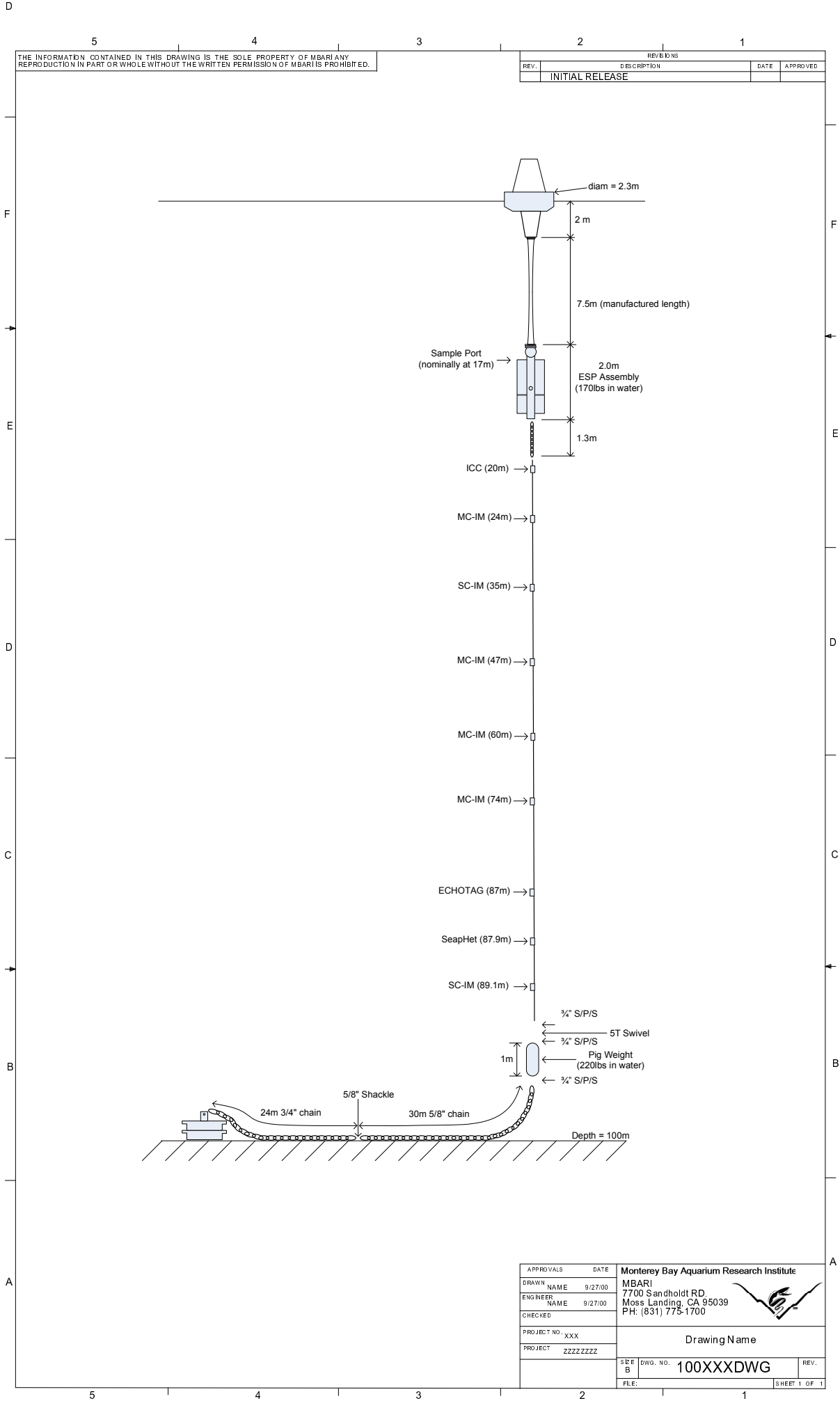
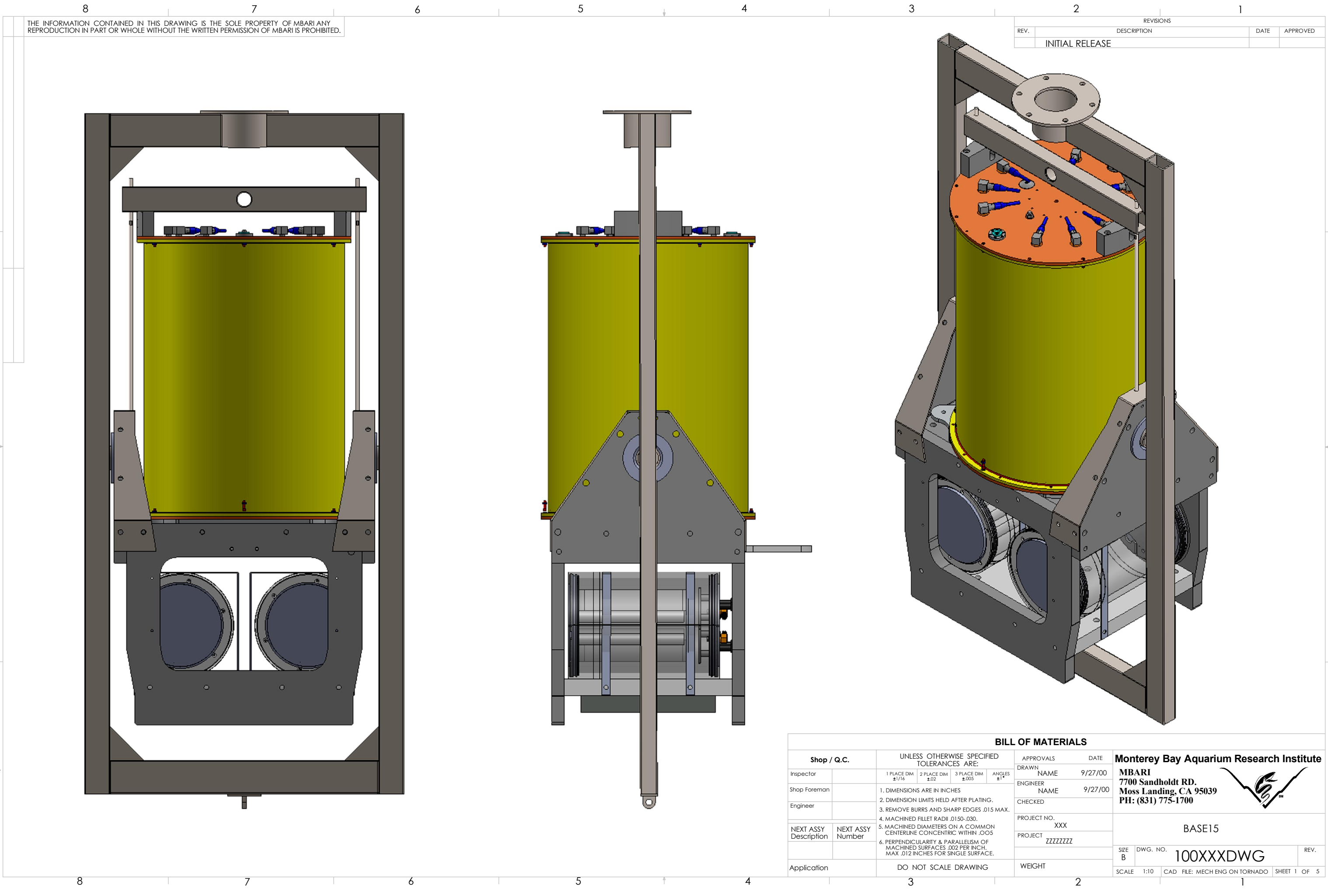




