Design Considerations and Structural Analysis of the Narrow Channel Facility

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1 Original Design Considerations

The narrow channel (NC) facility design is based on the GALCIT Detonation Tube (GDT) test section design of Mike Kaneshige [3]. The main differences are 1) the design of the longitudinal bolted joint was simplified and 2) the keys for the flanges are not designed to assist with shear loading. The GDT side windows and PLIF window may be used in the NC facility. 304 SS was chosen for its excellent corrosion resistance. The yield strength is 275 MPa. 304 SS is non-magnetic and is therefore more difficult to grind on a table with magnetic locking. All four plates were blanchard ground (using mechanical locking to the table through some of the bolt holes which were drilled before grinding) by a subcontractor for Hales. All pieces were machined by Hales except the initiator, window sealing plates, end flange sealing plates which were made by the Aeroshop. Hales also supplied the material and checked the assembly of the pieces. After delivery from Hales, the internal surfaces of the four channel plates were hand-sanded to a mirror finish.

1.1 Design Loading

The facility has a maximum reflected pressure of 2.2 MPa which results in a design pressure of 8.5 MPa. This corresponds to a CJ pressure of about 0.85 MPa. The design pressure was chosen based on the CJ pressure of a range of mixtures of interest to this study: from Ar-diluted H_2-O_2 to N_2-diluted hydrocarbons with sufficiently large cell size for flow visualization. The reflected pressure in a DDT event was estimated to be 16 MPa (Shepherd 92). The resulting loading is calculated to be less than the ultimate tensile strength of the material.

The design load was used to determine the side plate thickness. Increasing the loading will require new plates. If the width of the channel (currently 18.3 mm) is changed, shear loading should be reconsidered for the bolts and the keyed flanges.

A considerable amount of time was spent designing the longitudinal joint, both for strength under loading and to prevent leaking. The joint constant was calculated [4]. A finite element calculation was used to check that the deflection of the joint under loading was less than the squeeze on the O-ring [1]. The corner radius of 0.125 inches (3.18 mm) was also found from this calculation by looking at the stress concentrations.

The four channel plates were assembled together with the four longitudinal O-rings. The bolts were tightened from the center of the channel outwards, tightening eight bolts in a diagonal pattern (four on each side) in both directions from the center until the ends of the channel were reached. This process was repeated several times. During the last pass, a torque wrench was used to acheive the correct prestress.

1.2 Sealing

A 3-D O-ring design based on that used in the previous GDT test section was used [3]. Four longitudinal O-rings run in grooves between the four channel plates. After the channel was bolted together (and after allowing some time to let the O-ring relax so as to avoid the rubber contracting and the end of the O-ring vanishing into the channel), the ends of the O-ring cord were cut flush with the end face of the channel. The ends of the O-rings were cleaned and some superglue was put on the exposed surface. An O-ring was then positioned in the sealing flanges, pressed up against the O-ring cord to meet at the four exposed points. The sealing plate was then screwed in place.

The leak rate of the facility with two solid end flanges and without the initiator is very good: 0.5 mbar in 12 hours. The main source of leaking is in the gap between the upstream flange and the initiator flange, which is very dependent on how perpendicularly the initiator is mounted. A second leak source is the through bolts which clamp the initiator. These were filled up with RTV silicone.

A helium pressure test was not done since we had considerable experience with facilities designed in this manner.

1.3 Supports

The supports were designed using SolidWorks to check the cantilevering displacement. The jacks under the three supports are actually redundent. They were put there to help during the assembly of the support system and left in place as an extra safety measure. A 1 g sideways earthquake loading was also considered in the design.

Using an extra precision level, the top plate of the supports was shimmed to be level in two planes to within 0.25 mm (10 mil). The channel slides on THK brand railings located on the top plate of the support. These were aligned using two methods: an alignment laser and a stretched piano wire.

2 Detailed Structural Analysis

2.1 Introduction

The original design of the NC facility was carried out using well-known mechanics of materials approximations and limited use of finite element methods for the analysis of certain joints for sealing. A more complete finite element analysis has since been conducted to more accurately explore the loading limits of the NC support structure, detonation tube, and detonation initiator. A schematic of the NC facility outlining these parts is shown in Figure 1. All parts were modelled in SolidWorks, and the finite element analysis was carried out in COSMOSWorks using meshed solid models. Note that the analysis is completely linear: as long as the stresses and deflections lie within the elastic regime of the materials, the stresses, factors of safety, and deflections can be scaled linearly with load.

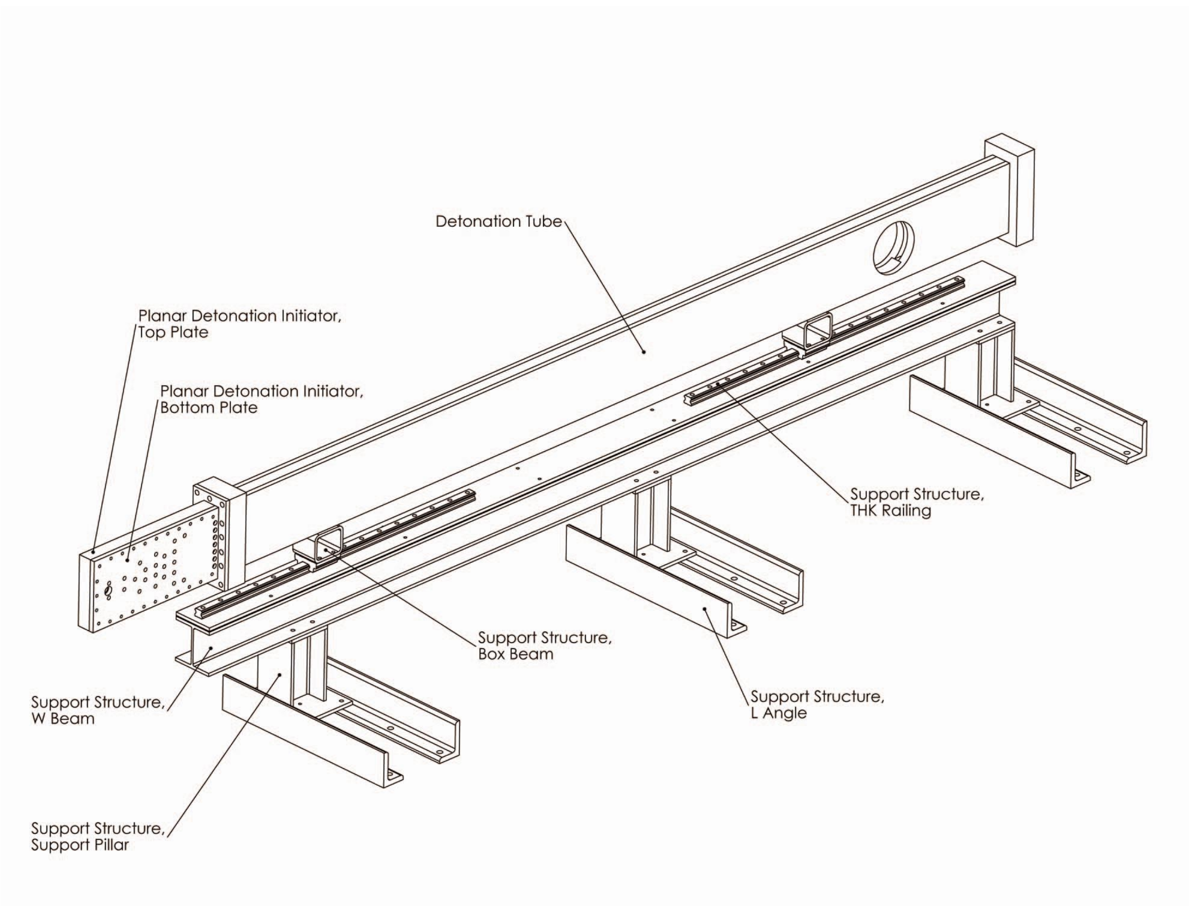

Figure 1: Schematic of the NC facility.

2.2 Narrow Channel Support Structure

The NC support structure, modelled with the full detonation tube mounted along the rails in the configuration representing the greatest loading (with the tube at the extreme end of the support structure with the extra overhang of the W beam), was explored in detail. Both a standard 1 g vertical loading and a 2 g horizontal loading to simulate an earthquake were considered. The materials and material strengths for the various components are shown in Table 1.

Material	Yield Strength [ksi]	Ultimate Strength [ksi]	Components
plain carbon steel	32	58	L angles, support pillars, W beam, box beams
AISI 304 SS	30	75	detonation tube walls, THK railing, THK slider
Al 6061-T6	35	38	detonation tube end flanges

Table 1: Materials and material strengths used in the support structure analysis.

A factor of safety (FOS) distribution for the NC support structure in 1 g vertical loading is shown in Figure 2. Note that the FOS is defined as:

$$\text{FOS} = \frac{\sigma_{yield}}{\sigma_{actual}}$$

where σ_{actual} is the maximum von Mises stress at a given point in the material.

The minimum FOS is 4.1 and is isolated along the inside edge of the bolt holes for mounting the structure. Moving just slightly from the edge of the bolt holes, the FOS jumps up to 14 and increases throughout the structure. The next local minimum FOS of approximately 22 occurs along the top edge of the L angles responsible for carrying the cantilever loading of the NC tube. This section of the structure is shown in detail in Figure 3. A displacement plot of the structure in this scenario is shown in Figure 4. The peak deflection of approximately 0.009 inches (0.2 mm) occurs at the far edge of the detonation tube.

The FOS distribution for the NC support structure in 2 g horizontal loading for earthquake simulation is shown in Figure 5. The structure sees much higher stress in this scenario. The FOS drops below 1 to a minimum of approximately 0.7, and, therefore, yielding will occur in some small regions in the thin section of the W beam where the support pillars are attached. Regions with a FOS below 1 are shown in Figure 6 in red. Note that under 1 g of horizontal loading, the minimum FOS will be approximately 1.4 in these same locations.

The minimum FOS in the L angles is approximately 7. The FOS distribution for this region is shown in detail in Figure 7. The displacement of the support structure under 2 g horizontal loading is shown in Figure 8. The maximum displacement of approximately 0.718 inches (18.2 mm) occurs at the top of the detonation tube. The limiting component in horizontal loading is, therefore, the long W beam. The minimum FOS of the support structure can be increased by welding in additional support pieces perpendicular to the axis of the W beam along its length to increase rigidity about the vertical center.

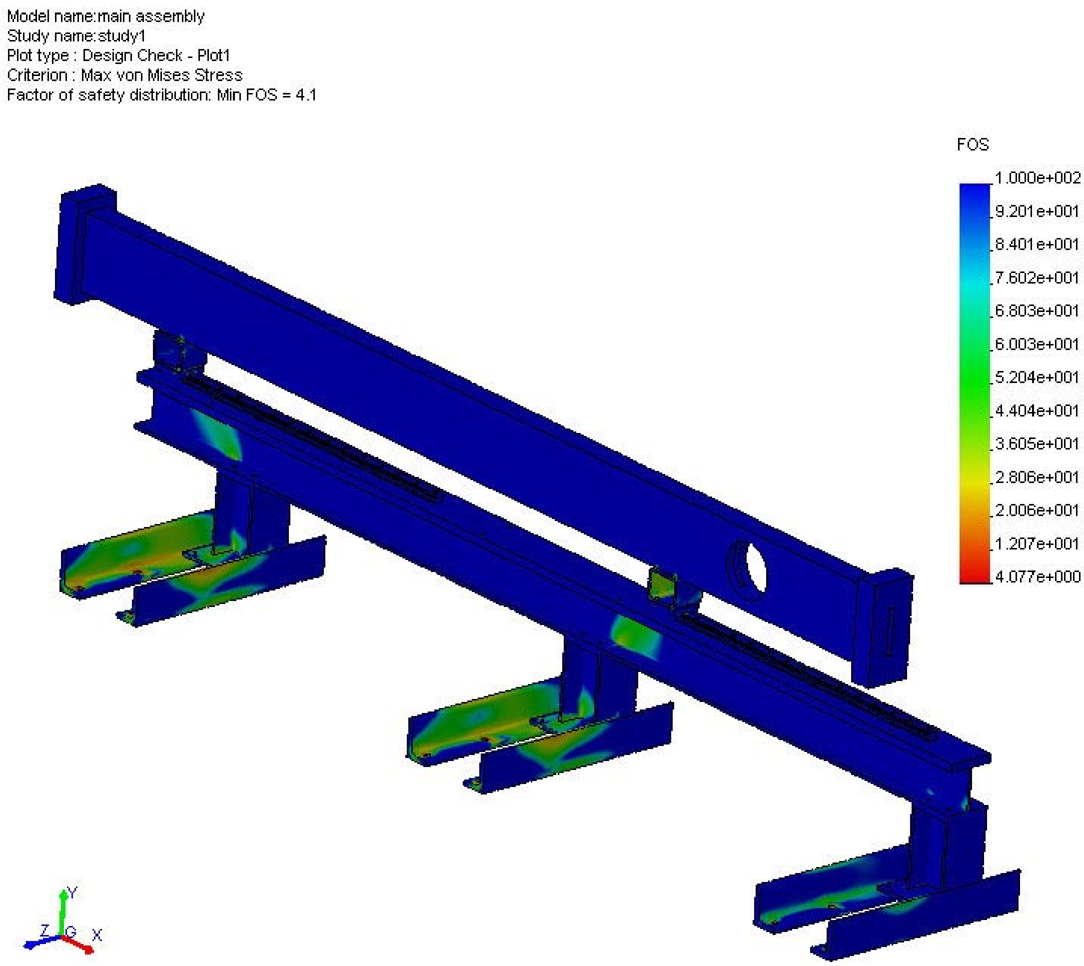

Figure 2: Support structure FOS distribution under 1 g of vertical loading.

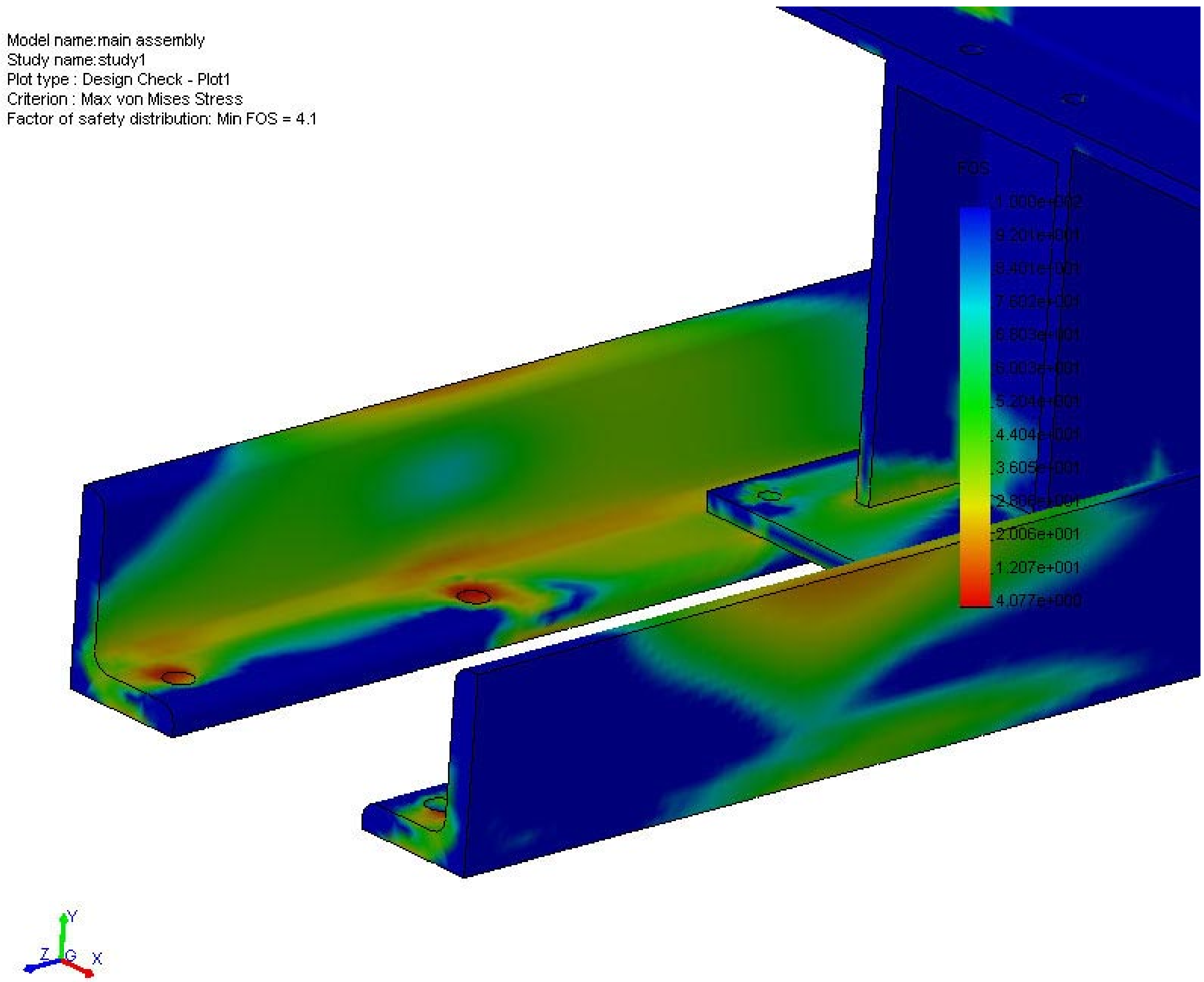

Figure 3: Enlarged view of support structure FOS distribution under 1 g of vertical loading.

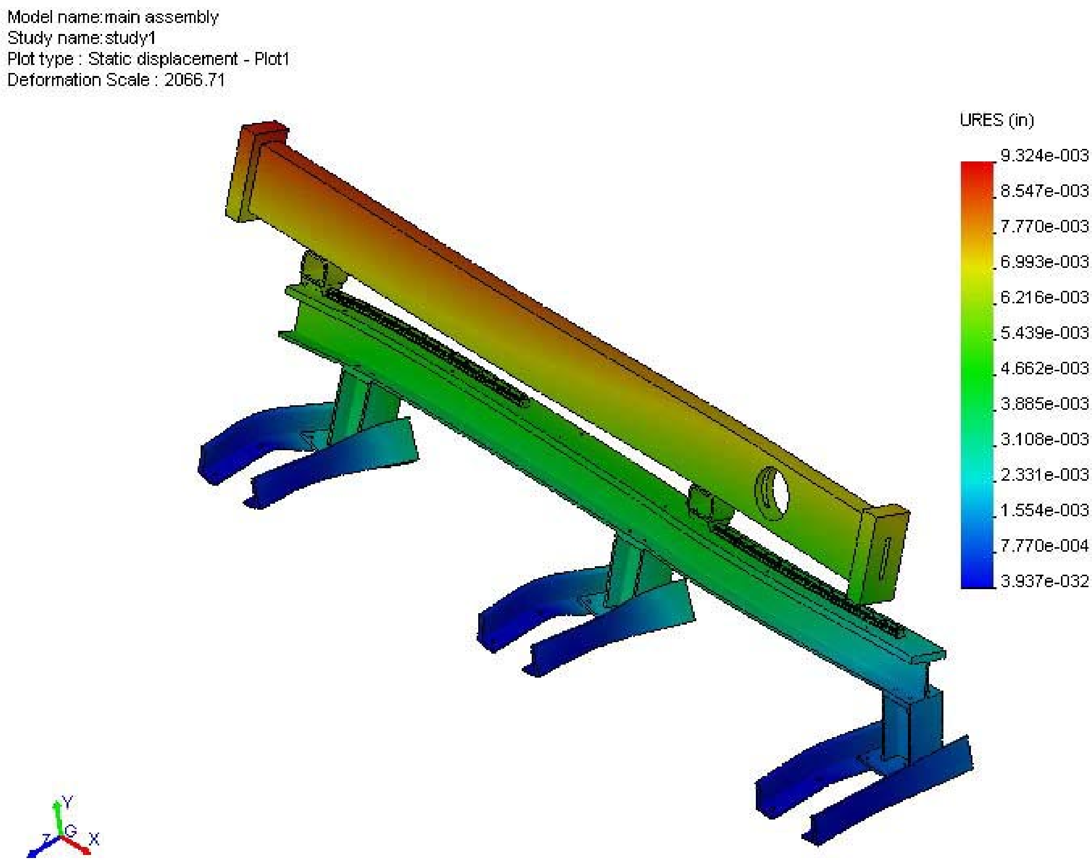

Figure 4: Enlarged view of support structure displacement under 1 g of vertical loading.

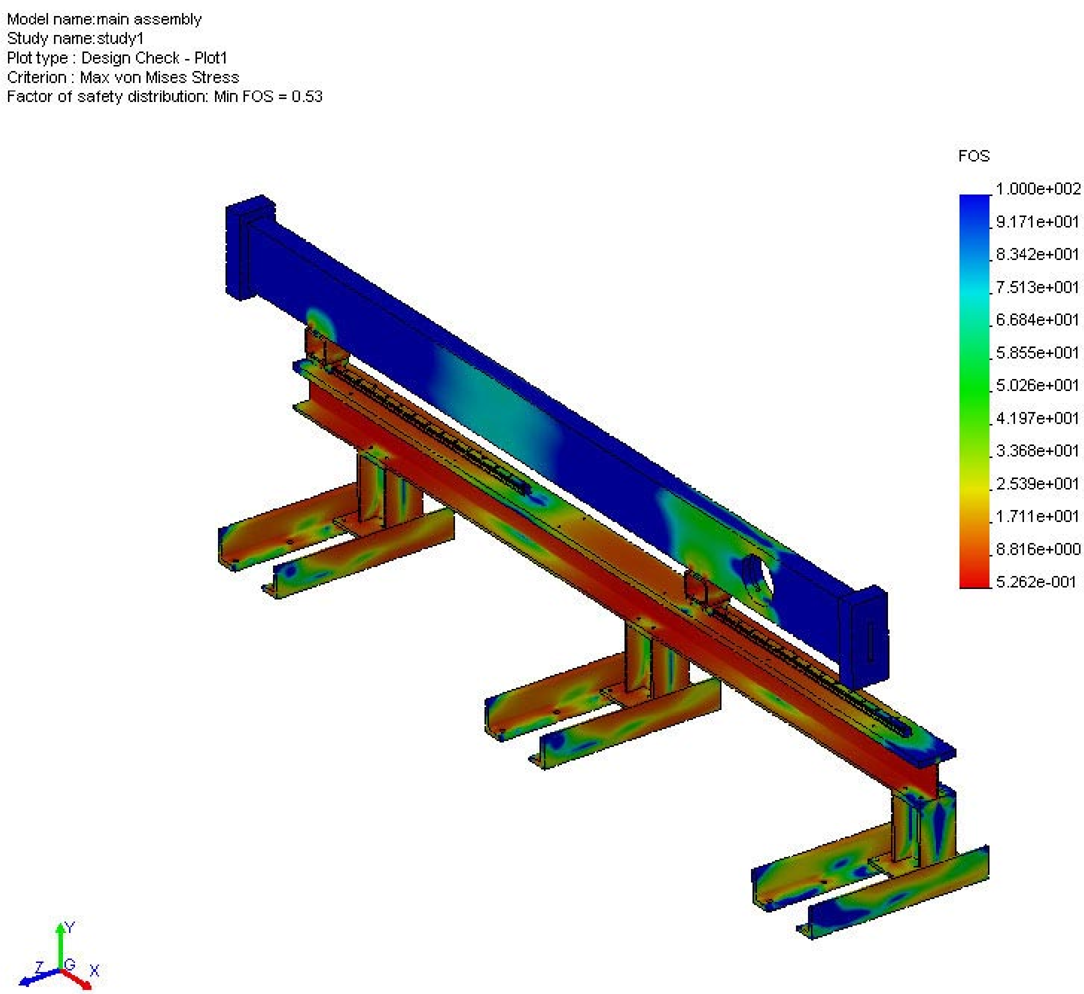

Figure 5: Support structure FOS distribution under 2 g of horizontal loading.

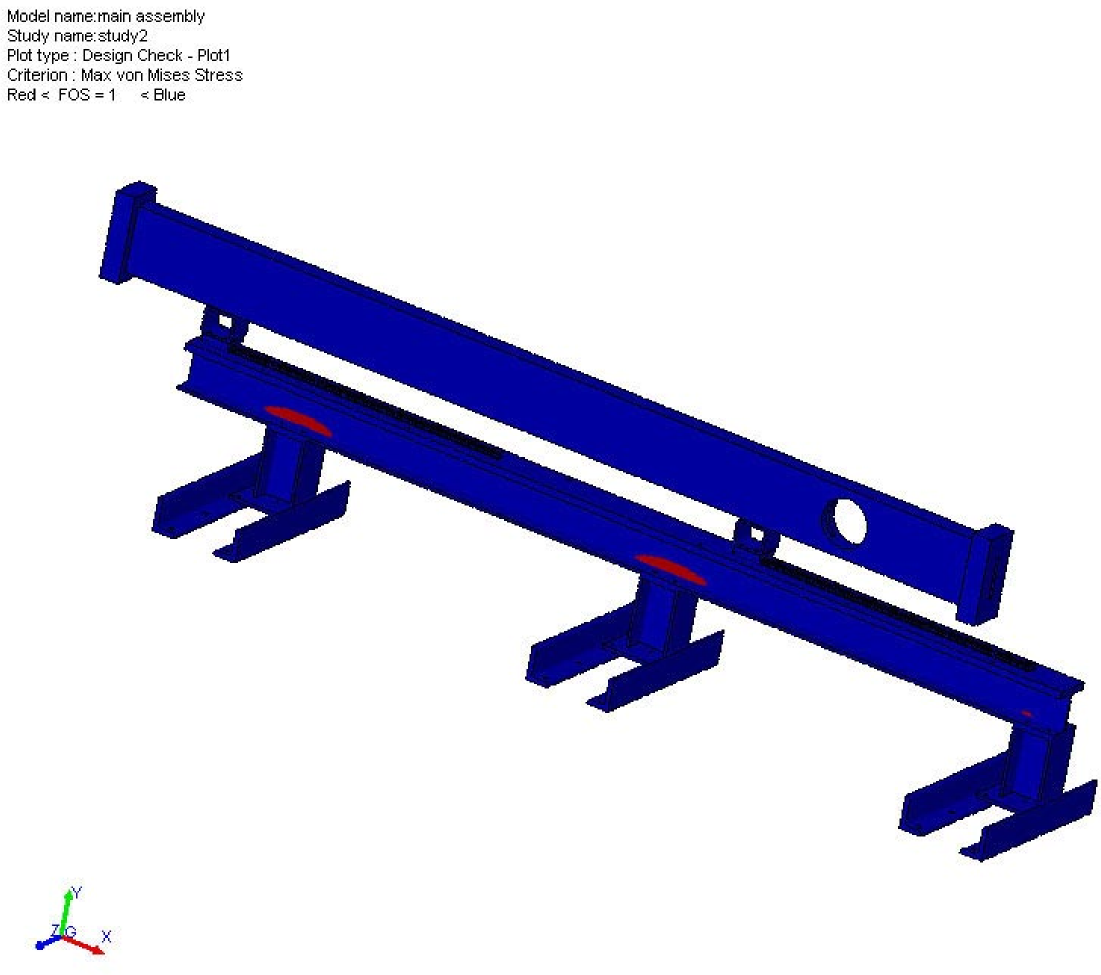

Figure 6: Support structure regions with FOS below 1 under 2 g of horizontal loading.

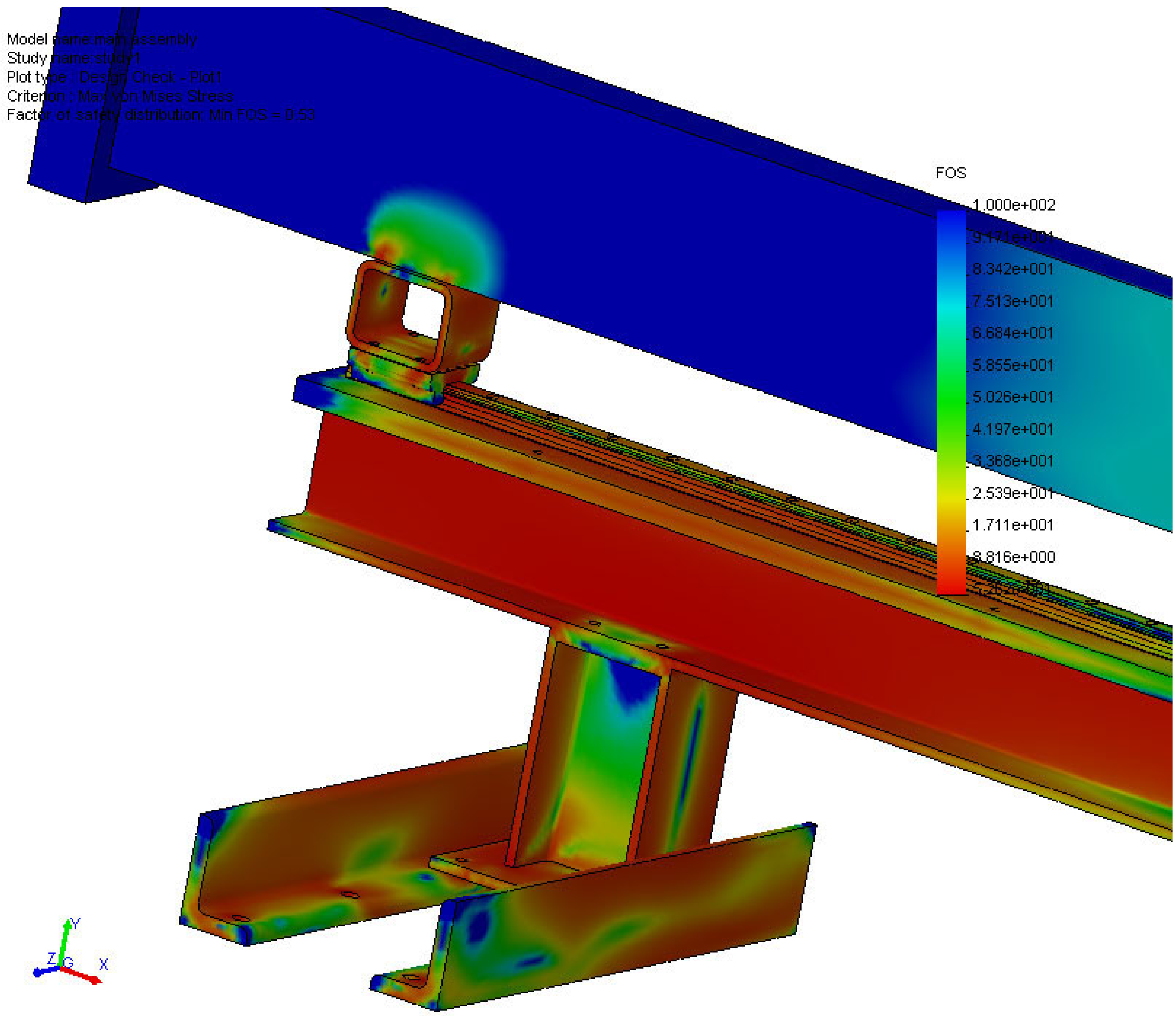

Figure 7: Enlarged view of support structure FOS distribution under 2 g of horizontal loading.

