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A.R.C. Technical Report

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MINISTRY OF SUPPLY

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Nozzle and Contraction Shapes of the R.A.E. 3 ft. x 3 ft. Supersonic Wind Tunnel

By

A. Stanbrook,

R.A.E., Bedford

LONDON: HER MAJESTY'S STATIONERY OFFICE

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ROYAL AIRCRAFT ESTABLISHMENT

Nozzle and Contraction Shapes of the R.A.E. 3 ft × 3 ft Supersonic Wind Tunnel

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SUMMARY

Ordinates of the contraction and of each of the solid liners of the 3 ft × 3 ft supersonic wind tunnel are tabulated.

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1 Introduction

In accordance with recent measures to make supersonic nozzle ordinates more widely available the ordinates for each of the solid nozzle liners used in the supersonic working section of the 3 ft × 3 ft wind tunnel are given here in tabulated form. For the sake of completeness details of the subsonic contraction have been included. The supersonic Mach number range of the tunnel is from 1.3 to 2.0 and interchangeable wooden nozzle blocks are used to vary M in finite steps.

2 General Description

A vertical section through the contraction and the working section is shown in Fig. 1. Only the top liners of the nozzle is changeable.

The cross section of the contraction* is rectangular with 45° corner fillets and is symmetrical about horizontal and vertical centre planes. All four sides are curved. The variation of half-height "Y", half-width "Z" and the fillet half-height are given in Table I. The side walls are parallel to the tunnel axis at the beginning and end of the contraction section and remain parallel, spaced 36 inches apart, downstream of the contraction. The last four inches of the top and bottom walls are straight and continuous with the bridge piece, which is also straight.

The bridge piece, in turn, is continuous with the nozzle, although there is a slight change in slope at the beginning of the nozzle due to the 0.004 inch per inch boundary layer correction which is applied downstream of this point. The side walls are parallel, the boundary layer correction being applied to the upper and lower walls of the section only. The ordinates of the supersonic nozzles and of the bottom liner (which is identical with the subsonic liner) are given in Table II. The axis for "y" is the false axis shown in Fig.1, 32 inches away from the centre line of the working section.

3 Method of Design of the Nozzles

The nozzles for M = 1.4, 1.6, 1.8 and 2.0 were designed by J.Y.G. Evans and D.E. Lindop who intend to prepare a report on the method of design used together with other methods they have used, more recently, for 8 ft × 8 ft and 4 ft × 3 ft tunnels at R.A.E., Bedford. Briefly, the method used was as follows:-

A perturbation method, similar to Sauer's but retaining more terms in the equations of motion, was used to calculate a flow in the throat which gave constant velocity gradient along the flat bottom liner. This solution was taken as far as a characteristic running down from the throat to a point on the bottom liner at which the Mach number had reached a convenient value. Downstream of this point the Mach number distribution along the bottom liner was taken to be of the form

$$M = M_0 + aX + bX^2 + cX^{n-1} + dX^n$$

where a and b were chosen to ensure continuity of the first and second derivatives at the upstream end (X = 0) and c and d were chosen to ensure zero first and second derivatives at the point (X = 1) where the design Mach number was reached. The value of n was determined in the following way. For each of the nozzles, the sonic point on the flat bottom liner was fixed in the same place (112 inches upstream of the centre of the window; X = 61 in Table II) and the design Mach number was required to

*The contraction was designed by R. Harrop[2].

be reached at the same point on the bottom liner (56 inches upstream of the centre of the window; $Z = 117$ in Table II). For the $M = 2.0$ nozzle the radius of curvature at the throat was taken to be 5 times the throat height. To satisfy these conditions n was required to be 7.673. In the final design work the top liner shape at the throat was approximated by a parabola with radius of curvature equal to that of the calculated streamline.

The nozzle shapes for $M = 1.3$, 1.5, 1.7 and 1.9 were obtained from the others by B.W. McMullen, using the following method. Interpolated values of the co-ordinates, slopes and curvatures, at the throat, the point of inflexion, and the end of the liner were obtained. The final ordinates were then determined by building up between these three points using interpolated values for the second differences of the ordinates and a numerical smoothing process.

