Complex System Design Cycle, Analysis and Test, Fabrication Package

Dr. Kathryn Wingate

ME 4182

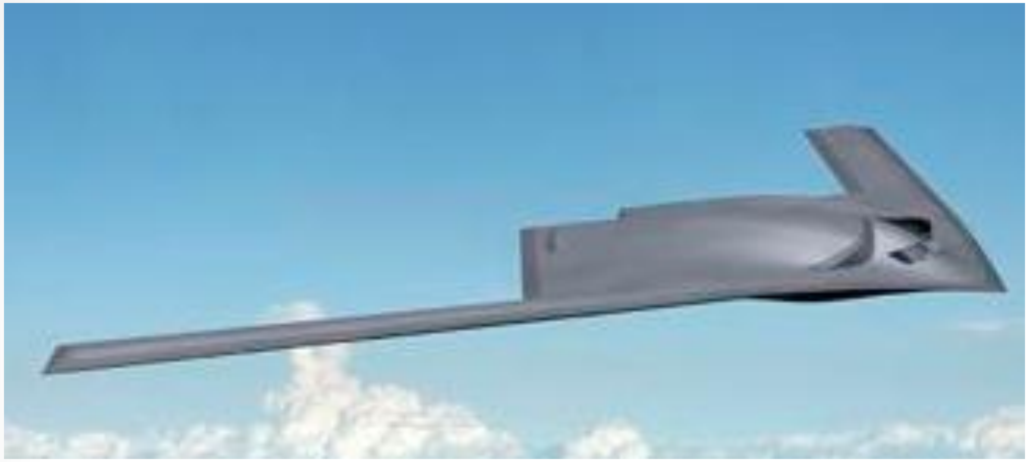
Overview

- Complex System Design Cycle
- Analysis and Test
- Fabrication Package

Learning Objectives

- Understand why analysis and test is critical
- What to analyze/test
- Develop concrete analysis and test plans
- Present analysis and test results
- What to include in fabrication packages

Long Range Strike Bomber

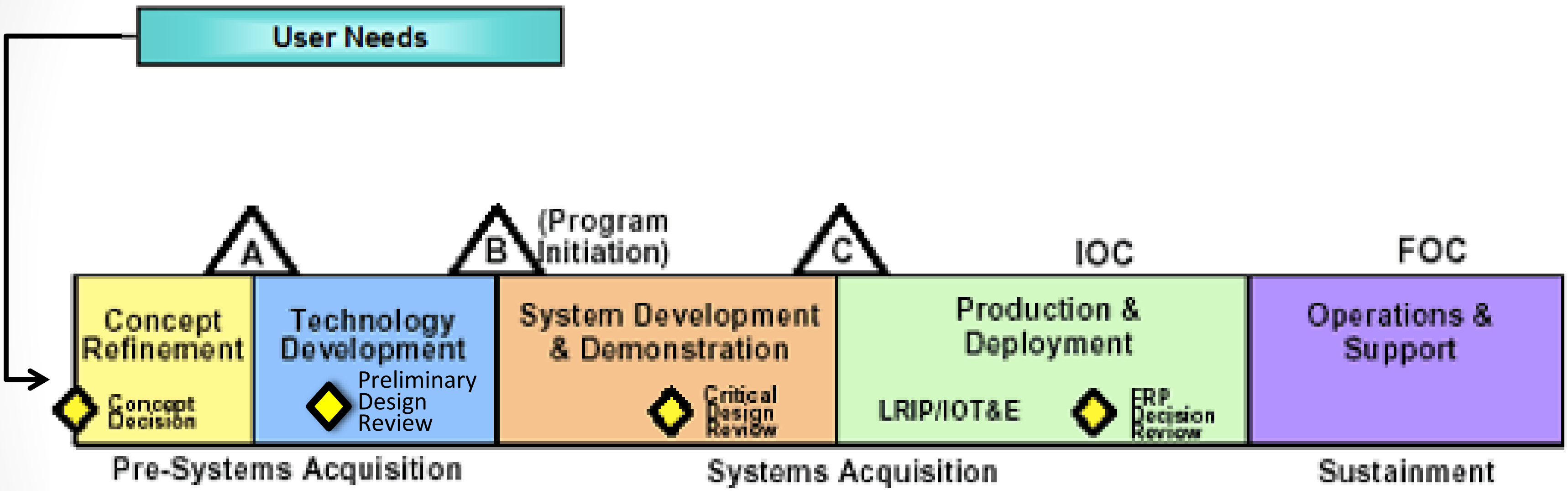


Boeing/Lockheed Martin
Concept Image

Northrop Grumman
Concept Image

The LRS-B will provide operational flexibility across a wide range of military operations.

