WYLE LABORATORIES - RESEARCH STAFF

TECHNICAL MEMORANDUM 65-4

SUPERSONIC TURBULENT SEPARATION TESTS IN THE MARSHALL SPACE FLIGHT CENTER 7" TUNNEL

Submitted on Contract NAS8-11308

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Prepared by M.V. Lowson
M.V. Lowson

Approved by K. McK. Eldred
K. McK. Eldred

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1.0 INTRODUCTION

Prediction of the acoustic environments beneath regions of separated flow and oscillating shocks is severely limited by the lack of experimental information on these flows. At the present time it is not possible to make realistic estimates of even the mean flow occurring in the separation region. In Reference (1) it was shown how separated flows on flares at supersonic speeds could be directed into three classes as shown in Figure (1). Each class is associated with a different flow pattern, and different fluctuating pressure environments may be expected for each type. Once the mean flow type can be defined, further prediction is practicable on the basis of available data. However, at present there are not sufficient experimental results to determine the flow type from known vehicle conditions.

Therefore, there is a definite requirement for further experimental work and this Memorandum has been prepared at the request of MSFC to specify the experiments and to give a detailed design for the models required. The experimental tests outlined below should provide sufficient information to define criteria separating one flow type from the other, and so should enable considerably improved acoustic environmental predictions to be made. In addition, these tests should have value in the prediction of vehicle loadings and stability.

2.0 DISCUSSION

The types of flow can be classified with reasonable accuracy merely by identification of their shadowgraph flow characteristics. Therefore, as a first stage, it is suggested that the tests be limited to a shadowgraph flow visualization. Recent tests at Ames have provided extensive data on the steady and fluctuating pressures caused by various supersonic flare induced turbulent separations, but unfortunately the Ames tests did not include shadowgraph information. The present tests could therefore be regarded as an extension of those at Ames, and will certainly greatly assist interpretation of that data. The present tests could also be combined with surface oil-flow visualization, and at a later stage the models could be instrumented for static pressure measurements. It would be desirable to make pressure fluctuation measurements, but development of a microphone suitable for the low intensities expected ($\approx$110 dB due to the low density) would cause difficulty. In view of the data already available from Ames it is not recommended that pressure fluctuation measurement be attempted at present. The critical parameter for these tests is the Reynolds number based on undisturbed boundary layer thicknesses, as shown by Kuehn in Reference (2). For values of this Reynolds number below 8×10^4 he found a significant variation of separation length with Reynolds number. However, for higher values the flow seems to reach an assymptotic state. It is therefore essential to run these tests at a sufficiently high Reynolds number, and this puts a limitation on the minimum boundary layer thickness, as shown in Table I below.

TABLE I

CHARACTERISTICS OF THE M.S.F.C. 7" WIND TUNNEL

Mach Number	Reynolds Number Per Inch	Minimum δ_0 (in.) for Re_{δ_0} 8×10^4	Typical Tunnel Floor Boundary Layer Thickness (in.)
1.54	360,353	0.22	0.2
1.99	305,185	0.262	0.3
2.44	250,000	0.32	0.32
3.00	185,608	0.433	0.3

The boundary layer thicknesses given in Table I would require body lengths of a foot or more for their natural generation. For many reasons it is undesirable to artificially increase the thickness of the boundary layer so that this body length requirement rules out the possibility of using axisymmetric bodies in the 7" tunnel. However, it will be observed that the tunnel wall boundary layer thickness is very close to that desired. Thus an alternative would be to use a two dimensional model mounted on the tunnel wall, but this becomes impractical in terms of tunnel blockage at the larger step heights required for the tests. In addition, the field of view of the shadowgraph in the 7" tunnel does not include the wall, thus involving further complications.

In view of the limitations discussed above it is suggested that the tests be made a semi-circular section cylinder-flare-cylinder half model mounted on the wall. This type model could utilize the wall boundary layer and thus satisfy the boundary layer thickness requirements. The top surface would be raised above the tunnel floor and thus come into the field of view of the shadowgraph. Also, shadowgraphs of axisymmetric bodies are generally clearer than equivalent two dimensional cases. Finally, the semi-circular section of the model will minimize the tunnel blockage occurring at any given step height.

The wall boundary layer is about 0.3" in thickness 8" in front of the nozzle trailing edge where separation is anticipated. Previous tests have shown that below step height/boundary layer thickness ratios of unity the flow patterns cannot be readily interpreted because of the small scale. Equally, Kuehn's tests in Reference 2 at step height/boundary layer thickness ratios above 8 always revealed a "flare reattachment" case for sufficiently low flare angles. Accordingly flare step heights of 0.3, 0.6, 1.2 and 2.4 inches have been chosen for the present tests giving setp height/undisturbed boundary layer thickness ratios of 1,2,4,and 8 respectively.

The range of flare angle for the present tests will clearly need to cover the range between the just separated case of 15° and the forward facing step of 90°. Particular interest attaches to the lower value of flare angle since this is more typical of the flares on large launch vehicles, and also since the major effects of flare angle are expected in this lower range. Thus, flare angles of 15,20,30,45,60 and 90 degrees are suggested for the present tests.

The Mach number in the MSFC 7" Tunnel is determined by fixed nozzle liners. The available Mach numbers lying in the present range of interest are 1.5, 2.0, 2.5 and 3 (approximately). Tests at Mach 1.5 with the largest step height will not be possible because of tunnel blockage. Practical considerations may also limit other projected tests. For instance, the low density of the Mach 3 flow may prejudice successful shadowgraph flow visualization. However, it is known that useful shadowgraphs can be obtained at Mach 2.5 so that this problem is not expected to be severe.