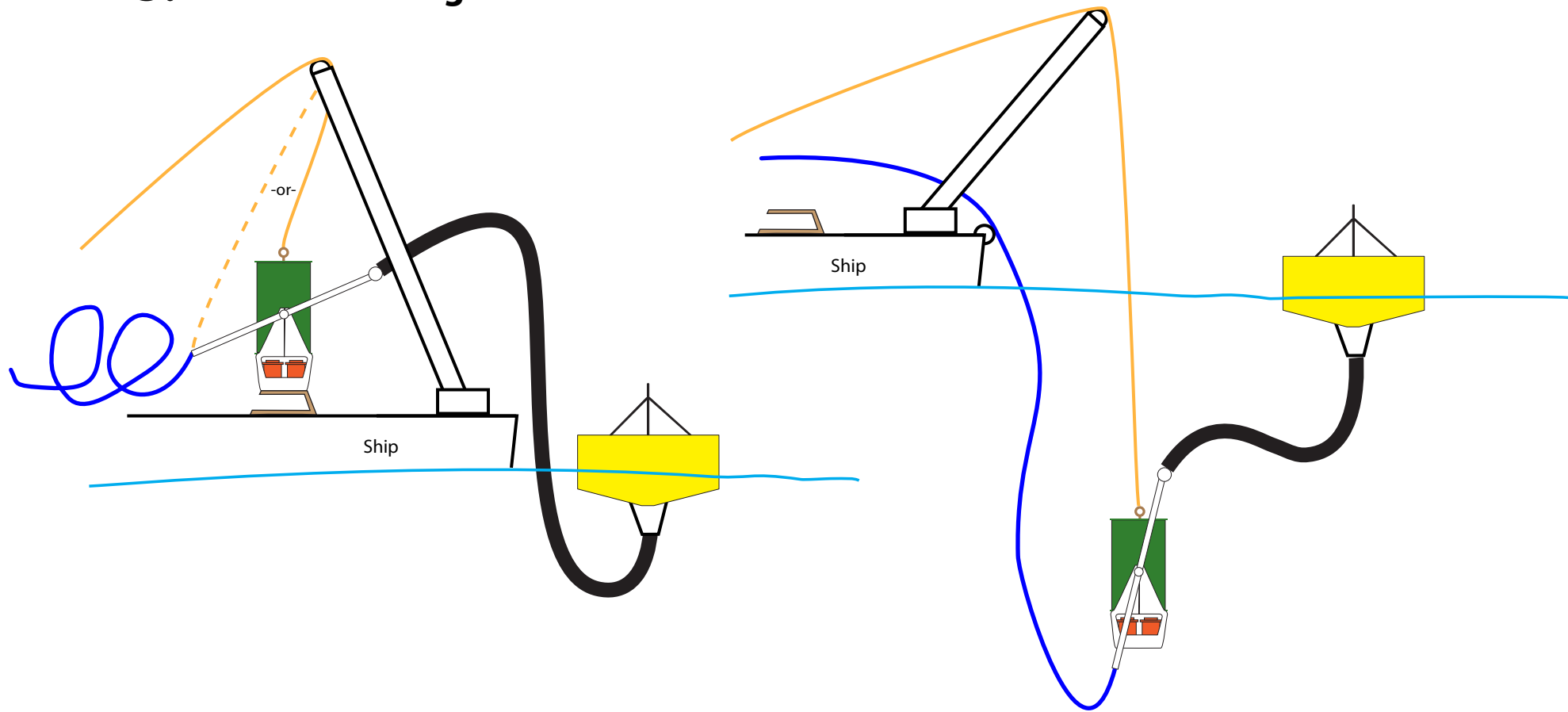


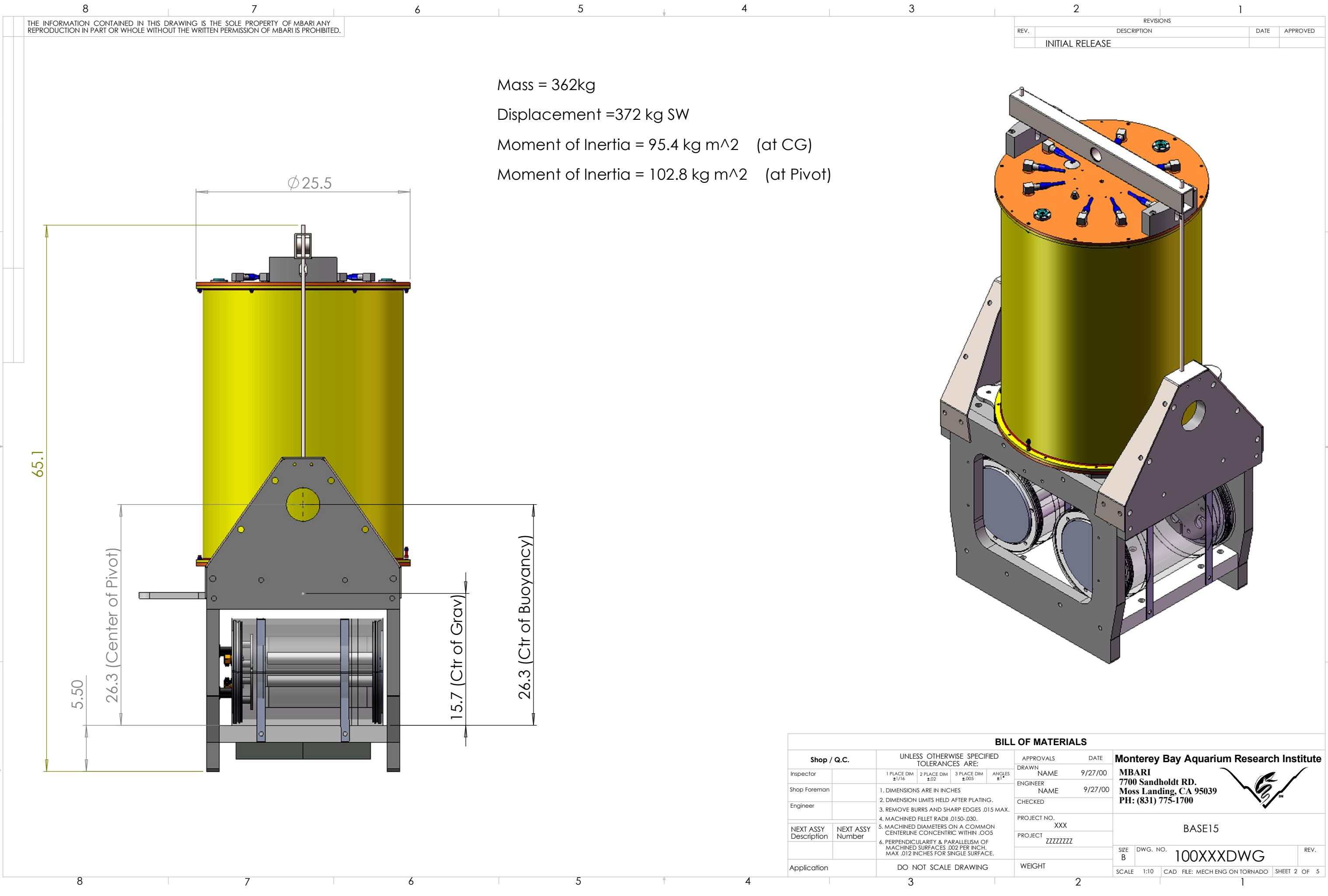
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REVISIONS			
REV.	DESCRIPTION	DATE	APPROVED
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BILL OF MATERIALS										
Shop / Q.C.		UNLESS OTHERWISE SPECIFIED TOLERANCES ARE:				APPROVALS		DATE		
Inspector		1 PLACE DIM ±1/16	2 PLACE DIM ±.02	3 PLACE DIM ±.005	ANGLES ±1°	DRAWN	NAME	9/27/00		
Shop Foreman		1. DIMENSIONS ARE IN INCHES 2. DIMENSION LIMITS HELD AFTER PLATING. 3. REMOVE BURRS AND SHARP EDGES .015 MAX. 4. MACHINED FILLET RADII .0150-.030. 5. MACHINED DIAMETERS ON A COMMON CENTERLINE CONCENTRIC WITHIN .005 6. PERPENDICULARITY & PARALLELISM OF MACHINED SURFACES .002 PER INCH. MAX .012 INCHES FOR SINGLE SURFACE.				ENGINEER	NAME	9/27/00		
Engineer						CHECKED				
NEXT ASSY Description	NEXT ASSY Number					PROJECT NO.	XXX			
		PROJECT	ZZZZZZZZ		BASE15					
Application		DO NOT SCALE DRAWING				WEIGHT		SIZE B	DWG. NO. 100XXXDWG	REV.
						SCALE 1:10		CAD FILE: MECH ENG ON TORNADO		SHEET 1 OF 5