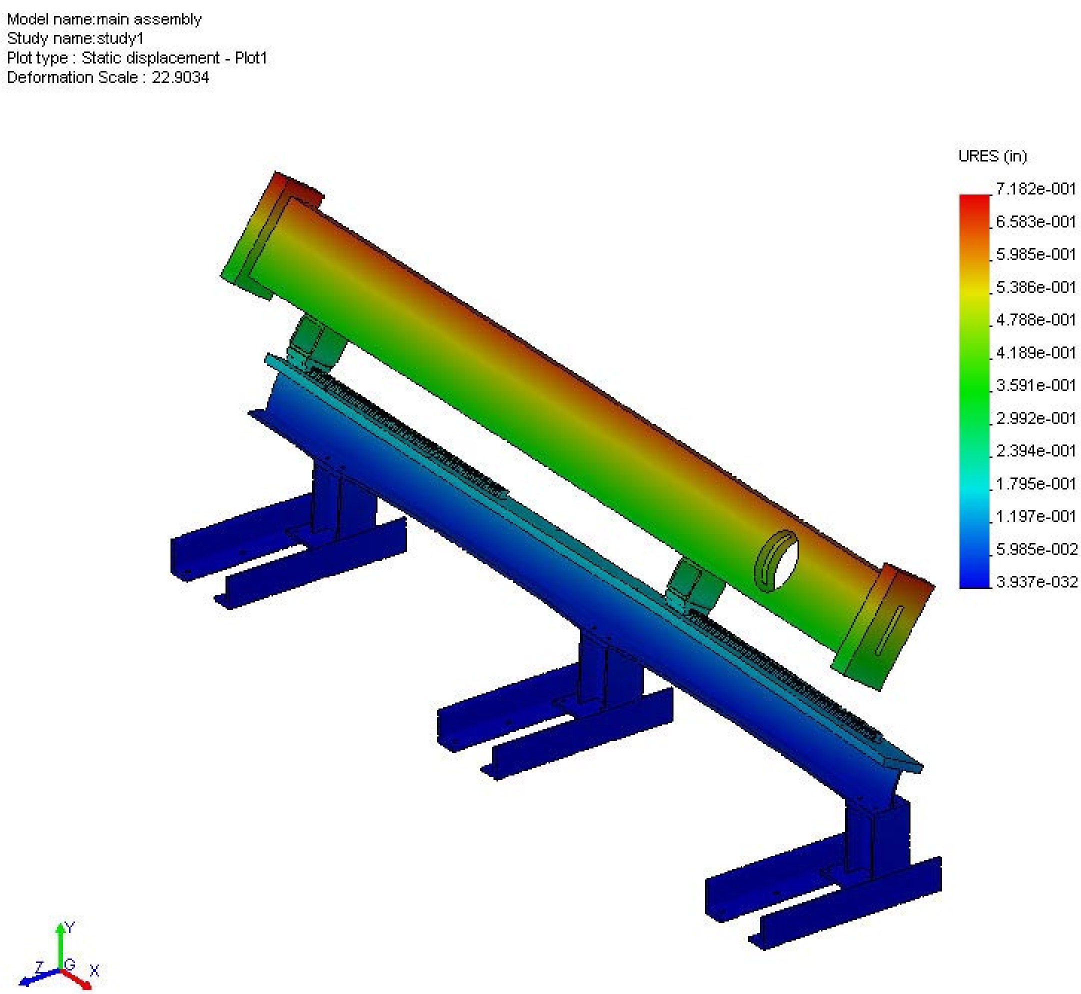

Figure 8: Support structure displacement under 2 g of horizontal loading.

2.3 Narrow Channel Detonation Tube

The design load for the NC detonation tube was 8.5 MPa. The weakest part of the structure under static pressure loading was found to be the side wall and, accordingly, it was chosen for detailed analysis. For ease of scaling the resuling displacements, stresses, and safety factors, a static pressure loading of 1.0 MPa was used throughout the analysis. The side wall was constructed out of 304 SS, and the assumed material strengths are shown in Table 2.

Material	Yield Strength [ksi]	Ultimate Strength [ksi]	Components
AISI 304 SS	30	75	detonation tube side wall

Table 2: Materials and material strengths used in the detonation tube analysis.

The FOS distribution in the side wall for a static loading of 1.0 MPa is shown in Figure 9. The minimum FOS of approximately 3.3 is seen around the viewing window area. This region is shown in detail in Figure 10.

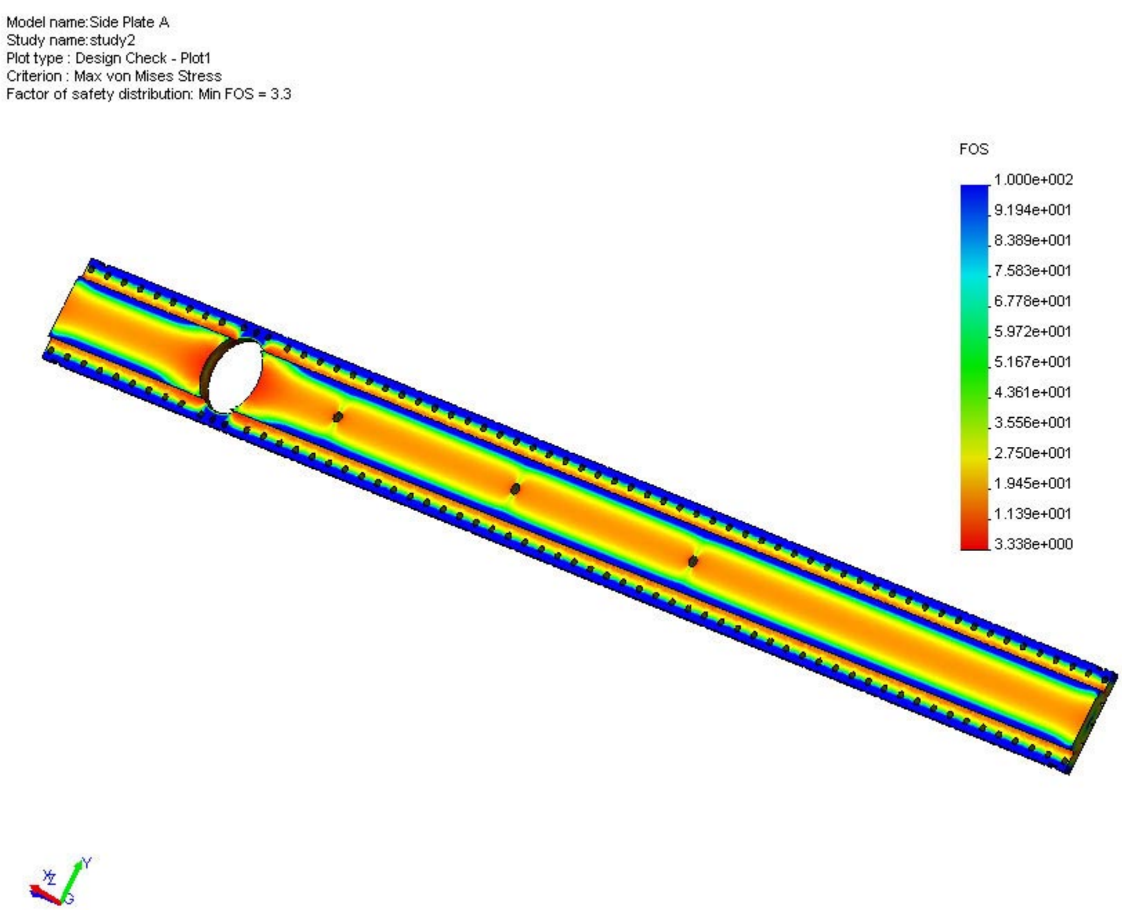

Figure 9: Detonation tube side wall FOS distribution under 1.0 MPa of loading.

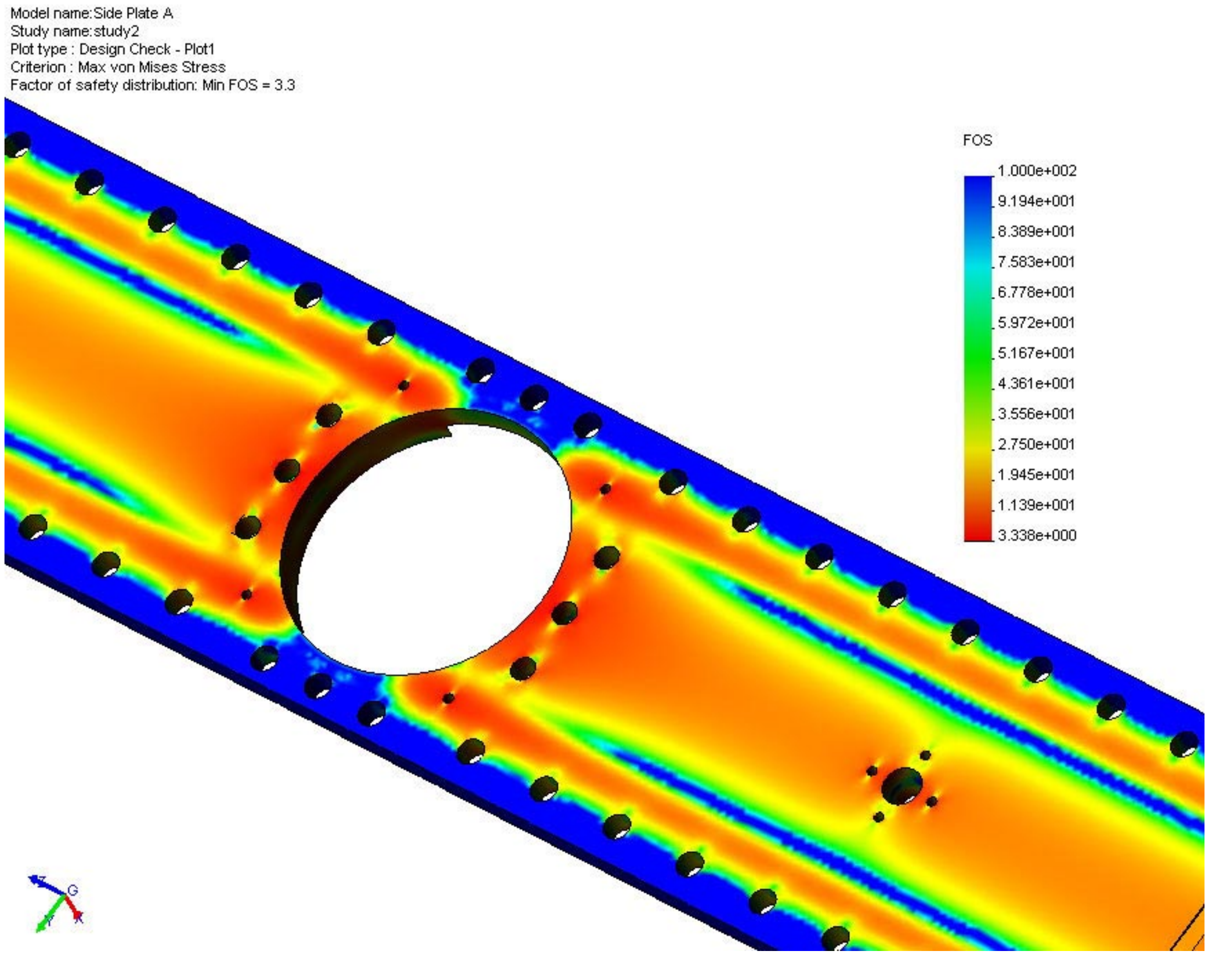

Figure 10: Enlarged view of detonation tube side wall FOS distribution under 1.0 MPa of loading.

At first glance, this minimum FOS of 3.3 looks quite low. However, these high stresses are localized in the areas surrounding the bolt holes near the viewing window and test ports. A plot of all areas with a FOS below 10 clearly shows this localization in Figure 11. If some minimal yielding is allowed around these bolt holes, then the remaining lines of high stress along the length of the side wall determine the maximum allowable loading. The minimum FOS along these lines of stress seen in the above plots is approximately 15. Given that the equivalent static pressure loading for a detonation is approximately five times the CJ pressure, the maximum allowable CJ pressure while retaining a FOS of 2 is approximately 1.5 MPa. The displacement of the side wall under 1.0 MPa of loading is shown in Figure 12, with the maximum value of approximately 0.001 inches (0.03 mm) occurring at the edge of the viewing plate.

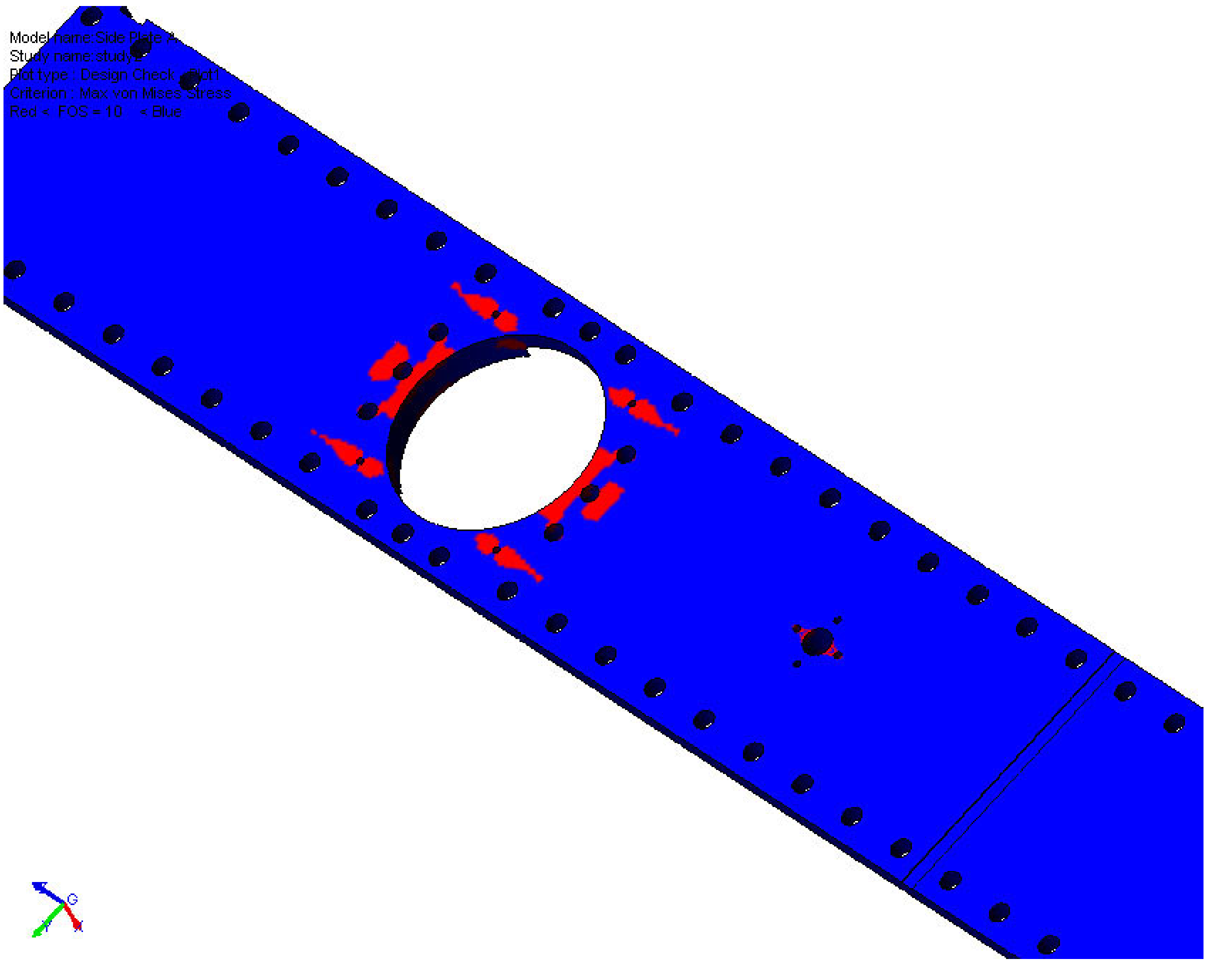

Figure 11: Detonation tube side wall regions with FOS below 10.

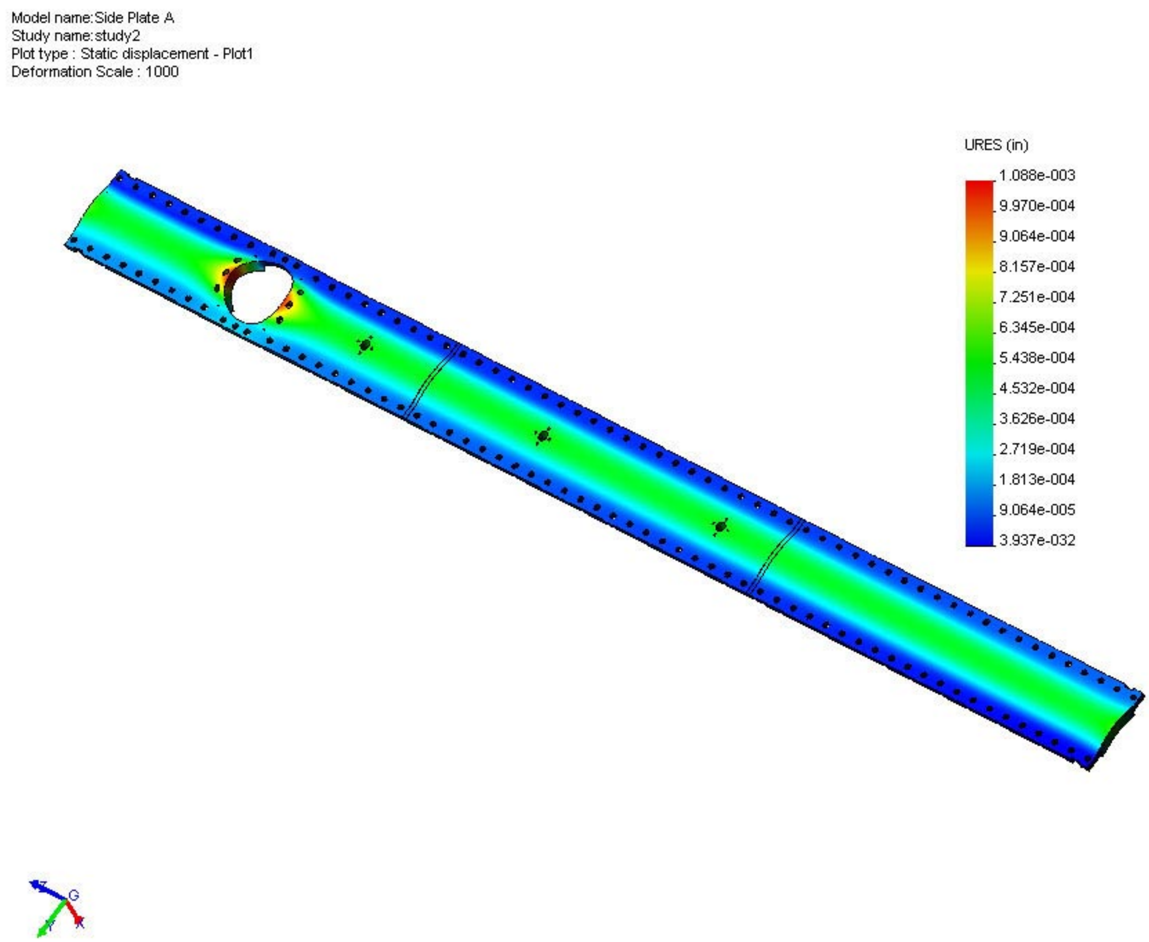

Figure 12: Detonation tube side wall displacement under 1.0 MPa of loading.

2.4 Narrow Channel Planar Detonation Initiator

The planar detonation initiator consists of a bottom plate that contains channels and a top plate that acts as a cover. An annealed copper sheet is used as a gasket and is crushed between the top and bottom plates to keep the channels separated and to seal them from the atmosphere. The design is adapted from a previous planar detonation initiator of a different channel layout [2].

Similarly to the NC side wall, the planar detonation initiator was loaded with 1.0 MPa for ease of scaling. In addition, it was loaded over the entire copper gasket contact face to simulate a worst-case gasket failure. The material and material strength for the planar detonation initiator is shown in Table 3.

Material	Yield Strength [ksi]	Ultimate Strength [ksi]	Components
Al 2024-T4	47	68	planar detonation initiator top and bottom plates

Table 3: Materials and material strengths used in the planar detonation initiator analysis.

The FOS distribution for the bottom plate is shown in Figure 13. The minimum FOS of 6.3 occurs at the edges of some bolt and PCB holes. The next minimum FOS of 10 occurs at the stress concentrated corners of the rectangular output area. The FOS then increases to its next minimum of 15 at the center of the output area. If some local yielding is allowed at the bolt and PCB holes, then a CJ pressure of approximately 1.0 MPa will allow no yielding of the output area with a FOS of 2. If some yielding of the corners of the output area is allowed, then a CJ pressure up to approximately 1.5 MPa can be tolerated. The displacement of the bottom plate under 1.0 MPa of loading is shown in Figure 14, with the maximum of approximately 0.004 inches (0.1 mm) occurring at the center of the output area.

The FOS distribution for the top plate is shown in Figure 15. The minimum FOS of 8.7 occurs at the very edge of the mounting holes. The FOS quickly increases to 25 just outside of the mounting hole edge and up to 50 at the center stress region corresponding to the ramp area in the bottom plate. If some very localized yielding is allowed around the bolt holes, then a CJ pressure of approximately 5.0 MPa can be tolerated with a FOS of 2. It is clear that the bottom plate is the limiting part in the detonation initiator. The displacement of the top plate under a load of 1.0 MPa is shown in Figure 16, with a maximum value of approximately 0.0007 inches (0.02 mm). The displacements of the top and bottom plate under loading are not significant given the operation of the Planar Detonation Initiator.

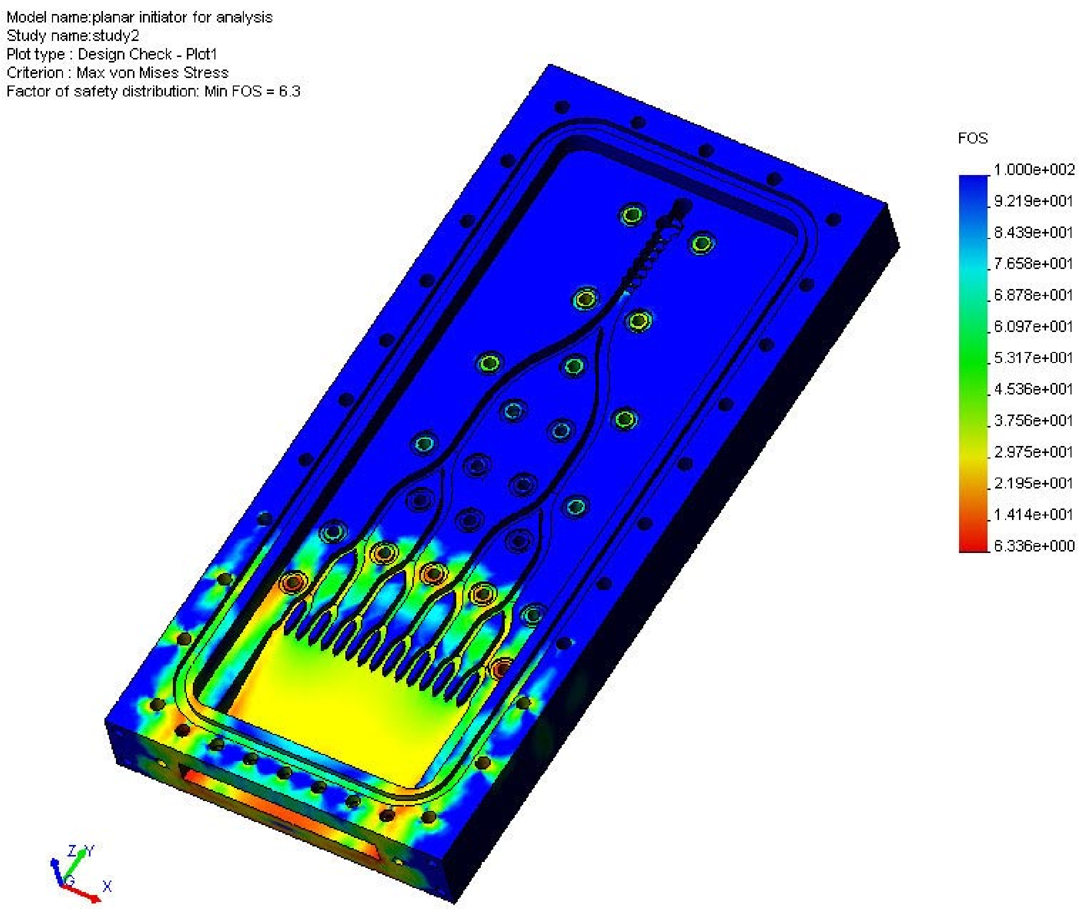

Figure 13: Planar detonation initiator bottom plate FOS distribution under 1.0 MPa of loading.

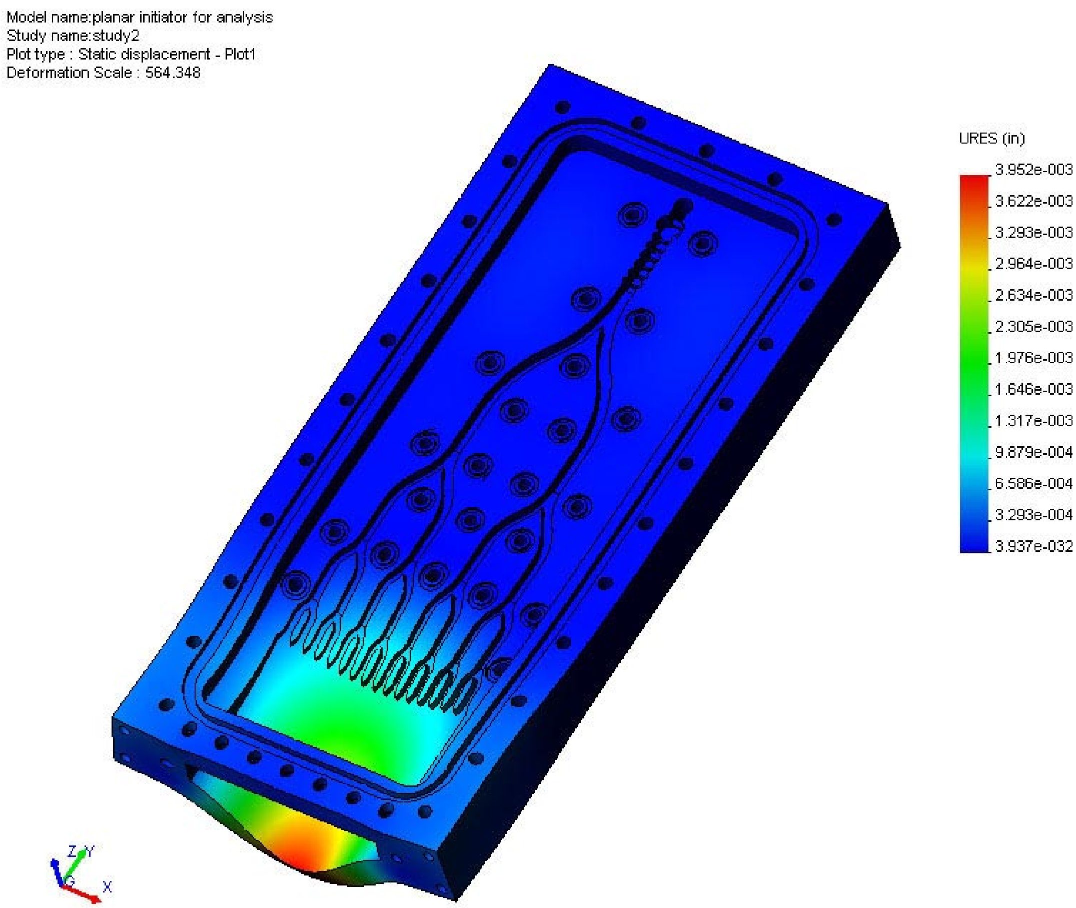

Figure 14: Planar detonation initiator bottom plate displacement under 1.0 MPa of loading.

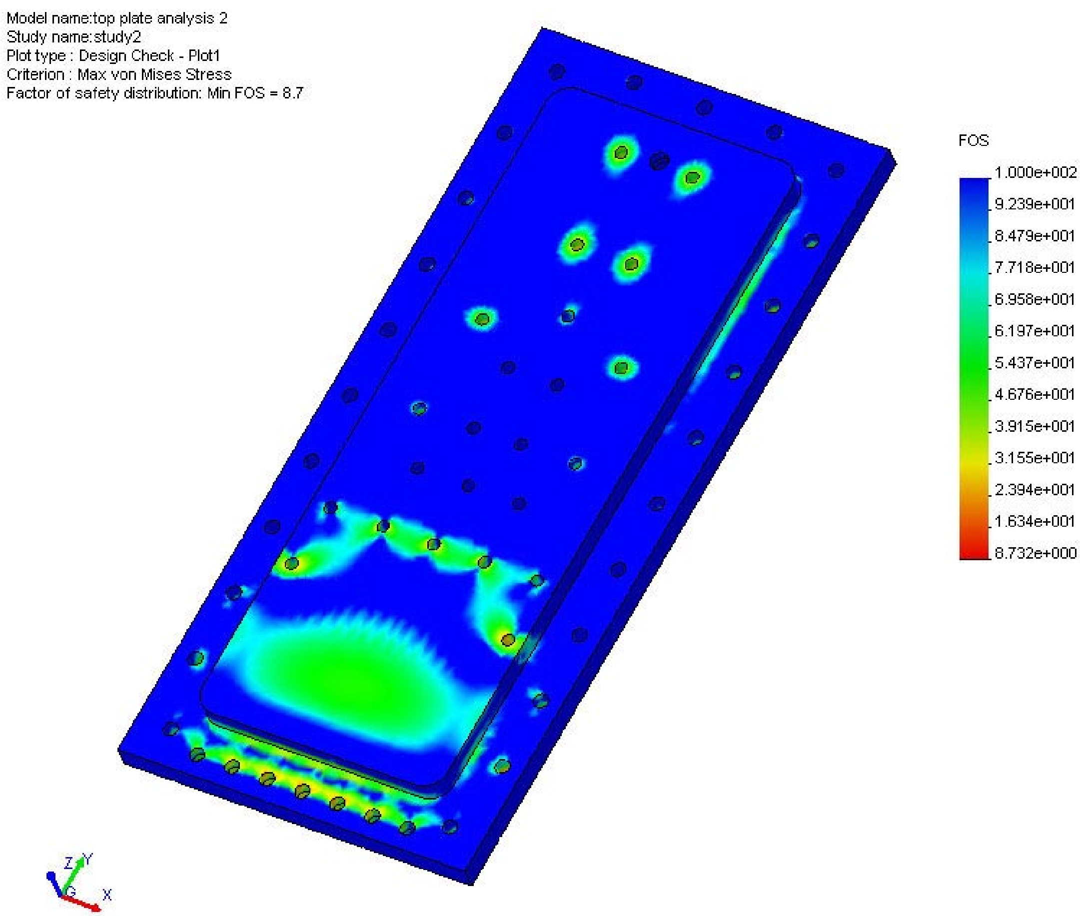

Figure 15: Planar detonation initiator top plate FOS distribution under 1.0 MPa of loading.