3.0 THE PROPOSED MODELS

In order to accomplish the test requirements set out in the above discussion it is proposed to make the cylinder-flare models in two parts. Separate cylinders will be required for each nozzle liner, but the flares will be constructed to fit over the cylinder in any liner. Thus, the following models will be required:

4 basic 1" diameter half cylinder models to fit Mach 1.5, 2, 2.5 and 3 nozzle liners.

24 flare models (0.3, 0.6, 1.2, 2.4 stepheights) x (15°, 20°, 45°, 60°, 90° Flare Angles).

A typical model is shown, in position on the tunnel wall, in Figure (2). (The particular flare model depicted is 0.6" step height, 30° flare angle). The models must be mounted on the removable plate shown in Figure (2) since no holes can be drilled in the nozzle liner. The removable plate lies at an angle to the nozzle axis so that the basic half cylinders will have to be contoured to fit the nozzle wall and the angle of this plate. The half cylinder mates with the wall so that some care must be taken with the fit, particularly since it is desired that the wall boundary layer flows over the cylinder.

Not all of the nozzle contours have been received. Thus a complete definition of the actual dimensions to be used in the shaping of the base of the half cylinder has not been made. The height of the cylinder above the tunnel wall is fixed by the shadowgraph requirement that the top of the model appears in the field of view. Measurements by MSFC staff give the following dimensions for the distance of the bottom of the window above the tunnel liner (in inches)

M =	1.5	2.0	2.5	3.0
East	0.3	0.54	0.42	0.61
West	0.35	0.59	0.16	0.57

It is therefore suggested that the top of the half cylinder model be positioned at a height of 0.7" above the nozzle liner datum. Details of the half cylinder model are shown in Figure (3).

On the other hand, the flare models mate with the cylinder and the only other requirement is that they clear the nozzle wall. Their bottom surface has therefore been designed to clear the liner for the M=3 case, and in general there will be a gap between the lower surface of the flare and the tunnel wall. The position of the flare shoulder has been chosen so that separation will occur approximately 8" in front of the nozzle trailing edge. Each model terminates as a backward facing step 6" behind the nozzle trailing edge. The dimensions of the flares are given in Table II. (all dimensions are in inches).

TABLE II

DIMENSIONS OF TRUNCATED CONE/CYLINDER "FLARE" MODELS

Step Height		0.3	0.6	1.2	2.4
External Radius		0.8	1.1	1.7	2.9
Length of flare from shoulder to front of Model.	15°	1.120	2.239	4.479	8.957
	20°	0.824	1.649	3.297	6.594
	30°	0.520	1.039	2.079	4.157
	45°	0.3	0.6	1.2	2.4
	60°	0.173	0.346	0.693	1.386
	90°	0	0	0	0
Distance Shoulder to rear of Model		12.75	11.75	9.5	5.0
Thus distance of shoulder in front of Nozzle T.E.		6.75	5.75	3.5	-1.0

The fixings for these models are shown in Figures (3, 4, and 5). The half cylinder model, Figure (3), is attached to the back plate by two 1/4 inch diameter counter sunk bolts with nuts on the reverse side of the plate. The flares, Figures (4 and 5), are attached by 1/4 inch diameter bolts which screw in from below the plate into tapped holes in the flare. It is proposed to make all the models from brass and to use steel bolts. Because of the dimensions of the fixture required to hold the flares the rear part of the 0.3" step height flares has had to be widened. Thus these smallest flares have a second shoulder positioned 6" from the rear of the model at the nozzle trailing edge. Advantage has been taken of this to make this second shoulder provide a second test and each second shoulder is constructed with a step height and flare angle equal to that occurring at the first, this is shown in Figure (5). Since the second shoulder is about 25 step heights behind the first it is not expected to interfere in any way with the earlier flow.

Note that Figures (3,4 and 5) are reduced scale versions of drawings available at Wyle Laboratories. It proved impossible to obtain reliable dimensions for the actual nozzle liners used at MSFC. Therefore, mould lines for the liners have been taken directly from the nozzle blocks. These mould lines are available at Wyle as drawing E 65349.

4.0 PROPOSED TEST SCHEDULE

The test schedule laid out below will only require two half cylinders and 18 flares for the first 38 tests. A total of 94 tests is suggested. Each of these tests will need to be only of short duration for the shadowgraph visualization. However, those tests for which oil flow visualization is desired will require somewhat longer run times. The proposed boundary layer tests will require the use of a rake already available at MSFC.

Test Number	Mach Number	Step Height (in.)	Flare Angles in Degrees
1	1.5		None-Boundary Layer Rake
2-7	1.5	0.3	15,20,30,45,60,90
8-13	1.5	0.6	" "
14-19	1.5	1.2	" "
20	2.0		None-Boundary Layer Rake
21-26	2.0	0.3	15,20,30,45,60,90
27-32	2.0	0.6	" "
33-38	2.0	1.2	" "
39-44	2.0	2.4	" "
45	2.5		None-Boundary Layer Rake
46-51	2.5	0.3	15,20,30,45,60,90
52-57	2.5	0.6	" "
58-63	2.5	1.2	" "
64-69	2.5	2.4	" "
70	3.0		None-Boundary Layer Rake
71-76	3.0	0.3	15,20,30,45,60,90
77-82	3.0	0.6	" "
83-88	3.0	1.2	" "
89-94	3.0	2.4	" "

REFERENCES

1. Wyle Laboratories Research Staff: Quarterly Progress Report for January February and March, 1965. Contract NAS8-11308.