3. Double Bail cage

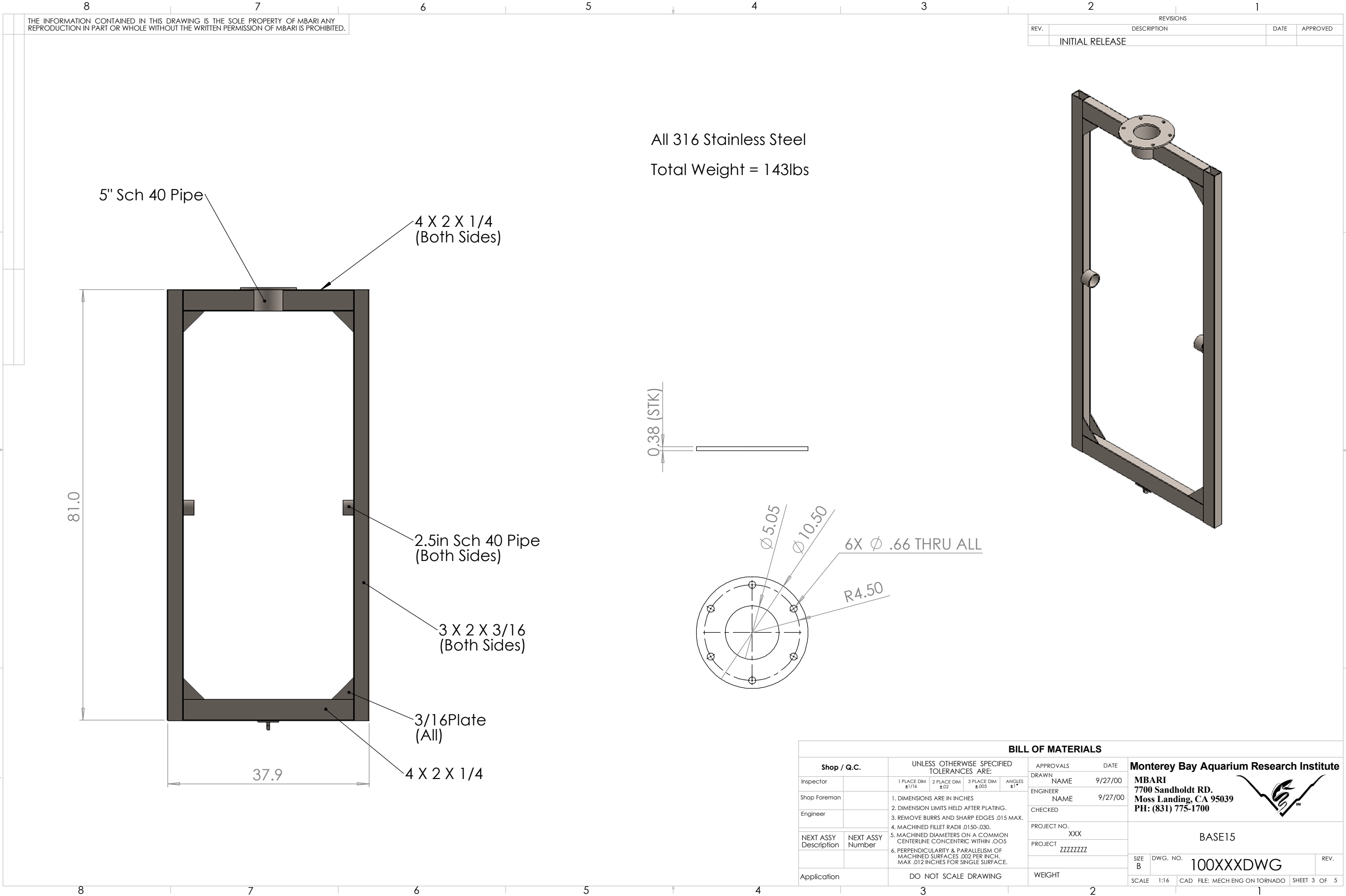




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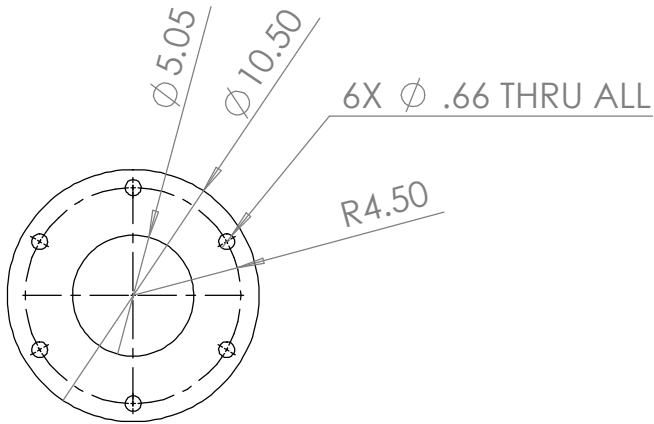
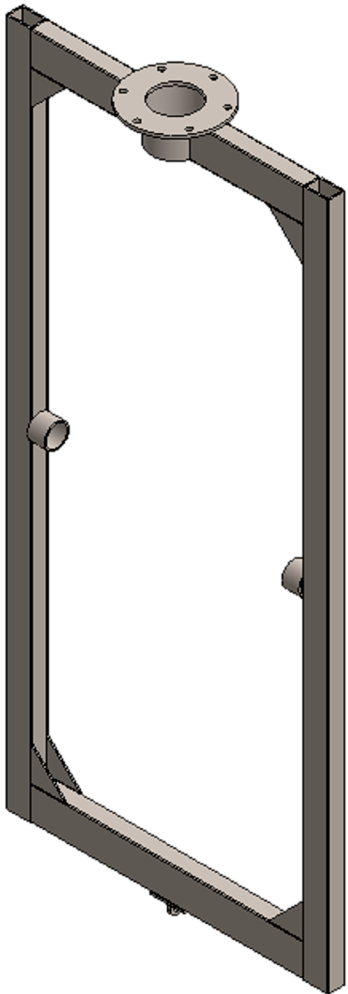
Shop / Q.C.				UNLESS OTHERWISE SPECIFIED TOLERANCES ARE:				APPROVALS		DATE		Monterey Bay Aquarium Research Institute							
Inspector				1 PLACE DIM ±1/16		2 PLACE DIM ±.02		3 PLACE DIM ±.005		ANGLES ±1°		DRAWN NAME		9/27/00		MBARI 7700 Sandholdt RD. Moss Landing, CA 95039 PH: (831) 775-1700			
Shop Foreman				1. DIMENSIONS ARE IN INCHES 2. DIMENSION LIMITS HELD AFTER PLATING. 3. REMOVE BURRS AND SHARP EDGES .015 MAX. 4. MACHINED FILLET RADII .0150-.030. 5. MACHINED DIAMETERS ON A COMMON CENTERLINE CONCENTRIC WITHIN .005 6. PERPENDICULARITY & PARALLELISM OF MACHINED SURFACES .002 PER INCH. MAX .012 INCHES FOR SINGLE SURFACE.								ENGINEER NAME		9/27/00					
Engineer												CHECKED							
NEXT ASSY Description		NEXT ASSY Number										PROJECT NO. XXX							
												PROJECT ZZZZZZZZ							
Application				DO NOT SCALE DRAWING								WEIGHT							
				3								2							
												1							



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All 316 Stainless Steel
Total Weight = 143lbs