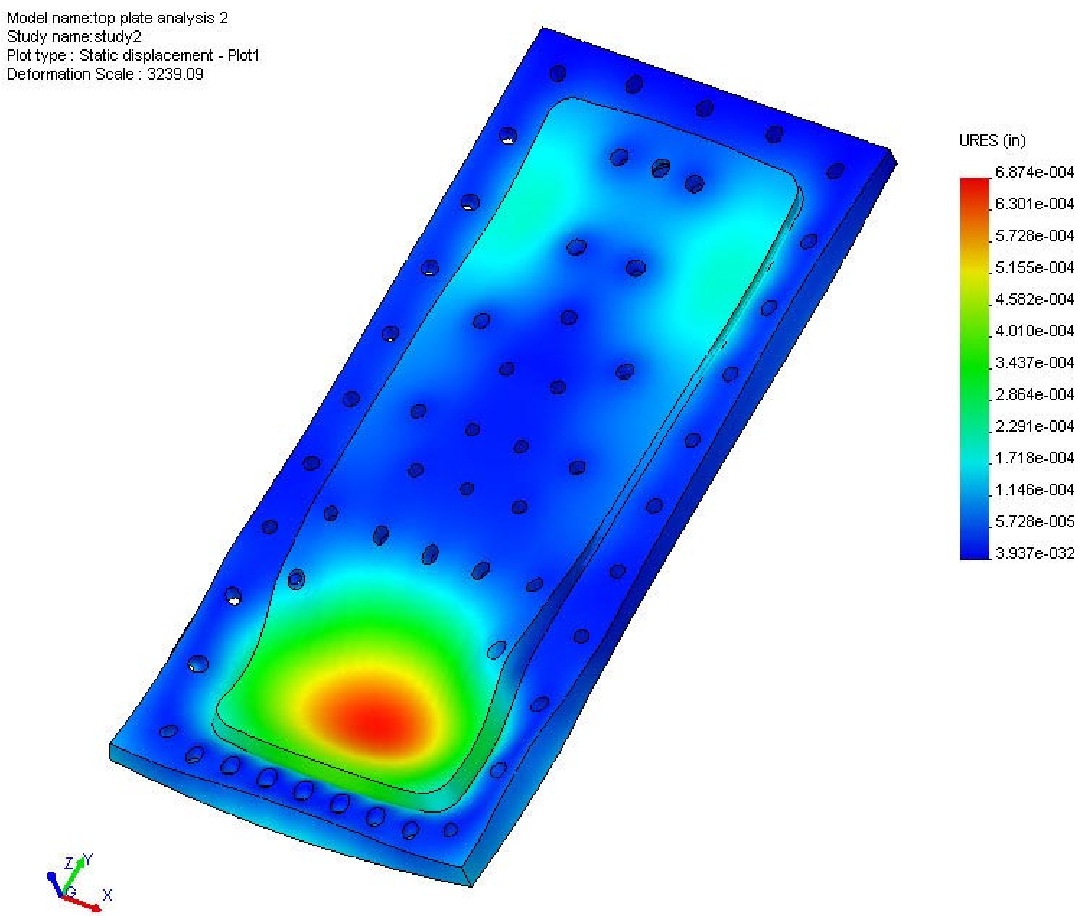

Figure 16: Planar detonation initiator top plate displacement under 1.0 MPa of loading.

3 Summary of Results

A summary of the maximum static loadings for the various NC structures is shown in Table 4. The "no yielding" loads are such that a FOS of 1 is just reached at a stress concentrated area of the structure, and the "minimal yielding" loads are such that a FOS of 1 is just reached in the next most stressed regions of the structure, allowing some local yielding around bolt holes or other small stress concentrated areas. This minimal yielding is acceptable given the scope and operation of the facility.

Structure	Max Static Loading, no yielding	Max Static Loading, minimal yielding
NC Support Structure, vertical loading	4.1 g	22 g
NC Support Structure, horizontal loading	1.4 g	2.0 g
NC Detonation Tube	3.3 MPa	15 MPa
NC Planar Detonation Initiator, bottom plate	6.3 MPa	10 MPa
NC Planar Detonation Initiator, top plate	8.7 MPa	25 MPa

Table 4: Maximum static loadings for no yielding and minimal yielding for the various Narrow Channel structures.

Users of the NC facility are most interested in the maximum CJ pressures that can be safely operated. The equivalent static loading for a given CJ pressure is found by multiplying by 2.5 for reflections against the end walls (which was conservatively assumed to act throughout the pressure loaded surfaces of the structure), again multiplying by 2 for the peak dynamic stresses in the material, and again multiplying by 2 for a FOS of 2, for a total multiplication factor of 10. Safe CJ pressures are, therefore, found by taking the maximum static loading pressure for a FOS of 1 and dividing by 10. The maximum safe CJ pressures for "no yielding" and "minimal yielding" are shown below in Table 5.

Structure	Max CJ Pressure, no yielding	Max CJ Pressure, minimal yielding
NC Detonation Tube	0.33 MPa	1.5 MPa
NC Planar Detonation Initiator, bottom plate	0.63 MPa	1.0 MPa
NC Planar Detonation Initiator, top plate	0.87 MPa	2.5 MPa

Table 5: Maximum safe CJ pressures for no yielding and minimal yielding for the various NC structures.

