FLOW DOCUMENTATION

The measurements were made in the Virginia Polytechnic Institute and State University Stability Wind Tunnel. This tunnel is a continuous, closed return, subsonic wind tunnel with a 7 m long and 1.8 m square test section. The regulated fan d.c. power source, a 9:1 area contraction , and seven wire-mesh screens provide low free-stream turbulence levels - of the order of 0.03%.

The 6:1 prolate spheroid used for these measurements is 1.37 m long and is constructed of a machined fiberglass skin bonded to an aluminum frame. A circumferential trip, consisting of posts 1.2 mm in diameter, 0.7 mm high and spaced 2.5 mm apart, was placed around the model at $x/L = 0.2$. This fixed the location of transition. Windows of size 30 × 150 × 0.75 mm were placed in the skin for optical (LDV) access to the flow[1, 5, 6]. The windows were molded to the curvature of the model and mounted flush with the model surface in order to minimize flow disturbances. Wax was used to fill any small gaps in the model surface. The model was supported with a rear-mounted, 0.75 m long sting aligned along the model axis and connected to a vertical post extended through the wind tunnel floor. All measurements were conducted at a constant Reynolds number, $Re_L = 4.20\times10^6$, (50.73 m/s < U_∞ < 55.25 m/s) and ambient temperature.

The pressure transducer used is an Endevco model 8507-C2 which is a circular deflection-type transducer and has a flat frequency response from 0 to 70 kHz. The transducer was mounted inside the model and fixed to one of the windows. The transducer signal was amplified by a Measurements Group model 2310 strain gage conditioning amplifier.

Access to the flow field was provided through a 0.5 mm diameter pinhole. This pinhole and the associated dead volume have a second order frequency transfer function with a resonant frequency near 12 kHz as shown from calibrations[7]. Contributions of sources that are smaller than the pinhole area are spatially integrated , and thereby attenuated. This effect has been investigated, and Corcos[8] provides a correction to the wall pressure spectrum in terms of $\omega d/2U_C$ where ω/U_C is the wave number. The correction given by Corcos[8] was applied to the spectra presented here.

The pressure fluctuations were sampled at 71 kHz with 12-bit precision. This sampling rate is higher than is commonly used. Twenty-five records of 16,384 data points each were acquired at each location. During post-processing, each of these contiguous records was divided into sub-records and the time-delay subtraction was carried out. Spectral values were calculated using at least 500 averages. Additional bin averaging was performed to produce the final spectrum[9]. The spectra presented here are single-sided.

REFERENCES

1) Chesnakas, C. J., and Simpson, R. L., "Measurements of the Turbulence Structure in the Vicinity of a 3-D Separation," *Journal of Fluids Engineering*, Vol. 118, No. 1, 1996, pp. 268-275.

2) Ahn, S., and Simpson, R. L., "Cross-flow Separation on a Prolate Spheroid at Angles of Attack," AIAA Paper 92-0428, Jan. 1992.

3) Barber, K. M., and Simpson, R. L., "Mean Velocity and Turbulence Measurements of Flow Around a 6:1 Prolate Spheroid," AIAA Paper 91-0255, Jan. 1991.

4) Chesnakas, C. J., Simpson, R. L., and Madden, M. M., "Three Dimensional Velocity Measurements on a 6:1 Prolate Spheroid at Angle of Attack," Data Report VPI-AOE-202, Dept. of Aero & Ocean Engr, VPI&SU, Blacksburg, VA, Aug. 1993.

5) Chesnakas, C. J., and Simpson, R. L., "Full Three-Dimensional Measurements of the Cross-flow Separation Region of a 6:1 Prolate Spheroid," *Experiments in Fluids*, Vol. 17, 1994 pp. 68-74.

6) Chesnakas, C. J., and Simpson, R. L., "A Detailed Investigation of the 3-D Separation about a 6:1 Prolate Spheroid at Angle of Attack," *AIAA Journal*, Vol., 35, No. 6, 1997, pp. 990-999.