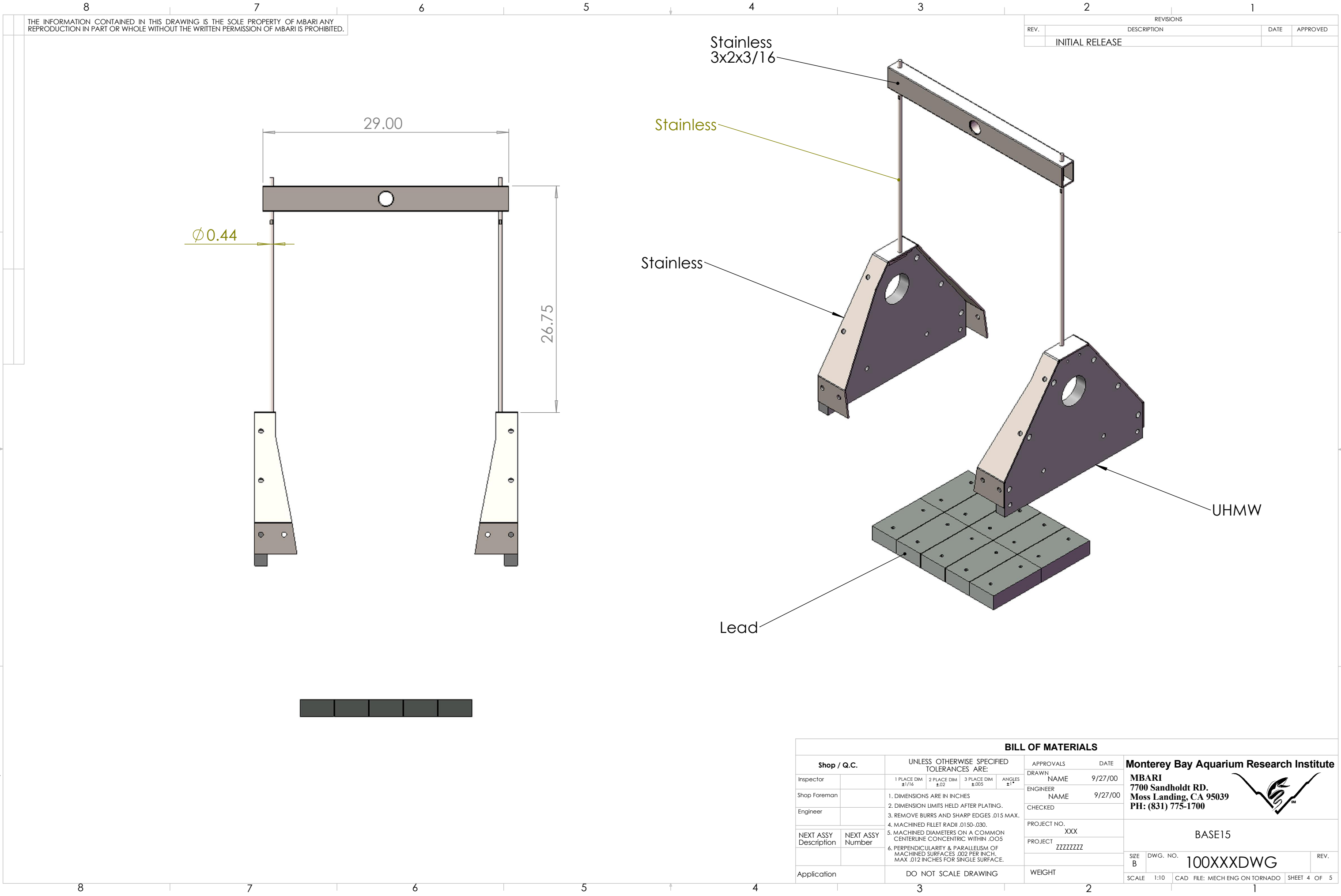
BILL OF MATERIALS									
Shop / Q.C.		UNLESS OTHERWISE SPECIFIED TOLERANCES ARE:				APPROVALS		DATE	
Inspector		1 PLACE DIM ±1/16	2 PLACE DIM ±.02	3 PLACE DIM ±.005	ANGLES ±1°	DRAWN	NAME	9/27/00	
Shop Foreman		1. DIMENSIONS ARE IN INCHES 2. DIMENSION LIMITS HELD AFTER PLATING. 3. REMOVE BURRS AND SHARP EDGES .015 MAX. 4. MACHINED FILLET RADII .0150-.030. 5. MACHINED DIAMETERS ON A COMMON CENTERLINE CONCENTRIC WITHIN .005 6. PERPENDICULARITY & PARALLELISM OF MACHINED SURFACES .002 PER INCH. MAX .012 INCHES FOR SINGLE SURFACE.				ENGINEER	NAME	9/27/00	
Engineer						CHECKED			
NEXT ASSY Description	NEXT ASSY Number					PROJECT NO.	XXX		
						PROJECT	ZZZZZZZZ		
Application		DO NOT SCALE DRAWING				WEIGHT			
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								CAD FILE: MECH ENG ON TORNADO	REV.
								SHEET 3 OF 5	

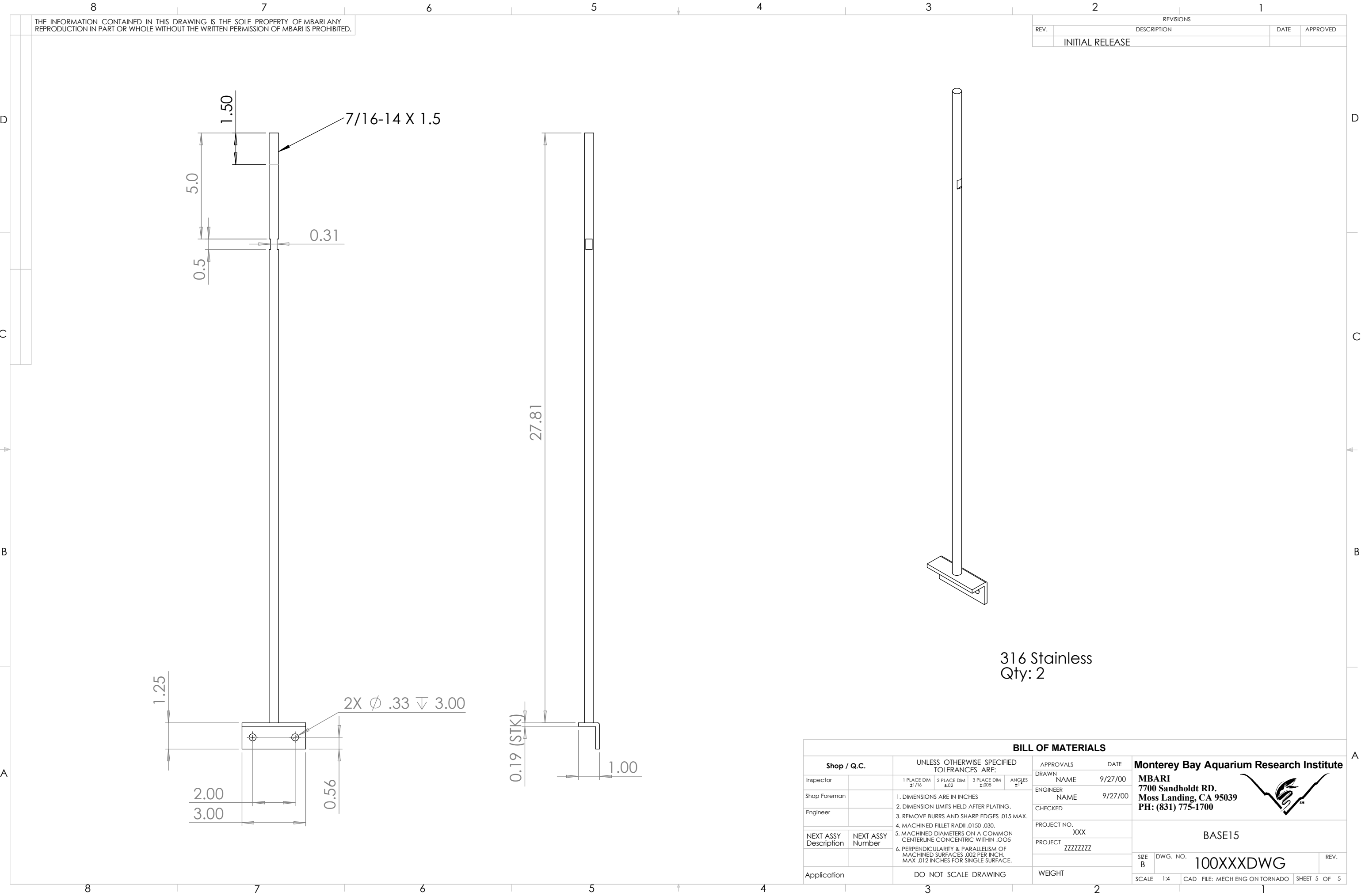
Monterey Bay Aquarium Research Institute
MBARI
7700 Sandholdt RD.
Moss Landing, CA 95039
PH: (831) 775-1700