Defense System Acquisition Framework



User Needs:

- Carry XX tons payload
- XX mile range without refueling
- Compatible with air to air refueling
- Stealth

Engineering Requirements:

- Carry XX tons of payload
- Carry XX tons of fuel
- Wing generate XX lbf lift
- Total weight of aircraft (tons)
- Total power

Long Range Bomber

Structure

Engines

Power

Payload Deployment

Comm

Electronic Warfare

Thermal/Cooling

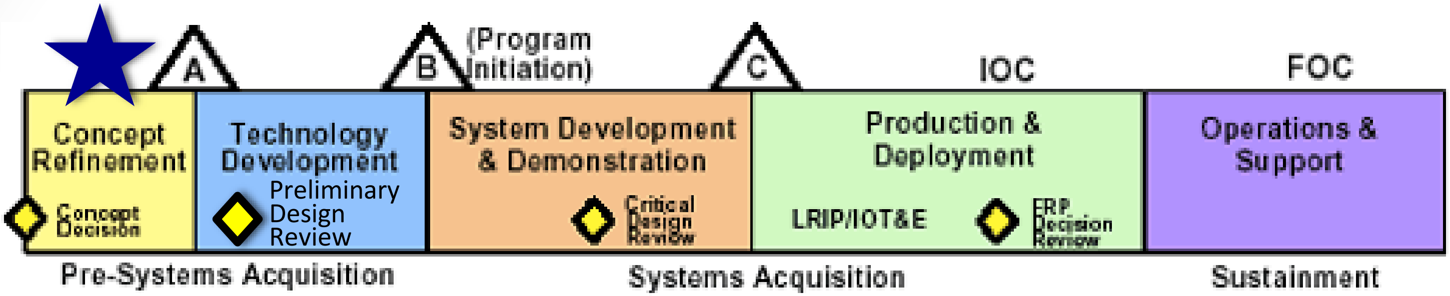
Flight Controls

Avionics

Hydraulic

- Weight
- Power
- Lift
- Stealth
- Thermal
- Environmental
- Volume

Concept Refinement



Engineering Requirements
Specification Sheets

Market Research
Problem Understanding
Ideation

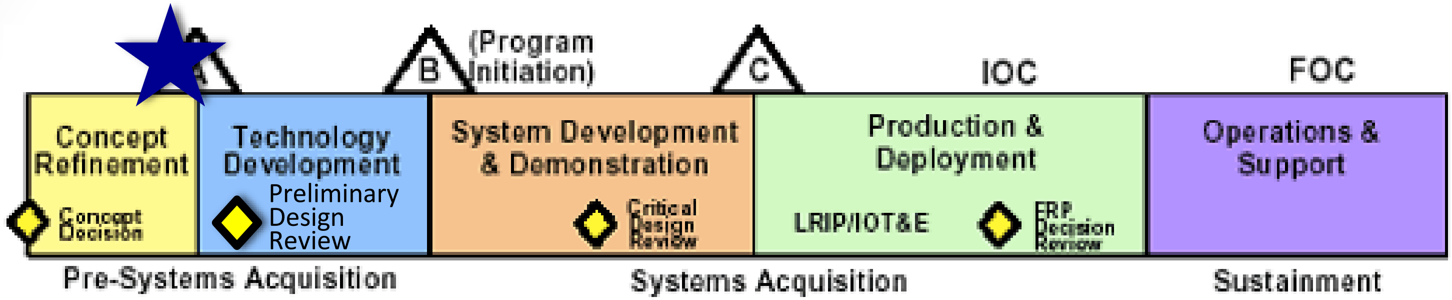
