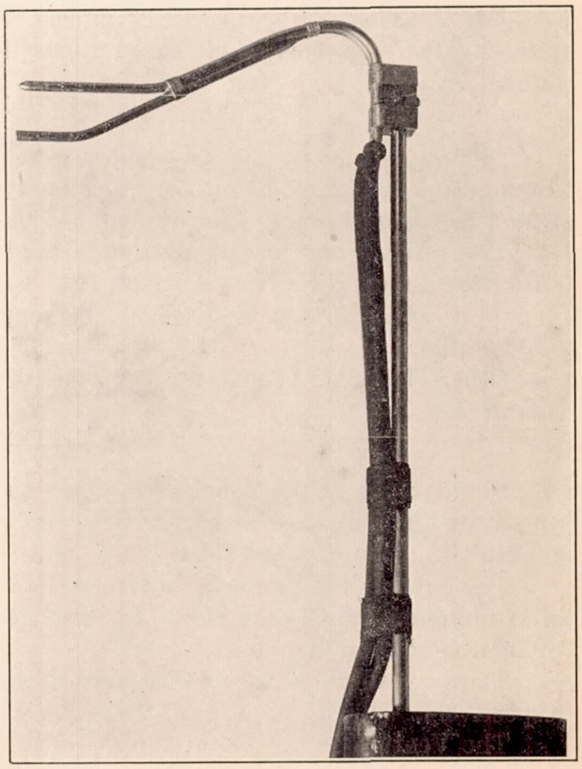

FIG. 4.—SQ-16 nozzle. Yaw mounting

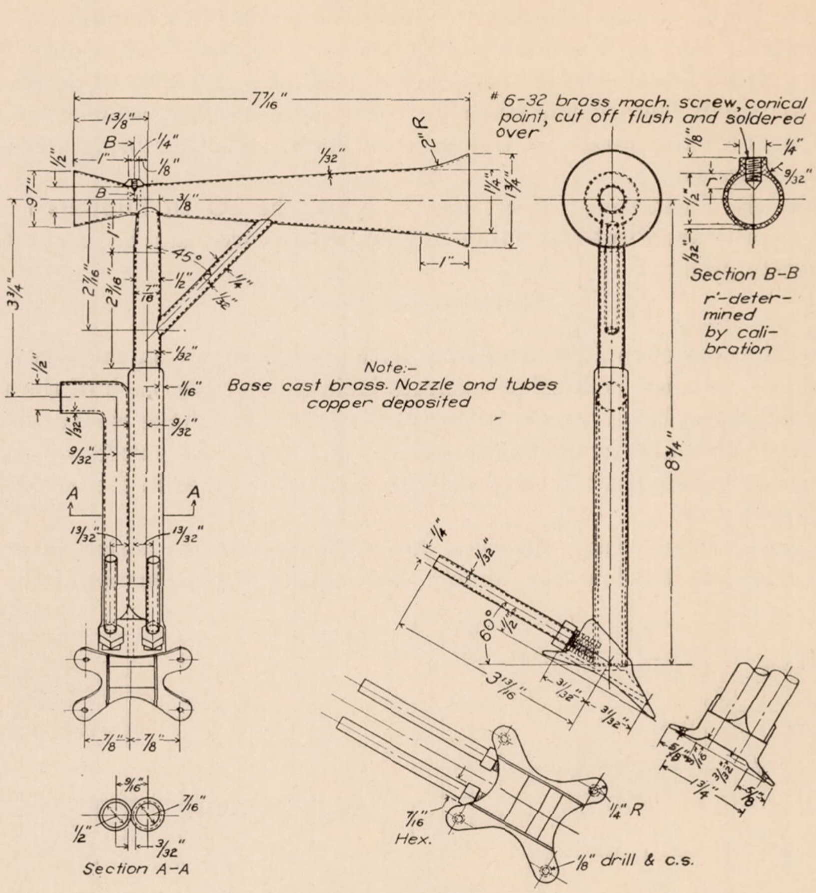

FIG. 5.—Navy-Zahm.—Pitot-Venturi nozzle

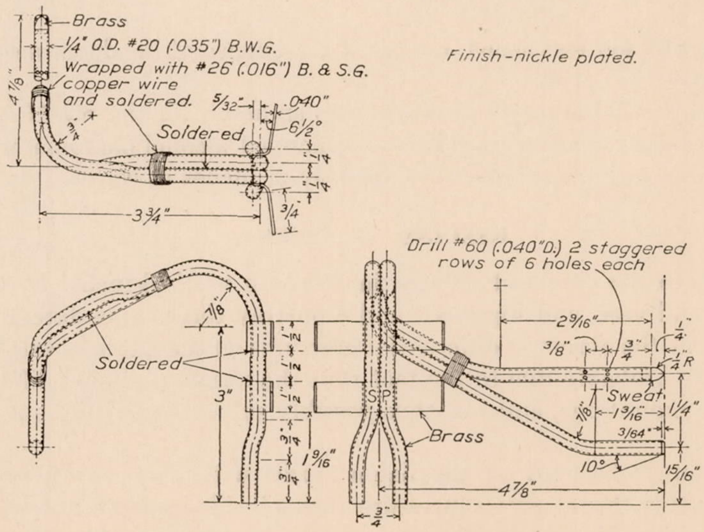

FIG. 6.—Navy SQ-16. Pitot-Static nozzle

in Figure 1 on the throat section opposite the Venturi duct, holds a standard 6–32 brass screw (fig. 5), which projects into the Venturi throat in the form of a 60° cone, slightly but uniformly truncated. By a slight adjustment of this screw in each of a given lot of nozzles it is possible to compensate for small factory variations in cone and throat dimensions causing variable differential pressures for the nozzles at the same air speed, and thus bring all into conformity with a standard calibration.

As seen from the illustrations of Figures 3 and 4, the SQ–16 Pitot-static nozzle differs essentially from an ordinary Pitot-static tube only in being shorter and having static and impact openings on separate prongs.