2. Kuehn D.M., "Turbulent Boundary Layer Separation Induced by Flares on Cylinders at Zero Angle of Attack", NASA TR-R117.

Figure 1a

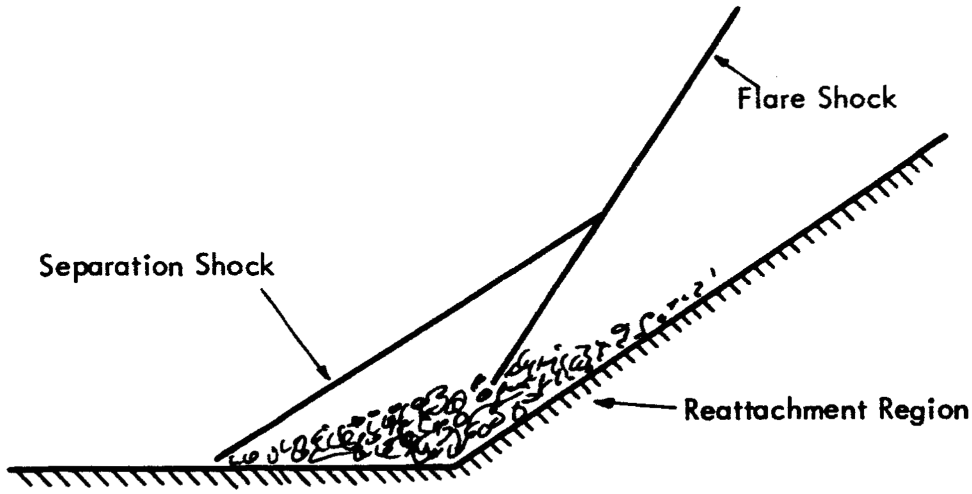


Figure 1b

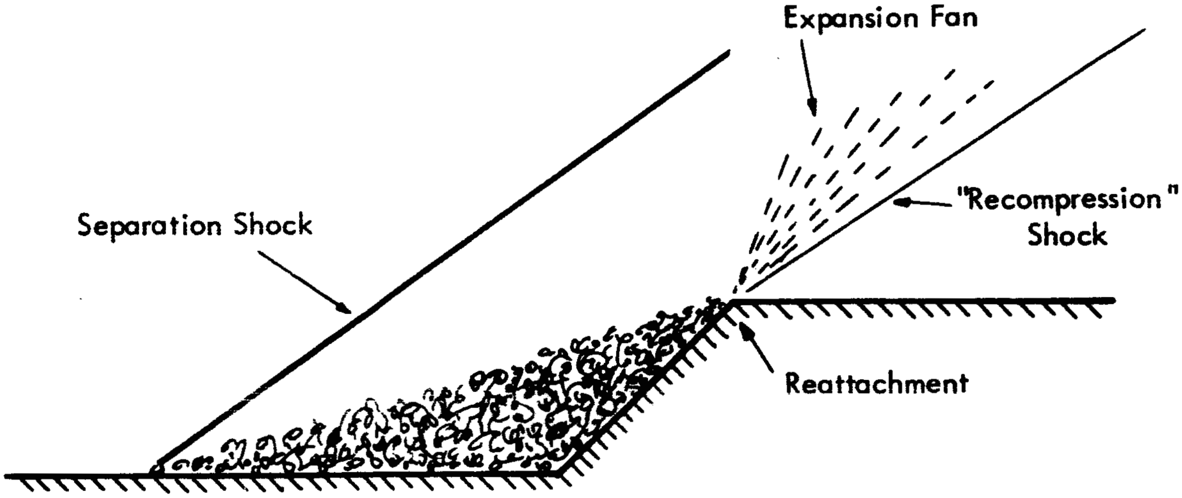


Figure 1c