BASE15

SCALE 1:16	CAD FILE: MECH ENG ON TORNADO	SHEET 3 OF 5
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grav = 9.8 m/s²
rho_sw = 1025 kg/m³

Number of Batt Housings 2
Number of Lead Bricks 10

	<i>Mass</i>		<i>Disp</i>	<i>Wet Weight</i>	
<i>Component</i>	<i>kg</i>	<i>lbs</i>	<i>m^3</i>	<i>N</i>	<i>lbs</i>
<i>ESP in Shallow housing</i>	120.0	264.0	0.2480	-1315.2	-295.5
<i>Battery Housings (each)</i>	18.2	40.1	0.0140	38.1	8.6
<i>Base And Lift Hardware</i>	90.5	199.1	0.0740	143.6	32.3
<i>CTD (shallow 19+)</i>	7.3	16.1	0.0049	22.3	5.0
<i>Ballast Bricks (each)</i>	11.5	25.3	0.0010	102.3	23.0
Sub Total (ESP in Frame)	369.3	812.4	0.3653	-50.5	-11.3
<i>Double Bale Weldment</i>	65.0	143.0	0.0081	555.4	124.8
Totals	434.3	955.4	0.4	504.9	113.5

Target 170
Delta -56.5

ESP itself weighs 110lbs with reagents, pucks, etc. Measured on 8/22/15

Not included in Solidworks model

Mass Properties

ProjectedAreaEstimate.SLDPRT

Options...

Override Mass Properties... Recalculate

☒ Include hidden bodies/components
☐ Create Center of Mass feature
☐ Show weld bead mass

Report coordinate values relative to: -- default --

Mass properties of ProjectedAreaEstimate
Configuration: Default
Coordinate system: -- default --

The mass properties were copied from an assembly when the assembly was saved as a part.
To update the mass properties, please open the assembly and resave it as a part.

Density = 1025.00000 kilograms per cubic meter

Mass = 365.80422 kilograms

Volume = 0.35688 cubic meters

Surface area = 16.24887 square meters

Center of mass: (meters)
X = 0.00001
Y = 0.71089
Z = 0.00007

Principal axes of inertia and principal moments of inertia: (kilograms * square meters)
Taken at the center of mass.

Ix = (-0.00005, 1.00000, -0.00097)	Px = 21.36148
Iy = (-1.00000, -0.00005, 0.00083)	Py = 68.82222
Iz = (0.00083, 0.00097, 1.00000)	Pz = 71.59552

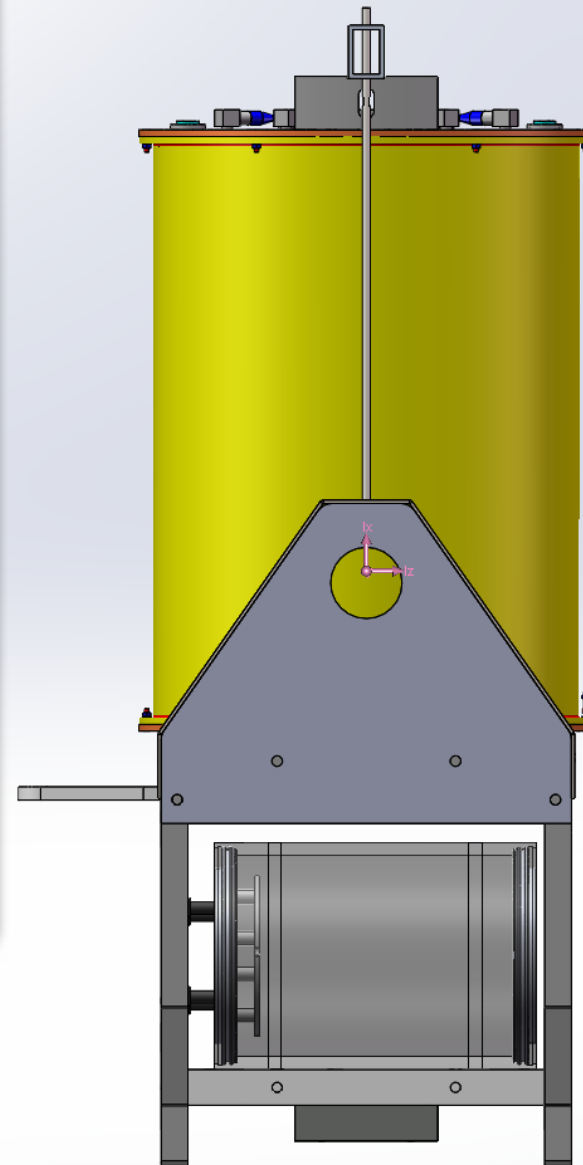
Moments of inertia: (kilograms * square meters)
Taken at the center of mass and aligned with the output coordinate system.