METHOD OF TESTS

In order that the nozzles could be rotated in both pitch and yaw on the vertical shaft of the wind tunnel balance, thereby facilitating accurate incidence setting, each of the two types was mounted on a small metal block, in which two three-eighths inch holes were drilled with axes at right angles to each other and to the nozzle axis. Thus fitted, the nozzle was mounted in the tunnel for testing on the end of a three-eighths inch drill rod clamped in the balance-shaft chuck, as shown in Figures 1 to 4.

The nozzle incidences were set in the usual way for models, on the horizontal graduated plate encircling the balance shaft below the tunnel. All angular displacements of the nozzles were

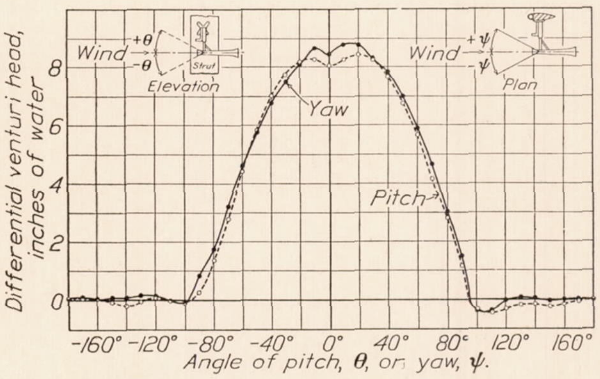

FIG. 7.—Zahm nozzle. Differential head versus angle of pitch or yaw at 50 M. P. H.