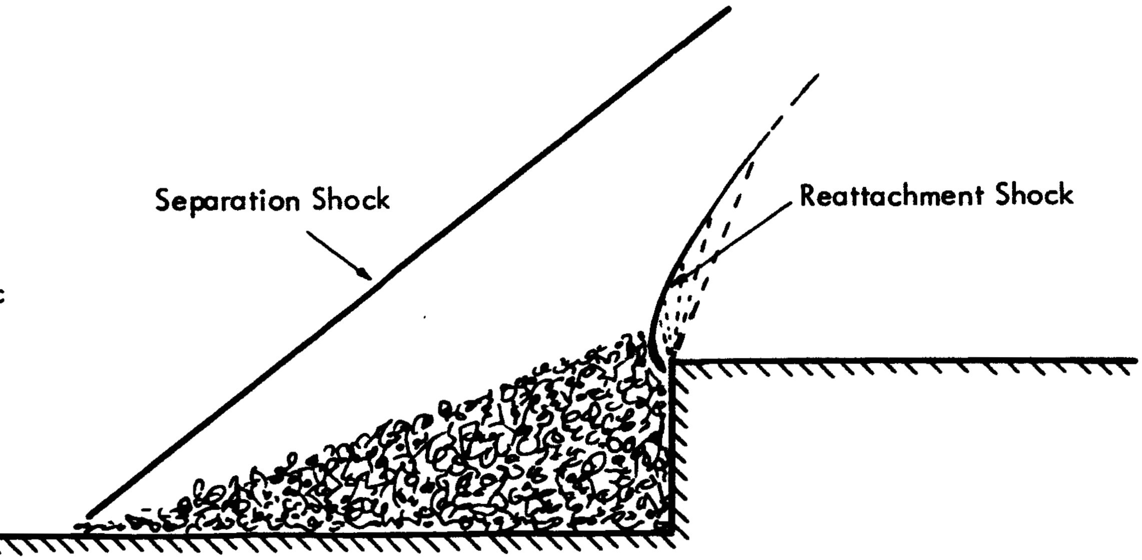


Figure 1: Types of Turbulent Supersonic Separated Flow

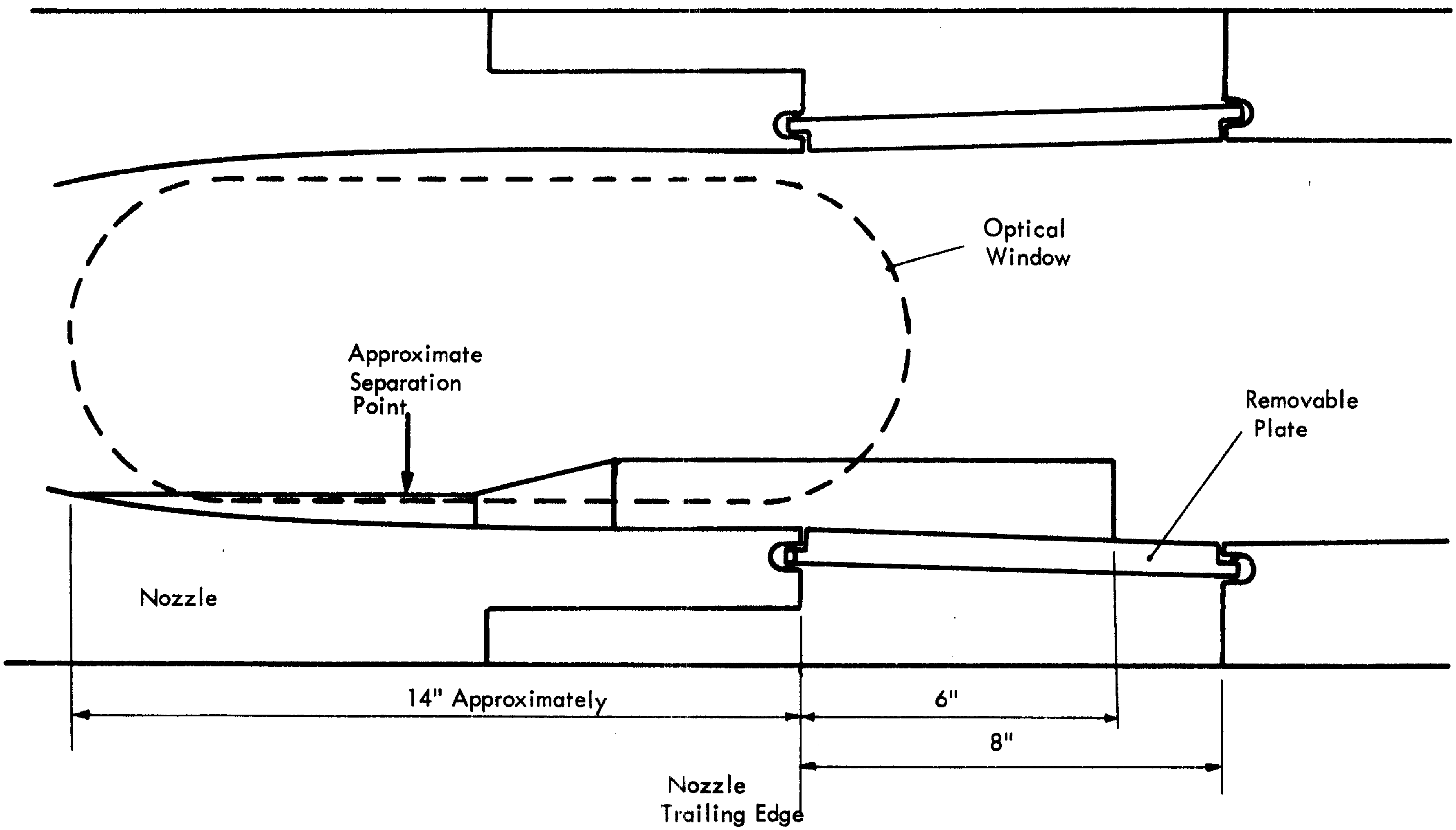
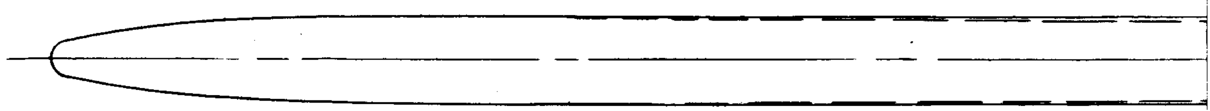
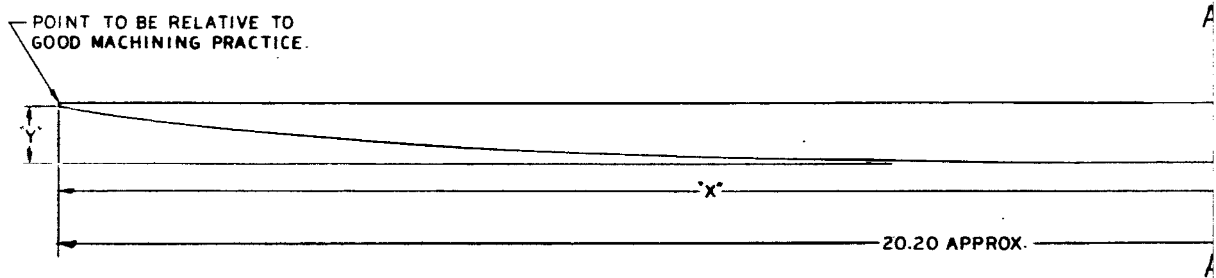


Figure 2: Sketch of Typical Half Model in 7" Tunnel.