A Narrow Channel Support Structure Drawings

A.1 Main Assembly (for reference), Dwg No. 1

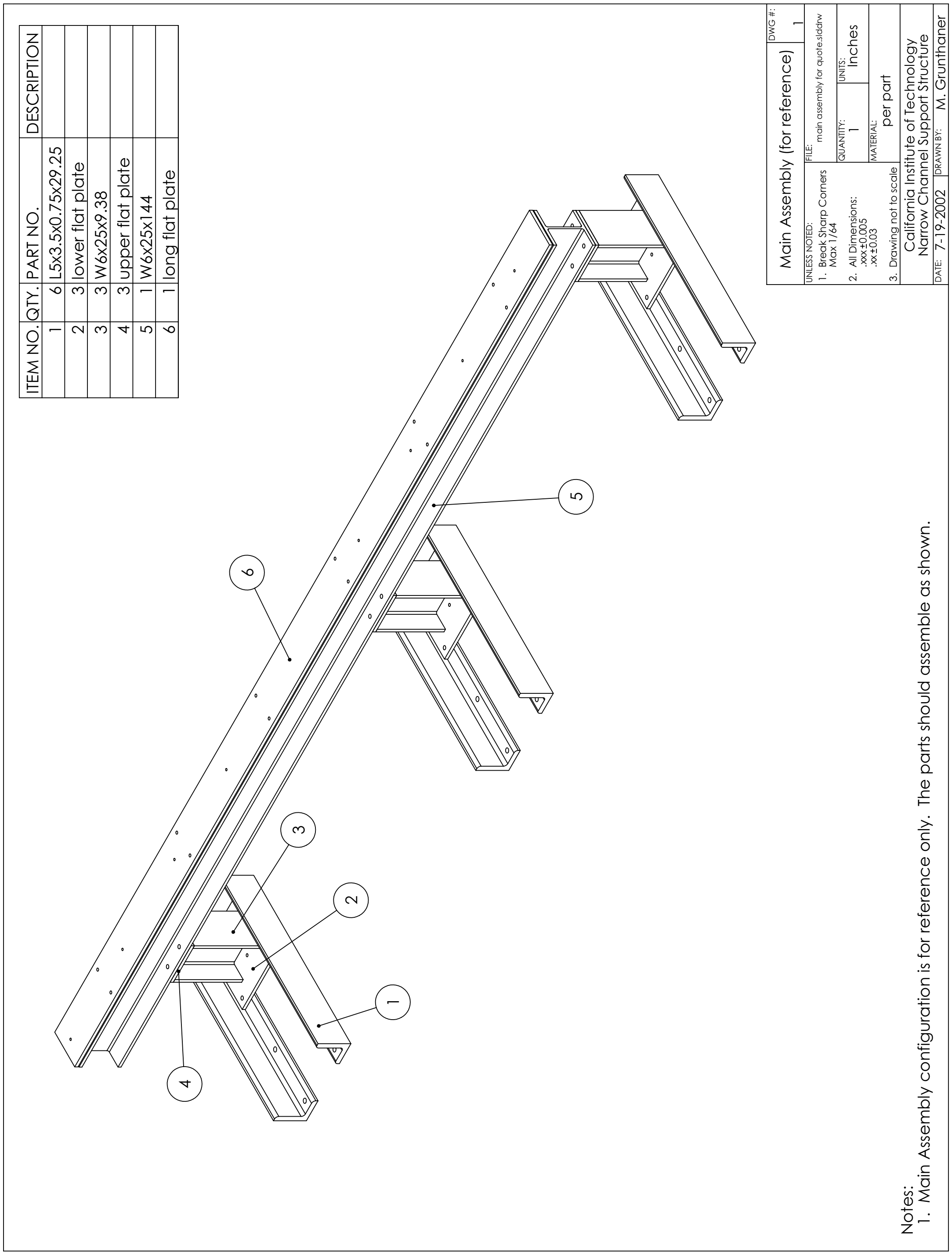

Figure 17: Main Assembly (for reference), Dwg No. 1

A.2 Long Flat Plate, Dwg No. 2

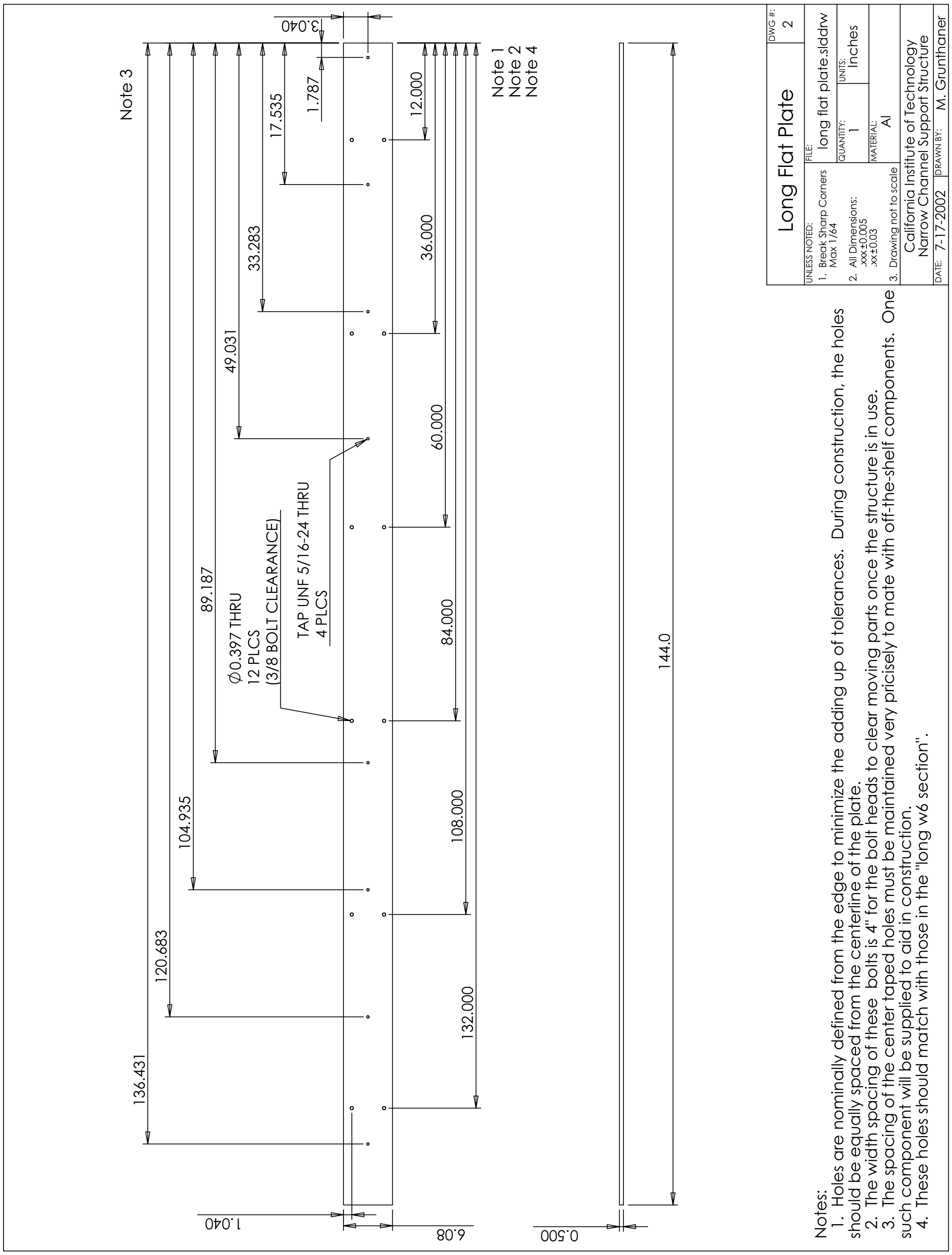

Figure 18: Long Flat Plate, Dwg No. 2

A.3 Long W6 Section, Dwg No. 3

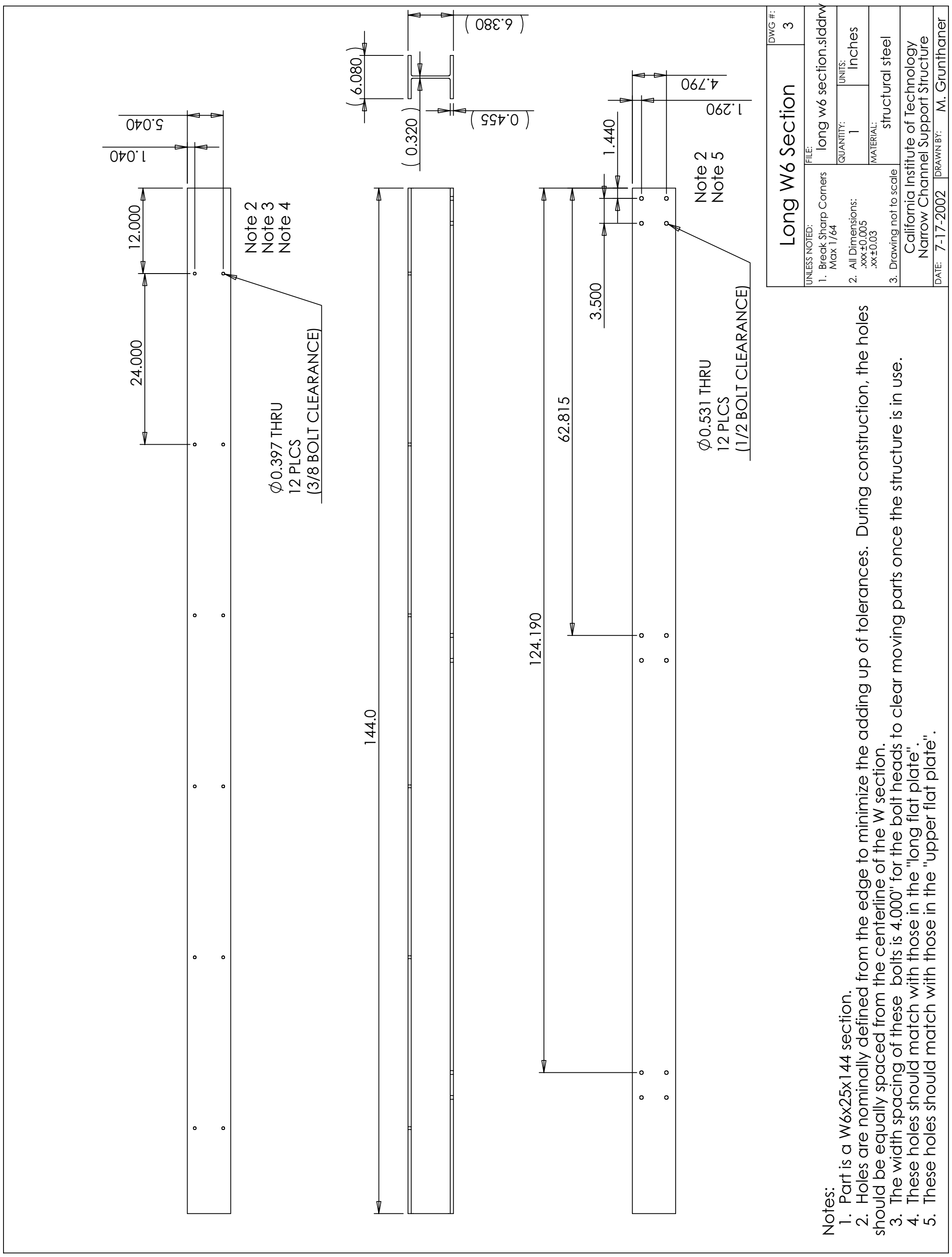

Figure 19: Long W6 Section, Dwg No. 3

A.4 Pillar Assembly, Dwg No. 4

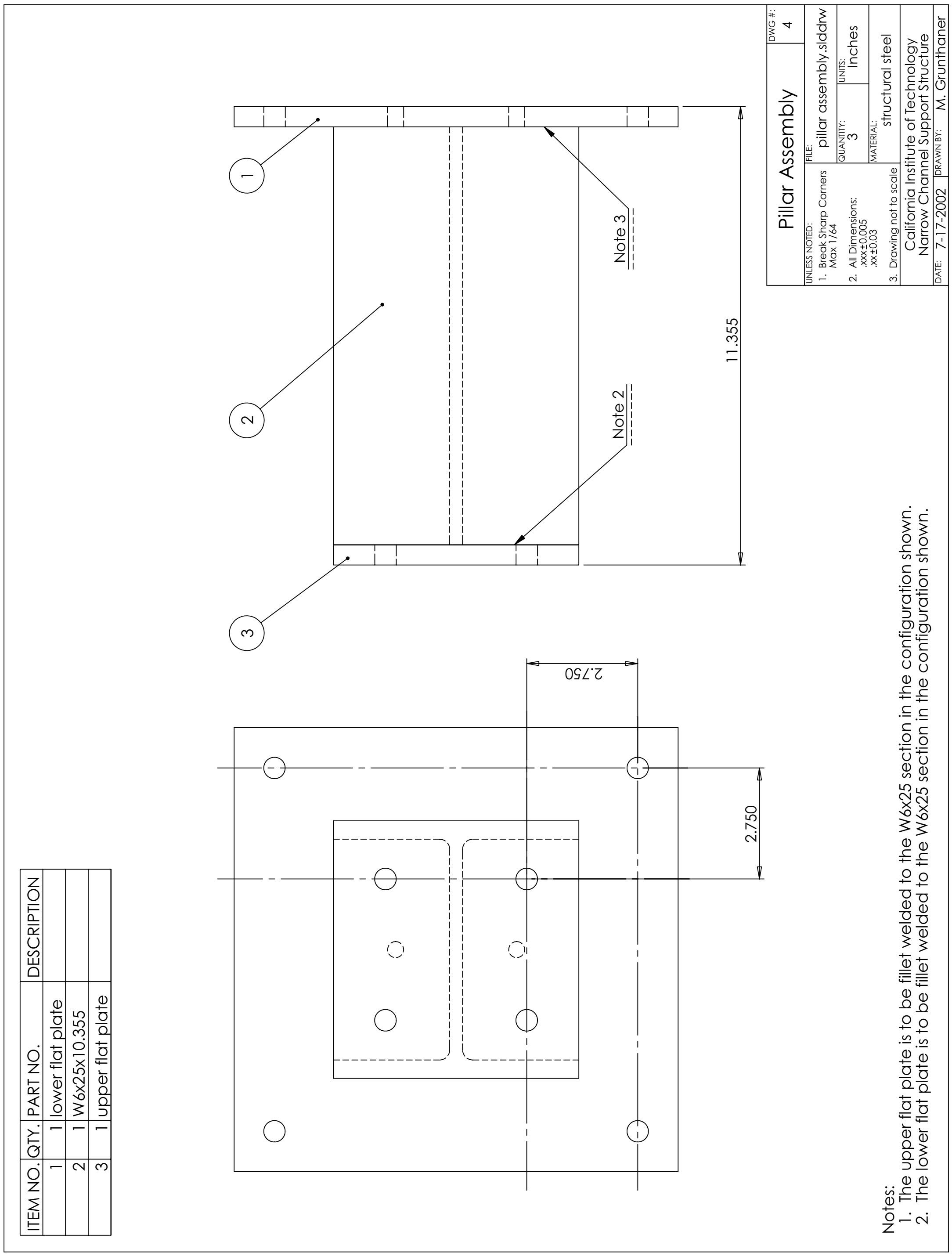

Figure 20: Pillar Assembly, Dwg No. 4

A.5 W6 Section, Dwg No. 5

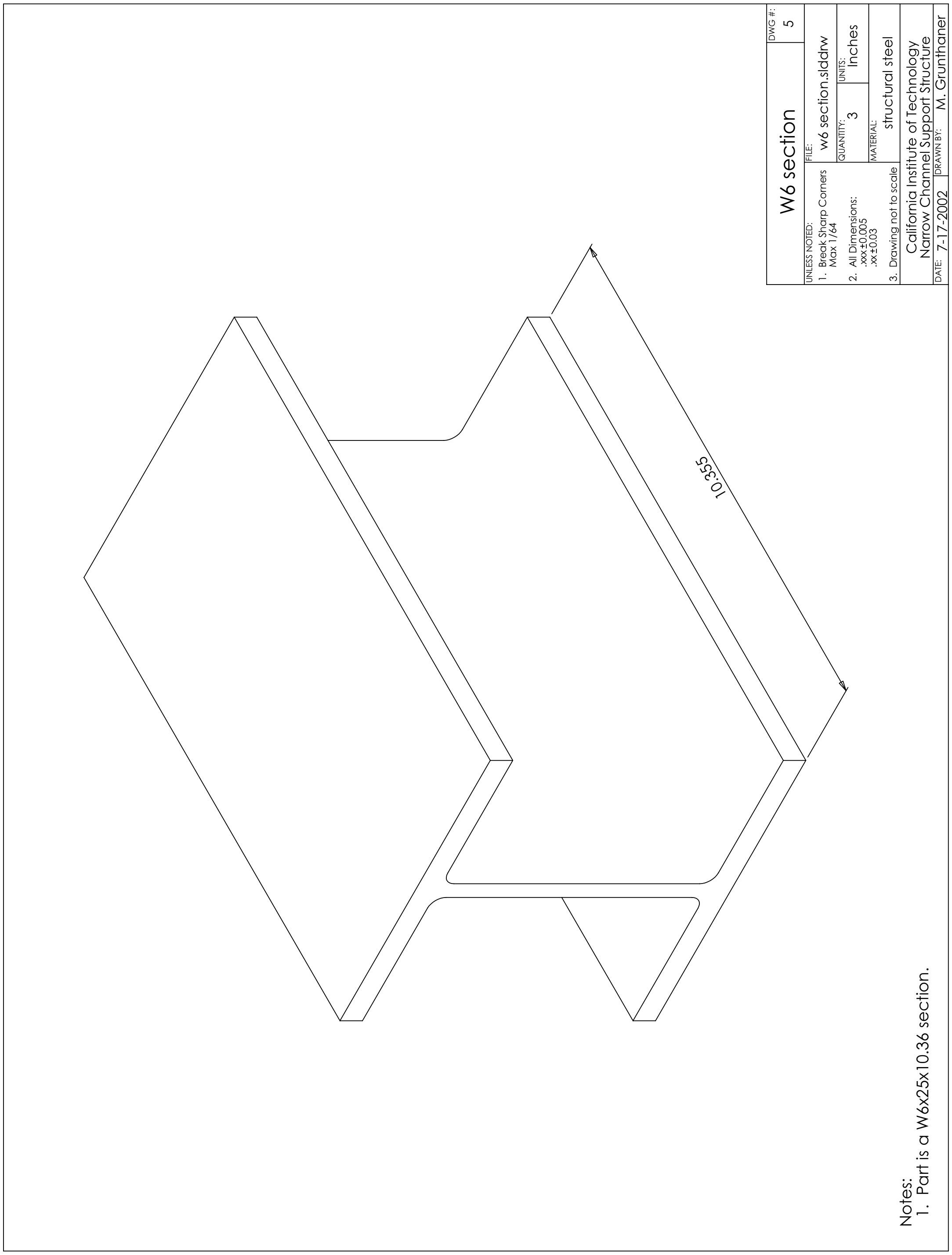

Figure 21: W6 Section, Dwg No. 5

A.6 Upper Flat Plate, Dwg No. 6

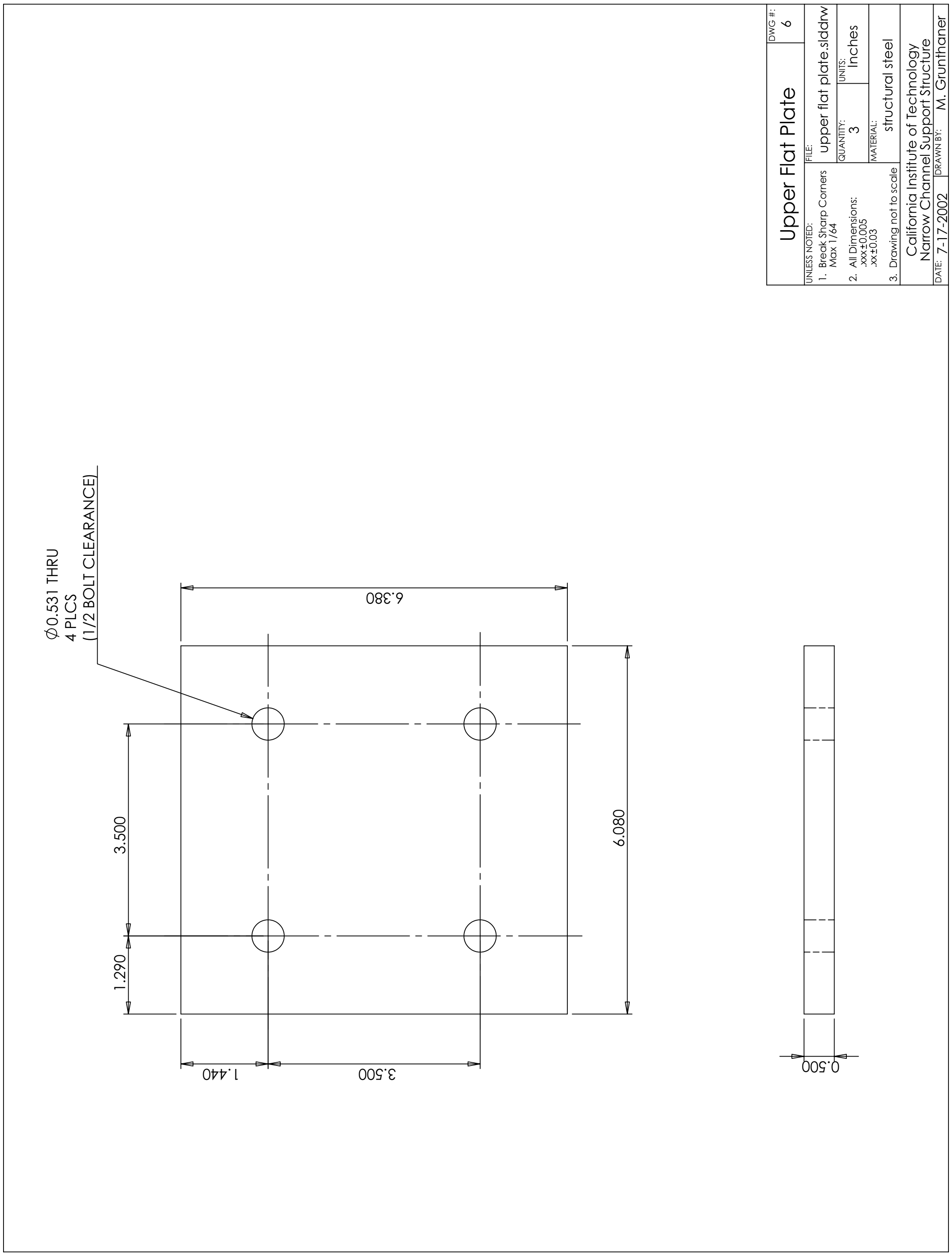

Figure 22: Upper Flat Plate, Dwg No. 6

A.7 Lower Flat Plate, Dwg No. 7

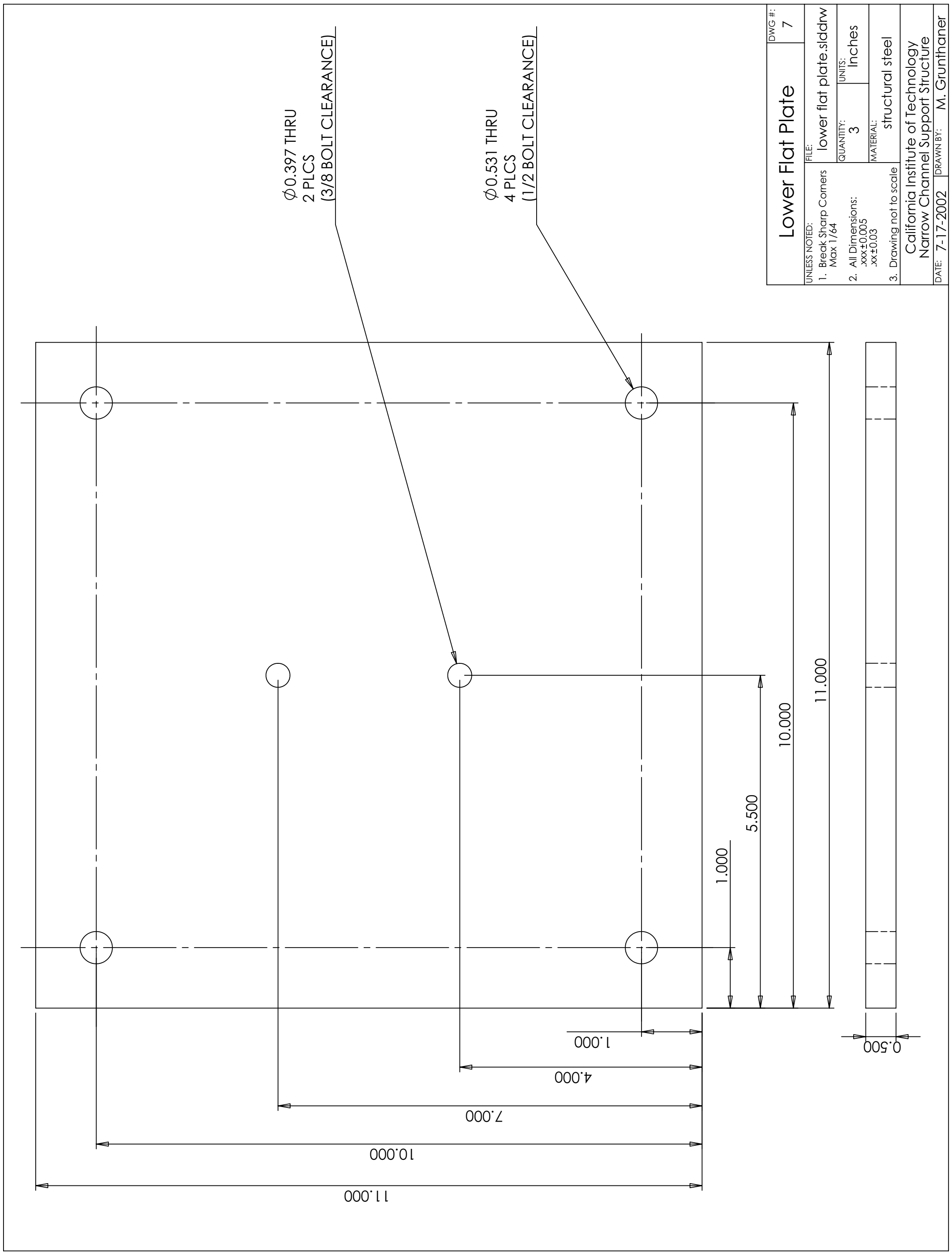

Figure 23: Lower Flat Plate, Dwg No. 7

A.8 L Angle 1, Dwg No. 8

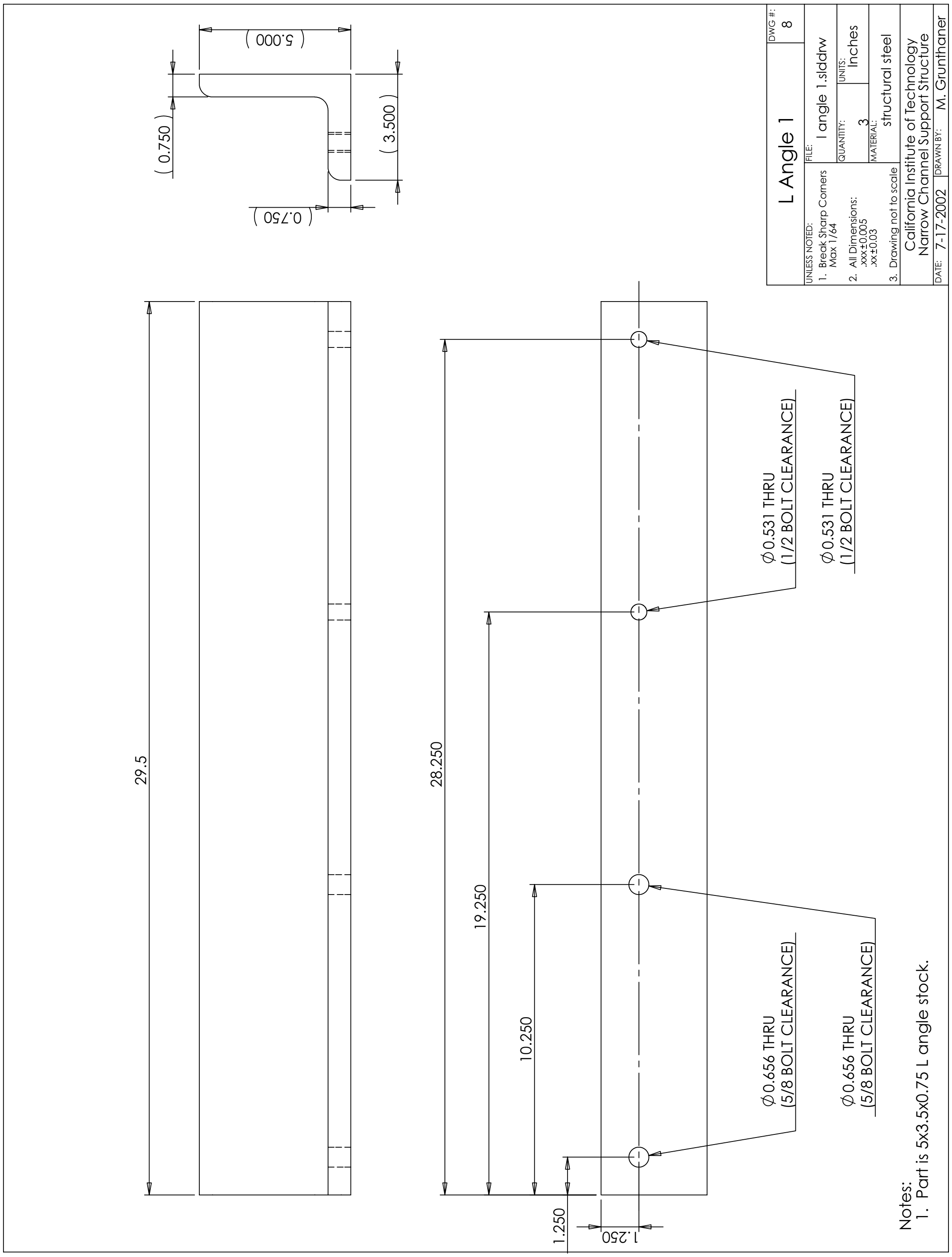

Figure 24: L Angle 1, Dwg No. 8

A.9 L Angle 2, Dwg No. 9

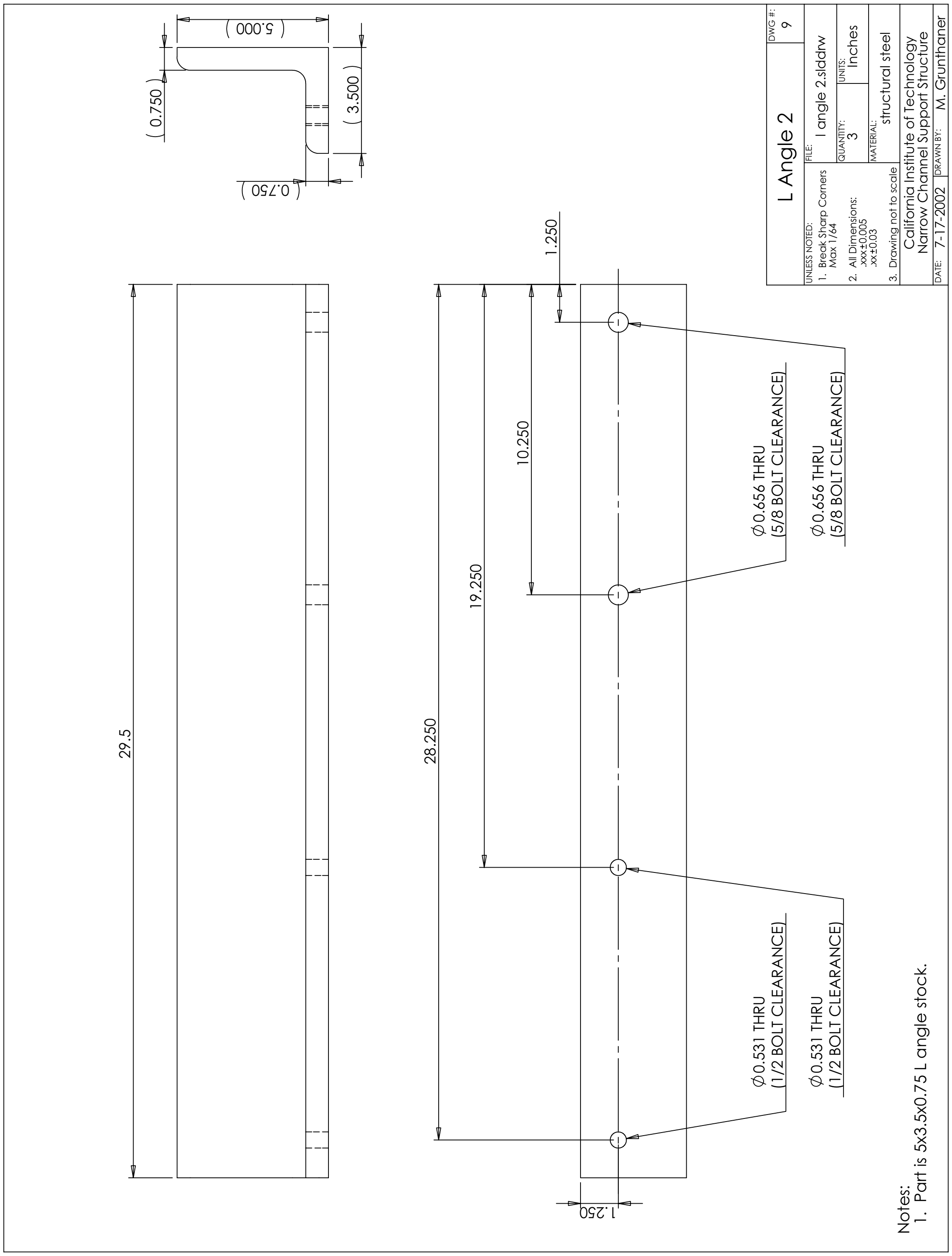

Figure 25: L Angle 2, Dwg No. 9

B Narrow Channel Detonation Tube Drawings

B.1 Notes

See /home/strehlow/NC/dwgs/eps for files.

Drawing 10: The PCB port was manufactured with scratches on the sealing face. These were removed using grinding paste and a piece of tool steel cut to the mate flush with the sealing face. Regular brass gaskets were used, although PCB did provide us with some teflon gaskets that may one day help. They are located in the NC folder.

Drawings 12 and 13: End flanges had to be modified from these drawings to fit end plate and mate with each other. The length of the step was decreased, the counterbore was increased on the end face of the flange and also for the two bolts on the side faces.

Drawing 17: Two end flanges - one with slits for the PLIF window (as per GDT design) and one with a central milled slot to match the initiator exit were made. A spare solid flange also exists as it was made with the wrong thickness by the shop.

Four additional ports and plugs were added to the top and bottom plates by the Aeroshop after delivery. Drawings for these can be found in /home/strehlow/NC/dwgs/mc-top.dwg and mc-topport.dwg.