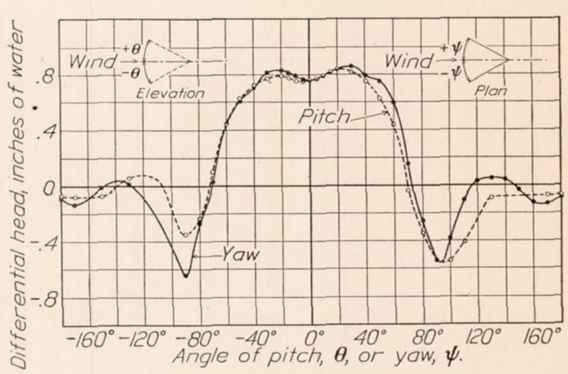

FIG. 8.—SQ–16 nozzle. Differential head versus angle of pitch or yaw at 40 M. P. H.

made in an air stream of fixed test speed, and with a sequence of incidence settings progressing from 0° to −180° and 0° to +180°.

The test speed for the Zahm nozzle was 50 miles an hour; for the SQ–16 40 miles an hour.

The differential pressure heads were read on an inclined alcohol manometer fixed below the tunnel at such a slope as to indicate pressures directly in inches of water.

RESULTS OF TESTS

Tables I and II give the observed differential heads in vertical inches of water for the two nozzles in both pitch and yaw, and Figures 7 and 8 portray these same data graphically.

The discrepancy in the observed differential pressures on the Zahm nozzle for the pitch and yaw mountings at 0° is probably due to the fact that the nozzle occupied different positions in the tunnel for the two mountings, and was thus possibly subjected to different types of air flow or interference effects.

Differential pressures observed on the Zahm nozzle with the calibration set-screw cone removed from the venturi throat give a pressure versus incidence curve for −20° to +20° yaw and pitch, having less depression near the center than the curves of Figure 7.

Table III gives comparative data for the two types of nozzle in the form of velocity ratios or "correction factors," based on the 0° pitch and yaw differential pressure heads. These data are plotted for graphical comparison in Figures 9 and 10.

Assuming the indicated velocity V to vary as the square root of the nozzle differential pressure, the factor K, tabulated and plotted, is defined as follows:

$$K=\frac{V \text{ at pitch, } \theta^\circ\text{, yaw } 0^\circ\text{; or yaw } \psi^\circ\text{, pitch } 0^\circ}{V \text{ at } 0^\circ \text{ pitch and yaw}}.$$

In the above form, K always has small finite values, which are hence better adapted for comparative plotting over the complete test range, than the larger values obtained at high angles

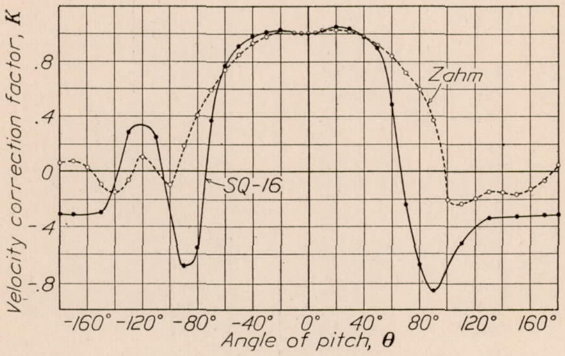

FIG. 9.—Velocity correction factor versus angle of pitch

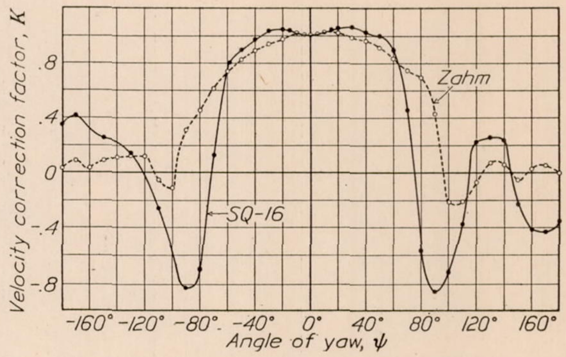

FIG. 10.—Velocity correction factor versus angle of yaw

from the inverse relation. The reciprocal $1/K$, however, is more convenient for use, as a multiplier, in the conversion of the indicated speed to the true one, and hence is given in Table IV for all angles of the test, and plotted in Figure 11 for a limited but ample range of pitch and yaw angles, including the practical flying attitudes. The percentage correction to be added algebraically to the indicated speed to obtain the true value is also here clearly shown for any practical nozzle attitude.