4 Concluding Remarks

At the time of writing this note the nozzles for $M = 1.3$, 1.4, 1.5, 1.6, 1.8 and 2.0 are in use and the remainder are being manufactured. Flow calibrations at some of these Mach numbers are reported in reference 1; to facilitate comparison the position of the centre of the window is quoted in Fig. 1.

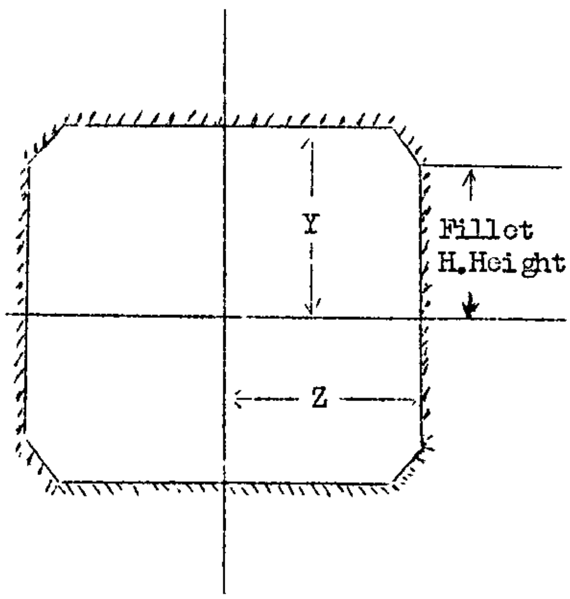
REFERENCES

No.	Author	Title, etc.
1	Morris, D.E.	Calibration of the flow in the working section of the 3 ft x 3 ft tunnel, National Aeronautical Establishment. C.P. 261, September 1954.
2	Harrop, R.	Method for designing wind tunnel contractions. R.A.E. Rept. Aero 2257 ARC 11,603. March 1948.

TABLE I

Contraction Ordinates

X	Contraction Wall Half Height "Y"	Contraction Wall Half Width "Z"	Fillet Half Height
0	115.50	111.00	115.50
12	115.00	110.75	111.25
24	114.50	110.25	107.00
36	114.00	109.75	103.50
48	113.50	109.25	100.50
60	112.75	108.62	97.50
72	112.00	107.88	95.50
84	111.25	107.09	93.50
96	110.28	106.00	92.50
108	109.25	105.00	91.50
120	108.12	104.00	90.25
132	106.94	102.75	89.00
144	105.50	101.25	87.75
156	104.00	99.50	86.25
168	102.25	97.50	84.75
180	100.25	95.00	83.25
192	97.75	91.75	81.50
204	94.75	87.25	79.50
216	91.25	81.25	77.25
228	87.00	73.50	74.50
240	82.00	63.75	71.25
252	75.84	52.44	67.22
256	73.53	48.91	65.78
260	71.09	45.47	64.22
264	68.56	42.22	62.53
268	65.94	39.22	60.72
272	63.22	36.41	58.78
276	60.44	33.75	56.75
280	57.59	31.25	54.62
284	54.72	28.91	52.41
288	51.81	26.78	50.16
292	48.91	24.91	47.88
296	46.03	23.22	45.56
300	43.22	21.72	43.22
304	40.50	20.44	
308	37.94	19.38	
312	35.56	18.59	
316	33.34	18.16	
320	31.19	18.00	