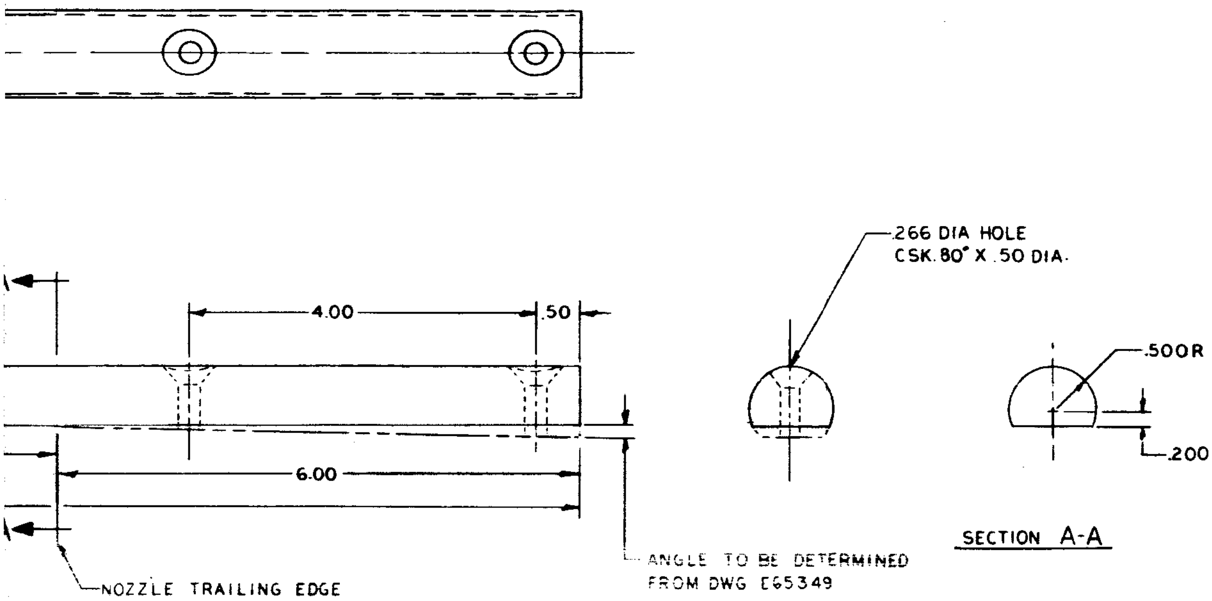




TABLE

"X"	ITEM 1 "Y"	ITEM 2 "Y"	ITEM 3 "Y"	ITEM 4 "Y"		"X"	ITEM 1 "Y"	ITEM 2 "Y"	ITEM 3 "Y"	ITEM 4 "Y"		X	ITEM 1 "Y"	ITEM 2 "Y"	ITEM 3 "Y"	IT

FIGUR



NOTES:
1. SURFACE FINISH 32
2. "X" & "Y" DIM. TO BE OBTAINED FROM DWG E65349

REQD	MATL.	WYLE LABORATORIES
	BRASS	HUNTSVILLE FACILITY
		CYLINDER MODEL "A"
		DRAWN · SCALE FULL · JOB NO 51700 · D65323
TOLERANCE		
DE: XX ±.03 XXX .015		

E 3.