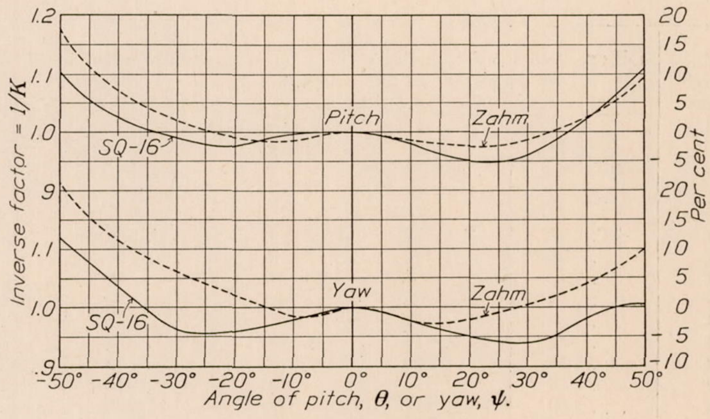

FIG. 11.—Inverse factor versus angles of pitch and yaw

REFERENCES

1. National Advisory Committee for Aeronautics. Development of Air-Speed Nozzles. N. A. C. A. Technical Report No. 31, 1919.

2. National Advisory Committee for Aeronautics. The Altitude Effect on Air-Speed Indicators. N. A. C. A. Technical Report No. 110, 1920.

3. National Advisory Committee for Aeronautics. Aircraft Speed Instruments. N. A. C. A. Technical Report No. 127, 1921.

4. National Advisory Committee for Aeronautics. The Altitude Effect on Air-Speed Indicators–II. N. A. C. A. Technical Report No. 156, 1922.

TABLE I

DIFFERENTIAL HEAD ON ZAHM NOZZLE AT 50 M. P. H.

Angle of pitch or yaw (degrees)	Differential head[1] (inches of water)		Angle of pitch or yaw (degrees)	Differential head[1] (inches of water)	
	Nozzle yawed	Nozzle pitched		Nozzle yawed	Nozzle pitched
0	+8. 43	+8. 03	0	+8. 40	+8. 02
+10	8. 80	8. 23	−10	8. 67	8. 23
20	8. 77	8. 41	−20	8. 07	8. 17
30	8. 27	8. 23	−30	7. 48	7. 71
40	7. 81	7. 64	−40	6. 77	7. 00
50	6. 96	6. 71	−50	5. 72	5. 78
60	5. 87	5. 64	−60	4. 60	4. 40
70	4. 63	4. 13	−70	3. 22	2. 78
80	3. 02	2. 83	−80	1. 75	1. 31
90	+1. 51	+1. 13	−90	+0. 84	+0. 28
100	−0. 39	−0. 32	−100	−0. 09	−0. 08
110	−0. 34	−0. 42	−110	−0. 02	0. 00
120	−0. 04	−0. 30	−120	+0. 13	+0. 09
130	+0. 05	−0. 16	−130	0. 13	−0. 03
140	+0. 04	−0. 16	−140	0. 09	−0. 19
150	−0. 02	−0. 21	−150	0. 08	−0. 07
160	+0. 01	−0. 12	−160	0. 01	+0. 01
170	+0. 03	−0. 03	−170	0. 08	0. 05
+180	0. 00	+0. 02	−180	+0. 01	+0. 03

[1] Tabulated differential head is mean of 10 readings.

TABLE II

DIFFERENTIAL HEAD ON SQ–16 NOZZLE AT 40 M. P. H.