7) Goody, M.C., "An Experimental Investigation of Pressure Fluctuations in Three-Dimensional Turbulent Boundary Layers," Ph.D. Dissertation, *Dept. of Aero & Ocean Engr*, *VPI&SU*, Blacksburg, VA, 1999.

8) Corcos, G. M., "Resolution of Pressure in Turbulence," *Journal of the Acoustical Society of America*, Vol. 35, No. 2, 1963, pp. 192-199.

9) Bendat, J. S., and Piersol, A. G., *Random Data: Analysis and Measurement*, 2nd ed., Wiley, New York, 1986, pp. 252-290.

10) Goody, M. C., Simpson, R. L., Engel M., Chesnakas, C. J., and Devenport, W. J., "Mean Velocity and Pressure and Velocity Spectral Measurements within a Separated Flow Around a Prolate Spheroid at Incidence", AIAA Paper 98-0630, Jan. 1998.

Table 1. Some boundary layer parameters of the flow at $\alpha = 10°$, $x/L = 0.600$.

ϕ deg	ρ kg/m^3	$\nu\,(\times 10^5)$ m²/s	u_τ † m/s	U_e ‡ m/s	U_∞ m/s	δ^* ‡ mm	d^+ †	Re_θ ‡
90	1.05	1.79	2.45	54.8	54.7	1.16	68	2483
95	1.05	1.80	2.42	55.3	55.2	1.25	67	2673
100	1.05	1.80	2.36	55.3	55.2	1.35	65	2863
105	1.05	1.80	2.31	55.3	55.2	1.45	64	3073
110	1.06	1.78	2.23	54.8	54.6	1.56	62	3283
115	1.06	1.78	2.17	54.7	54.4	1.79	61	3739
120	1.06	1.76	2.10	54.2	53.9	2.01	60	4195
125	1.10	1.67	1.91	51.3	51.1	2.34	57	4797
130	1.10	1.66	1.82	51.1	50.9	2.66	55	5399
135	1.10	1.66	1.76	50.9	50.7	3.03	53	6084
140	1.10	1.66	1.70	50.9	50.7	3.40	51	6770
145	1.10	1.66	1.70	50.9	50.7	3.58	51	7182
150	1.10	1.65	1.70	50.8	50.6	3.76	51	7594
155	1.10	1.66	1.74	51.0	50.8	3.65	52	7501
160	1.10	1.66	1.77	51.0	50.8	3.55	53	7407
165	1.10	1.66	1.82	51.2	50.8	3.30	55	7031
170	1.10	1.66	1.88	51.6	51.0	3.05	56	6654
175	1.10	1.66	1.90	51.6	51.0	2.86	57	6254
180	1.10	1.66	1.92	51.5	51.0	2.67	58	5855

† Calculated using the C_f measurements of Chesnakas and Simpson[6]

‡ Calculated using the δ^*, θ, and U_e/U_∞ measurements of Goody *et al.*[10]

Table 2. Some boundary layer parameters of the flow at $\alpha = 10°$, $x/L = 0.772$.

ϕ deg	ρ kg/m^3	$\nu\,(\times 10^5)$ m²/s	u_τ † m/s	U_e ‡ m/s	U_∞ m/s	δ^* ‡ mm	d^+ †	Re_θ ‡
90	1.06	1.79	2.25	58.0	54.7	1.47	63	3145
95	1.05	1.80	2.23	58.0	55.0	1.59	62	3368
100	1.05	1.79	2.19	57.3	54.8	1.70	61	3592
105	1.06	1.79	2.07	56.8	54.7	1.99	58	4122
110	1.06	1.77	1.94	55.9	54.1	2.28	55	4651
115	1.07	1.76	1.82	55.3	53.8	2.79	52	5555
120	1.07	1.75	1.70	54.9	53.6	3.31	49	6458
125	1.07	1.74	1.65	54.6	53.4	4.06	47	7716
130	1.07	1.74	1.50	56.2	53.2	5.62	43	10417
135	1.07	1.73	1.47	55.6	53.1	6.39	42	11636
140	1.07	1.74	1.50	55.2	53.2	7.33	43	13394
145	1.07	1.74	1.61	54.4	53.2	7.24	46	14016
150	1.07	1.73	1.71	53.5	53.1	7.16	49	14637
155	1.08	1.73	1.84	52.5	52.9	5.81	53	12549
160	1.08	1.72	1.95	51.3	52.6	4.47	57	10640
165	1.09	1.70	2.01	51.2	52.0	3.57	59	8430
170	1.09	1.69	2.08	51.4	51.7	2.67	62	6400
175	1.09	1.68	2.06	51.3	51.5	2.25	61	5307
180	1.10	1.67	2.02	50.9	51.0	1.83	61	4213