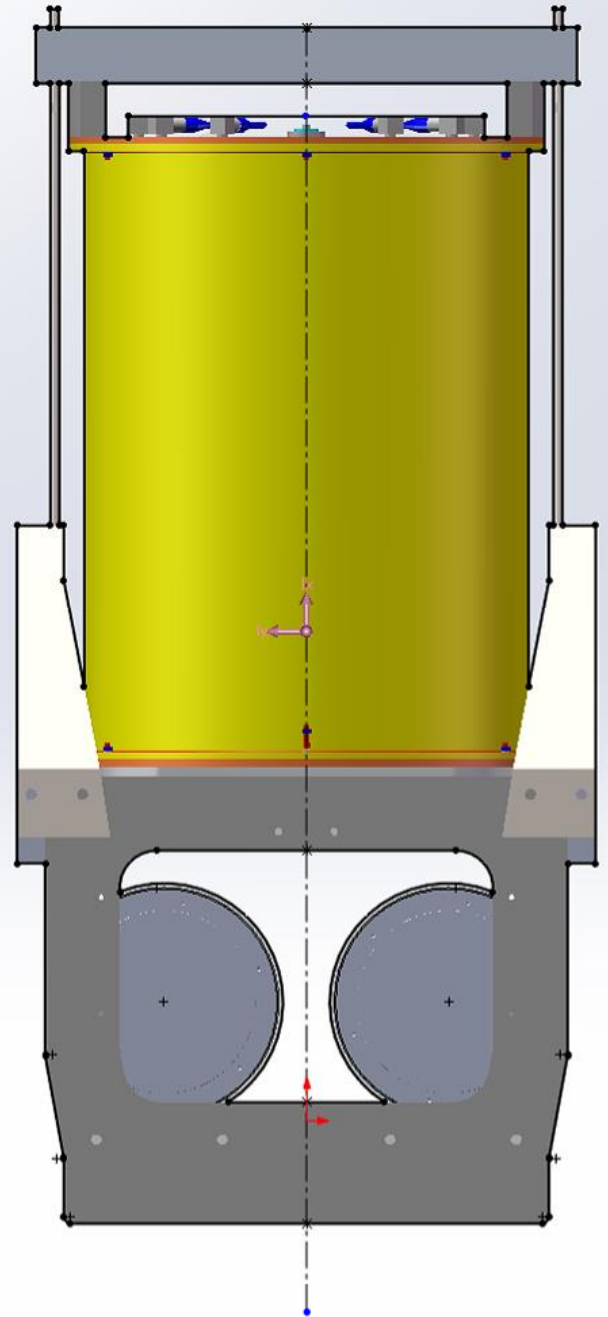
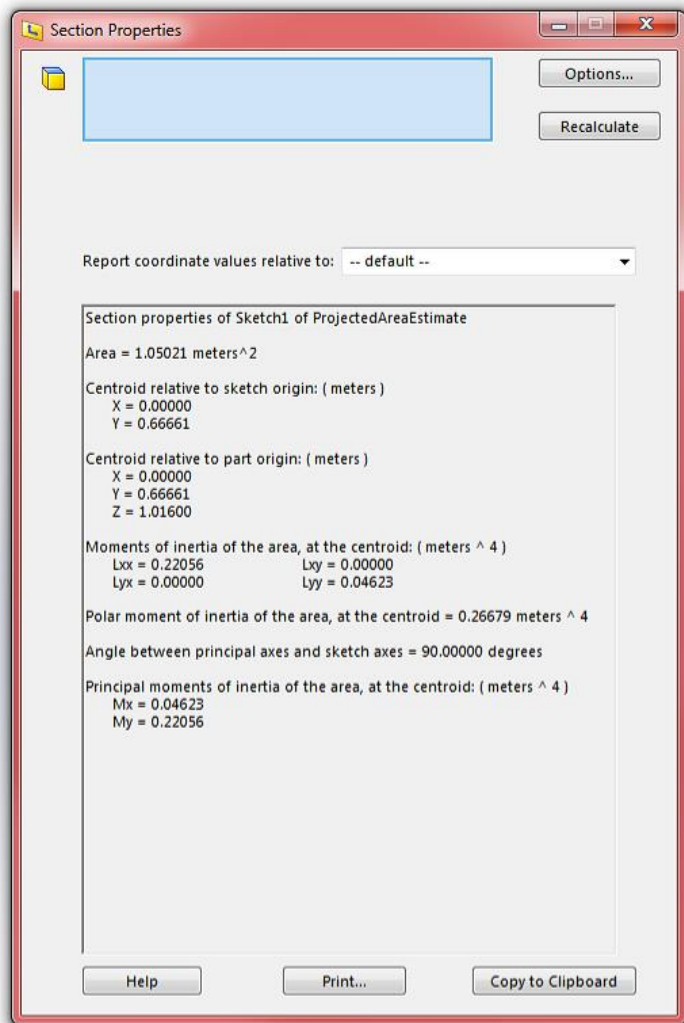
Lxx = 68.82222	Lxy = -0.00247	Lxz = -0.00229
Lyx = -0.00247	Lyx = 21.36152	Lyz = -0.04892
Lzx = -0.00229	Lzy = -0.04892	Lzz = 71.59547

Moments of inertia: (kilograms * square meters)
Taken at the output coordinate system.

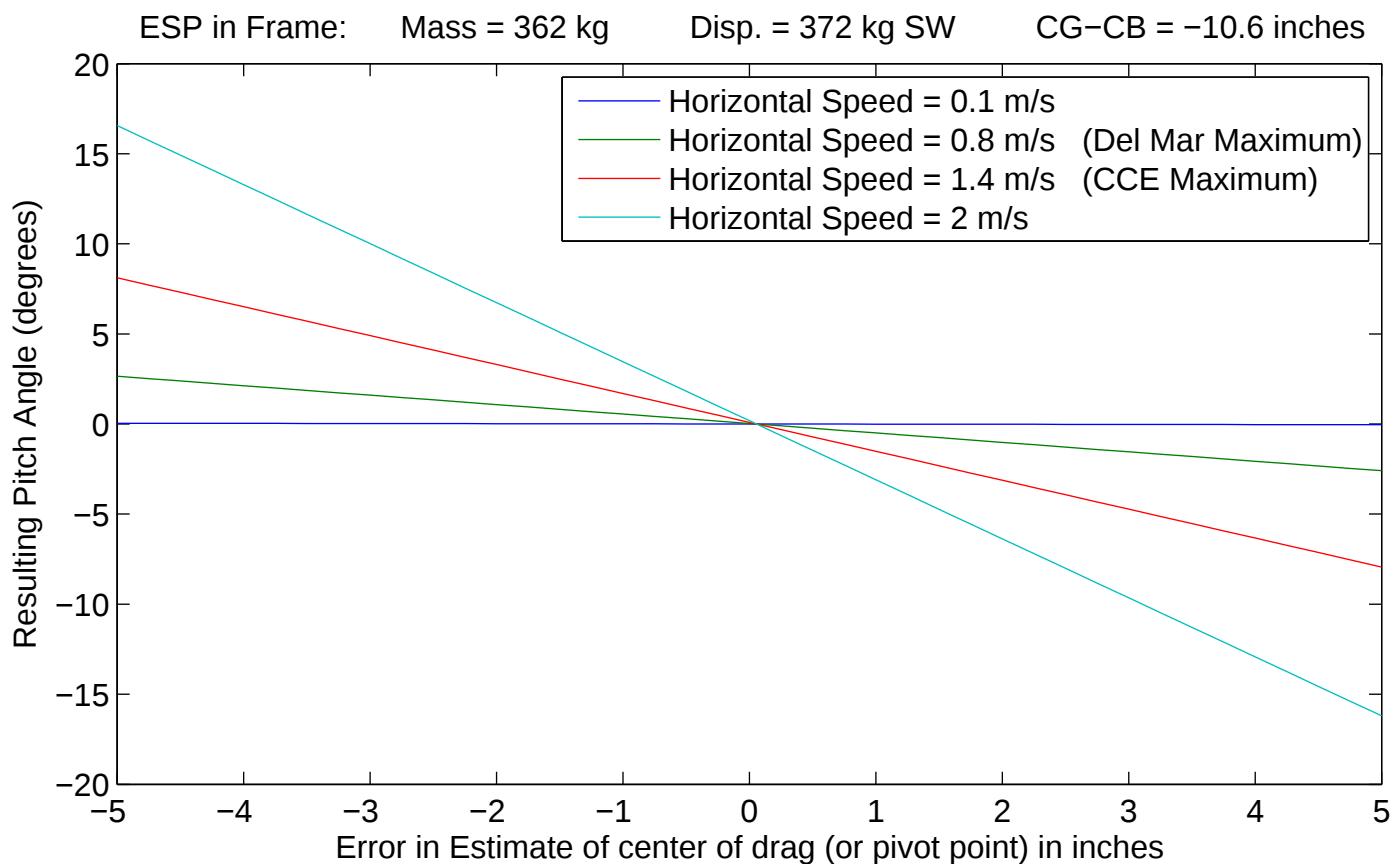
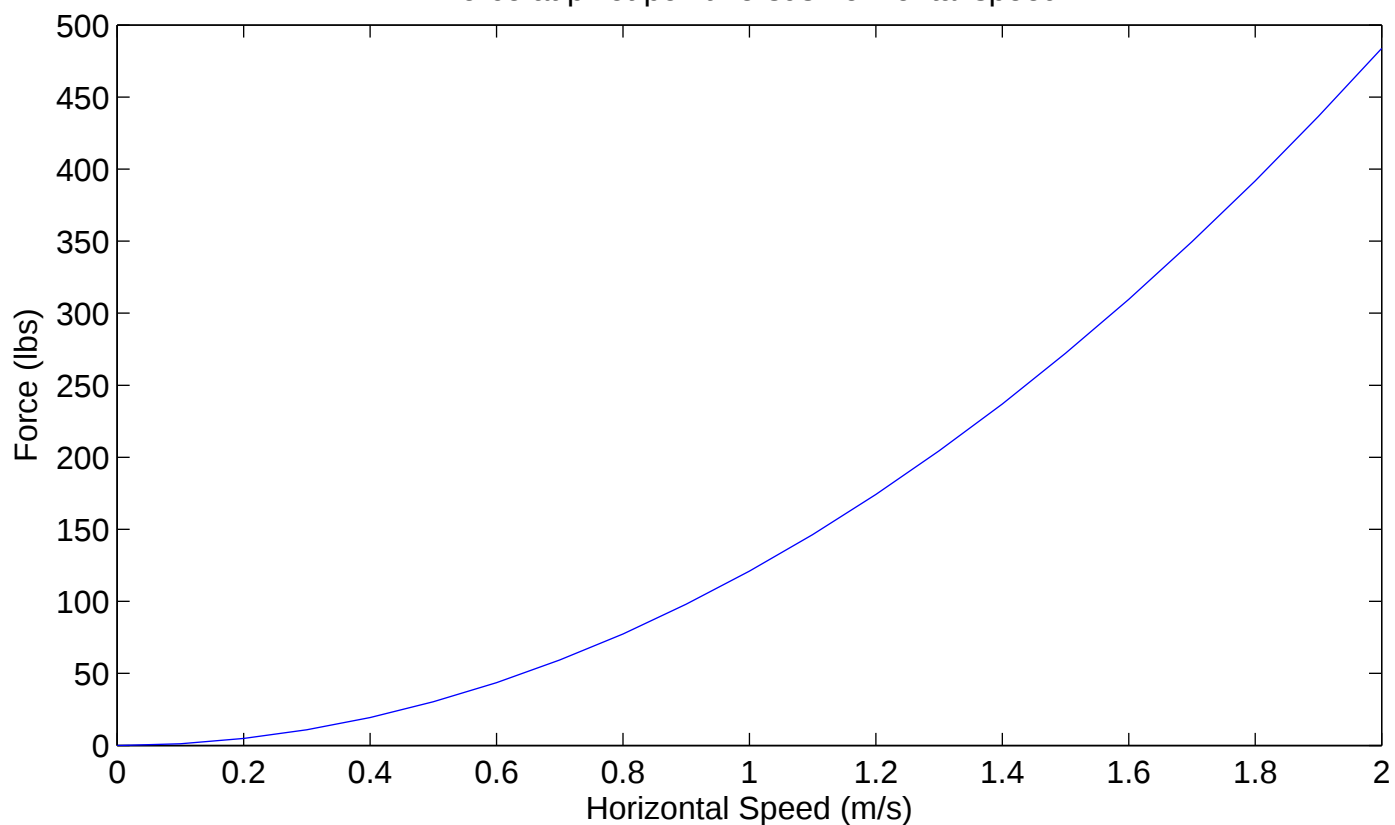
Ixx = 253.68868	Ixy = -0.00055	Ixz = -0.00229
Iyx = -0.00055	Iyy = 21.36153	Iyz = -0.03148
Izx = -0.00229	Izy = -0.03148	Izz = 256.46193