B.2 Side Plate A (sheet 1 of 3), Dwg No. 1

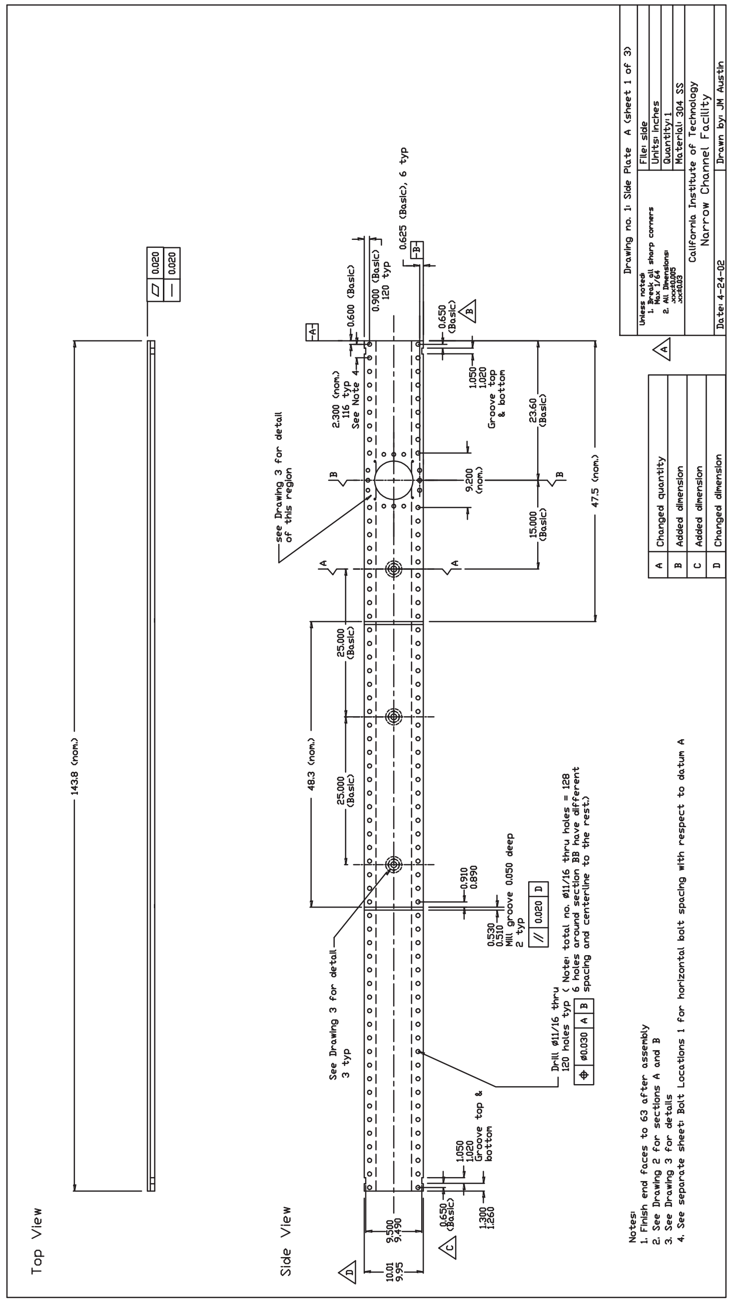

Figure 26: ide Plate A (sheet 1 of 3), Dwg No. 1

B.3 Side Plate A (sheet 2 of 3), Dwg No. 2

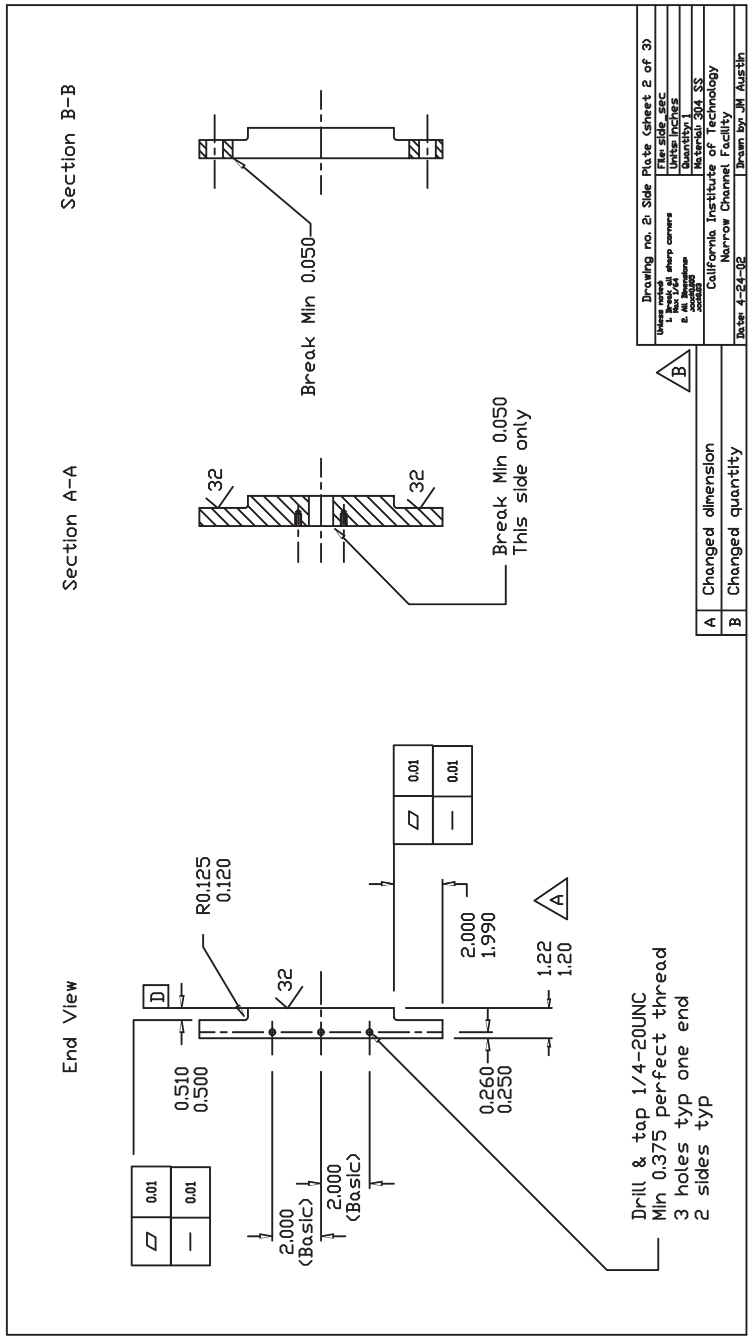

Figure 27: Side Plate A (sheet 2 of 3), Dwg No. 2

B.4 Side Plate A (sheet 3 of 3), Dwg No. 3

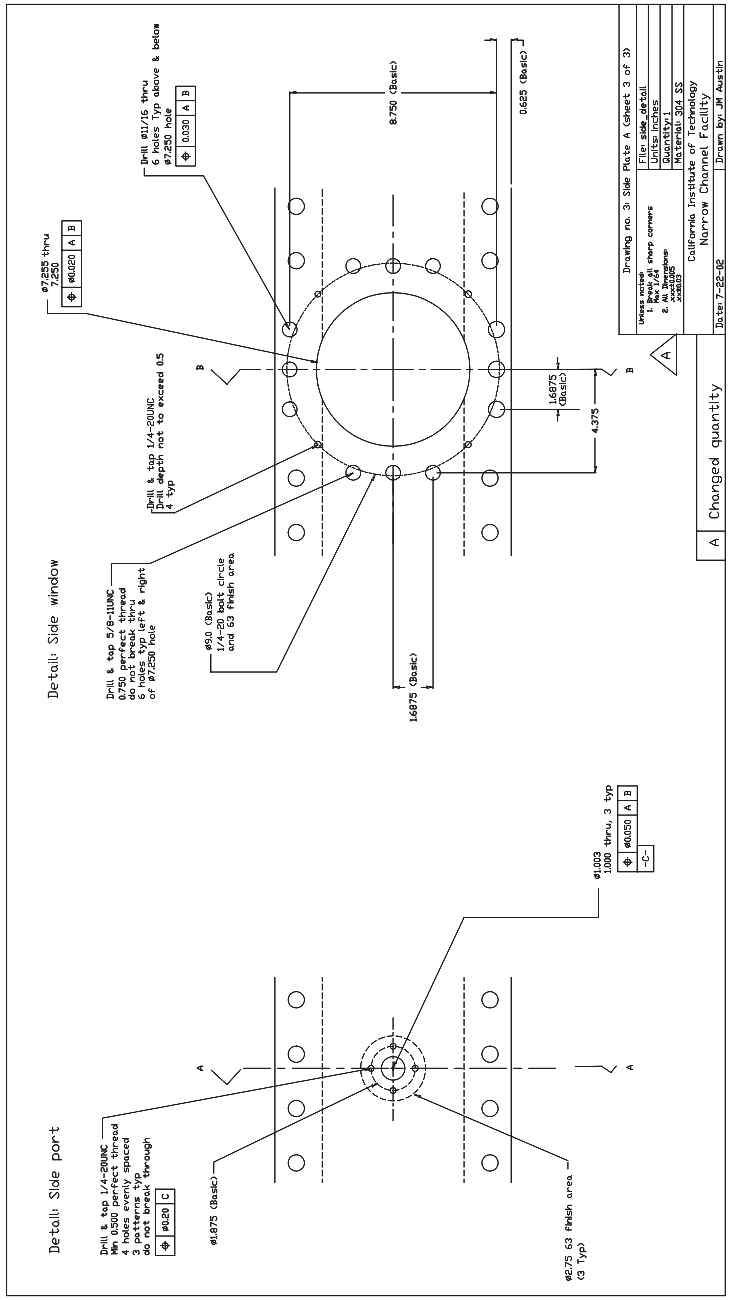

Figure 28: Side Plate A (sheet 3 of 3), Dwg No. 3

B.5 Side Plate B (sheet 1 of 3), Dwg No. 4

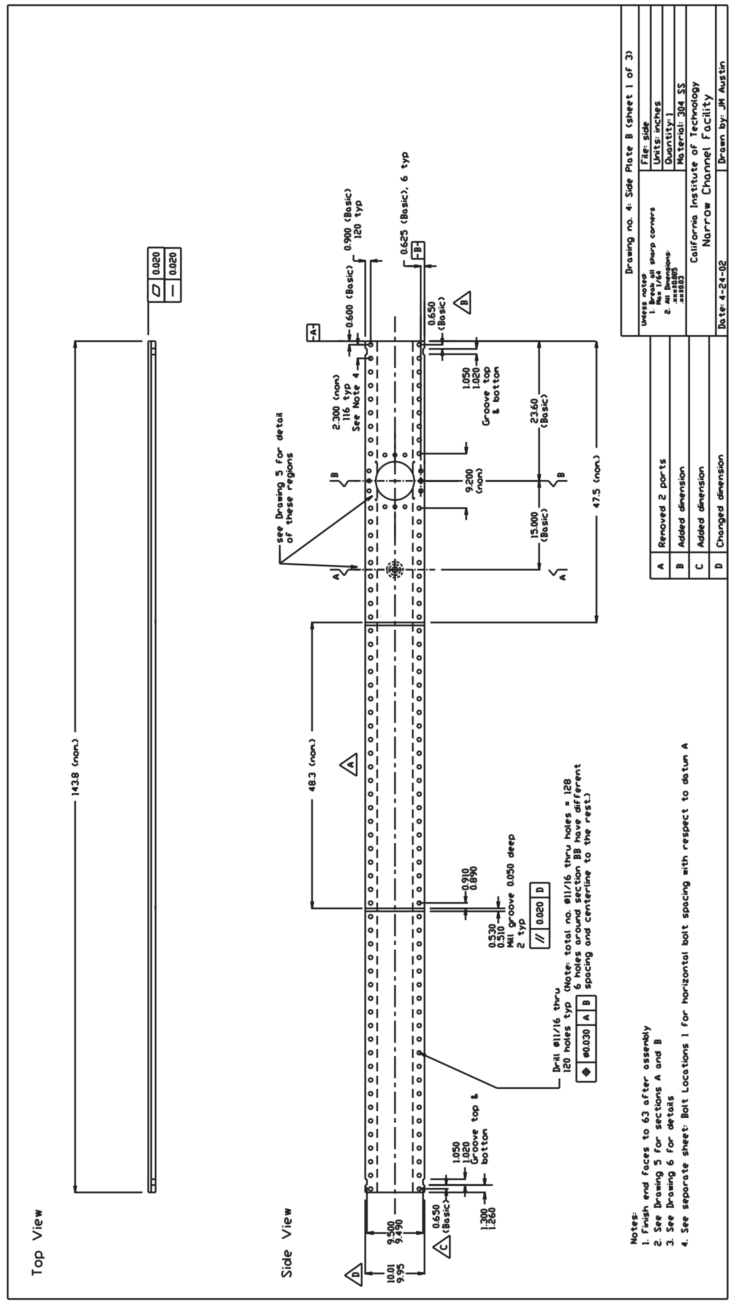

Figure 29: Side Plate B (sheet 1 of 3), Dwg No. 4

B.6 Side Plate B (sheet 2 of 3), Dwg No. 5

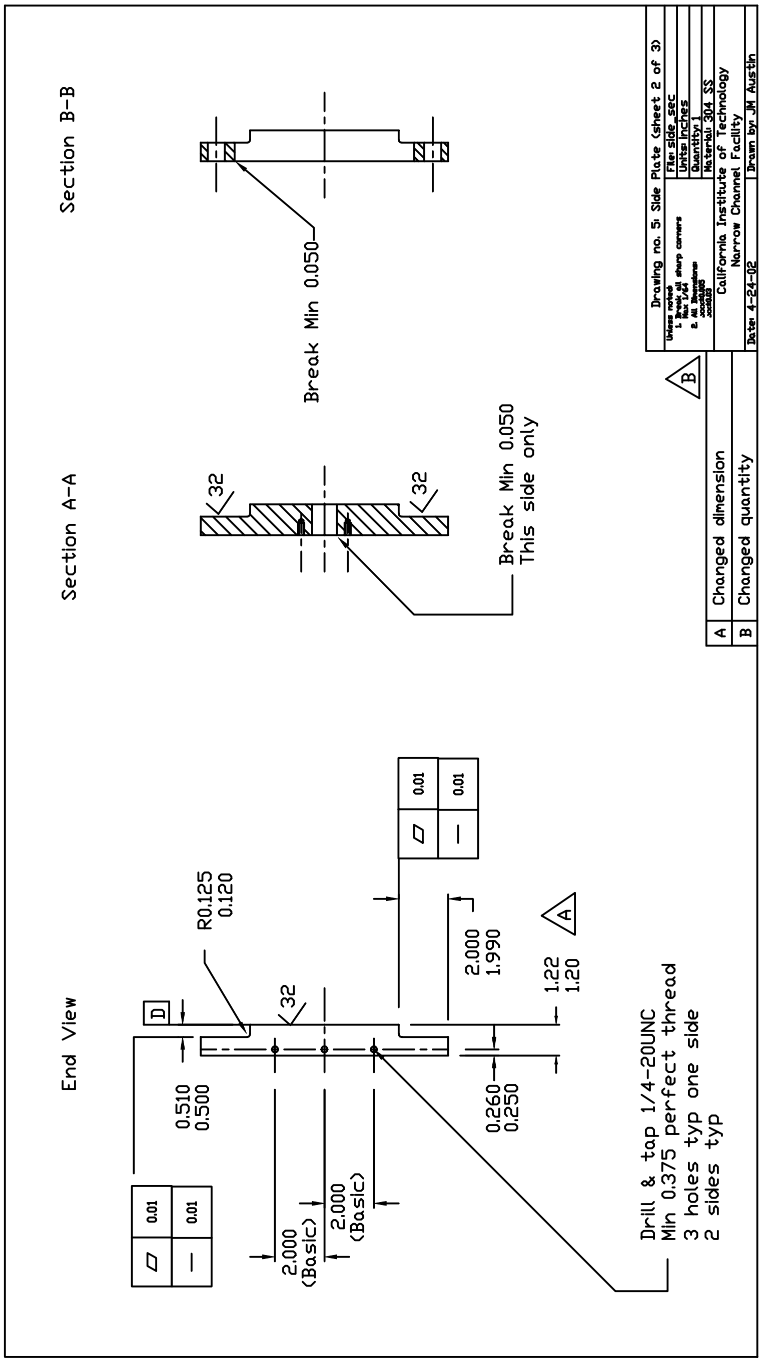

Figure 30: Side Plate B (sheet 2 of 3), Dwg No. 5

B.7 Side Plate B (sheet 3 of 3), Dwg No. 6

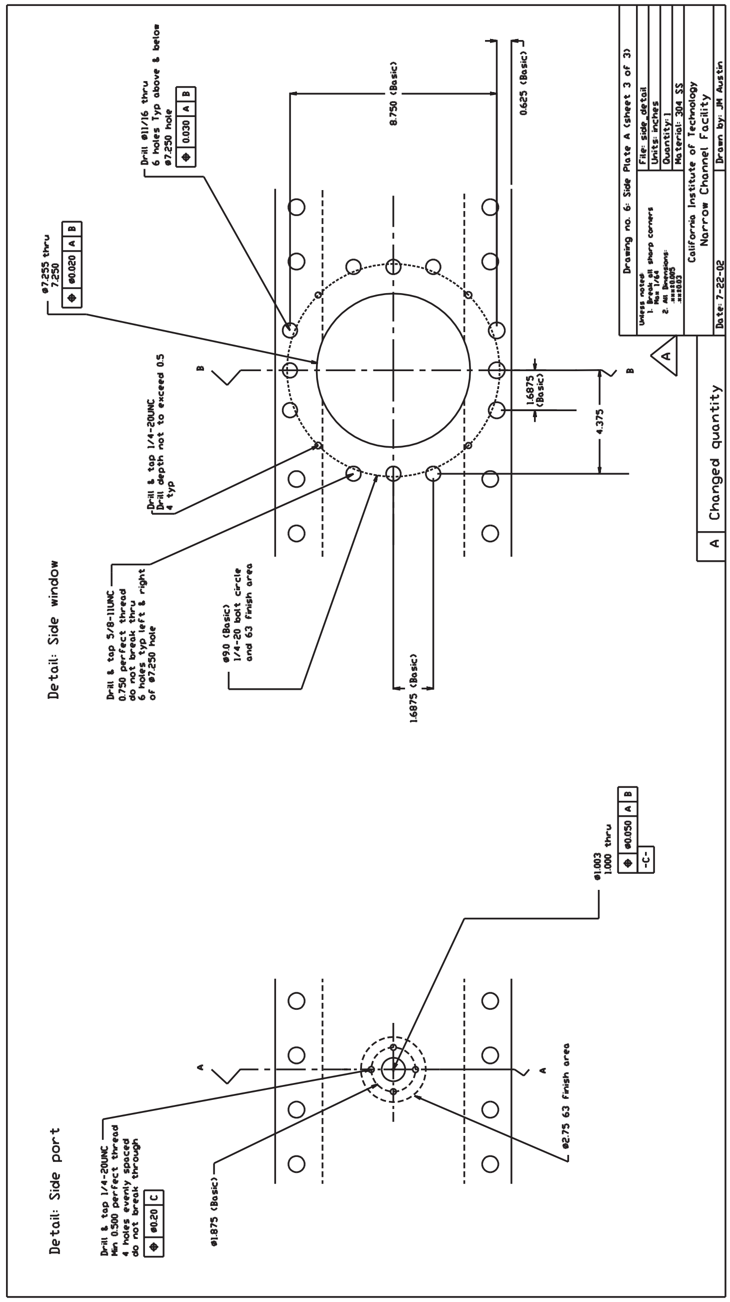

Figure 31: Side Plate B (sheet 3 of 3), Dwg No. 6

B.8 Top Plate (sheet 1 of 2), Dwg No. 7

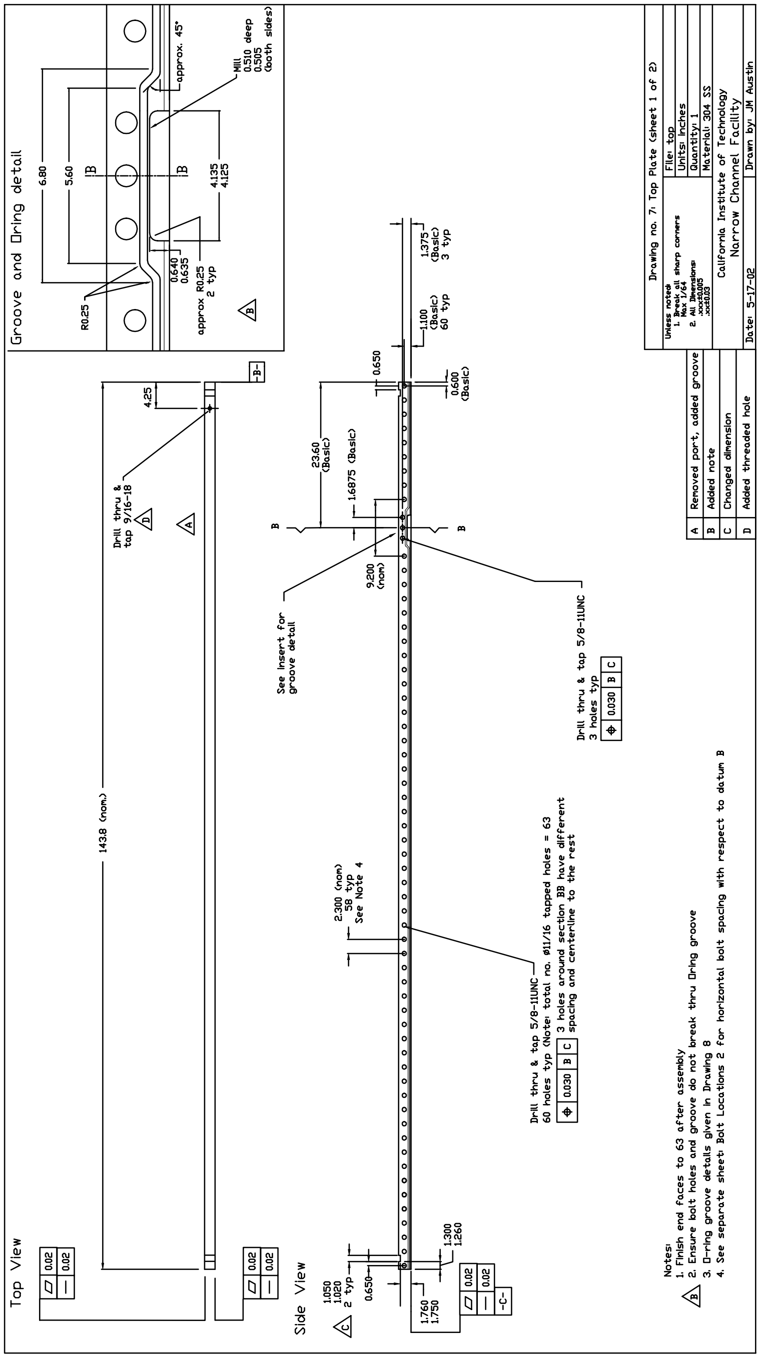

Figure 32: Top Plate (sheet 1 of 2), Dwg No. 7

B.9 Top Plate (sheet 2 of 2), Dwg No. 8

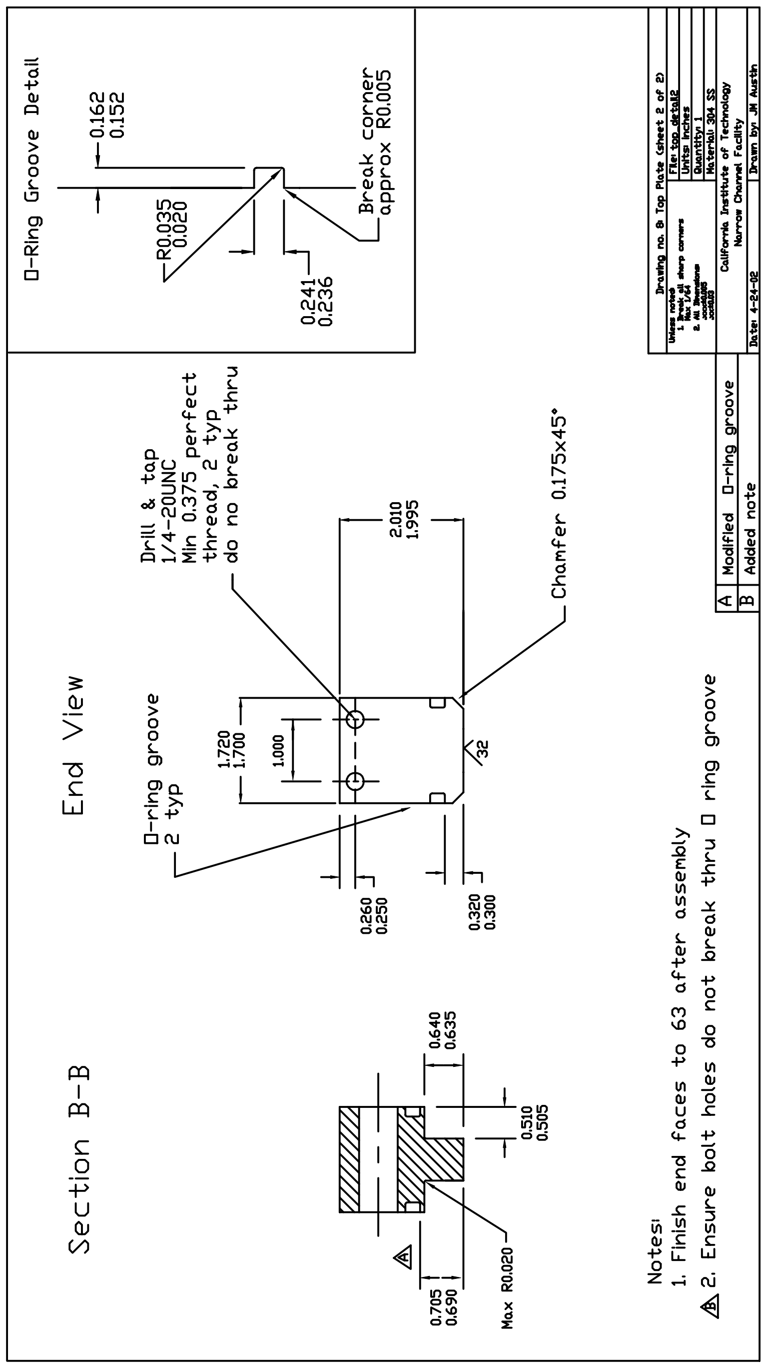

Figure 33: Top Plate (sheet 2 of 2), Dwg No. 8

B.10 Bottom Plate (sheet 1 of 3), Dwg No. 9

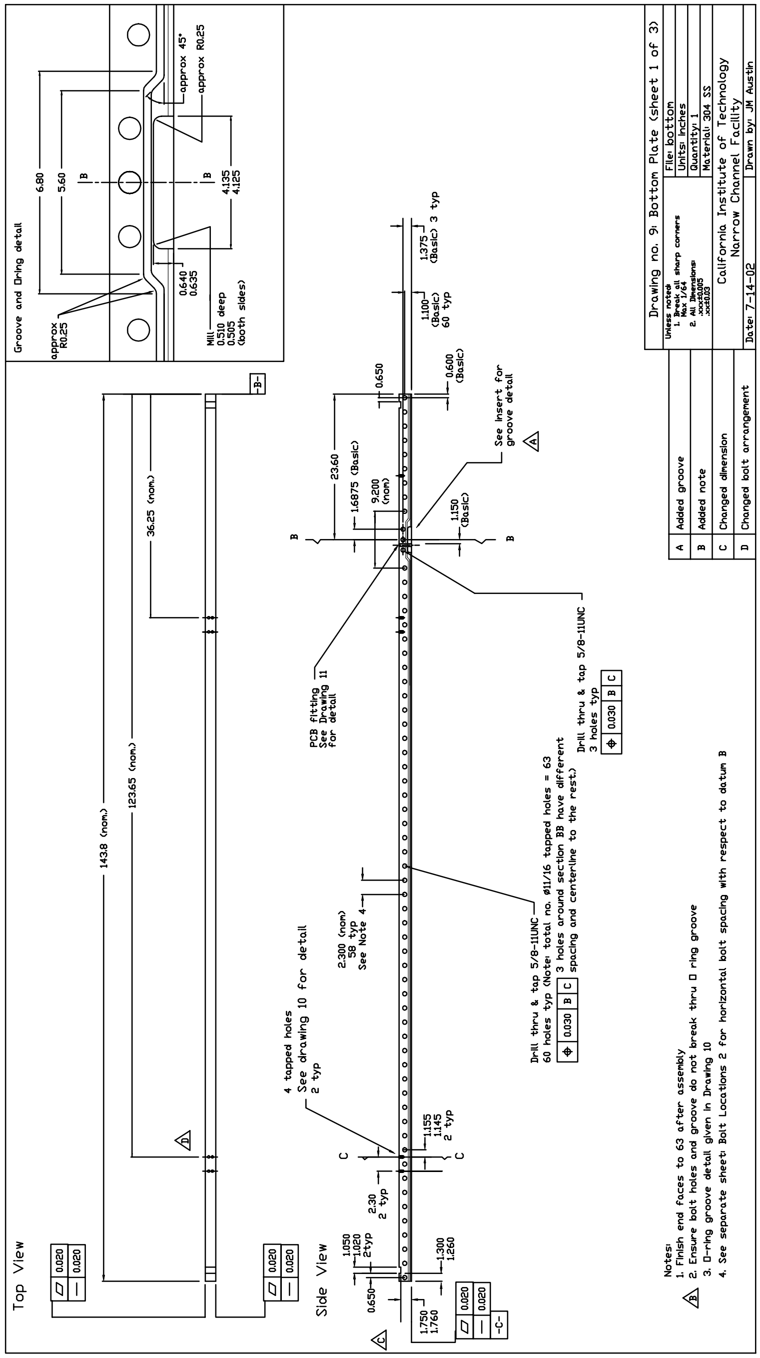

Figure 34: Bottom Plate (sheet 1 of 3), Dwg No. 9

B.11 Bottom Plate (sheet 2 of 3), Dwg No. 10

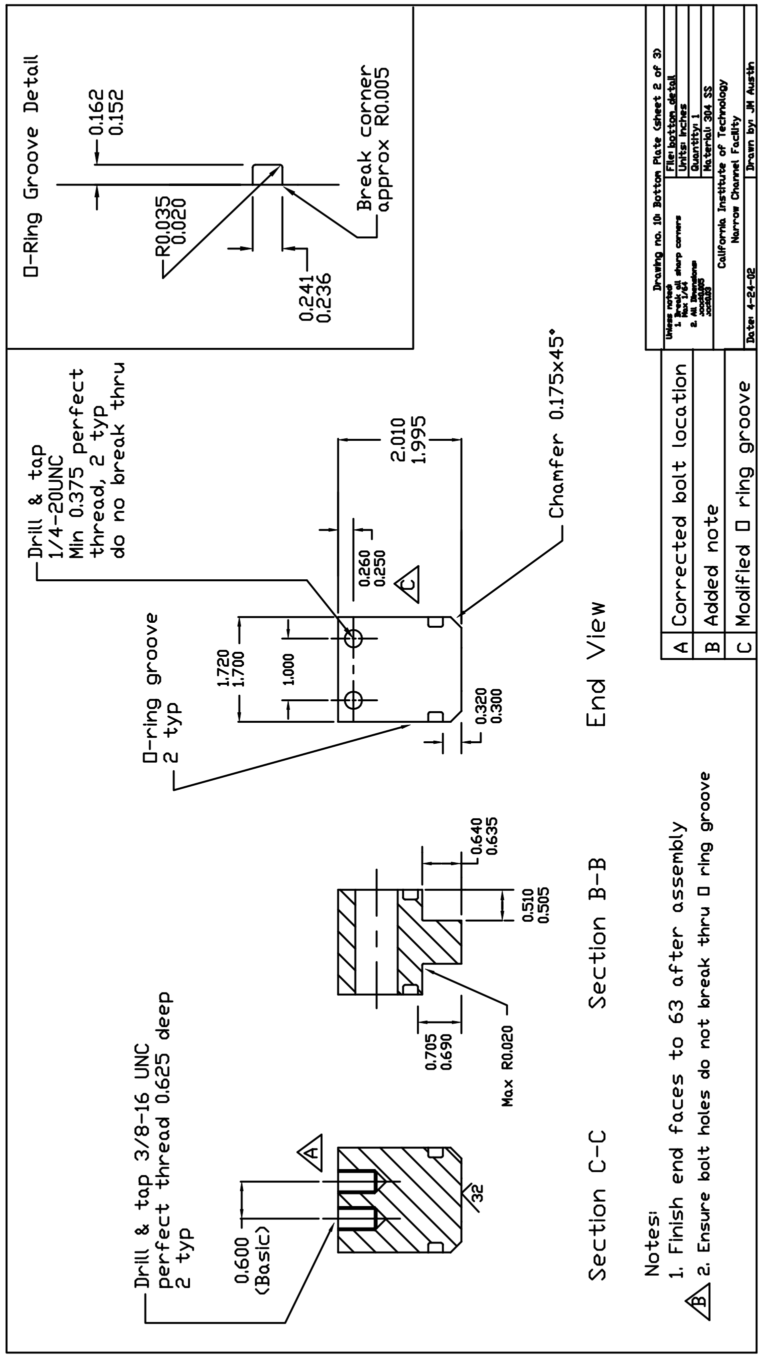

Figure 35: Bottom Plate (sheet 2 of 3), Dwg No. 10

B.12 Bottom Plate (sheet 3 of 3), Dwg No. 11

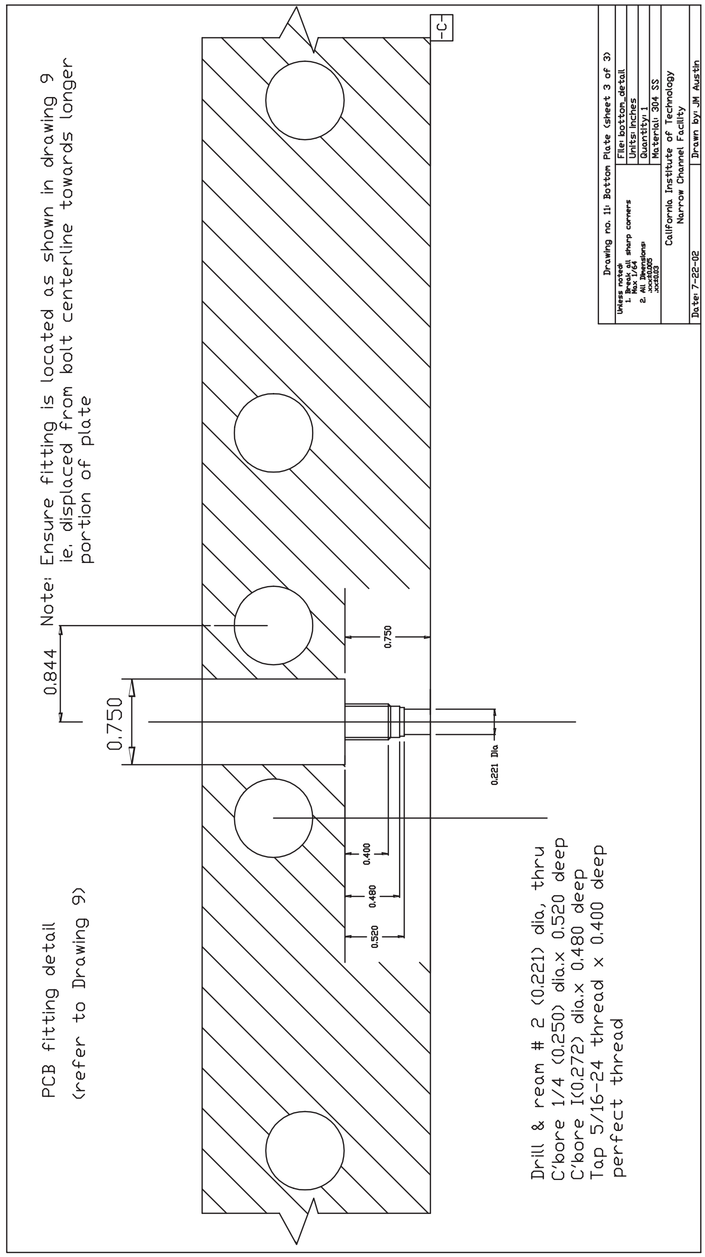

Figure 36: Bottom Plate (sheet 3 of 3), Dwg No. 11

B.13 End Flange, Bottom Half, Dwg No. 12

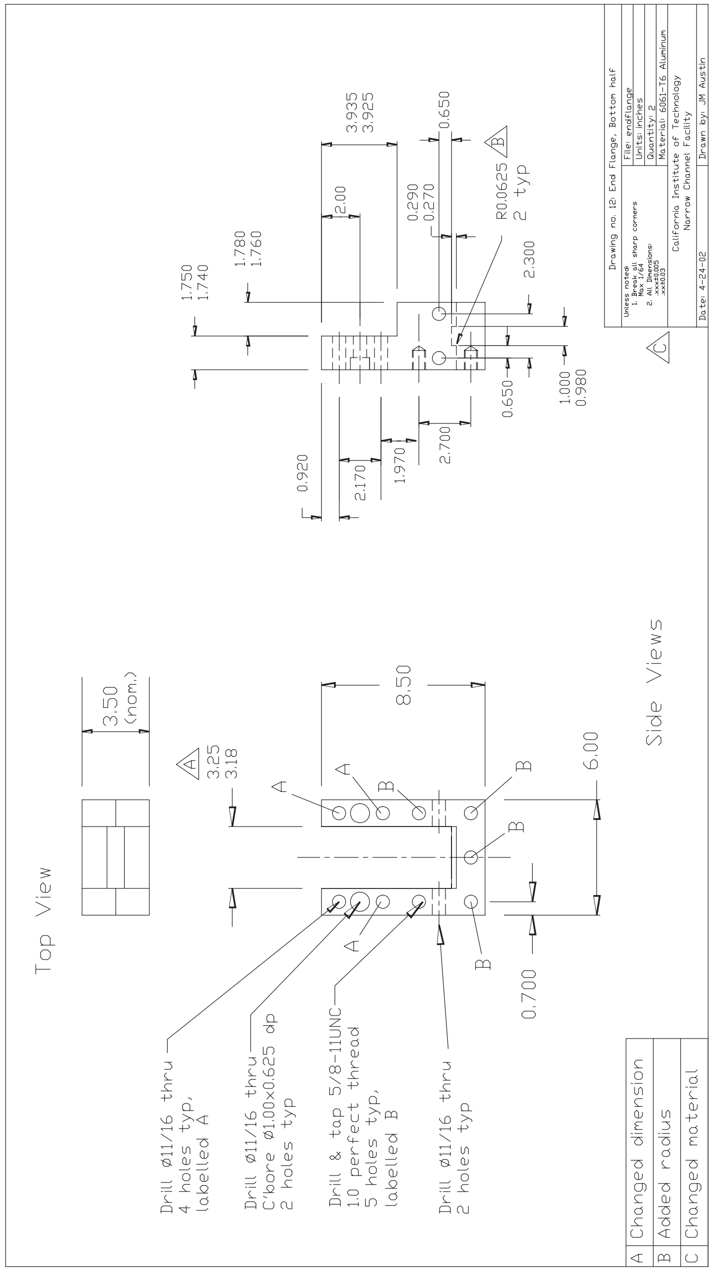

Figure 37: End Flange, Bottom Half, Dwg No. 12

B.14 End Flange, Top Half, Dwg No. 13

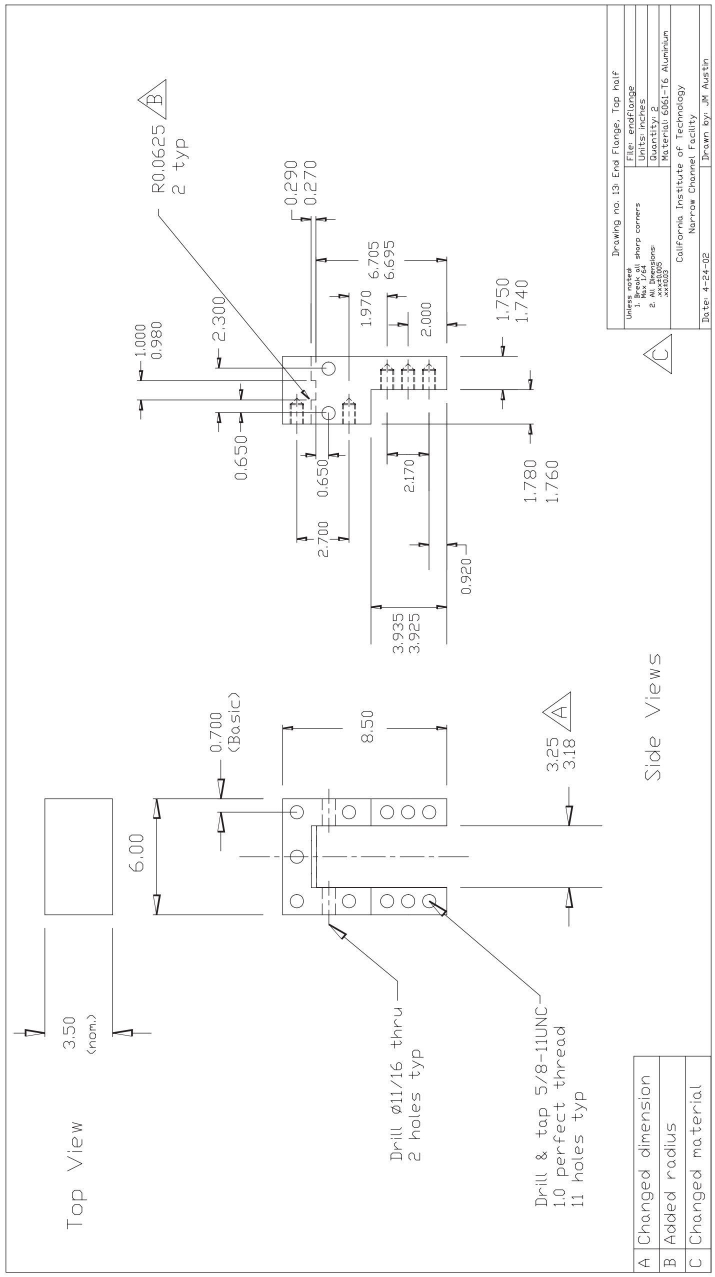

Figure 38: End Flange, Top Half, Dwg No. 13

B.15 Assembly (sheet 1 of 3), Dwg No. 14

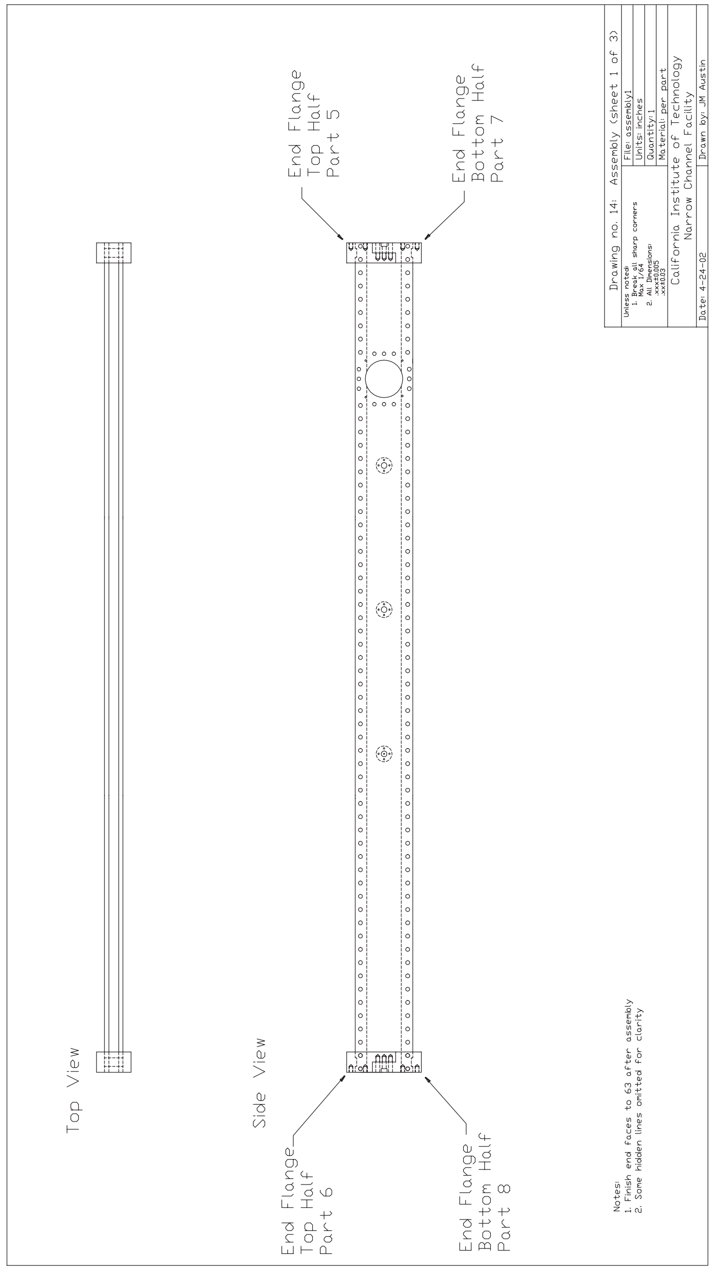

Figure 39: Assembly (sheet 1 of 3), Dwg No. 14

B.16 Assembly (sheet 2 of 3), Dwg No. 15

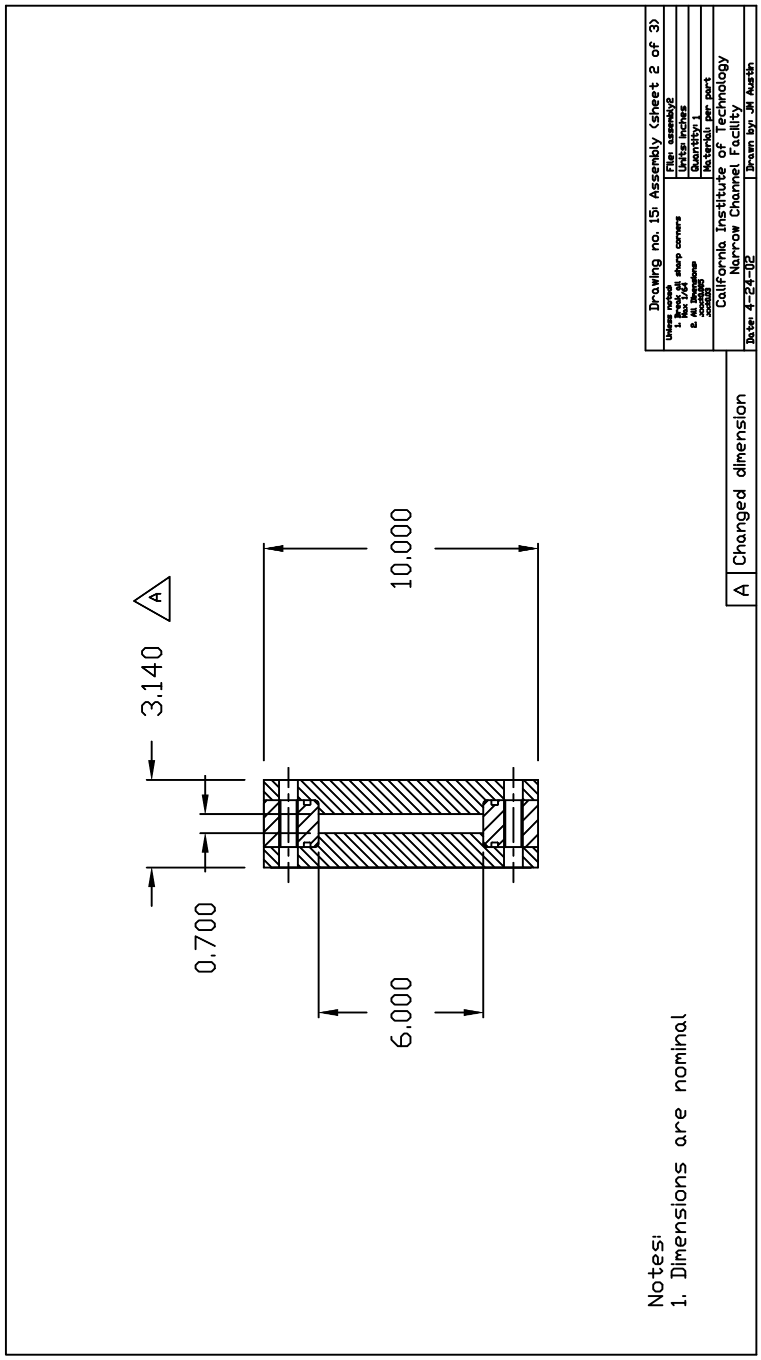

Figure 40: Assembly (sheet 2 of 3), Dwg No. 15

B.17 Assembly (sheet 3 of 3), Dwg No. 16

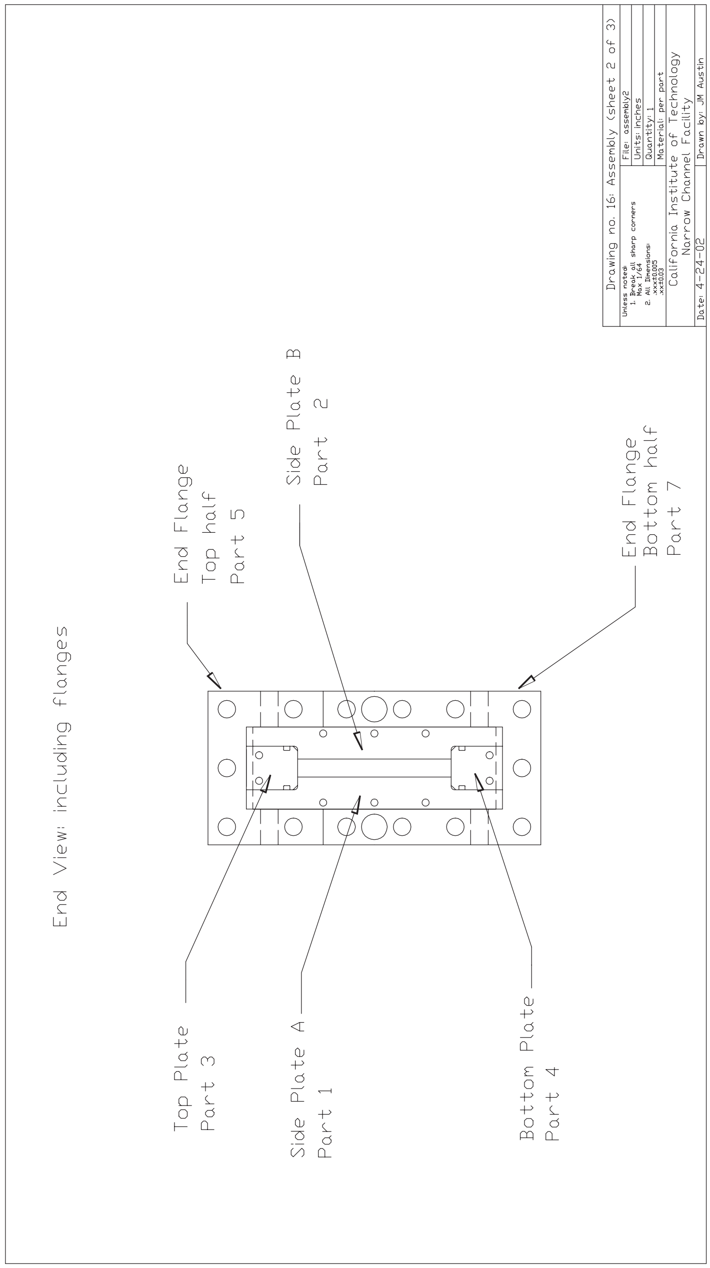

Figure 41: Assembly (sheet 3 of 3), Dwg No. 16

B.18 End Plate, Dwg No. 17

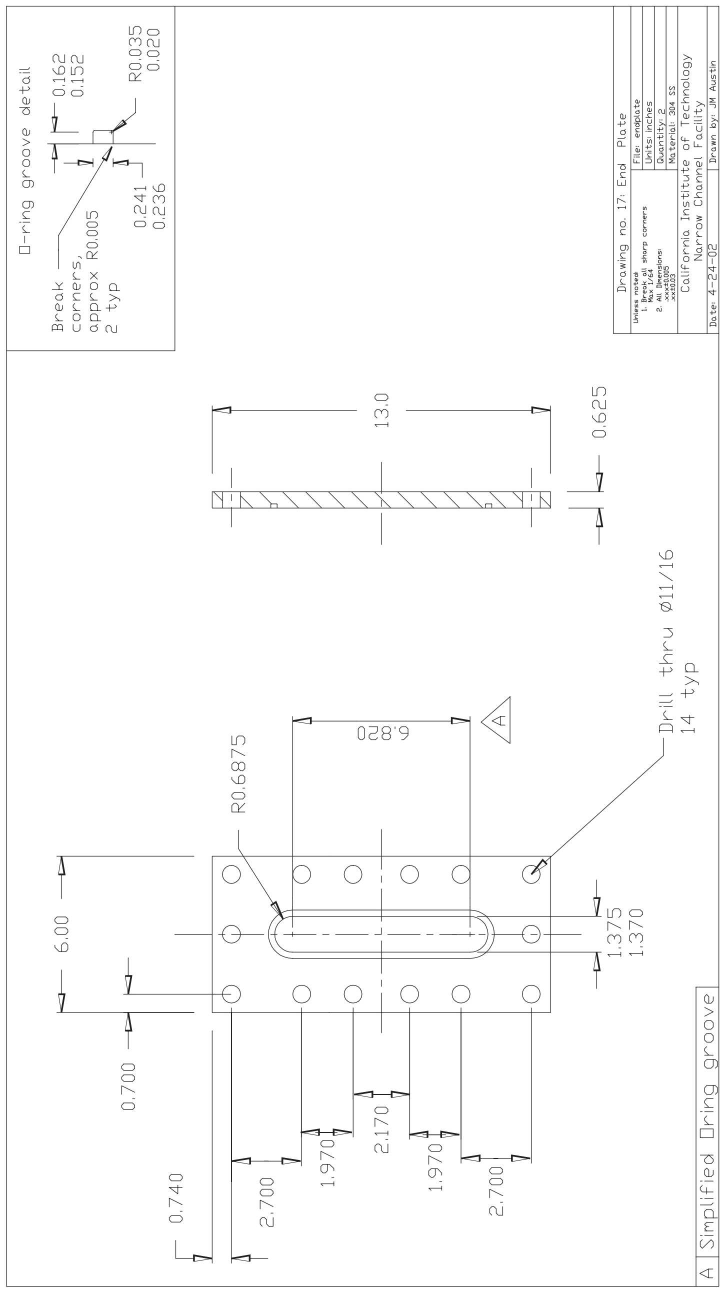

Figure 42: End Plate, Dwg No. 17

B.19 End Sealing Plate, Dwg No. 20

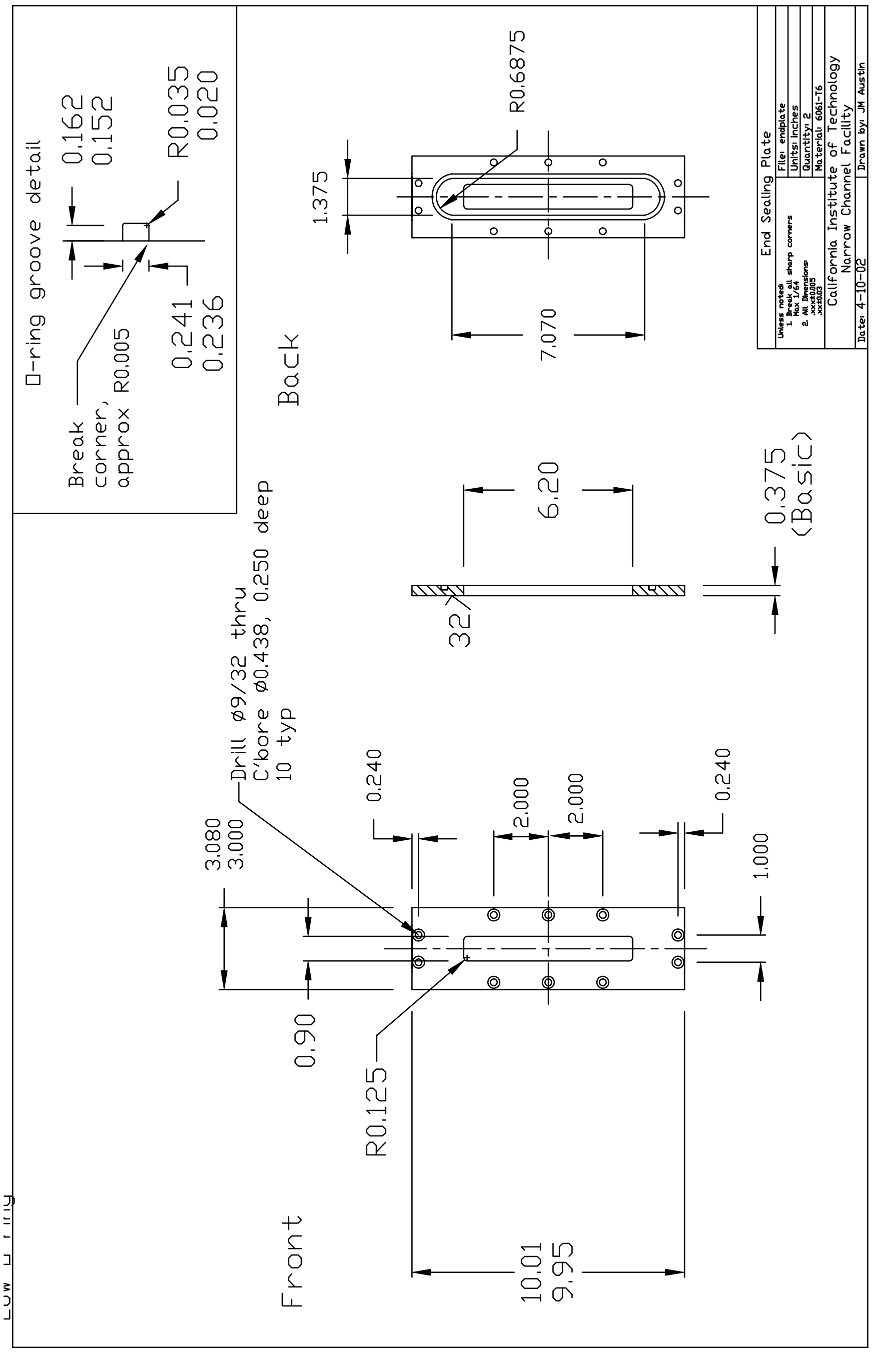

Figure 43: End Sealing Plate, Dwg No. 20

B.20 Window Sealing Plate, Dwg No. 21

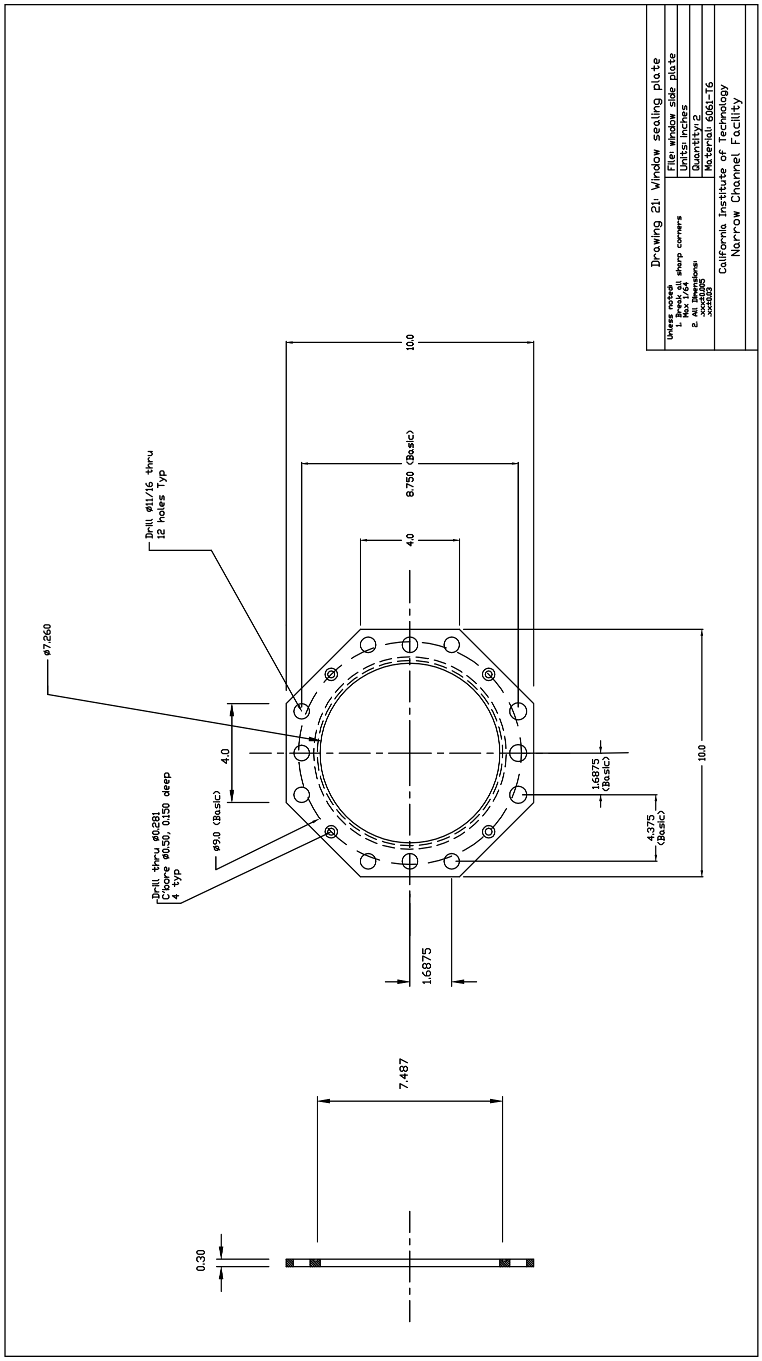

Figure 44: Window Sealing Plate, Dwg No. 21

C Narrow Channel Planar Detonation Initiator Drawings

C.1 Planar Initiator Assembly, Dwg No. 1

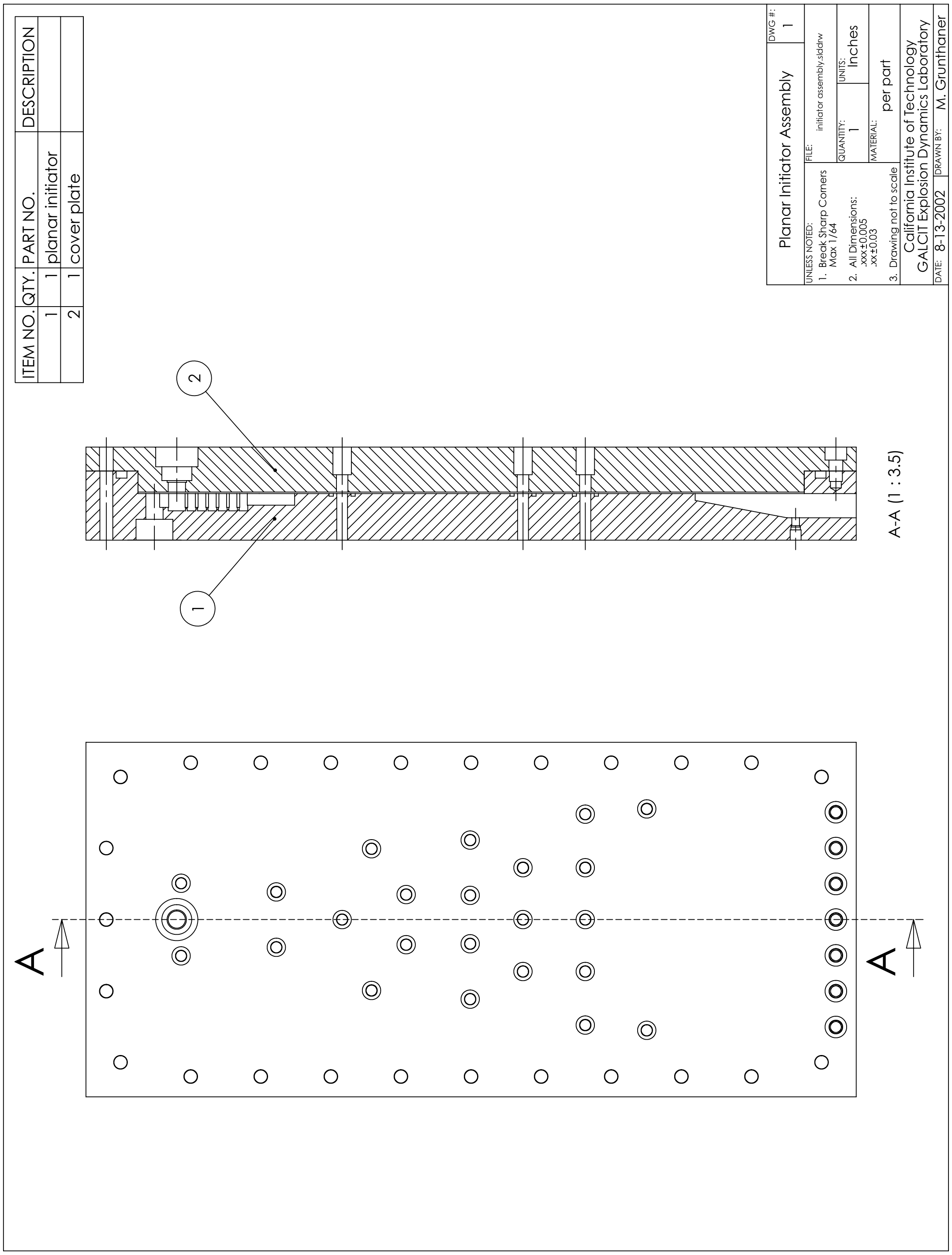

Figure 45: Planar Initiator Assembly, Dwg No. 1

C.2 Planar Initiator - Isometric, Dwg No. 2

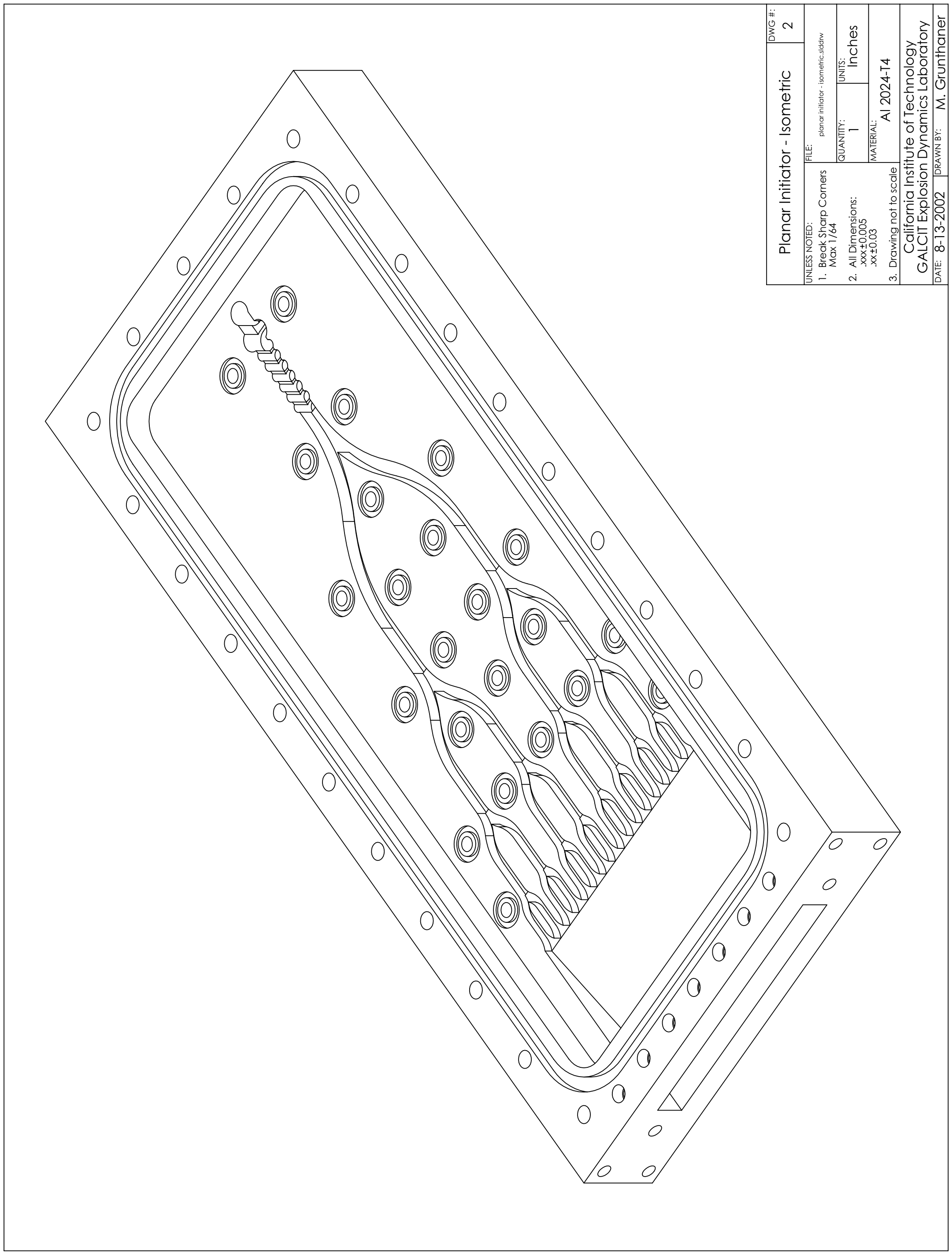

Figure 46: Planar Initiator - Isometric, Dwg No. 2

C.3 Planar Initiator - Outer Dimensions, Dwg No. 3

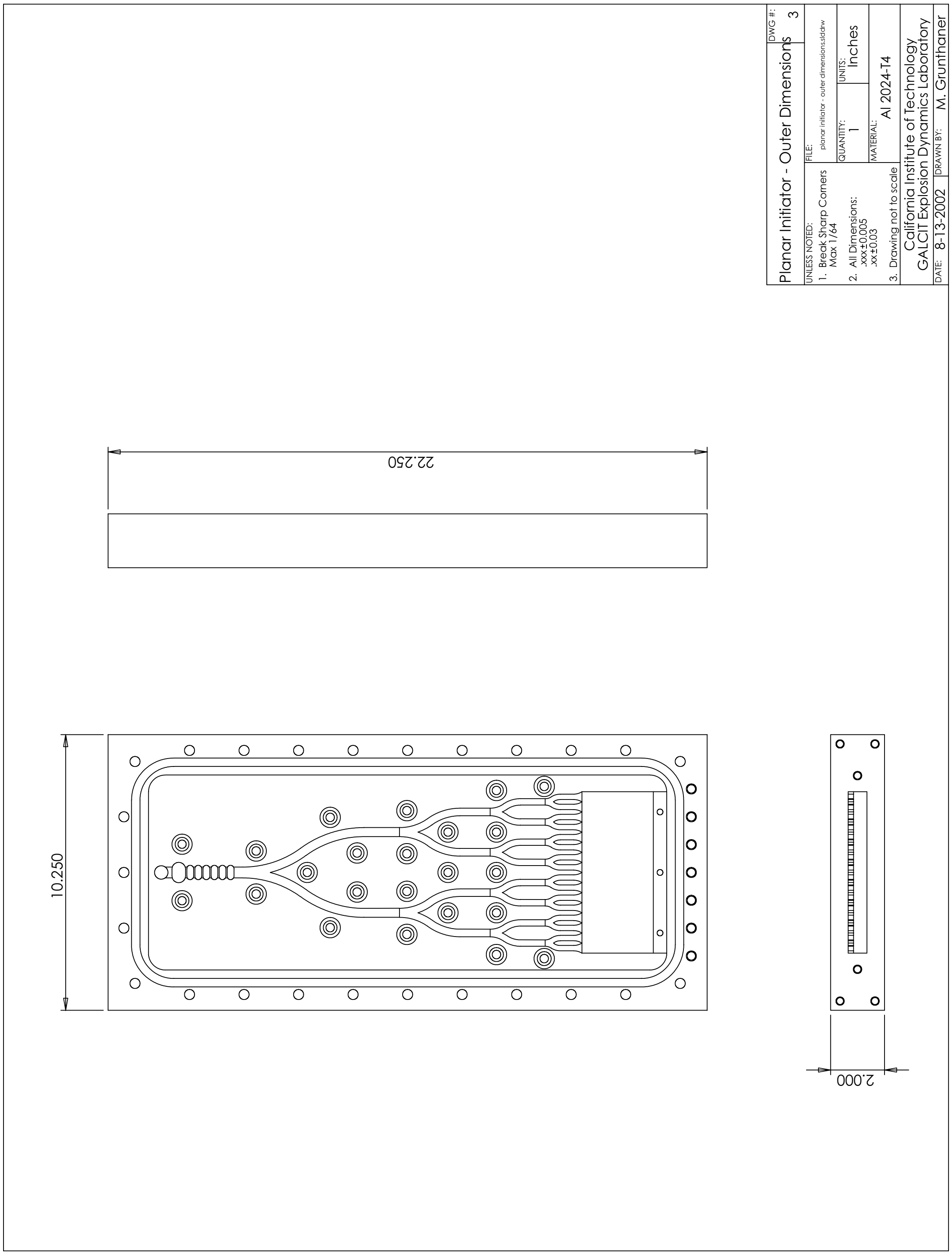

Figure 47: Planar Initiator - Outer Dimensions, Dwg No. 3

C.4 Planar Initiator - Outer Bolts, Dwg No. 4

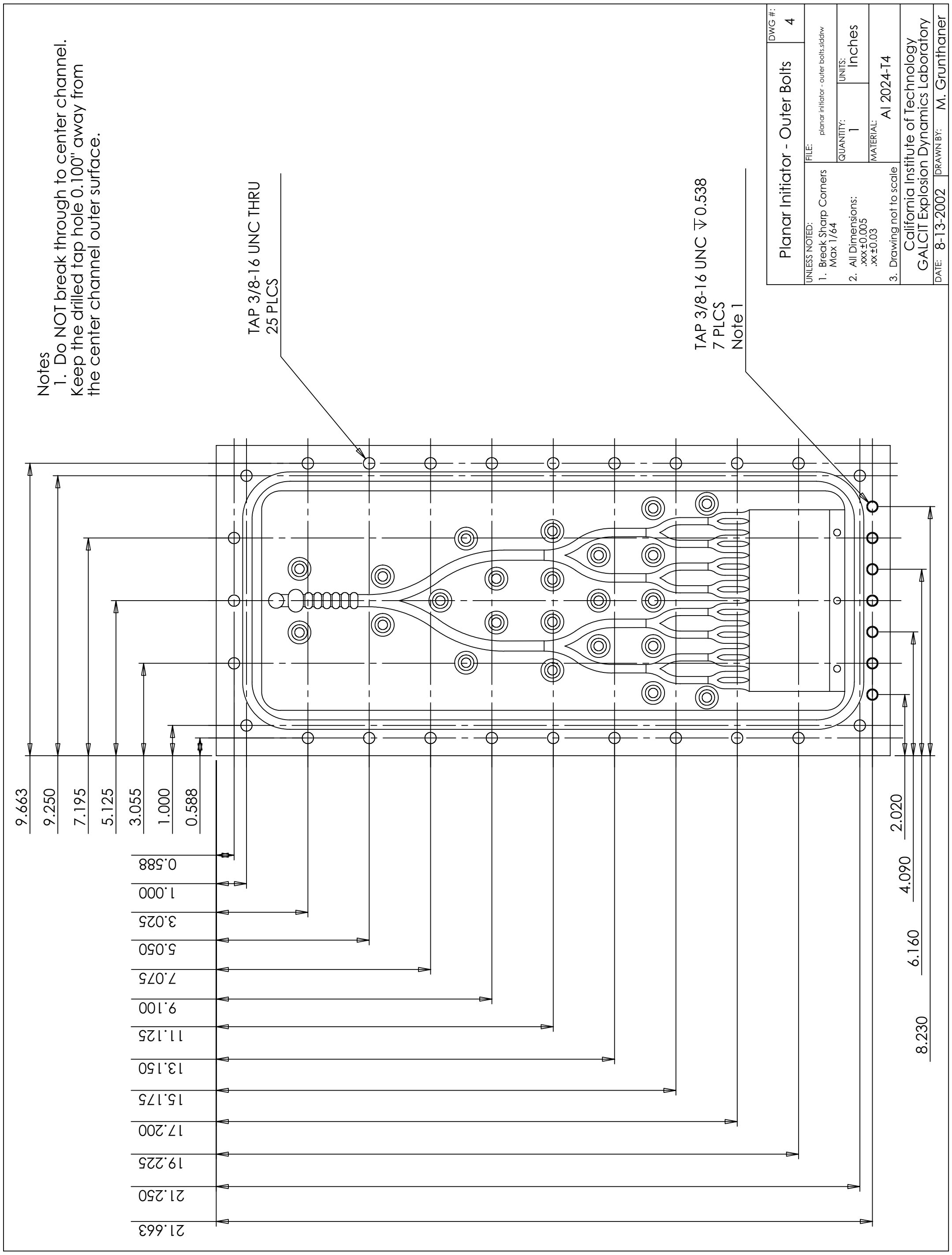

Figure 48: Planar Initiator - Outer Bolts, Dwg No. 4

C.5 Planar Initiator - Outer O-Ring, Dwg No. 5

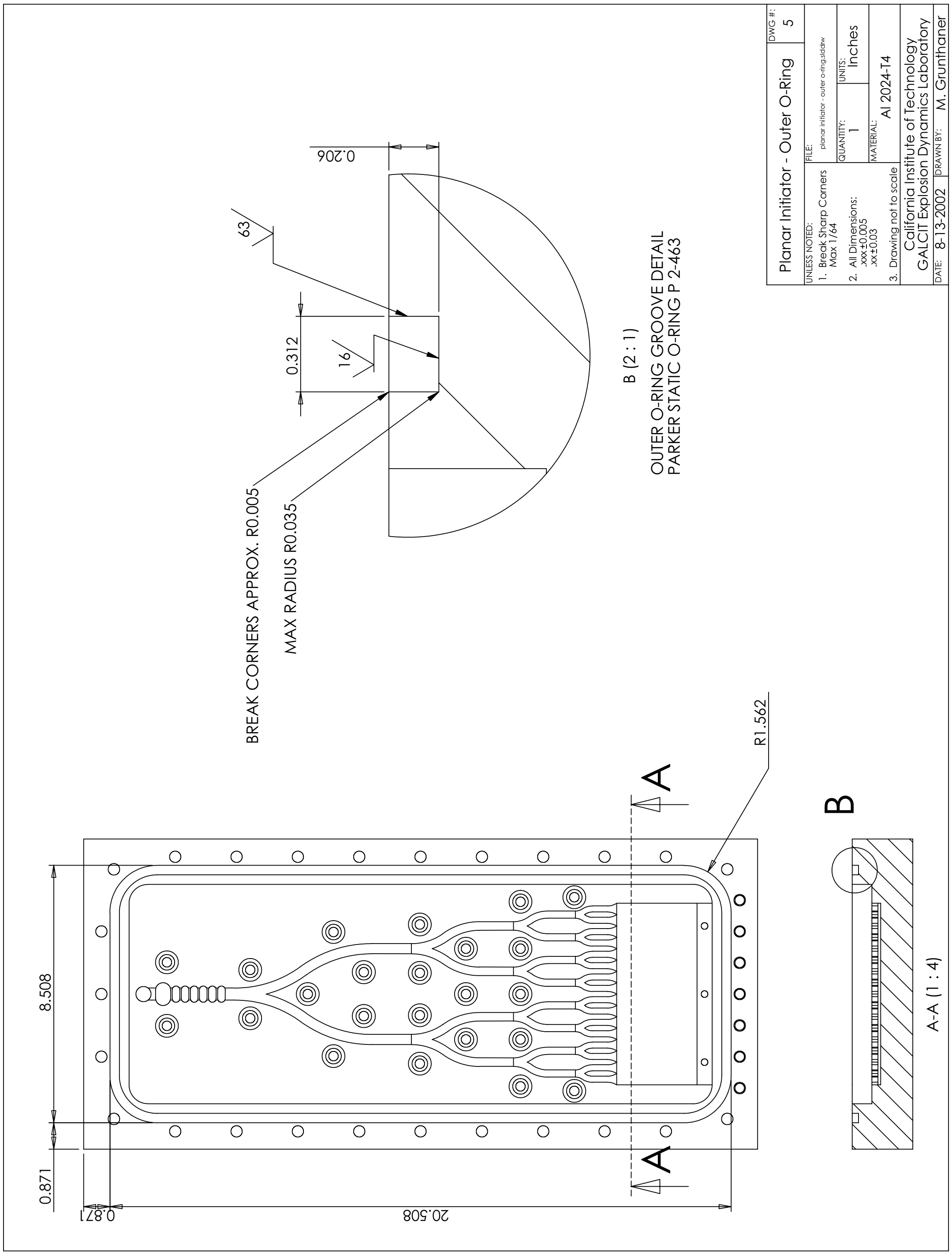

Figure 49: Planar Initiator - Outer O-Ring, Dwg No. 5

C.6 Planar Initiator - Bath Tub, Dwg No. 6

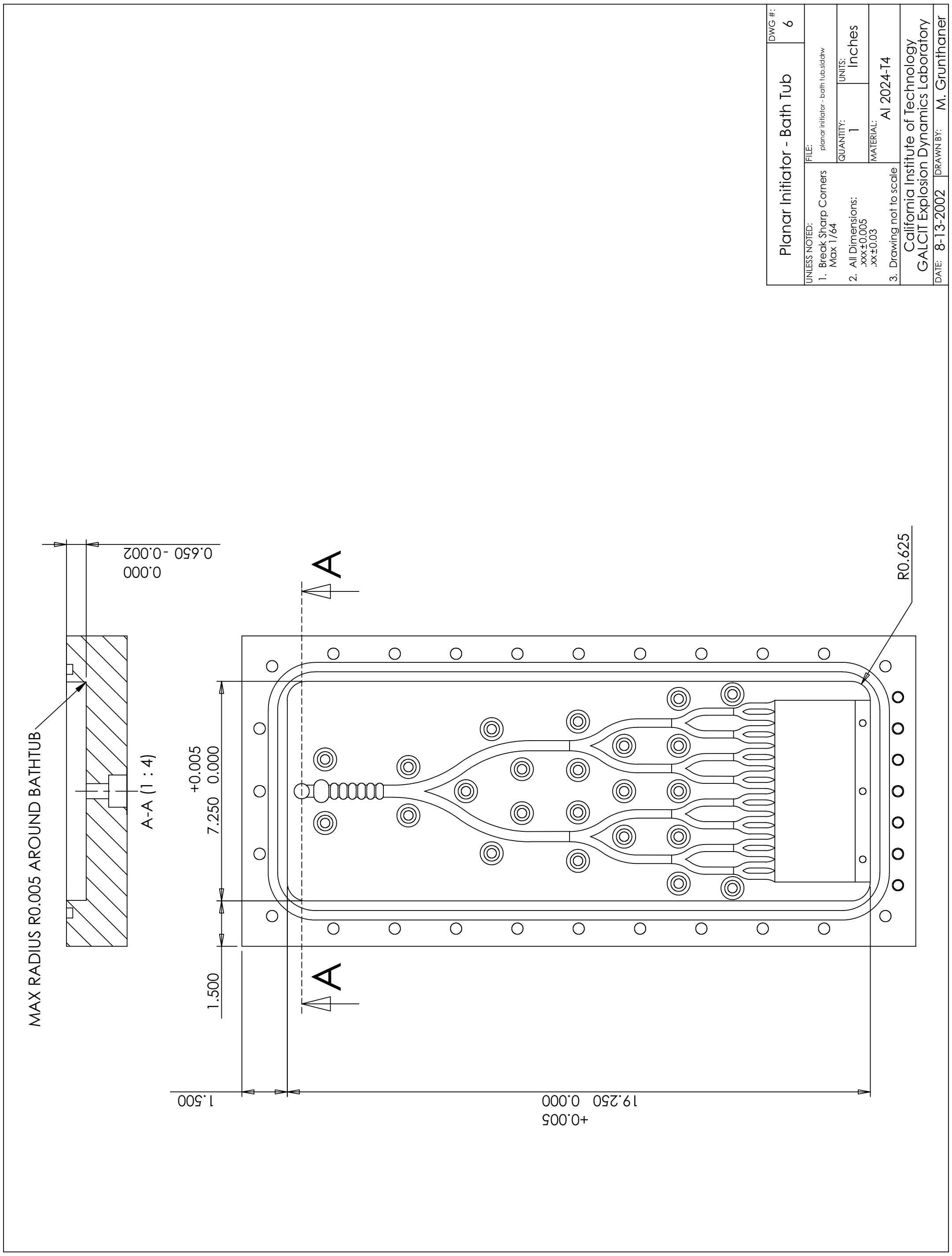

Figure 50: Planar Initiator - Bath Tub, Dwg No. 6

C.7 Planar Initiator - Inner Bolts, Dwg No. 7

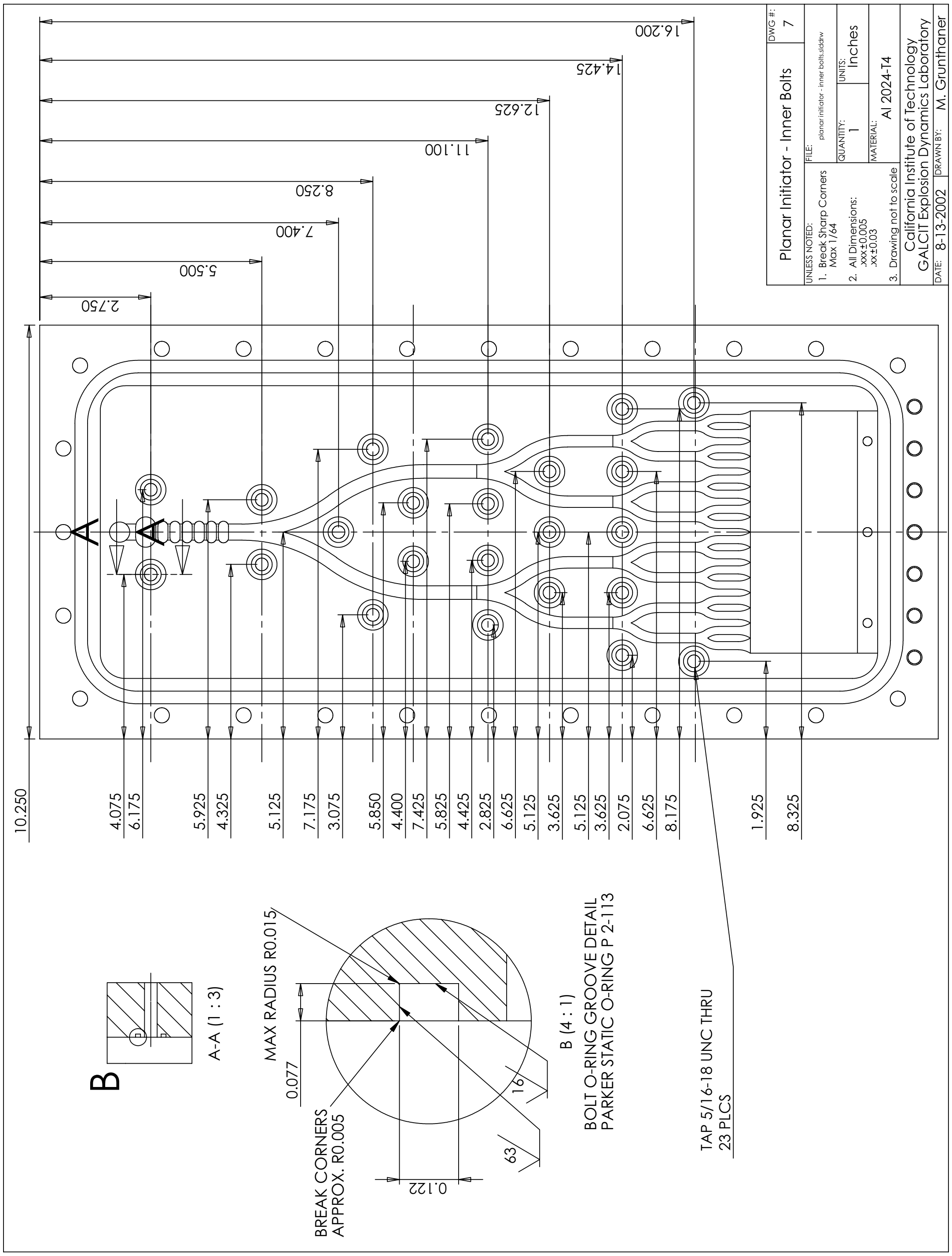

Figure 51: Planar Initiator - Inner Bolts, Dwg No. 7

C.8 Planar Initiator - Cutting Path, Dwg No. 8

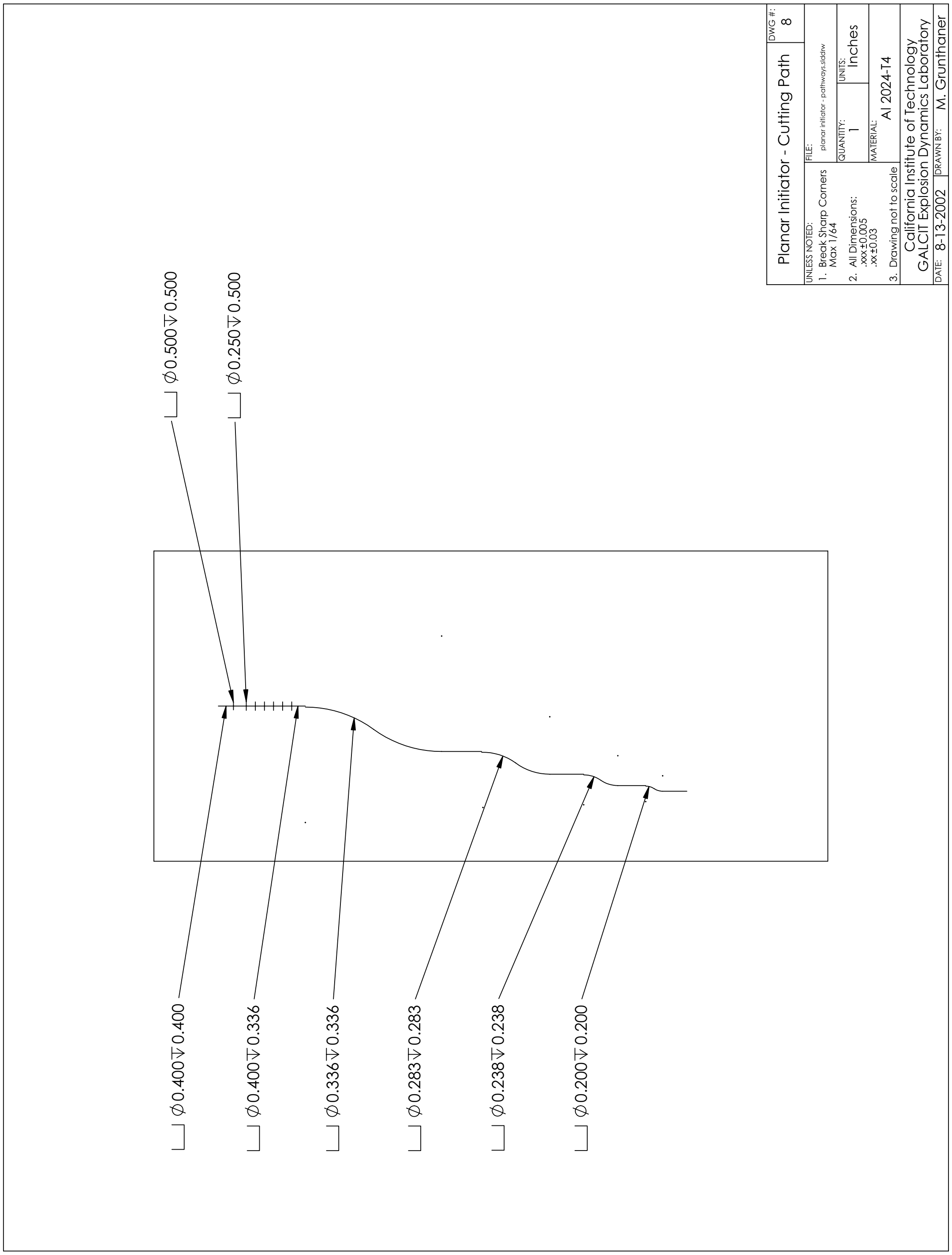

Figure 52: Planar Initiator - Cutting Path, Dwg No. 8

C.9 Planar Initiator - Channel Dimensions, Dwg No. 9

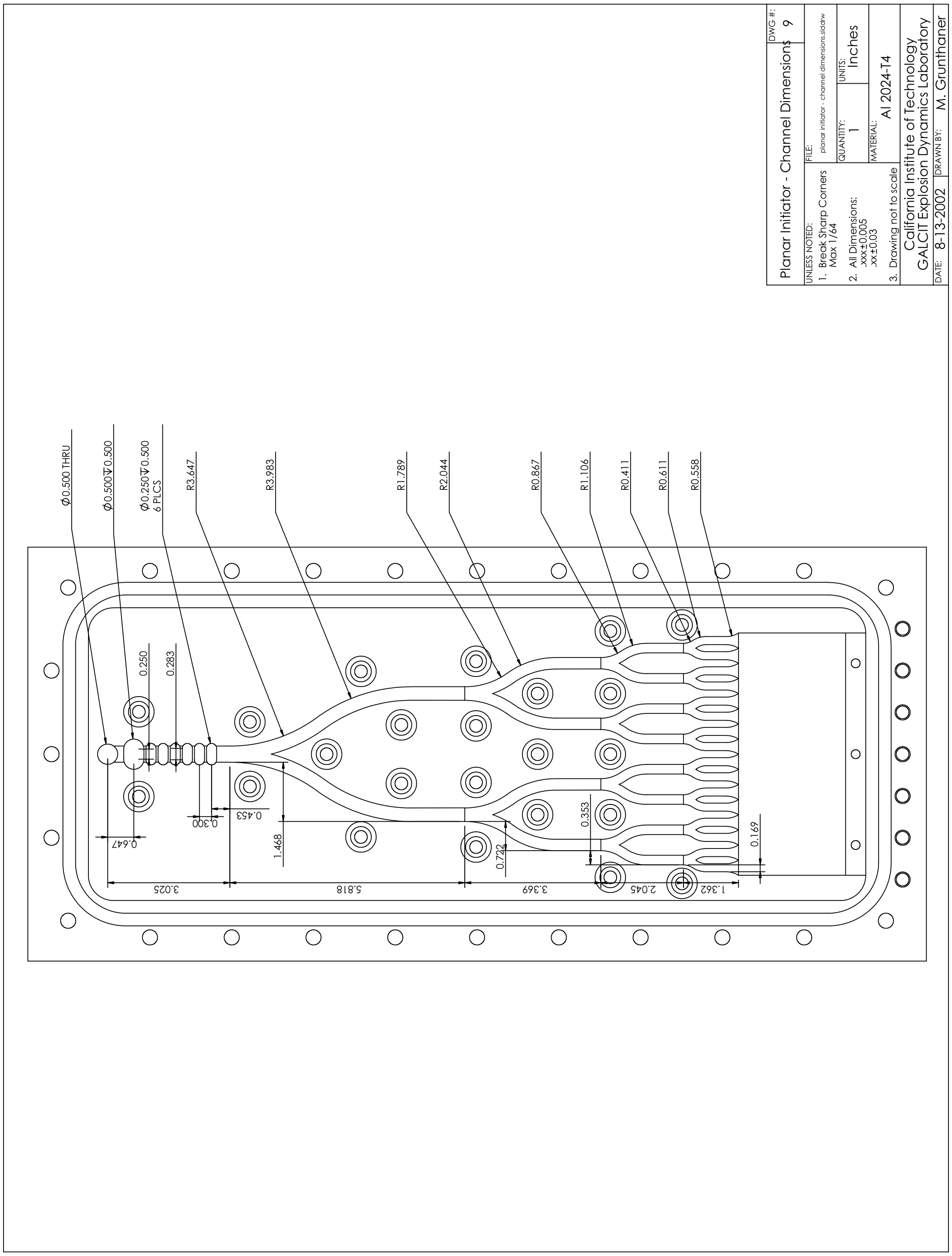

Figure 53: Planar Initiator - Channel Dimensions, Dwg No. 9

C.10 Planar Initiator - Exit Ramp, Dwg No. 10

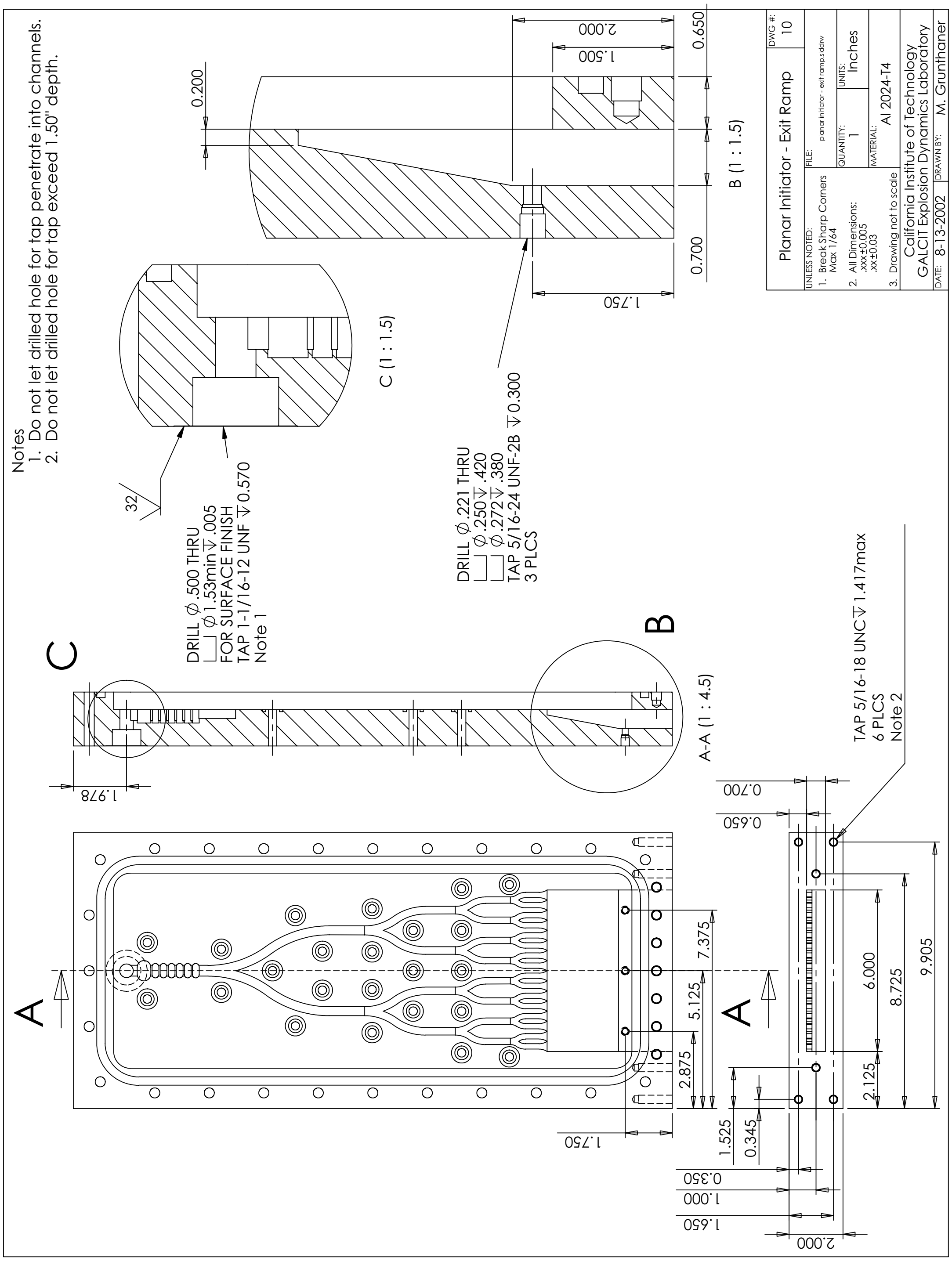

Figure 54: Planar Initiator - Exit Ramp, Dwg No. 10

C.11 Cover Plate - Isometric, Dwg No. 11

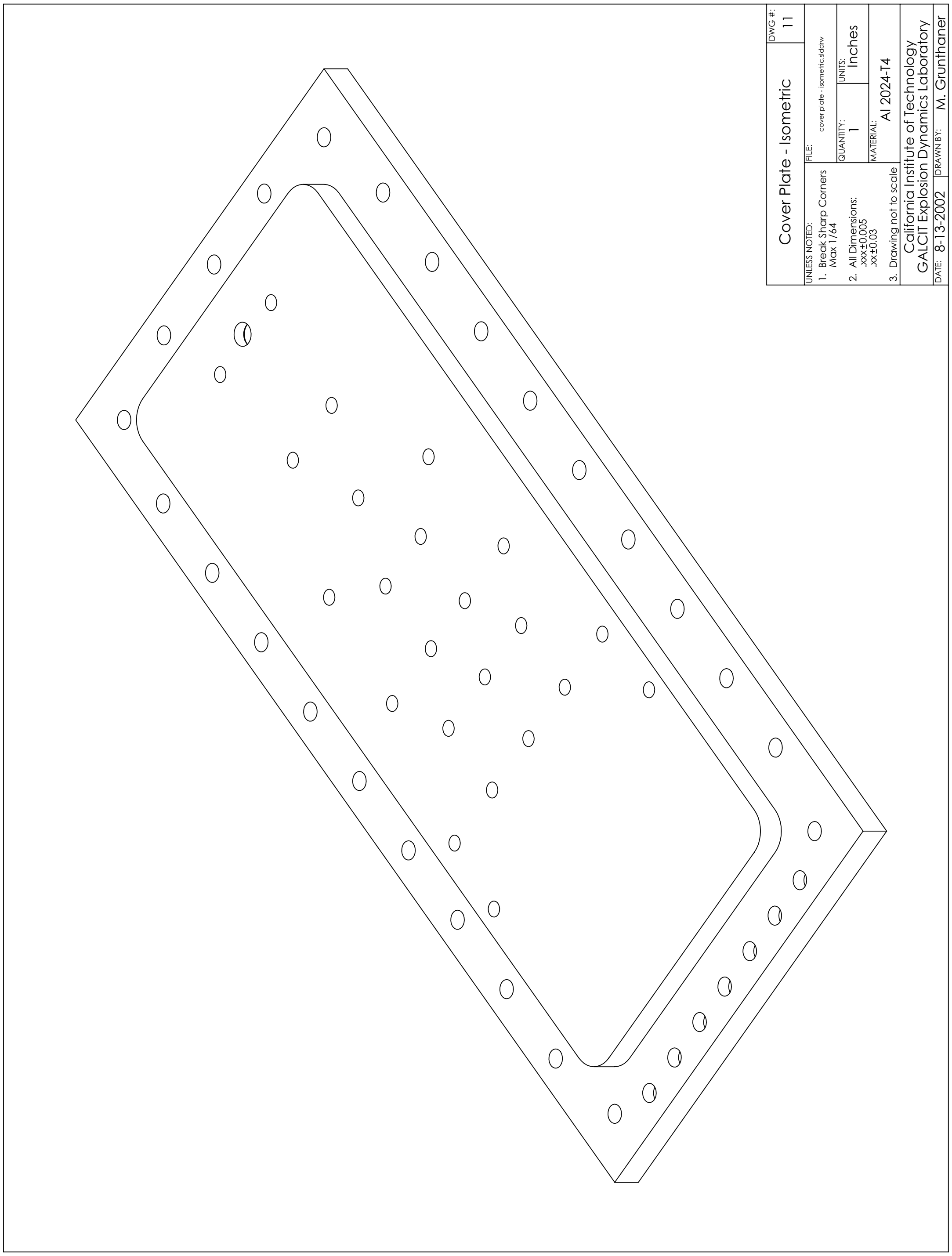

Figure 55: Cover Plate - Isometric, Dwg No. 11

C.12 Cover Plate - Outer Dimensions, Dwg No. 12

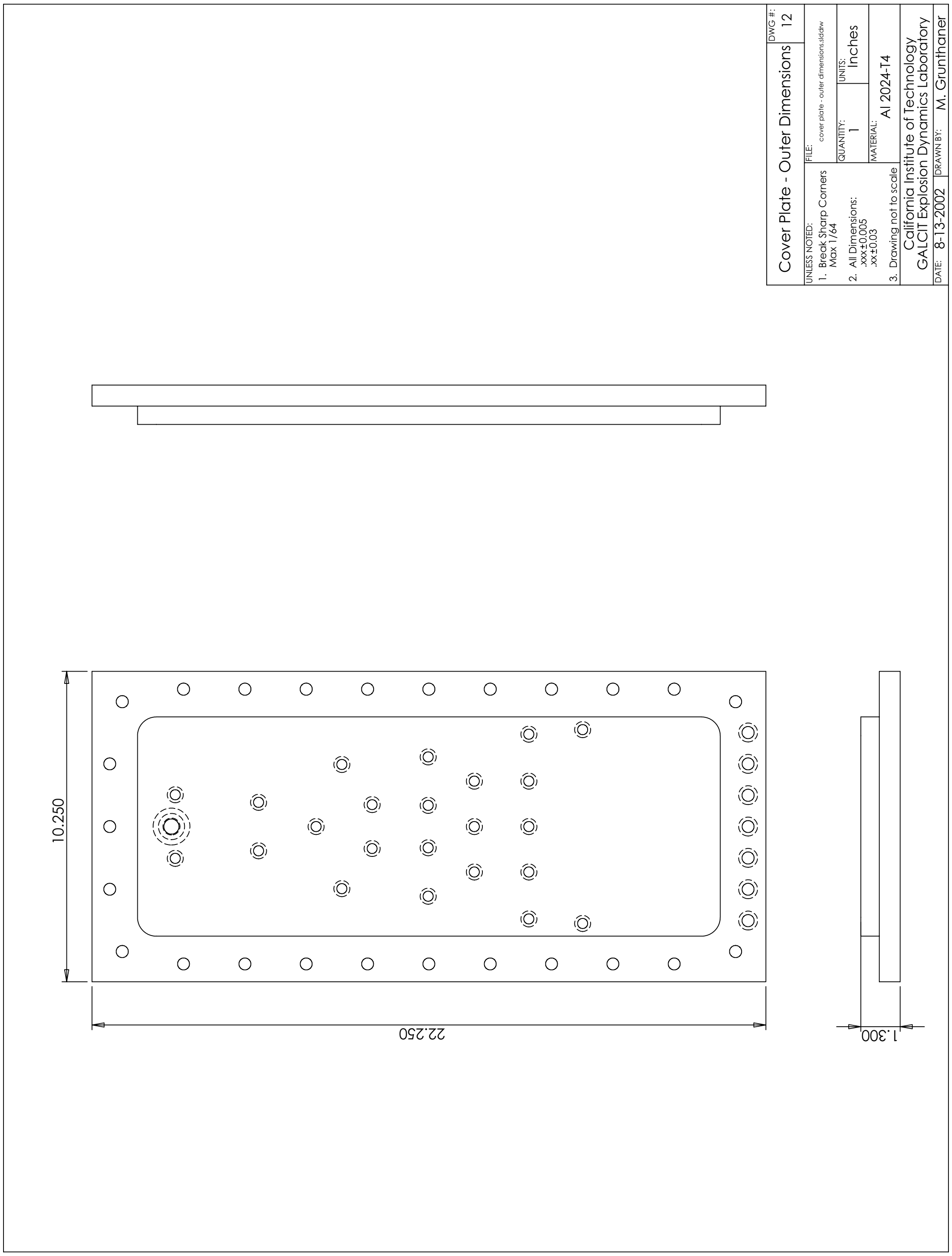

Figure 56: Cover Plate - Outer Dimensions, Dwg No. 12

C.13 Cover Plate - Outer Bolts, Dwg No. 13

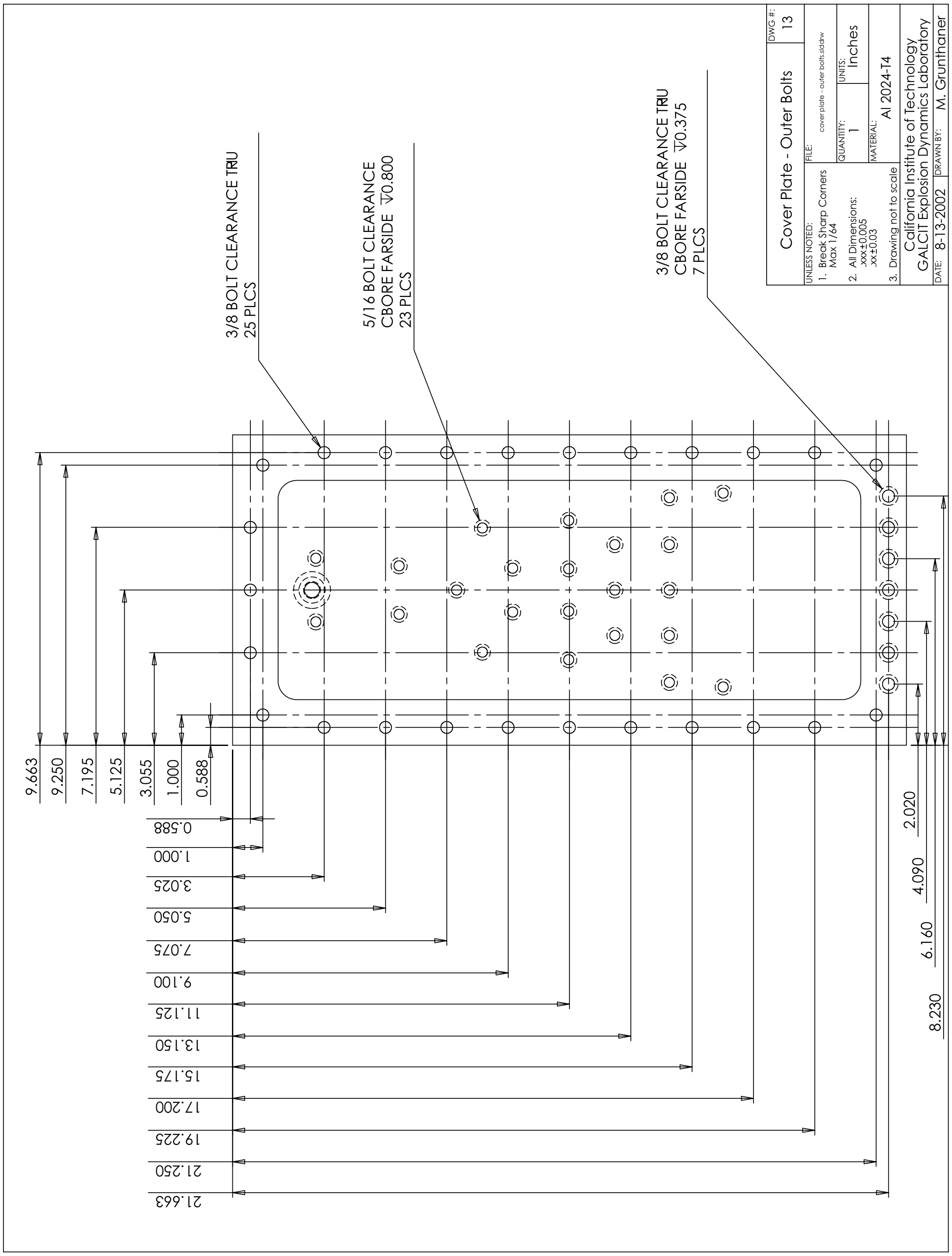

Figure 57: Cover Plate - Outer Bolts, Dwg No. 13

C.14 Cover Plate - Bath Tub, Dwg No. 14

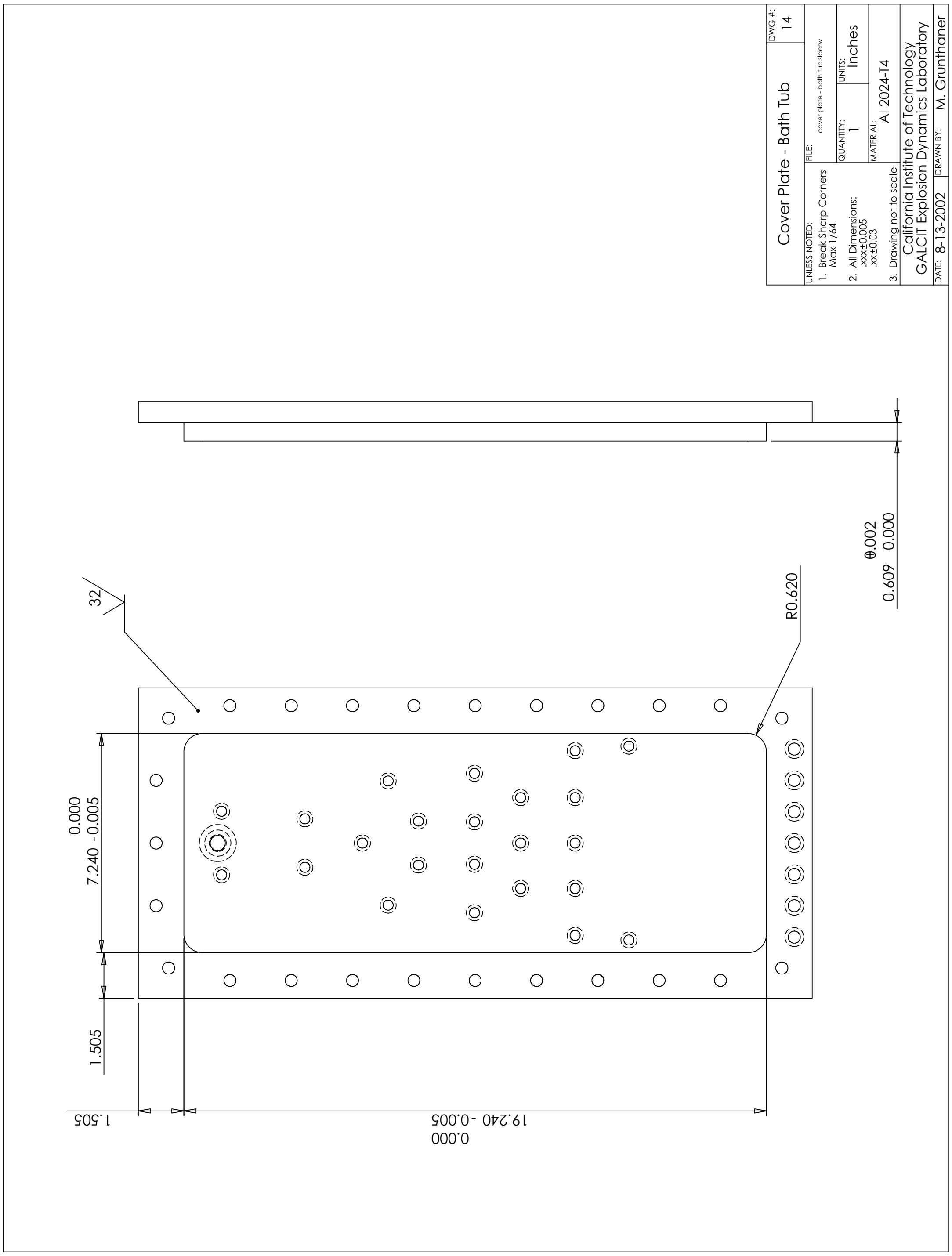

Figure 58: Cover Plate - Bath Tub, Dwg No. 14

C.15 Cover Plate - Inner Bolts, Dwg No. 15

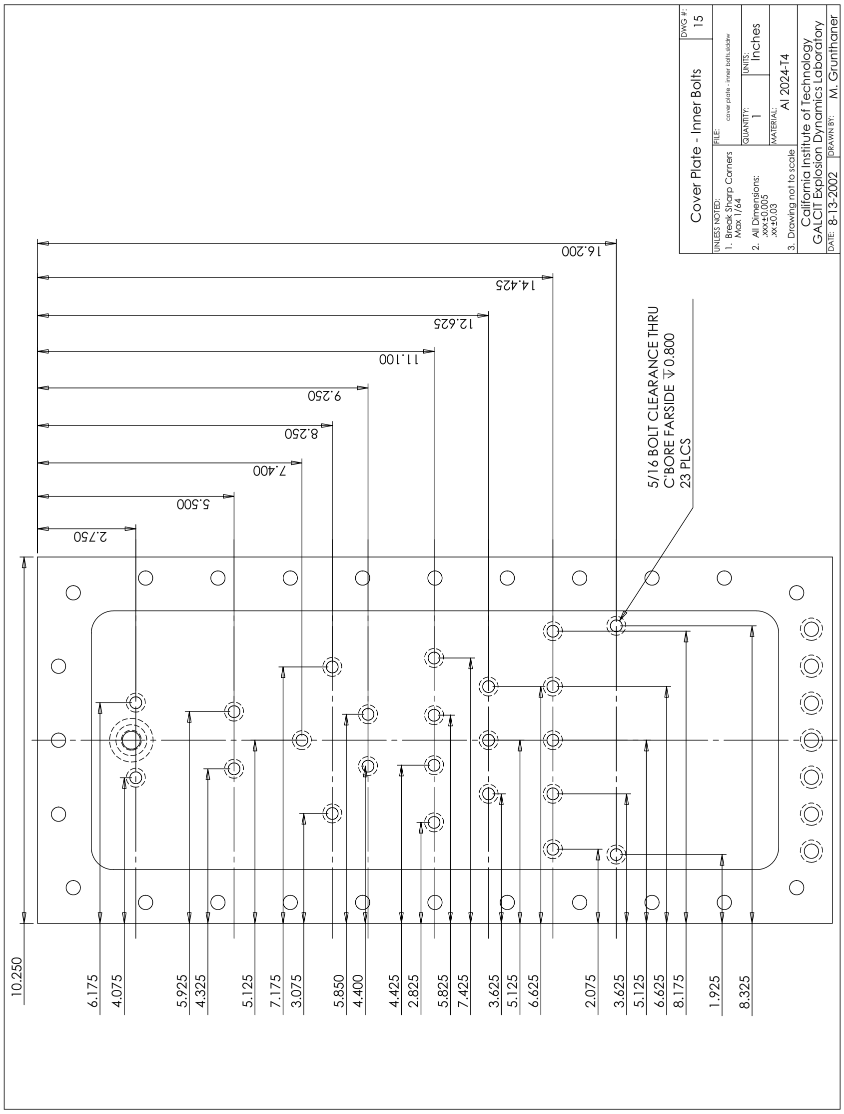

Figure 59: Cover Plate - Inner Bolts, Dwg No. 15

C.16 Cover Plate - Spark Plug, Dwg No. 16

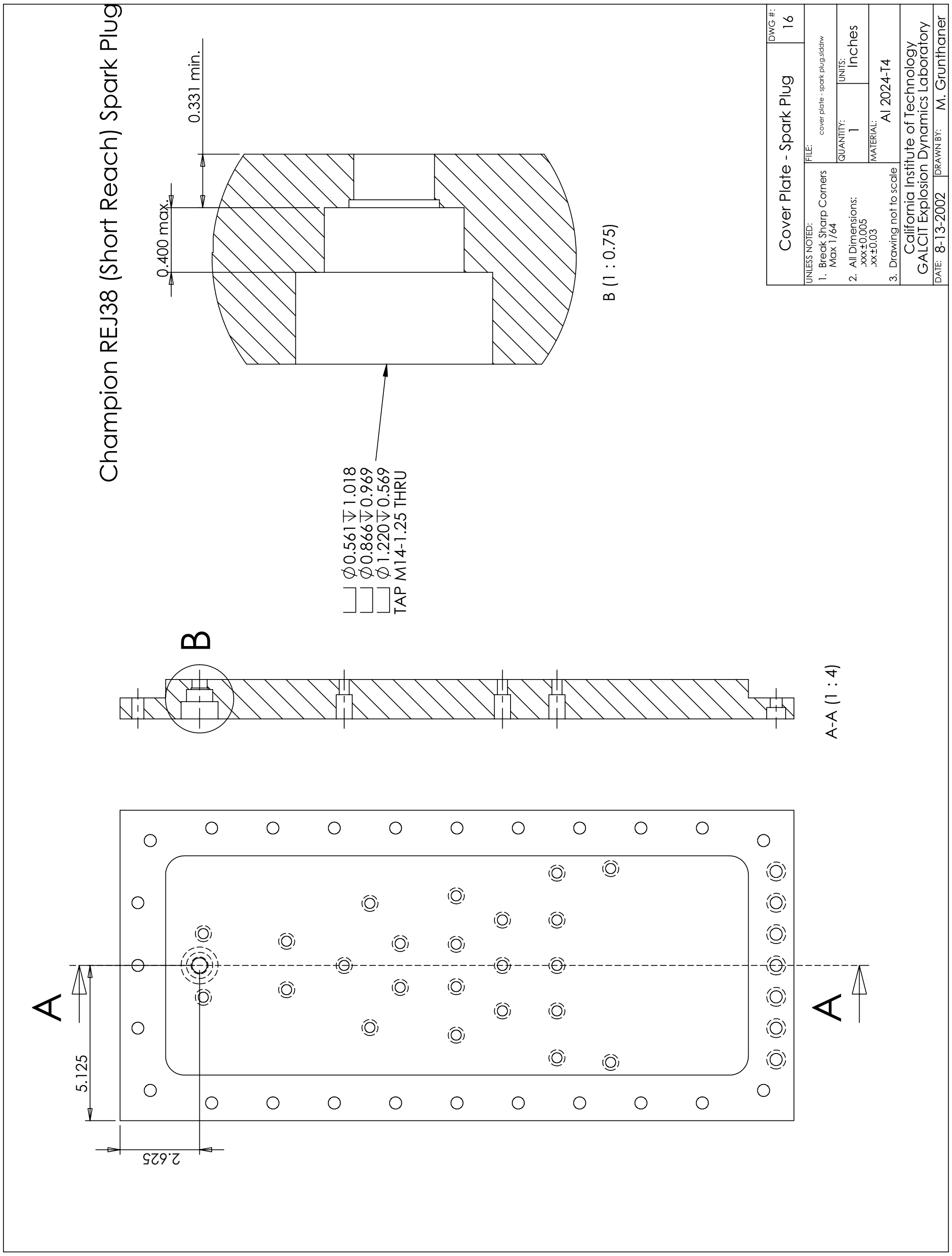

Figure 60: Cover Plate - Spark Plug, Dwg No. 16

D Narrow Channel Detonation Tube Miscellaneous Documentation

D.1 Material Certificate of Analysis and Tests (sheet 1 of 4)

ALCOA

Alcoa Engineered Products
Cressona, PA 17929
(570) 385-5000

CERTIFIED INSPECTION REPORT
AND TEST RESULTS
WROUGHT PRODUCTS

CODE NUMBER: 00318001
ORDER NUMBER: CA 173864

COAST ALUM & ARCHITECTURAL
687 SANDOVAL WAY
HAYWARD CA 94544

COAST ALUM & ARCHITECTURAL
687 SANDOVAL WAY
HAYWARD CA 94544

INVOICE NO.
INVOICE DATE: / /
GROSS WEIGHT: 3069
B/L NO.: 513247
DATE SHIPPED: / /
VIA: FORK-LIFT
F.O.B.: DEST N

CUSTOMER P.O. NO.: 32481