† Calculated using the C_f measurements of Chesnakas and Simpson[6]

‡ Calculated using the δ^*, θ, and U_e/U_∞ measurements of Goody *et al.*[10]

Table 3. Some boundary layer parameters of the flow at $\alpha = 20°$, $x/L = 0.600$.

ϕ deg	ρ kg/m^3	$\nu\,(\times 10^5)$ m²/s	u_τ † m/s	U_e ‡ m/s	U_∞ m/s	δ^* ‡ mm	d^+ †	Re_θ ‡
90	1.10	1.66	2.55	51.0	50.9	0.67	77	1406
95	1.10	1.66	2.47	51.0	50.9	0.76	74	1586
100	1.10	1.66	2.38	50.9	50.9	0.85	71	1767
105	1.10	1.66	2.24	50.9	50.9	1.01	67	2056
110	1.10	1.66	2.10	50.9	50.9	1.18	63	2346
115	1.10	1.66	1.88	50.8	50.9	1.80	56	3358
120	1.10	1.66	1.62	50.8	50.9	2.42	49	4370
125	1.10	1.66	1.41	50.6	50.9	3.5	43	5790
130	1.10	1.66	1.29	50.4	50.9	4.98	39	10827
135	1.10	1.66	1.70	50.2	50.9	5.94	51	10546
140	1.10	1.66	1.91	50.0	50.9	6.24	57	12940
145	1.10	1.66	1.88	56.1	50.9	5.47	57	12242
150	1.10	1.66	2.44	54.8	50.9	4.57	73	10889
155	1.10	1.66	2.88	51.8	50.9	4.34	87	10405
160	1.10	1.66	3.04	49.5	50.9	4.00	92	9493
165	1.10	1.66	2.93	49.9	50.9	2.14	88	5045
170	1.10	1.66	2.80	50.4	50.9	0.28	84	597
175	1.10	1.66	2.71	50.7	50.9	0.37	81	781
180	1.10	1.66	2.61	51.0	50.9	0.45	78	965

† Calculated using the C_f measurements of Chesnakas and Simpson[6]

‡ Calculated using the δ^*, θ, and U_e/U_∞ measurements of Goody *et al.*[10]

Table 4. Some boundary layer parameters of the flow at $\alpha = 20°$, $x/L = 0.772$.

ϕ deg	ρ kg/m^3	$\nu\,(\times 10^5)$ m²/s	u_τ † m/s	U_e ‡ m/s	U_∞ m/s	δ^* ‡ mm	d^+ †	Re_θ ‡
90	1.07	1.74	2.36	59.4	53.3	0.82	68	1647
95	1.06	1.77	2.21	64.7	54.3	1.05	62	2055
100	1.06	1.77	2.00	68.8	54.3	1.28	56	2462
105	1.06	1.77	1.82	57.6	54.2	1.75	51	3249
110	1.05	1.79	1.56	57.5	54.9	2.60	44	4458
115	1.05	1.79	1.35	56.8	54.9	3.80	38	5910
120	1.06	1.78	1.53	55.7	54.5	5.19	43	8136
125	1.05	1.80	1.96	57.1	55.3	6.23	54	11434
130	1.05	1.80	2.29	57.7	55.1	7.28	64	14732
135	1.05	1.79	2.45	53.7	54.9	6.08	68	13550
140	1.05	1.80	2.62	50.2	55.3	4.88	73	12368
145	1.05	1.80	1.83	56.4	55.3	6.40	51	14625
150	1.05	1.80	2.21	57.3	55.1	5.29	61	13406
155	1.05	1.80	3.08	56.2	55.3	3.52	85	8935
160	1.05	1.79	3.29	55.5	54.9	2.60	92	6348
165	1.06	1.78	3.20	56.8	54.5	1.44	90	3474
170	1.05	1.80	3.15	58.9	55.0	0.28	88	600
175	1.05	1.79	2.99	58.0	54.8	0.34	84	727
180	1.05	1.79	2.83	57.2	54.8	0.39	79	854