Trade Studies
System Optimization

Analysis: Demonstrate Design Functionality

Proposal: Preliminary Design

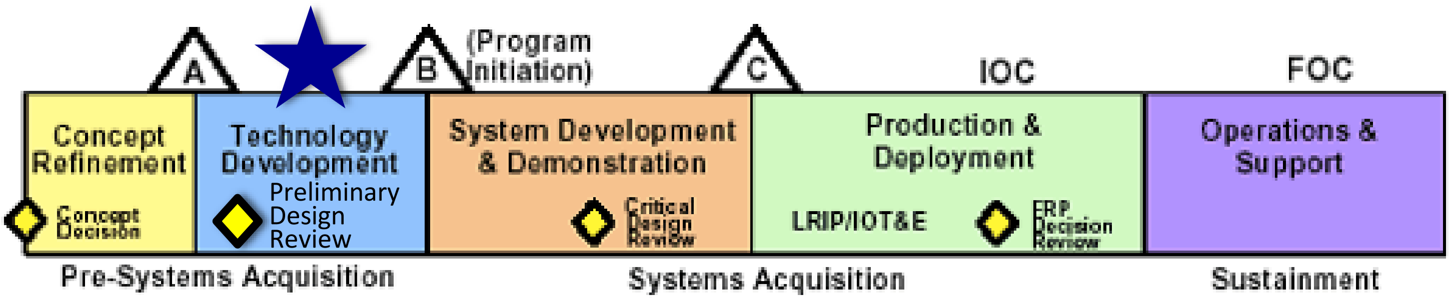
Congressional Lobbying

Proposal Awarded



Requirement Creep.

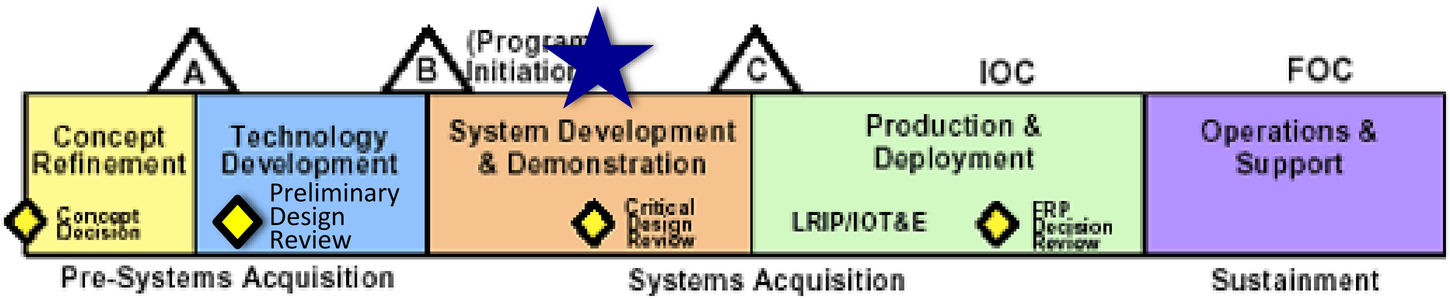
Technology Development: Preliminary Design Review



Detailed Preliminary Design

- Engineering Requirements/ Specification Sheet
- Preliminary Analysis
- Testing: qualification of new materials and designs

System Development & Demonstration
Critical Design Review



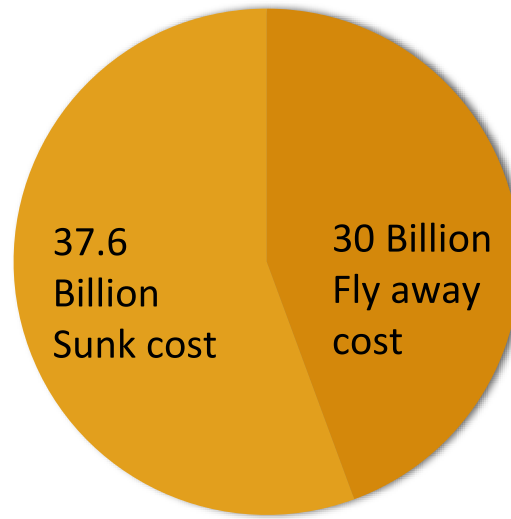
Detailed Final Design

- Engineering Requirements/ Specification Sheet
- Analysis
- Testing: Accelerated Life, Qual
- Production Test Build