All ordinates are in inches

TABLE II

Nozzle Ordinates

X	Bottom liner and subsonic liner	Y							
		M = 1.3	M = 1.4	M = 1.5	M = 1.6	M = 1.7	M = 1.8	M = 1.9	M = 2.0
0	7.793	7.793	7.793	7.793	7.793	7.793	7.793	7.793	7.793
1	8.333	8.326	8.326	8.326	8.326	8.326	8.326	8.326	8.326
2	8.873	8.859	8.859	8.859	8.859	8.859	8.859	8.859	8.859
3	9.413	9.392	9.392	9.392	9.392	9.392	9.392	9.392	9.392
4	9.948	9.923	9.925	9.925	9.925	9.925	9.925	9.925	9.925
5	10.476	10.450	10.456	10.455	10.458	10.458	10.458	10.458	10.458
6	10.985	10.970	10.979	10.978	10.989	10.991	10.991	10.991	10.991
7	11.459	11.478	11.488	11.490	11.514	11.524	11.524	11.524	11.524
8	11.878	11.971	11.976	11.987	12.030	12.055	12.057	12.057	12.057
9	12.242	12.444	12.438	12.467	12.533	12.582	12.590	12.590	12.590
10	12.560	12.890	12.871	12.927	13.020	13.102	13.123	12.123	12.123
11	12.839	13.300	13.274	13.364	13.487	13.613	13.656	13.656	13.656
12	13.085	13.670	13.648	13.777	13.933	14.113	14.188	14.189	14.189
13	13.303	14.002	13.993	14.167	14.358	14.598	14.719	14.722	14.722
14	13.496	14.297	14.309	14.533	14.763	15.065	15.247	15.255	14.255
15	13.667	14.554	14.597	14.875	15.147	15.514	15.769	15.788	15.788
16	13.819	14.773	14.858	15.191	15.510	15.943	16.282	16.321	16.321
17	13.954	14.953	15.092	15.484	15.853	16.351	16.782	16.853	16.854
18	14.073	15.093	15.300	15.750	16.175	16.739	17.264	17.384	17.387
19	14.177	15.205	15.485	15.992	16.477	17.109	17.725	17.912	17.920
20	14.267	15.301	15.650	16.210	16.761	17.461	18.163	18.435	18.453
21	14.345	15.388	15.799	16.408	17.028	17.795	18.578	18.950	18.986
22	14.412	15.467	15.935	16.591	17.280	18.112	18.972	19.455	19.519
23	14.468	15.540	16.062	16.768	17.520	18.414	19.346	19.948	20.051
24	14.514	15.607	16.182	16.940	17.750	18.702	19.702	20.426	20.582
25	14.550	15.670	16.297	17.107	17.973	18.979	20.042	20.882	21.111
26	14.577	15.730	16.408	17.269	18.189	19.247	20.367	21.311	21.636
27	14.595	15.788	16.515	17.425	18.398	19.507	20.678	21.708	22.154
28	14.605	15.844	16.619	17.576	18.601	19.758	20.976	22.078	22.662
29	14.609	15.899	16.719	17.722	18.797	20.001	21.263	22.428	23.157
30	14.609	15.952	16.816	17.863	18.986	20.235	21.540	22.759	23.632
31	14.608	16.003	16.910	17.999	19.168	20.461	21.808	23.074	24.078
32	14.604	16.052	17.000	18.130	19.343	20.678	22.066	23.375	24.492
33	14.600	16.099	17.086	18.256	19.512	20.887	22.314	23.663	24.873
34	14.596	16.144	17.169	18.377	19.674	21.088	22.552	23.939	25.222
35	14.592	16.187	17.248	18.493	19.829	21.280	22.780	24.203	25.542
36	14.588	16.228	17.324	18.604	19.977	21.464	22.998	24.455	25.836
37	14.584	16.267	17.396	18.710	20.118	21.640	23.206	24.695	26.109
38	14.580	16.305	17.465	18.810	20.253	21.807	23.403	24.923	26.366
39	14.576	16.341	17.530	18.905	20.381	21.966	23.590	25.139	26.608
40	14.572	16.375	17.592	18.995	20.502	22.116	23.767	25.343	26.836
41	14.568	16.407	17.650	19.080	20.616	22.258	23.935	25.536	27.052
42	14.564	16.437	17.705	19.160	20.724	22.391	24.093	25.717	27.256
43	14.560	16.465	17.756	19.235	20.825	22.516	24.241	25.887	27.447
44	14.556	16.491	17.804	19.305	20.919	22.632	24.378	26.045	27.626
45	14.552	16.515	17.848	19.370	21.006	22.740	24.505	26.192	27.792
46	14.548	16.537	17.889	19.433	21.086	22.840	24.623	26.327	27.946
47	14.544	16.557	17.926	19.485	21.159	22 931	24.731	26.451	28.088
48	14.540	16.576	17.960	19.534	21.226	23.014	24.829	26.564	28.217
49	14.536	16.593	17.990	19.578	21.286	23.088	24.916	26.665	28.334
50	14.532	16.608	18.017	19.617	21.339	23.154	24.993	26.755	28.439
51	14.528	16.621	18.041	19.651	21.385	23.211	25.061	26.834	28.531
52	14.524	16.632	18.061	19.680	21.424	23.260	25.119	26.901	28.611
53	14.520	16.641	18.077	19.704	21.457	23.300	25.167	26.957	28.678
54	14.516	16.648	18.090	19.723	21.483	23.332	25.204	27.002	28.733
55	14.512	16.653	18.099	19.737	21.502	23.355	25.231	27.035	28.775
56	14.508	16.656	18.105	19.746	21.514	23.370	25.249	27.057	28.805
57	14.504	16.657	18.107	19.750	21.519	23.376	25.257	27.068	28.823
58	14.500	16.656	18.106	19.749	21.518	23.374	25.254	27.067	28.828
59	14.496	16.653	18.101	19.743	21.510	23.364	25.241	27.055	28.820
60	14.492	16.647	18.093	19.732	21.495	23.344	25.218	27.030	28.800
61	14.488	16.639	18.081	19.715	21.472	23.314	25.183	26.993	28.764
62	14.484	16.629	18.066	19.692	21.440	23.273	25.134	26.939	28.709