2

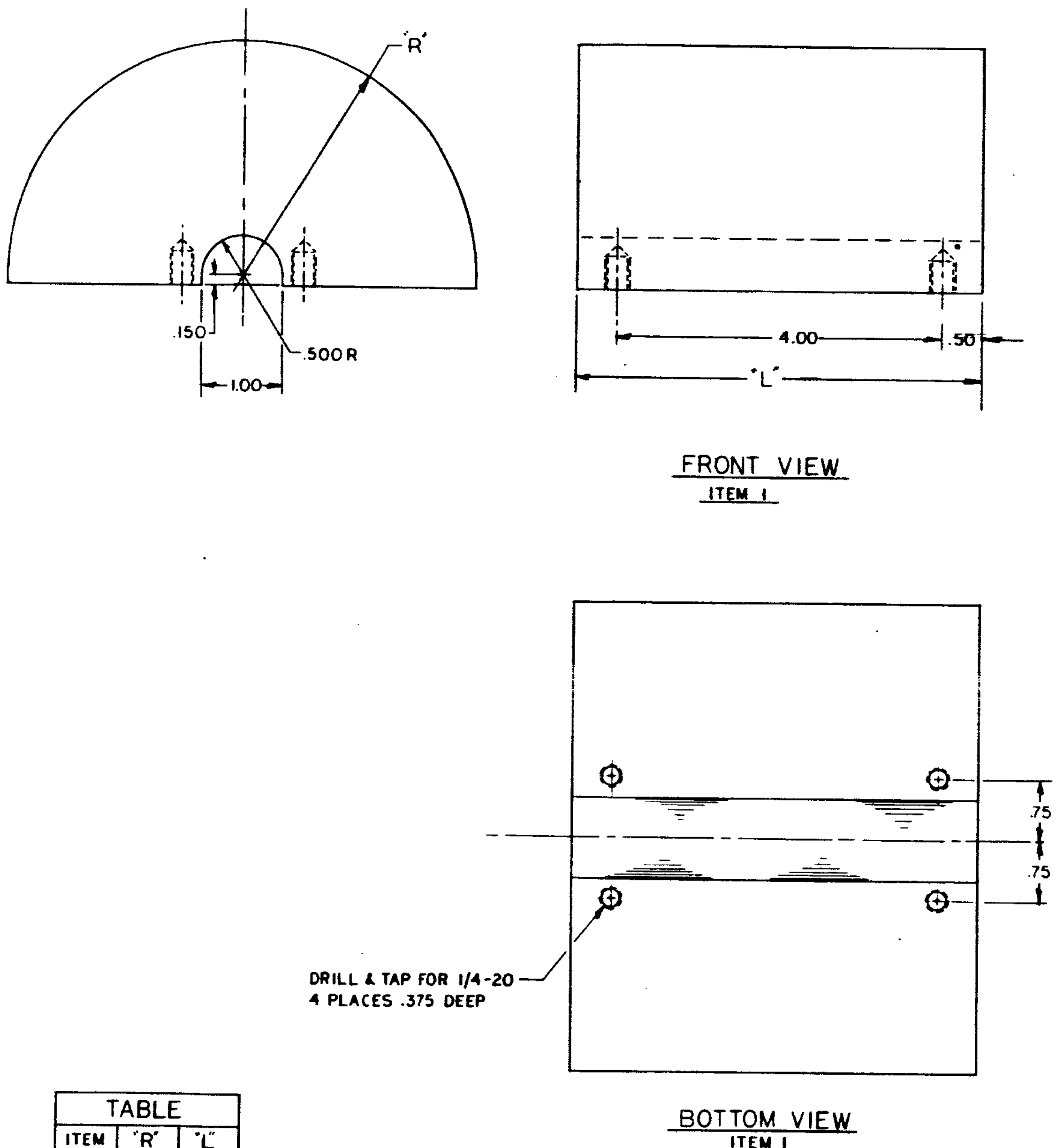
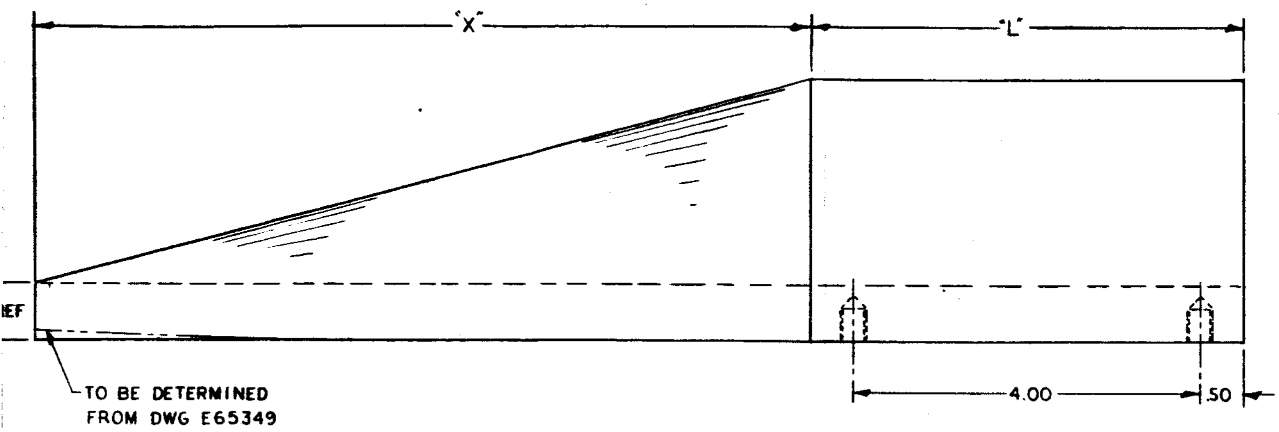