Help Print... Copy to Clipboard





Force at pivot point versus horizontal speed

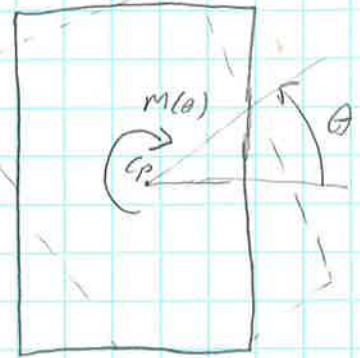


ESP HOUSING + FRAME PITCH MOTIONS

$$I^p = \text{mass moments of inertia} \quad [kg \cdot m^2]$$

$$a^p = \text{added mass} \quad [kg \cdot m^2]$$

$$M(\theta)$$



ANGULAR POSITION: $\theta(t) = \text{Re}[g e^{i\omega t}]$ $g = \text{COMPLEX PITCH AMPLITUDE}$

$$\dot{\theta}(t) = \text{Re}[g i \omega e^{i\omega t}]$$

$$\ddot{\theta}(t) = \text{Re}[-g \omega^2 e^{i\omega t}]$$

MOMENTS ACTING ON BODY

STABILITY: $M(\theta) = -\bar{B}G m_g \sin \theta$

$$\approx -\bar{B}G m_g \theta \quad [N \cdot m]$$

$$= \text{Re}[-\bar{B}G m_g g e^{i\omega t}]$$

RADIATION

$$M_r(t) = -a_{66} \ddot{\theta}(t) - b_{66} \dot{\theta}(t)$$

$$= \text{Re}[g e^{i\omega t} (a_{66} \omega^2 - i \omega b_{66})]$$

$a_{66} = \text{PITCH ADDED MASS}$

$b_{66} = \text{PITCH DAMPING}$

EXCITING

$$F_6^E(t) = \text{Re}[A X_6 e^{i\omega t}] \quad X_6 = \text{COMPLEX PITCH EXCITING FORCE}$$

$$I \ddot{\theta} = \Sigma M$$

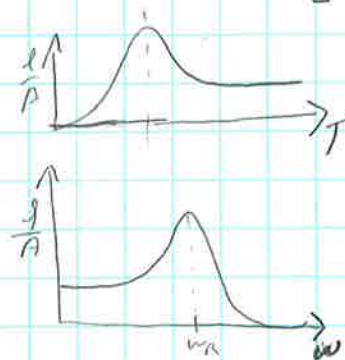
$$\text{Re}[-I g \omega^2 e^{i\omega t}] = \text{Re}[-\bar{B}G m_g g e^{i\omega t} + g a_{66} \omega^2 e^{i\omega t} - i \omega b_{66} g e^{i\omega t} + A X_6 e^{i\omega t}]$$

$$g[-(I + a_{66}) \omega^2 + \bar{B}G m_g + i \omega b_{66}] = A X_6$$

$$\boxed{\frac{g}{A} = \frac{X_6}{-\omega^2(I + a_{66}) + i \omega b_{66} + \bar{B}G m_g}}$$

RESONANCE: $-\omega^2(I + a_{66}) + i \omega b_{66} + \bar{B}G m_g = 0$

$$\omega = \sqrt{\frac{\bar{B}G m_g}{(I + a_{66})}}$$

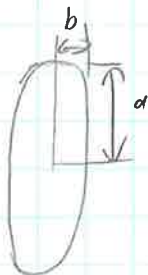


PITCH ADDED MASS (INERTIA)

8/16/15 - JAH

ESTIMATE: MODEL ESP+ FRAME AS A PROLATE SPHEROID OF SIMILAR LENGTH AND DIAMETER TO DETERMINE APPROXIMATE ADDED-MASS COEFF, THEN APPLY THAT COEFF TO THE PITCH MOMENT OF INERTIA OF THE DISPLACED WATER.

PROLATE SPHEROID $a = .8 \text{ m}$
 $b = .3 \text{ m}$



$$b/a = .375$$

$$m_{66}' \approx 0.4 = \frac{m_{66}}{\frac{4}{15} \pi \rho a b^2 (a^2 + b^2)} \left. \vphantom{\frac{m_{66}}{\frac{4}{15} \pi \rho a b^2 (a^2 + b^2)}} \right\} \text{NEWMAN PP 147}$$

$$m_{66} = 18 \text{ kg} \cdot \text{m}^2 \left. \vphantom{m_{66}} \right\} \rightarrow \text{FOR ACTUAL PROLATE SPHEROID OF } a = 0.8 \text{ m AND } b = 0.3 \text{ m}$$

SINCE THE MOMENT OF INERTIA OF THE WATER DISPLACED BY THE ESP+ FRAME IS DIFFERENT, APPLY m_{66}' TO MOMENT OF INERTIA OF THE WATER DISPLACED.