TABLE II (Contd)

X	Bottom liner and subsonic liner	Y							
		M = 1.3	M = 1.4	M = 1.5	M = 1.6	M = 1.7	M = 1.8	M = 1.9	M = 2.0
63	14.480	16.617	18.047	19.664	21.399	23.219	25.068	26.864	28.628
64	14.476	16.603	18.025	19.629	21.348	23.151	24.983	26.764	28.515
65	14.472	16.587	17.999	19 588	21.287	23.068	24.877	26.637	28.365
66	14.468	16.569	17.969	19.541	21.216	22.970	24.750	26.483	28.178
67	14.464	16.549	17.935	19.483	21.135	22.858	24.604	26.303	27.963
68	14.460	16.527	17.898	19.429	21.045	22.734	24.444	26.110	27.739
69	14.456	16.503	17.856	19.362	20.946	22.599	24.274	25.909	27.509
70	14.452	16.477	17.810	19.288	20.839	22.457	24.098	25.703	27.276
71	14.448	16.449	17.760	19.208	20.725	22.311	23.918	25.495	27.041
72	14.444	16.419	17.705	19.123	20.605	22.162	23.736	25.286	26.805
73	14.440	16.387	17.647	19.033	20.481	22.010	23.553	25.076	26.568
74	14.436	16.353	17.585	18.939	20.354	21.856	23.370	24.865	26.331
75	14.432	16.317	17.519	18.841	20.225	21.700	23.186	24.654	26.094
76	14.428	16.278	17.450	18.741	20.095	21.543	23.002	24.443	25.857
77	14.424	16.237	17.378	18.640	19.964	21.385	22.818	24.232	25.620
78	14.420	16.193	17.304	18.538	19.832	21.227	22.634	24.021	25.384
79	14.416	16.147	17.229	18.435	19.700	21.069	22.450	23.811	25.150
80	14.412	16.100	17.153	18.331	19.568	20.911	22.267	23.603	24.917
81	14.408	16.052	17.076	18.227	19.437	20.754	22.085	23.395	24.685
82	14.404	16.003	16.999	18.123	19.307	20.597	21.903	23.188	24.454
83	14.400	15.953	16.922	18.019	19.177	20.441	21.722	22.982	24.225
84	14.396	15.903	16.845	17.916	19.048	20.286	21.542	22.777	23.998
85	14.392	15.853	16.768	17.813	18.920	20.131	21.363	22.574	23.772
86	14.388	15.804	16.692	17.710	18.792	19.977	21.186	22.372	23.548
87	14.384	15.755	16.616	17.608	18.666	19.825	21.010	22.172	23.326
88	14.380	15.706	16.540	17.507	18.541	19.674	20.835	21.974	23.105
89	14.376	15.657	16.465	17.407	18.417	19.524	20.661	21.778	22.887
90	14.372	15.609	16.391	17.308	18.294	19.375	20.489	21.584	22.671
91	14.368	15.562	16.317	17.210	18.172	19.228	20.318	21.392	22.456
92	14.364	15.515	16.244	17.113	18.051	19.082	20.149	21.201	22.244
93	14.360	15.469	16.172	17.018	17.932	18.937	19.982	21.012	22.034
94	14.356	15.424	16.101	16.924	17.814	18.793	19.817	20.825	21.826