Angle of pitch or yaw (degrees)	Differential head[1] (inches of water)		Angle of pitch or yaw (degrees)	Differential head[1] (inches of water)	
	Nozzle pitched	Nozzle yawed		Nozzle pitched	Nozzle yawed
0	+0. 757	+0. 757	0	+0. 757	+0. 757
−5	. 758	. 767	5	. 766	. 767
−10	. 758	. 787	10	. 788	. 789
−15	. 778	. 808	15	. 817	. 815
−20	. 794	. 822	20	. 836	. 838
−30	. 771	. 816	30	. 817	. 857
−40	. 721	. 706	40	. 751	. 784
−50	. 623	. 615	50	. 615	. 748
−60	. 440	. 447	60	+. 428	. 595
−70	+. 104	+. 011	70	−. 042	+. 157
−80	−. 236	−. 367	80	−. 345	−. 253
−90	−. 356	−. 646	90	−. 545	−. 544
−100			100		−. 383
−110	+. 046	−. 250	110	−. 200	−. 106
−120			120		+. 038
−130	+. 060	+. 015	130	−. 083	+. 049
−140			140		+. 045
−150	−. 068	−. 005	150	−. 078	−. 038
−160			160		−. 125
−170	−. 076	−. 133	170	−. 071	−. 129
−180	−. 073	−. 091	180	−. 073	−. 092

[1] Tabulated differential head is mean of five readings.

TABLE III

VELOCITY CORRECTION FACTOR [1]

Angle of pitch or yaw (degrees)	SQ–16 nozzle		Zahm nozzle		Angle of pitch or yaw (degrees)	SQ–16 nozzle		Zahm nozzle	
	In pitch	In yaw	In pitch	In yaw		In pitch	In yaw	In pitch	In yaw
0	+1.000	+1.000	+1.000	+1.000	0	+1.000	+1.000	+1.000	+1.000
−5	1.001	1.007	--------	--------	5	1.006	1.007	--------	--------
−10	1.001	1.020	1.013	1.015	10	1.021	1.021	1.013	1.022
−15	1.014	1.033	--------	--------	15	1.039	1.038	--------	--------
−20	1.024	1.043	1.009	.979	20	1.051	1.052	1.024	1.020
−30	1.009	1.038	.980	.942	30	1.039	1.064	1.013	.991
−40	.976	.965	.934	.897	40	.978	1.017	.976	.963
−50	.907	.894	.849	.824	50	.901	.994	.914	.909
−60	.762	.769	.741	.739	60	+.492	.886	.838	.835
−70	+.371	+.121	.590	.618	70	−.236	+.455	.717	.742
−80	−.559	−.697	.406	.456	80	−.675	−.578	.594	.599
−90	−.686	−.924	+.187	+.316	90	−.848	−.848	+.375	+.424
−100	--------	--------	−.100	−.103	100	--------	−.711	−.200	−.215
−110	+.247	−.575	.000	−.049	110	−.514	−.375	−.229	−.201
−120	--------	--------	+.106	+.124	120	--------	−.224	−.193	−.069
−130	+.282	+.141	−.061	.124	130	−.331	−.254	−.141	+.077
−140	--------	--------	−.154	.103	140	--------	−.244	−.141	+.069
−150	−.300	−.257	−.094	.098	150	−.321	−.224	−.162	−.049
−160	--------	--------	+.035	.034	160	--------	−.407	−.122	−.034
−170	−.317	−.420	.079	.098	170	−.307	−.413	−.061	−.060
−180	−.310	−.347	+.061	+.034	180	−.310	−.348	+.050	.000

[1] Data of Tables I and II used in computing these factors.

TABLE IV

INVERSE VELOCITY CORRECTION FACTOR [1]