† Calculated using the C_f measurements of Chesnakas and Simpson[6]

‡ Calculated using the δ^*, θ, and U_e/U_∞ measurements of Goody *et al.*[10]

Table 5. Variation of $\overline{p^2}/Q_\infty^2$ with ϕ at α = 10°, x/L = 0.600 showing the contribution of various frequency ranges to the $\overline{p^2}$ integral including the Analytical Integral Contribution (AIC). The values presented here were calculated by integrating the p spectra.

ϕ	Total $\overline{p^2}/Q_\infty^2$	Contribution to $\overline{p^2}/Q_\infty^2$ (× 10^5)					
deg	(× 10^5)	$f \leq$ 994 Hz		994 Hz < $f \leq$ 25 kHz		f > 25 kHz (AIC)	
90	14.5	2.5	17%	8.7	60%	3.3	23%
95	13.2	2.4	18%	8.1	61%	2.7	21%
100	12.2	2.3	19%	7.8	64%	2.1	17%
105	11.1	2.2	20%	7.2	65%	1.7	15%
110	10.4	2.3	22%	6.9	66%	1.2	12%
115	9.6	2.3	24%	6.4	67%	0.9	9%
120	9.3	2.5	28%	6.1	65%	0.7	7%
125	7.9	2.1	26%	5.5	70%	0.3	4%
130	7.1	2.1	29%	4.8	68%	0.2	3%
135	6.4	2.1	32%	4.2	66%	0.1	2%
140	6.1	2.2	36%	3.8	63%	0.09	1%
145	5.4	1.9	35%	3.4	63%	0.09	2%
150	5.5	2.0	36%	3.4	63%	0.09	1%
155	5.7	2.0	34%	3.6	64%	0.1	2%
160	6.1	2.0	33%	4.0	65%	0.1	2%
165	6.8	2.0	30%	4.6	67%	0.2	3%
170	7.5	2.0	27%	5.2	69%	0.3	4%
175	7.9	2.1	26%	5.5	70%	0.3	4%
180	8.0	2.0	25%	5.6	70%	0.4	5%

Table 6. Variation of $\overline{p^2}/Q_\infty^2$ with ϕ at α = 10°, x/L = 0.772 showing the contribution of various frequency ranges to the $\overline{p^2}$ integral including the Analytical Integral Contribution (AIC). The values presented here were calculated by integrating the p spectra.

ϕ deg	Total $\overline{p^2}/Q_\infty^2$ (× 10^5)	Contribution to $\overline{p^2}/Q_\infty^2$ (× 10^5) $f \le$ 994 Hz		994 Hz < $f \le$ 25 kHz		f > 25 kHz (AIC)	
90	11.9	2.3	19%	8.2	69%	1.4	12%
95	11.0	2.3	21%	7.6	68%	1.2	11%
100	10.4	2.4	24%	7.0	67%	1.0	9%
105	9.3	2.4	25%	6.4	69%	0.5	6%
110	8.9	3.0	34%	5.6	63%	0.3	3%
115	7.9	3.0	37%	4.8	61%	0.1	2%
120	6.6	2.7	41%	3.8	58%	0.06	1%
125	5.8	2.8	47%	3.0	52%	0.04	1%
130	5.0	2.6	53%	2.4	47%	0.01	0%
135	4.5	2.7	60%	1.8	40%	0.01	0%
140	4.1	2.5	60%	1.6	40%	0.01	0%
145	4.5	2.3	51%	2.2	48%	0.03	1%
150	5.6	2.4	43%	3.1	56%	0.07	1%
155	6.7	2.3	35%	4.2	63%	0.2	2%
160	8.1	2.2	27%	5.6	69%	0.3	4%
165	9.6	2.3	24%	6.8	71%	0.5	5%
170	10.3	2.0	19%	7.5	73%	0.8	8%
175	10.5	2.0	20%	7.7	73%	0.8	7%
180	10.7	2.2	21%	7.8	73%	0.7	6%

Table 7. Variation of $\overline{p^2}/Q_\infty^2$ with ϕ at $\alpha = 20°$, $x/L = 0.600$ showing the contribution of various frequency ranges to the $\overline{p^2}$ integral including the Analytical Integral Contribution (AIC). The values presented here were calculated by integrating the p spectra.