95	14.352	15.379	16.031	16.831	17.697	18.650	19.653	20.640	21.620
96	14.348	15.335	15.962	16.739	17.582	18.508	19.491	20.457	21.416
97	14.344	15.291	15.893	16.648	17.468	18.368	19.331	20.276	21.215
98	14.340	15.247	15.826	16.558	17.356	18.230	19.173	20.098	21.016
99	14.336	15.204	15.760	16.470	17.245	18.094	19.017	19.922	20.820
100	14.332	15.161	15.695	16.383	17.136	17.960	18.863	19.748	20.627
101	14.328	15.119	15.631	16.298	17.028	17.828	18.711	19.577	20.436
102	14.324	15.077	15.568	16.214	16.922	17.698	18.561	19.408	20.248
103	14.320	15.036	15.506	16.131	16.818	17.571	18.414	19.242	20.062
104	14.316	14.995	15.446	16.049	16.715	17.446	18.269	19.078	19.879
105	14.312	14.955	15.387	15.969	16.614	17.324	18.127	18.916	19.699
106	14.308	14.915	15.329	15.891	16.515	17.205	17.987	18.756	19.522
107	14.304	14.876	15.272	15.815	16.418	17.089	17.849	18.599	19.348
108	14.300	14.838	15.216	15.740	16.322	16.976	17.713	18.444	19.176
109	14.296	14.801	15.162	15.666	16.228	16.866	17.580	18.292	19.007
110	14.292	14.765	15.109	15.594	16.136	16.758	17.450	18.143	18.841
111	14.288	14.730	15.057	15.524	16.046	16.652	17.322	17.996	18.678
112	14.284	14.696	15.007	15.456	15.958	16.549	17.196	17.852	18.517
113	14.280	14.663	14.958	15.390	15.872	16.448	17.073	17.711	18.360
114	14.276	14.631	14.910	15.326	15.788	16.349	16.952	17.573	18.206
115	14.272	14.600	14.864	15.264	15.706	16.252	16.834	17.438	18.055
116	14.268	14.570	14.819	15.204	15.626	16.156	16.719	17.306	17.906
117	14.264	14.542	14.776	15.145	15.548	16.063	16.606	17.177	17.760
118	14.260	14.515	14.734	15.087	15.472	15.972	16.496	17.051	17.617
119	14.256	14.489	14.694	15.031	15.398	15.882	16.388	16.928	17.477
120	14.252	14.464	14.655	14.976	15.326	15.794	16.283	16.808	17.341
121	14.248	14.440	14.618	14.923	15.257	15.708	16.180	16.691	17.208
122	14.244	14.417	14.582	14.872	15.190	15.624	16.080	16.577	17.077
123	14.240	14.394	14.548	14.823	15.125	15.542	15.983	16.465	16.949
124	14.236	14.372	14.515	14.776	15.062	15.463	15.888	16.356	16.824
125	14.232	14.351	14.484	14.730	15.001	15.386	15.795	16.250	16.702
126	14.228	14.331	14.454	14.686	14.942	15.311	15.705	16.147	16.584
127	14.224	14.312	14.426	14.644	14.886	15.239	15.618	16.046	16.469