Angle of pitch or yaw (degrees)	SQ-16 nozzle		Zahm nozzle		Angle of pitch or yaw (degrees)	SQ-16 nozzle		Zahm nozzle	
	In pitch	In yaw	In pitch	In yaw		In pitch	In yaw	In pitch	In yaw
0	+1.000	+1.000	+1.000	+1.000	0	+1.000	+1.000	+1.000	+1.000
−5	.999	.993	--------	--------	5	.994	.993	--------	--------
−10	.999	.980	.987	.985	10	.979	.979	.987	.978
−15	.986	.968	--------	--------	15	.962	.963	--------	--------
−20	.977	.959	.991	1.021	20	.951	.951	.977	.980
−30	.991	.963	1.020	1.062	30	.962	.940	.987	1.009
−40	1.025	1.036	1.071	1.114	40	1.022	.983	1.025	1.038
−50	1.103	1.119	1.178	1.214	50	1.110	1.006	1.094	1.100
−60	1.312	1.300	1.350	1.353	60	+2.033	1.129	1.193	1.198
−70	+2.695	+8.264	1.695	1.618	70	−4.237	+2.198	1.395	1.348
−80	−1.789	−1.435	2.463	2.193	80	−1.481	−1.730	1.684	1.669
−90	−1.458	−1.082	+5.348	+3.165	90	−1.179	−1.179	+2.667	+2.358
−100	--------	--------	−10.000	−9.709	100	--------	−1.406	−5.000	−4.651
−110	+4.049	−1.739	∞	−20.408	110	−1.946	−2.667	−4.367	−4.975
−120	--------	--------	+9.434	+8.065	120	--------	−4.464	−5.181	−14.493
−130	+3.546	+7.092	−16.393	8.065	130	−3.021	−3.937	−7.092	+12.987
−140	--------	--------	−6.494	9.709	140	--------	−4.098	−7.092	+14.493
−150	−3.333	−3.891	−10.638	10.204	150	−3.115	−4.464	−6.173	−20.408
−160	--------	--------	+28.571	29.411	160	--------	−2.457	−8.197	−29.412
−170	−3.155	−2.381	12.658	10.204	170	−3.257	−2.421	−16.393	−16.667
−180	−3.226	−2.882	+16.393	+29.412	180	−3.226	−2.874	+20.000	∞

[1] Reciprocal of value in Table III.

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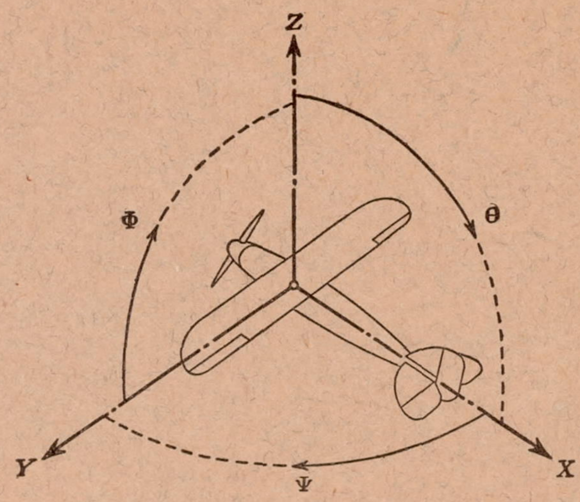

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	rolling	L	$Y \longrightarrow Z$	roll	Φ	u	p
Lateral	Y	Y	pitching	M	$Z \longrightarrow X$	pitch	Θ	v	q
Normal	Z	Z	yawing	N	$X \longrightarrow Y$	yaw	Ψ	w	r

Absolute coefficients of moment

$$C_L=\frac{L}{qbS}\quad C_M=\frac{M}{qcS}\quad C_N=\frac{N}{qfS}$$

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter.
p_e, Effective pitch
p_g, Mean geometric pitch.
p_s, Standard pitch.
p_v, Zero thrust.
p_a, Zero torque.
p/D, Pitch ratio.
V', Inflow velocity.
V_s, Slip stream velocity.

T, Thrust.
Q, Torque.
P, Power.
(If "coefficients" are introduced all units used must be consistent.)
η, Efficiency $=T\,V/P$.
n, Revolutions per sec., r. p. s.
N, Revolutions per minute., R. P. M.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi rn}\right)$

5. NUMERICAL RELATIONS

1 HP = 76.04 kg/m/sec. = 550 lb./ft./sec.
1 kg/m/sec. = 0.01315 HP.
1 mi./hr. = 0.44704 m/sec.
1 m/sec. = 2.23693 mi./hr.

1 lb. = 0.4535924277 kg.
1 kg = 2.2046224 lb.
1 mi. = 1609.35 m = 5280 ft.
1 m = 3.2808333 ft.