GOVT. CONTRACT NO.

Products as follows
ASTM B 221-96
QQ-A-200/8F AMS-QQ-A-200/8
ASME SB 221
MEETS T6 TEMPER REQUIREMENTS
MARKED

AUTHORIZED SIGNATURE(S)
Elizabeth J. Chirico
ELIZABETH J. CHIRICO 06/07/00
QUALITY SYSTEMS MANAGER

We hereby certify that the material covered by this report has been inspected and tested in accordance with the Seller's standard sampling plan or the requirements of any specifications of the material described in this report and has been found to meet the applicable requirements described herein, and that samples representative of the material met the composition limits and had the mechanical properties shown. Also, note that Mercury is not a normal contaminant in aluminum alloys. Neither Mercury nor any of its compounds are used in the manufacture of our extrusions.

Alcoa Engineered Products

ORDER NUMBER: 173864
ALLOY AND TEMPER: 6061-T6511

ITEM	ITEM DESCRIPTION	PRODUCT CODE	QUANTITY SHIPPED PCS., FT., ETC.	WGT. IN LBS. OR AS INDICATED
001	C/P 46B61 RECTANGULAR BAR 4.000 X 6.000 SEC 4.000 6.000 .000 LEN 12' WFC (W 28.224 F 01 C 7.20)	L10022	9 PC 108.0 FT 3 BNDLS	3051

MECHANICAL PROPERTIES

LOT NUMBER	RACK FROM/TO	** NUMBER OF TESTS	TENSILE MIN.	TENSILE MAX.	YIELD*** MIN.	YIELD*** MAX.	CONDUCTIVITY MIN.	CONDUCTIVITY MAX.	ELONG % IN 2" OR 4D MIN.	ELONG % IN 2" OR 4D MAX.
169051-001	A /B	1	59.1	59.1	54.8	54.8			10.5	10.5

(STRENGTH KSI*)

CHEMICAL COMPOSITION IN PERCENT MAXIMUM UNLESS SHOWN AS A RANGE

ALLOY	SILICON	IRON	COPPER	MANGANESE	MAGNESIUM	CHROMIUM	ZINC	TITANIUM
6061	0.40-0.8	0.7	0.15-0.40	0.15	0.8-1.2	0.04-0.35	0.25	0.15

OTH/EACH	OTH/TOT	ALUMINUM
0.05	0.15	REMAINDER

CUSTOMER ______
P.O. NO. ______
APPROVED ______ DATE ______
TITLE ______

* KIPS PER SQUARE INCH. ONE KIP EQUALS ONE THOUSAND POUNDS.
** WHEN 2 OR MORE TESTS PER RACK ARE MADE, THE HIGHEST AND LOWEST VALUES ARE REPORTED.
*** YIELD STRENGTH IS DETERMINED BY THE 0.2% OFFSET METHOD.

Alcoa Extrusions, Inc.

32481-01.02
H94547
1787-001
T7

Figure 61: Material Certificate of Analysis and Tests (sheet 1 of 4)

D.2 Material Certificate of Analysis and Tests (sheet 2 of 4)

ESCO SDD Lot #: 1365-5-1

AvestaPolarit STAINLESS

AvestaPolarit, Inc.
Plate Products

Certificate of Analysis and Tests

OUR ORDER 1591 - 05 HEAT & PIECE 813212-2A 12

SOLD TO ESCO CORP
ATTENTION: HEATHER JOHNSON
P. O. BOX 10123
PORTLAND OR 97210

SHIP TO ESCO CORP.
6415 EAST CORVETTE
213-722-0300
LOS ANGELES CA
395001-0003

---------------- YOUR ORDER & DATE ----------------

1365 0/00/00

H 9545

ITEM DESCRIPTION

HEAT & PIECE 813212 - 2A
WEIGHT 12819
FINISH 1
GRADE 304L UNS-S30403
DIMENSIONS 1.750 X 96.000 X 261.000 EXACT

SPECIFICATIONS

*** MFG IN NEW CASTLE, IN, USA FROM SLABS IMPORTED FROM BRITAIN
AMS 5511G EXCEPT LINE MARK
QQ-S-766D AMENDIII EX.P4.5.2
QQ-S-763F COND A CHEM ONLY
ASTM A167-93, ASME SA167-92
ASTM A480-00 ASME SA480-01ED
LIST HEAT/PIECES ON INVOICE
.005 MAX SULFUR
ASTM A262-98 PRAC A

ASTM A240-01 ASME SA240 01ED
ASTM A276-00 CHEM ONLY
ASTM A479-00 CHEMISTRY ONLY
MIL-S-5059D WITH EXCEPTIONS
ASME SA479-01ED CHMONLY
NO SPECS REQUIRED ON INVOICE
ASTM A262-98 PRAC E

PLATES & TEST PCS SOLUTION ANNEALED @ 1950 DEGREES FARENHEIT MINIMUM
THEN WATER COOLED OR RAPIDLY COOLED BY AIR
FREE OF MERCURY CONTAMINATION
HOT ROLLED, ANNEALED & PICKLED (HRAP)

---------------- MECHANICAL & OTHER TESTS

HARDNESS RB	75
GRAIN SIZE	3
YIELD STRENGTH (PSI)	36394
TENSILE STRENGTH (PSI)	84468
INTERGRANULAR CORROSION	OK
ELONGATION % IN 2"	64.8
REDUCTION OF AREA %	68.0

ISO 9002-195
QMI Cert. #
003861

---------------- CHEMICAL COMPOSITION

CARBON	(C)	.015
MANGANESE	(MN)	1.48
PHOSPHORUS	(P)	.026
SULFUR	(S)	.002
SILICON	(SI)	.26
CHROMIUM	(CR)	18.23
NICKEL	(NI)	8.60
COBALT	(CO)	.12
COPPER	(CU)	.23
MOLY	(MO)	.27
NITROGEN	(N)	.07
COLUMBIUM	(CB)	.007
TITANIUM	(TI)	.003
ALUMINUM	(AL)	.006
TIN	(SN)	.011

1187-001

KNOWINGLY & WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM, OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

JAMES DOUBMAN, QUALITY ASSURANCE MANAGER

AvestaPolarit, Inc.
Plate Products
P.O. Box 370
New Castle, Indiana 47362

Figure 62: Material Certificate of Analysis and Tests (sheet 2 of 4)

D.3 Material Certificate of Analysis and Tests (sheet 3 of 4)

AvestaPolarit, Inc.
Plate Products

AvestaPolarit STAINLESS

Certificate of Analysis and Tests

OUR ORDER 1489 - 03 HEAT & PIECE 601004-1A 10/19/01

SOLD TO ESCO CORP
ATTENTION: HEATHER JOHNSON
P. O. BOX 10123
PORTLAND OR 97210

SHIP TO: ESCO CORP
30640 SAN CLEMENTE STREET
510-429-0100
HAYWARD CA 94544

0395001-0017

YOUR ORDER & DATE --------------

P11001JF001 0/00/00

ITEM DESCRIPTION

H 9568

HEAT & PIECE 601004 - 1A
WEIGHT 8129
FINISH 1
GRADE 304L UNS-S30403
DIMENSIONS 1.375 X 78.000 X 258.000 EXACT

SPECIFICATIONS ----------------

*** MFG IN NEW CASTLE, IN, USA FROM SLABS IMPORTED FROM SWEDEN
AMS 5511G EXCEPT LINE MARK
QQ-S-766D AMENDIII EX.P4.5.2
QQ-S-763F COND A CHEM ONLY
ASTM A167-93, ASME SA167-92
ASTM A480-00 ASME SA480-01ED
LIST HEAT/PIECES ON INVOICE
.005 MAX SULFUR
NO WELD REPAIRS
ASTM A262-98 PRAC A

ASTM A240-01 ASME SA240 01ED
ASTM A276-00 CHEM ONLY
ASTM A479-00 CHEMISTRY ONLY
MIL-S-5059D WITH EXCEPTIONS
ASME SA479-01ED CHMONLY
NO SPECS REQUIRED ON INVOICE
NO GRIPPER MARKS
ASTM A262-98 PRAC E

PLATES & TEST PCS SOLUTION ANNEALED @ 1950 DEGREES FARENHEIT MINIMUM
THEN WATER COOLED OR RAPIDLY COOLED BY AIR