TABLE II (Contd)

X	Bottom liner and subsonic liner	Y							
		M = 1.3	M = 1.4	M = 1.5	M = 1.6	M = 1.7	M = 1.8	M = 1.9	M = 2.0
128	14.220	14.294	14.399	14.604	14.832	15.169	15.533	15.947	16.356
129	14.216	14.278	14.374	14.565	14.780	15.101	15.451	15.851	16.246
130	14.212	14.263	14.350	14.528	14.730	15.036	15.371	15.758	16.139
131	14.208	14.249	14.328	14.493	14.682	14.973	15.294	15.668	16.035
132	14.204	14.236	14.307	14.459	14.636	14.913	15.220	15.580	15.934
133	14.200	14.224	14.288	14.427	14.592	14.855	15.148	15.495	15.836
134	14.196	14.213	14.270	14.397	14.550	14.799	15.079	15.412	15.741
135	14.192	14.203	14.253	14.368	14.511	14.745	15.012	15.332	15.649
136	14.188	14.194	14.236	14.341	14.474	14.694	14.948	15.254	15.560
137	14.184	14.187	14.224	14.316	14.439	14.645	14.886	15.179	15.473
138	14.180	14.181	14.212	14.293	14.406	14.598	14.827	15.107	15.389
139	14.176	14.176	14.201	14.272	14.375	14.553	14.770	15.038	15.308
140	14.172	14.172	14.190	14.253	14.346	14.511	14.716	14.972	15.231
141	14.168	14.168	14.181	14.236	14.319	14.471	14.664	14.909	15.156
142	14.164	14.164	14.173	14.220	14.294	14.434	14.615	14.848	15.084
143	14.160	14.160	14.166	14.206	14.271	14.399	14.569	14.790	15.014
144	14.156	14.156	14.160	14.193	14.249	14.367	14.525	14.734	14.947
145	14.152	14.152	14.154	14.181	14.229	14.337	14.483	14.681	14.883
146	14.148	14.148	14.149	14.170	14.211	14.309	14.444	14.630	14.822
147	14.144	14.144	14.144	14.160	14.195	14.283	14.407	14.582	14.764
148	14.140	14.140	14.140	14.151	14.181	14.259	14.372	14.537	14.708
149	14.136	14.136	14.136	14.143	14.168	14.237	14.340	14.494	14.654
150	14.132	14.132	14.132	14.136	14.156	14.217	14.310	14.454	14.603
151	14.128	14.128	14.128	14.130	14.145	14.199	14.282	14.417	14.555
152	14.124	14.124	14.124	14.125	14.136	14.182	14.256	14.382	14.509
153	14.120	14.120	14.120	14.120	14.128	14.167	14.233	14.349	14.466
154	14.116	14.116	14.116	14.116	14.121	14.154	14.211	14.318	14.425
155	14.112	14.112	14.112	14.112	14.115	14.142	14.191	14.289	14.386
156	14.108	14.108	14.108	14.108	14.109	14.131	14.173	14.262	14.350
157	14.104	14.104	14.104	14.104	14.104	14.121	14.157	14.236	14.316
158	14.100	14.100	14.100	14.100	14.100	14.112	14.143	14.212	14.285
159	14.096	14.096	14.096	14.096	14.096	14.104	14.130	14.190	14.256
160	14.092	14.092	14.092	14.092	14.092	14.097	14.118	14.170	14.229
161	14.088	14.088	14.088	14.088	14.088	14.091	14.107	14.152	14.204
162	14.084	14.084	14.084	14.084	14.084	14.085	14.098	14.135	14.182
163	14.080	14.080	14.080	14.080	14.080	14.080	14.090	14.120	14.161
164	14.076	14.076	14.076	14.076	14.076	14.076	14.083	14.107	14.142
165	14.072	14.072	14.072	14.072	14.072	14.072	14.076	14.095	14.125
166	14.068	14.068	14.068	14.068	14.068	14.068	14.070	14.085	14.110
167	14.064	14.064	14.064	14.064	14.064	14.064	14.065	14.076	14.096
168	14.060	14.060	14.060	14.060	14.060	14.060	14.060	14.068	14.084
169	14.056	14.056	14.056	14.056	14.056	14.056	14.056	14.061	14.073
170	14.052	14.052	14.052	14.052	14.052	14.052	14.052	14.055	14.064
171	14.048	14.048	14.048	14.048	14.048	14.048	14.048	14.049	14.056
172	14.044	14.044	14.044	14.044	14.044	14.044	14.044	14.044	14.049
173	14.040	14.040	14.040	14.040	14.040	14.040	14.040	14.040	14.043
174	14.036	14.036	14.036	14.036	14.036	14.036	14.036	14.036	14.037
175	14.032	14.032	14.032	14.032	14.032	14.032	14.032	14.032	14.032
176	14.028	14.028	14.028	14.028	14.028	14.028	14.028	14.028	14.028
177	14.024	14.024	14.024	14.024	14.024	14.024	14.024	14.024	14.024
178	14.020	14.020	14.020	14.020	14.020	14.020	14.020	14.020	14.020
179	14.016	14.016	14.016	14.016	14.016	14.016	14.016	14.016	14.016
180	14.012	14.012	14.012	14.012	14.012	14.012	14.012	14.012	14.012
181	14.008	14.008	14.008	14.008	14.008	14.008	14.008	14.008	14.008
182	14.004	14.004	14.004	14.004	14.004	14.004	14.004	14.004	14.004
183	14.000	14.000	14.000	14.000	14.000	14.000	14.000	14.000	14.000

All ordinates are in inches

The liners are straight above the single line and below the double line.