TABLE		
ITEM	"R"	"L"
1A	2.90	5.00
1B	1.70	9.50
1C	1.10	11.75

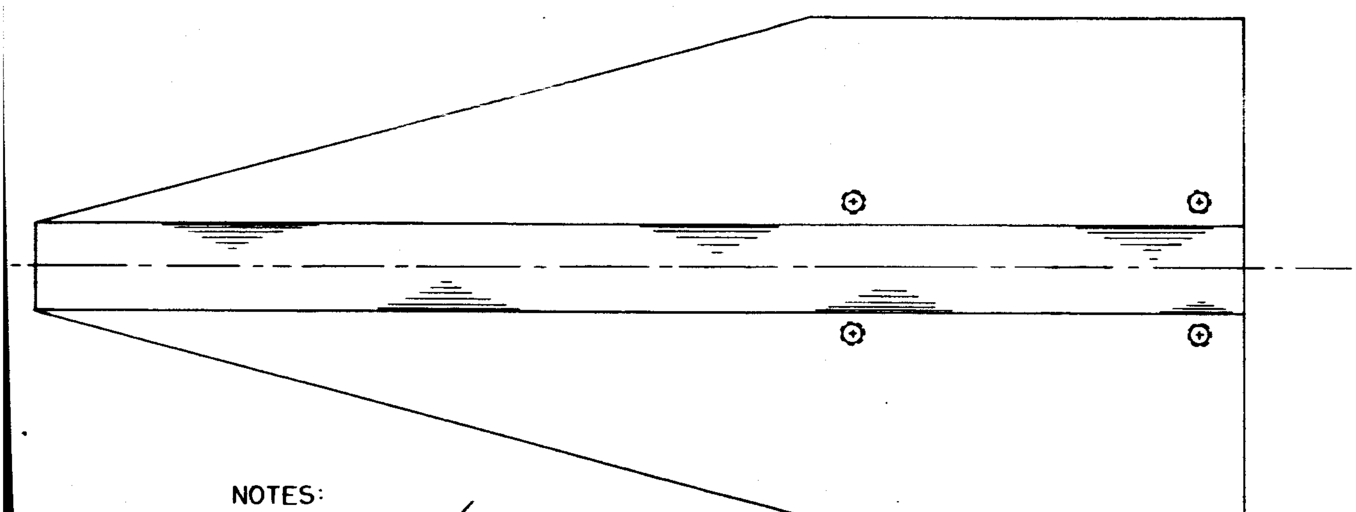
.65

TABLE					
ITEM	"R"	"L"	"X"	ITEM	"R
5A	2.90	5.00	6.594	2A	2.9
5B	1.70	9.50	3.297	2B	1.7
5C	1.10	11.75	1.649	2C	1.1
6A	2.90	5.00	8.957	3A	2.9
6B	1.70	9.50	4.479	3B	1.7
6C	1.10	11.75	2.239	3C	1.1
				4A	2.9
				4B	1.7
				4C	1.1

FI



FRONT VIEW
ITEMS 2 THRU 6



NOTES:
1. SURFACE FINISH 32

BOTTOM VIEW
ITEMS 2 THRU 6 (ALL DIM. SAME AS ITEM I EXCEPT AS NOTED)

"L"	"X"
5.00	1.386
9.50	.693
11.75	.346
5.00	2.4
9.50	1.2
11.75	.6
5.00	4.157
9.50	2.079
11.75	1.039

REQD	MATL.
SEE TABLE	BRASS

TOLERANCE
DEC: XX ±.03 XXX ±.015

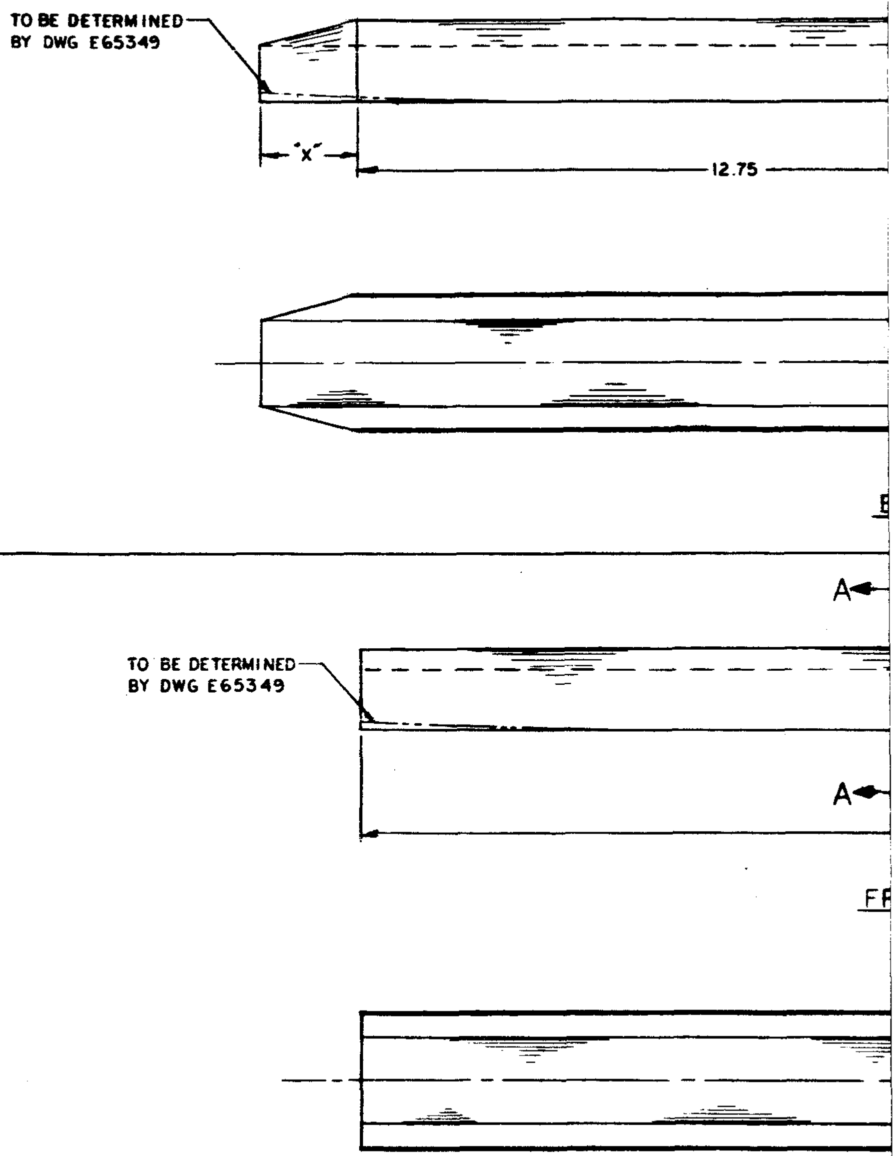
WYLE LABORATORIES
HUNTSVILLE FACILITY

FLARE MODEL "C"