FREE OF MERCURY CONTAMINATION
HOT ROLLED, ANNEALED & PICKLED (HRAP)

ISO 9002-1994
QMI Certified
003861

------------------------------ MECHANICAL & OTHER TESTS

HARDNESS RB	75
GRAIN SIZE	4
YIELD STRENGTH (PSI)	35183
TENSILE STRENGTH (PSI)	83028
INTERGRANULAR CORROSION	OK
ELONGATION % IN 2"	60.6
REDUCTION OF AREA %	68.3

-------------------------------- CHEMICAL COMPOSITION

CARBON	(C)	.017
MANGANESE	(MN)	1.54
PHOSPHORUS	(P)	.028
SULFUR	(S)	.001
SILICON	(SI)	.34
CHROMIUM	(CR)	18.25
NICKEL	(NI)	8.61
COBALT	(CO)	.11
COPPER	(CU)	.44
MOLY	(MO)	.37
NITROGEN	(N)	.07
COLUMBIUM	(CB)	.006
TITANIUM	(TI)	.001
ALUMINUM	(AL)	.001
TIN	(SN)	.013

1787-001

KNOWINGLY & WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM, OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

James Doubman

JAMES DOUBMAN, QUALITY ASSURANCE MANAGER

AvestaPolarit, Inc.
Plate Products
P.O. Box 370
New Castle, Indiana 47362

ESCO SDD Lot #: M4152

Figure 63: Material Certificate of Analysis and Tests (sheet 3 of 4)

D.4 Material Certificate of Analysis and Tests (sheet 4 of 4)

Avesta Sheffield

Avesta Sheffield Plate Inc.

Certificate of Analysis and Tests

OUR ORDER 1067 - 01

HEAT & PIECE 810355-1B 1/10/01

SOLD TO: ESCO CORP
ATTENTION: HEATHER JOHNSON
P. O. BOX 10123
PORTLAND OR 97210

SHIP TO: ESCO CORP.
6415 EAST CORVETTE
213-722-0300
LOS ANGELES CA 90040
395001-0003

-------------------------------- YOUR ORDER & DATE --------------------------------

P01228JF004 0/00/00

-------------------------------- ITEM DESCRIPTION --------------------------------

HEAT & PIECE	810355 - 1B	
WEIGHT	4579	
FINISH	1	
GRADE	304L	UNS-S30403
DIMENSIONS	.625 X 96.000 X 256.000	EXACT

-------------------------------- SPECIFICATIONS --------------------------------

*** MFG IN NEW CASTLE, IN, USA
AMS 5511G EXCEPT LINE MARK
QQ-S-766D AMENDIII EX.P4.5.2
QQ-S-763F COND A CHEM ONLY
ASTM A167-93, ASME SA167-92
ASTM A480-99 ASME SA480-98ED
LIST HEAT/PIECES ON INVOICE
NO GRIPPER MARKS
ASTM A262-98 PRAC A

FROM SLABS IMPORTED FROM BRITAIN
ASTM A240-00 ASME SA240-98ED
ASTM A276-00 CHEM ONLY
ASTM A479-00 CHEMISTRY ONLY
MIL-S-5059D WITH EXCEPTIONS
ASME SA479-98ED 00A CHM ONLY
NO SPECS REQUIRED ON INVOICE
NO WELD REPAIRS
ASTM A262-98 PRAC E

PLATES & TEST PCS SOLUTION ANNEALED @ 1950 DEGREES FARENHEIT MINIMUM.
THEN WATER COOLED OR RAPIDLY COOLED BY AIR
FREE OF MERCURY CONTAMINATION
HOT ROLLED, ANNEALED & PICKLED (HRAP)

-------------------------------- MECHANICAL & OTHER TESTS --------------------------------

HARDNESS RB	84
GRAIN SIZE	5
YIELD STRENGTH (PSI)	48830
TENSILE STRENGTH (PSI)	89569
BEND	OK
INTERGRANULAR CORROSION	OK
ELONGATION % IN 2"	57.0
REDUCTION OF AREA %	65.4

-------------------------------- CHEMICAL COMPOSITION --------------------------------

CARBON	(C)	.018
MANGANESE	(MN)	1.44
PHOSPHORUS	(P)	.030
SULFUR	(S)	.024
SILICON	(SI)	.42
CHROMIUM	(CR)	18.09
NICKEL	(NI)	8.42
COBALT	(CO)	.10
COPPER	(CU)	.32
MOLY	(MO)	.24
NITROGEN	(N)	.06
COLUMBIUM	(CB)	.008
TITANIUM	(TI)	.002
ALUMINUM	(AL)	.006
TIN	(SN)	.015

KNOWINGLY & WILLFULLY FALSIFYING OR CONCEALING A MATERIAL FACT ON THIS FORM, OR MAKING FALSE, FICTITIOUS OR FRAUDULENT STATEMENTS OR REPRESENTATIONS HEREIN COULD CONSTITUTE A FELONY PUNISHABLE UNDER FEDERAL STATUTES.

JAMES DOUBMAN, QUALITY ASSURANCE MANAGER

Avesta Sheffield Plate Inc.
P O Box 370
New Castle, Indiana 47362

H 95 46

1787-0027

ESCO SDD Lot #: M3819

Figure 64: Material Certificate of Analysis and Tests (sheet 4 of 4)

D.5 List of O-Ring Seals

Piece	Parker O ring no.
End flange	387
End sealing plate	387
Window sealing plate	169
Ports	216
Longitudinal	0.210 diam. cord
Initiator bolts	113
Initiator bath	463

Table 6: List of O-Ring Seals

D.6 Side Plate Bolt Locations (sheet 1 of 2)

This was sent together with the drawings to Hales to ensure tolerances didn't add up on the bolt locations.

BOLT LOCATION 1

Part 1: Side Plate A
Bolt location with respect to datum A
Tolerance is +/- 0.010
Reference: Drawing 1

bolt no.	location	bolt no.	location
1	0.600	46	111.000
2	2.900	47	113.300
3	5.200	48	115.600
4	7.500	49	117.900
5	9.800	50	120.200
6	12.100	51	122.500
7	14.400	52	124.800
8	16.700	53	127.100
9	19.000	54	129.400
10	28.200	55	131.700
11	30.500	56	134.000
12	32.800	57	136.300
13	35.100	58	138.600
14	37.400	59	140.900
15	39.700	60	143.200
16	42.000		
17	44.300		
18	46.600		
19	48.900		
20	51.200		
21	53.500		
22	55.800		
23	58.100		
24	60.400		
25	62.700		
26	65.000		
27	67.300		
28	69.600		
29	71.900		
30	74.200		
31	76.500		
32	78.800		
33	81.100		
34	83.400		
35	85.700		
36	88.000		
37	90.300		
38	92.600		
39	94.900		
40	97.200		
41	99.500		
42	101.800		
43	104.100		
44	106.400		
45	108.700		

Part 2: Side Plate B
Bolt location with respect to datum A
Tolerance is+/- 0.010
Reference: Drawing 4

bolt no.	location	bolt no.	location
1	0.600	46	111.000
2	2.900	47	113.300
3	5.200	48	115.600
4	7.500	49	117.900
5	9.800	50	120.200
6	12.100	51	122.500
7	14.400	52	124.800
8	16.700	53	127.100
9	19.000	54	129.400
10	28.200	55	131.700
11	30.500	56	134.000
12	32.800	57	136.300
13	35.100	58	138.600
14	37.400	59	140.900
15	39.700	60	143.200
16	42.000		
17	44.300		
18	46.600		
19	48.900		
20	51.200		
21	53.500		
22	55.800		
23	58.100		
24	60.400		
25	62.700		
26	65.000		
27	67.300		
28	69.600		
29	71.900		
30	74.200		
31	76.500		
32	78.800		
33	81.100		
34	83.400		
35	85.700		
36	88.000		
37	90.300		
38	92.600		
39	94.900		