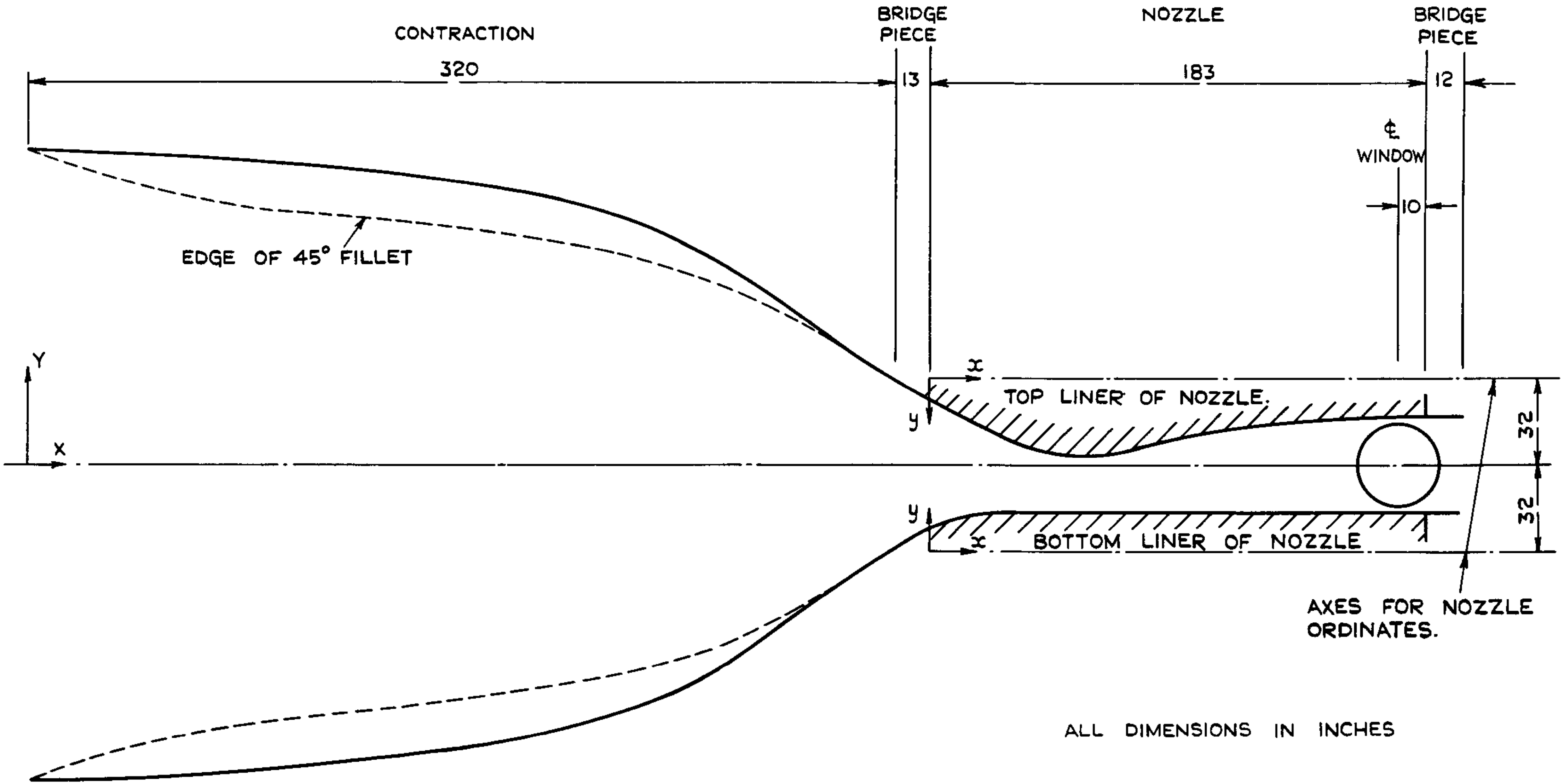


FIG. 1. VERTICAL SECTION THROUGH CONTRACTION AND WORKING SECTION.

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