$$I_{66}^{H_2O} = 69 \text{ kg} \cdot \text{m}^2 \left. \vphantom{I_{66}^{H_2O}} \right\} \text{AT CENTER OF DISPLACEMENT, WHICH IS CLOSE TO THE PIVOT POINT SO THIS IS OK AS AN ESTIMATE}$$

$$m_{66}^{\text{ESP+FRAME}} = 0.4 (69 \text{ kg} \cdot \text{m}^2) = \underline{28 \text{ kg} \cdot \text{m}^2} \leftarrow \text{ESTIMATE OF PITCH ADDED MOMENT OF INERTIA}$$

ESTIMATED PITCH RESONANT FREQUENCY

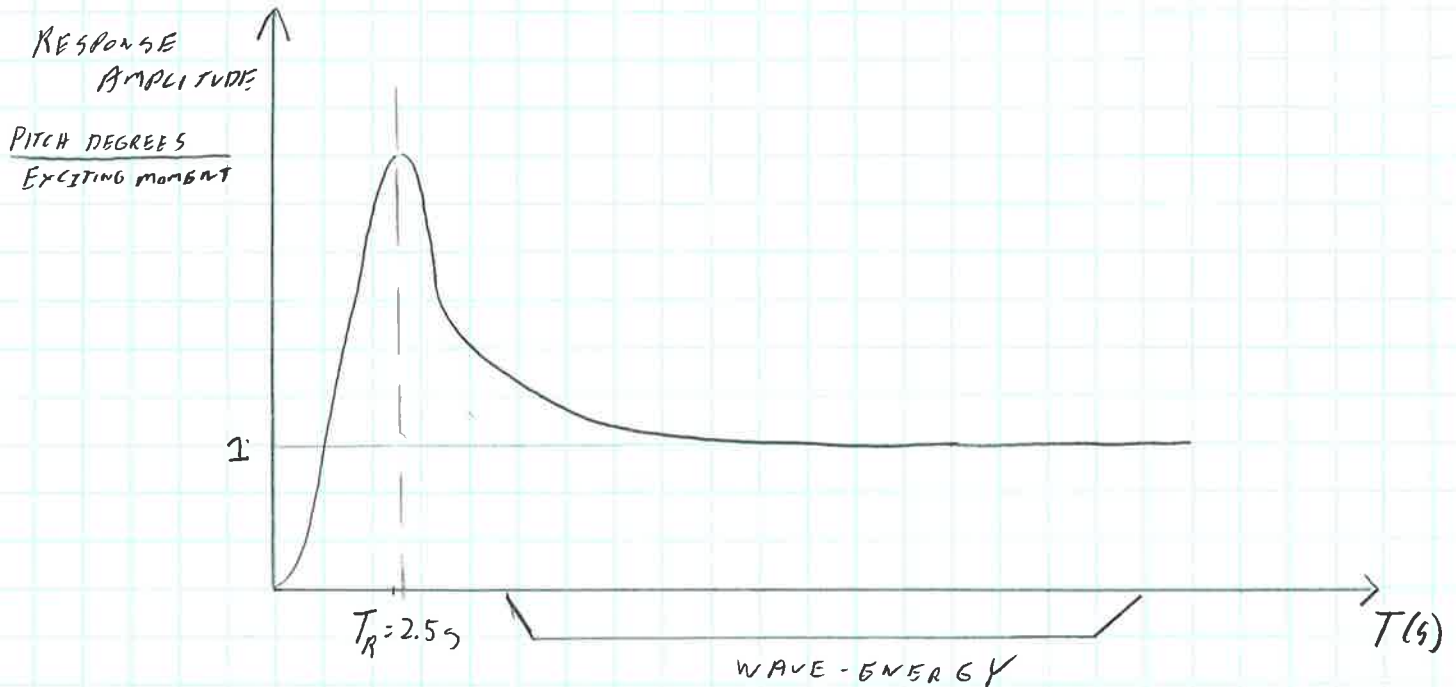
8/16/15-JAH

$$\omega_R = \sqrt{\frac{\bar{B}_G m g}{(I + m_{66})}}$$

$$\begin{aligned}\bar{B}_G &= 26.3'' - 15.7'' \\ &= 10.6'' \\ &= 0.27m\end{aligned}$$

$$\begin{aligned}\omega_R &= \sqrt{\frac{0.27m \cdot 362kg \cdot 9.81m/s^2}{(102.8 kgm^2 + 28kgm^2)}} = 2.7 \frac{rad}{s} \\ &= .4 Hz\end{aligned}$$

$$T_R = 2.5s \quad \left. \vphantom{\begin{matrix} T_R = 2.5s \\ \end{matrix}} \right\} \text{RESONANT PERIOD ESTIMATE}$$



Beam Calculations for Top and Bottom Cross Members

Applied Force = **1000 lbs**

Length = 32 in

Tube width = 2 in

Tube height = 4 in

Tube thickness = 0.25 in

Material Modulus = 30000000 psi

Cross sectional area = 2.75 in²

2nd Moment of area = 5.3073 in⁴

Maximum Bending Moment = 8000 in-lb

Maximum Shear Force = 500 lbs

Maximum Deflection = -0.0042876 in

Maximum Stress due to Bending = 3014.7203 psi

Maximum Stress due to Shear = 181.8182 psi

Beam Calculations for Vertical Legs

Applied Force = **500 lbs**

Length = 77 in

Tube width = 3 in

Tube height = 2 in

Tube thickness = 0.1875 in

Material Modulus = 30000000 psi

Cross sectional area = 1.7344 in²

2nd Moment of area = 1.0613 in⁴

Maximum Bending Moment = 9625 in-lb

Maximum Shear Force = 250 lbs

Maximum Deflection = -0.14936 in

Maximum Stress due to Bending = 9068.7216 psi

Maximum Stress due to Shear = 144.1441 psi

Beam Calculations for Lift Bar

Applied Force = **1000 lbs**

Length = 28 in

Tube width = 2 in

Tube height = 3 in

Tube thickness = 0.1875 in

Material Modulus = 30000000 psi

Cross sectional area = 1.7344 in²

2nd Moment of area = 2.0506 in⁴

Maximum Bending Moment = 7000 in-lb

Maximum Shear Force = 500 lbs

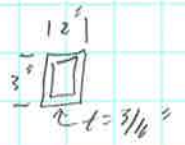
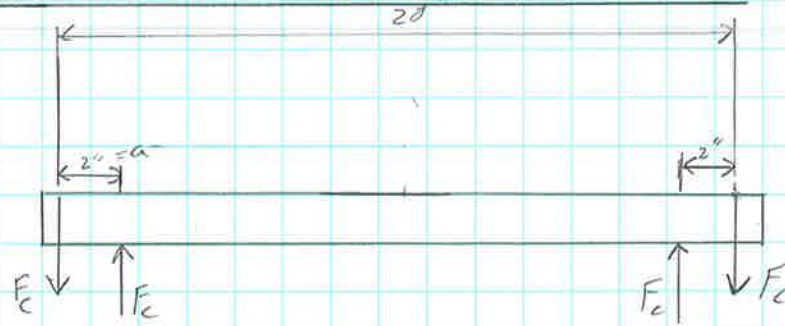
Maximum Deflection = -0.0074341 in

Maximum Stress due to Bending = 5120.4572 psi

Maximum Stress due to Shear = 288.2883 psi

9/11/15 JAH

LIFT BAR STRESS DUE TO THE ROD CLAMP FORCE



$$I = 2.05 \text{ in}^4$$

$$F_c = 70\% \text{ OF ROD YIELD STRENGTH}$$

$$\text{ROD YIELD STRENGTH} = \sigma_y \cdot \frac{\pi d^2}{4}$$

$$d = 7/16"$$

$$\sigma_y = 30,000 \text{ psi}$$

$$= 30,000 \times .15 \text{ in}^2 = 4500 \text{ lbs}$$

$$\underline{F_c = 3100 \text{ lbs}}$$

$$M_{max} = F_c \cdot a = 6200 \text{ in} \cdot \text{lbs}$$

$$\sigma_{max} = \frac{M_{max} C}{I} = \frac{6200 \text{ in} \cdot \text{lbs} \cdot 3^{3/2}}{2.05 \text{ in}^4} = \underline{4540 \text{ psi}}$$