40	97.200		
41	99.500		
42	101.800		
43	104.100		
44	106.400		
45	108.700		

Figure 65: Side Plate Bolt Locations (sheet 1 of 2)

D.7 Side Plate Bolt Locations (sheet 2 of 2)

Part 3: Top Plate
Bolt location with respect to datum B
Tolerance is+/- 0.010
Reference: Drawing 7

bolt no.	location	bolt no.	location
1	0.600	46	111.000
2	2.900	47	113.300
3	5.200	48	115.600
4	7.500	49	117.900
5	9.800	50	120.200
6	12.100	51	122.500
7	14.400	52	124.800
8	16.700	53	127.100
9	19.000	54	129.400
10	28.200	55	131.700
11	30.500	56	134.000
12	32.800	57	136.300
13	35.100	58	138.600
14	37.400	59	140.900
15	39.700	60	143.200
16	42.000		
17	44.300		
18	46.600		
19	48.900		
20	51.200		
21	53.500		
22	55.800		
23	58.100		
24	60.400		
25	62.700		
26	65.000		
27	67.300		
28	69.600		
29	71.900		
30	74.200		
31	76.500		
32	78.800		
33	81.100		
34	83.400		
35	85.700		
36	88.000		
37	90.300		
38	92.600		
39	94.900		
40	97.200		
41	99.500		
42	101.800		
43	104.100		
44	106.400		
45	108.700		

Part 4: Bottom Plate
Bolt location with respect to datum B
Tolerance is+/- 0.010
Reference: Drawing 9

bolt no.	location	bolt no.	location
1	0.600	46	111.000
2	2.900	47	113.300
3	5.200	48	115.600
4	7.500	49	117.900
5	9.800	50	120.200
6	12.100	51	122.500
7	14.400	52	124.800
8	16.700	53	127.100
9	19.000	54	129.400
10	28.200	55	131.700
11	30.500	56	134.000
12	32.800	57	136.300
13	35.100	58	138.600
14	37.400	59	140.900
15	39.700	60	143.200
16	42.000		
17	44.300		
18	46.600		
19	48.900		
20	51.200		
21	53.500		
22	55.800		
23	58.100		
24	60.400		
25	62.700		
26	65.000		
27	67.300		
28	69.600		
29	71.900		
30	74.200		
31	76.500		
32	78.800		
33	81.100		
34	83.400		
35	85.700		
36	88.000		
37	90.300		
38	92.600		
39	94.900		
40	97.200		
41	99.500		
42	101.800		
43	104.100		
44	106.400		
45	108.700		

Figure 66: Side Plate Bolt Locations (sheet 2 of 2)

D.8 Shot Checklist (sheet 1 of 2)

Narrow Channel Shot Checklist Last Modified: April 9, 2003

Shot: ________ Date: ________ Time: ________

Operator(s): ____________________ Series: ____________________

Estimated reflected wave pressure: ________ bar ($\leq$2.2 MPa) Driver Settings:

Ignition Delay		dial
Flow Duration		dial

Preparation and Pump Down

1. ___ Turn on Main Control Panel 12 V relay and close it
2. ___ Open T1 and T2
3. ___ Open vacuum isolation valve
4. ___ Switch on thermocouple vacuum gauge
5. ___ Open F1 (gas supply needle valve)
6. ___ Close L1 (vacuum manifold leak-up valve)
7. ___ Check that EDL is not using vacuum pump
8. ___ Open vacuum manifold valve (at pump); set vacuum pump status indicator
9. ___ Connect Spark Box to spark plug
10. ___ Wait for pressure to drop below 200 millitorr - Final level: ________ millitorr
11. ___ Check Driver arm is off (if light is on go to misfire procedures)
12. ___ Set zero on Heise gauge(s)
13. ___ Close V1
14. ___ Close vacuum manifold valve (at pump); set vacuum pump status indicator

Gas Fill Procedure

15. ___ Turn on warning lights and check that doors are closed - **Laboratory Access is Restricted**
16. ___ Turn on gas supply wall switch

Fill to desired pressure using external block valves, gas supply valves, and fill valve, F1. If atmospheric air is used, fill it first, using V1 and L1. **Evacuate lines between filling with different gases.**

Gas	Target Fraction	Target Partial Pressure	Target Final Pressure	Final Pressure
		mbar	mbar	mbar
		mbar	mbar	mbar
		mbar	mbar	mbar
		mbar	mbar	mbar
		mbar	mbar	mbar

17. ___ Turn off gas supply wall switch
18. ___ Close F1 and gas supply ball valves
19. ___ Run circulation pump for 5 minutes: Final pressure ________ torr Final temperature ________ °C
20. ___ Close T1, T2

Firing Procedure

21. ___ Arm data acquisition system(s)
22. ___ Close Heise gauge isolation valve(s)
23. ___ Turn off electronic Heise gauge
24. ___ Align tube to "fire" position; check that movement is free.
25. ___ Switch off 12 V relay (on Main Control Panel)
26. ___ Open and close O2 (regular valve) to fill oxygen reservior
27. ___ Open and close A2 (regular valve) to fill oxygen reservior
28. ___ Reset Controller
29. ___ Arm Driver
30. ___ Turn on Driver Injection

Figure 67: Shot Checklist (sheet 1 of 2)

D.9 Shot Checklist (sheet 2 of 2)

31. ___ Turn on Spark Box
32. ___ Check data acquisition system(s); rearm if necessary
33. ___ To initiate shot, press and hold red Fire button Time: ________
34. ___ If system misfires, execute Misfire Procedure and continue with item 38
35. ___ Download data
36. ___ Turn off Spark Box
37. ___ Turn off warning lights - **Laboratory Access is Unrestricted**

Tube Venting Procedure

38. ___ Switch on 12 V relay on Main Control Panel and close it
39. ___ Switch on electronic Heise gauge
40. ___ Check that EDL is not using pump
41. ___ Open vacuum manifold valve (at pump); set vacuum pump status indicator
42. ___ Open V1 and Heise gauge isolation valve Final pressure: ________ torr
43. ___ When pressure drops to about 200 millitorr, open T1, T2
44. ___ When pressure reaches 200 millitorr, close vacuum manifold valve (at pump); set vacuum pump status indicator
45. ___ Open L1 to vent vessel up to atmospheric pressure

Initiator arrival times:

	1	2	3
Times	μs	μs	μs

Record wave speeds:

	4	5	6	7	CJ Speed
Times	μs	μs	μs	μs	
Speeds	m/s	m/s	m/s	m/s	

Remarks:

Figure 68: Shot Checklist (sheet 2 of 2)

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