ϕ	Total $\overline{p^2}/Q_\infty^2$	Contribution to $\overline{p^2}/Q_\infty^2$ $(\times 10^5)$					
deg	$(\times 10^5)$	$f \leq 994$ Hz		994 Hz $< f \leq 25$ kHz		$f > 25$ kHz (AIC)	
90	26.8	1.9	7%	11.4	43%	13.5	50%
95	24.4	1.9	8%	11.4	46%	11.1	46%
100	21.3	2.0	9%	11.1	52%	8.2	39%
105	17.9	2.0	11%	10.5	59%	5.4	30%
110	14.7	2.2	15%	9.7	66%	2.8	19%
115	11.5	2.4	20%	8.4	73%	0.7	7%
120	10.1	2.8	28%	7.1	70%	0.2	2%
125	8.2	3.3	41%	4.9	59%	0.03	0%
130	6.1	3.5	58%	2.6	42%	0.01	0%
135	5.5	3.1	57%	2.3	42%	0.07	1%
140	9.2	4.1	44%	4.7	51%	0.4	5%
145	12.3	3.9	32%	7.3	59%	1.1	9%
150	24.9	4.0	16%	9.9	40%	11.0	44%
155	45.2	4.2	9%	10.9	24%	30.1	67%
160	58.3	4.0	7%	11.8	20%	42.5	73%
165	46.8	3.2	7%	11.9	25%	31.7	68%
170	38.0	2.7	7%	12.0	32%	23.3	61%
175	30.5	2.0	7%	11.1	36%	17.4	57%
180	27.1	2.1	8%	10.8	40%	14.2	52%

Table 8. Variation of $\overline{p^2}/Q_\infty^2$ with ϕ at $\alpha = 20°$, $x/L = 0.772$ showing the contribution of various frequency ranges to the $\overline{p^2}$ integral including the Analytical Integral Contribution (AIC). The values presented here were calculated by integrating the *p* spectra.

ϕ	Total $\overline{p^2}/Q_\infty^2$	Contribution to $\overline{p^2}/Q_\infty^2$ ($\times 10^5$)					
deg	($\times 10^5$)	$f \leq 994$ Hz		994 Hz $< f \leq$ 23 kHz		$f > 23$ kHz (AIC)	
90	22.4	3.1	14%	11.2	50%	8.1	36%
95	18.7	3.3	18%	10.8	58%	4.6	24%
100	15.6	3.8	24%	10.0	65%	1.8	11%
105	12.9	4.1	32%	8.3	64%	0.5	4%
110	10.5	4.5	43%	5.9	56%	0.07	1%
115	8.2	5.4	66%	2.8	34%	0.006	0%
120	9.9	6.1	62%	3.7	37%	0.08	1%
125	14.9	6.6	45%	7.2	48%	1.1	7%
130	27.4	9.6	35%	13.7	50%	4.1	15%
135	44.9	22.0	49%	17.2	38%	5.7	13%
140	18.2	9.0	50%	6.8	37%	2.4	13%
145	23.9	10.0	42%	13.3	55%	0.6	3%
150	35.8	18.3	51%	11.7	33%	5.8	16%
155	59.5	8.0	14%	10.2	17%	41.3	69%
160	66.8	4.4	7%	11.0	16%	51.4	77%
165	54.9	2.7	5%	11.0	20%	41.2	75%
170	47.5	2.6	6%	10.5	22%	34.4	72%
175	40.2	2.3	6%	10.6	26%	27.3	68%
180	34.7	2.4	7%	10.1	29%	22.2	64%