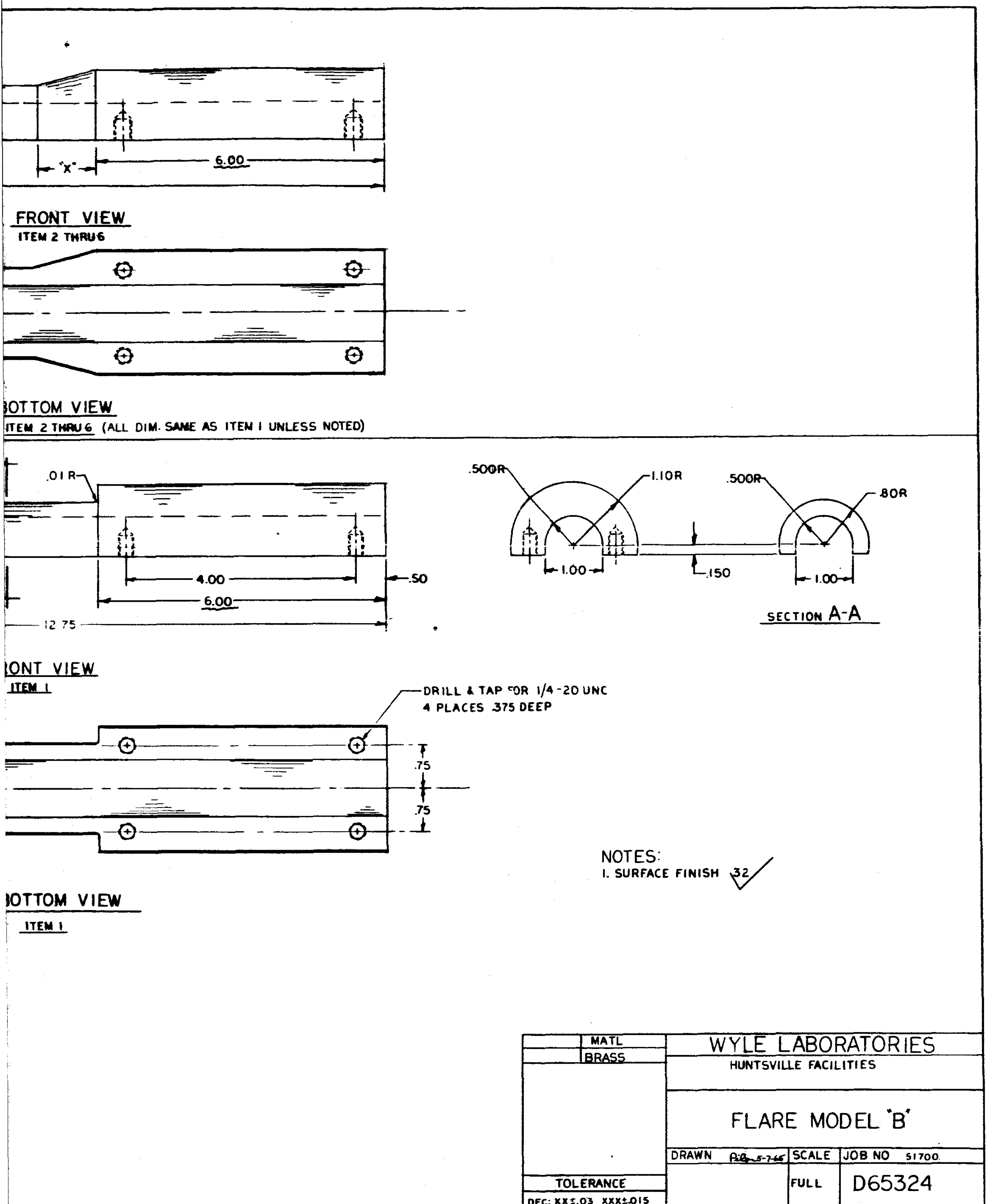
DRAWN	SCALE	JOB NO. 51700
5-10-65	FULL	D65325

URE 4.-2

TABLE	
ITEM	"X"
2	.173
3	.30
4	.52
5	.824
6	1.12



FIG



"X"
6.00
FRONT VIEW
ITEM 2 THRU 6
BOTTOM VIEW
ITEM 2 THRU 6 (ALL DIM. SAME AS ITEM I UNLESS NOTED)
.01 R
4.00
.50
6.00
12.75
.500R
1.10R
.500R
.80R
1.00
.150
1.00
SECTION A-A
RONT VIEW
ITEM 1
DRILL & TAP FOR 1/4-20 UNC
4 PLACES .375 DEEP
.75
.75
BOTTOM VIEW
ITEM 1
NOTES:
1. SURFACE FINISH 32
MATL
BRASS
WYLE LABORATORIES
HUNTSVILLE FACILITIES
FLARE MODEL "B"
DRAWN
SCALE
FULL
JOB NO 51700
D65324
TOLERANCE
DEC: XX±.03 XXX±.015

URE 5. - 2