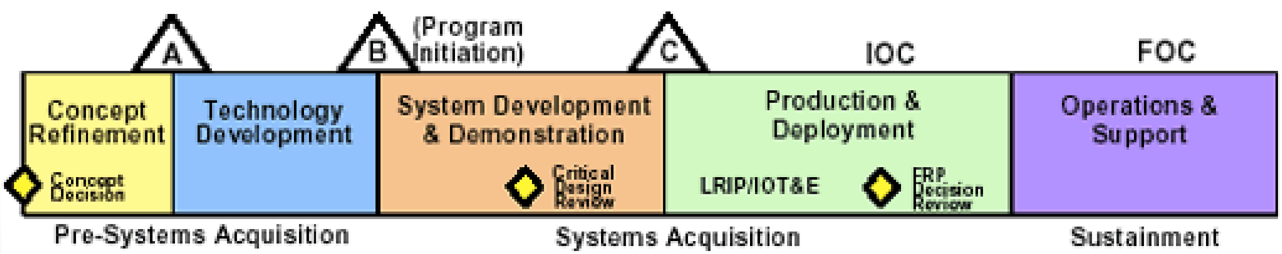
Why do we go through this prior to production?

Design <-> Cost

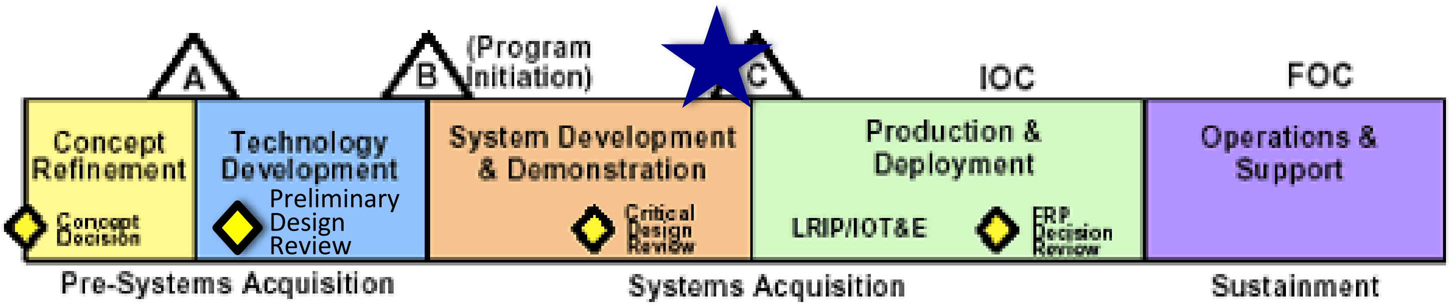
F-22: 67 billion



- Failures in production -> major cost.



System Development and Demonstration: Manufacturing Readiness Review

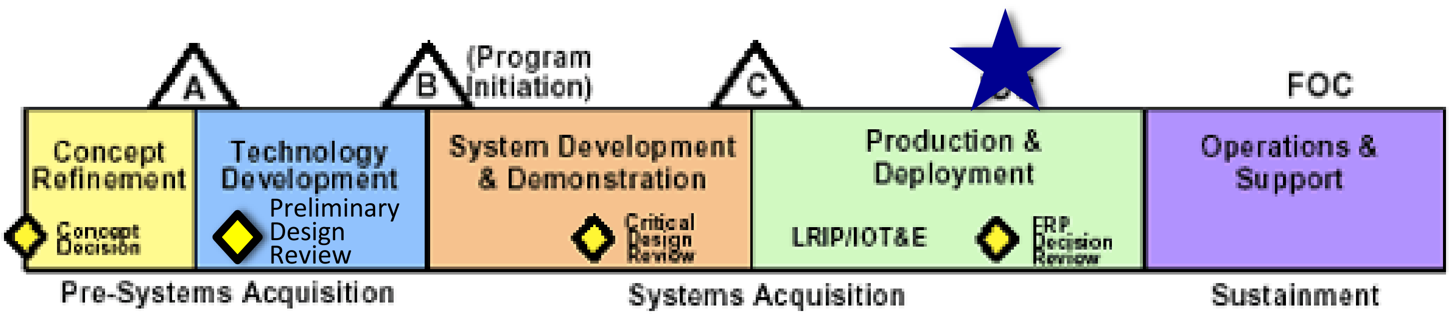


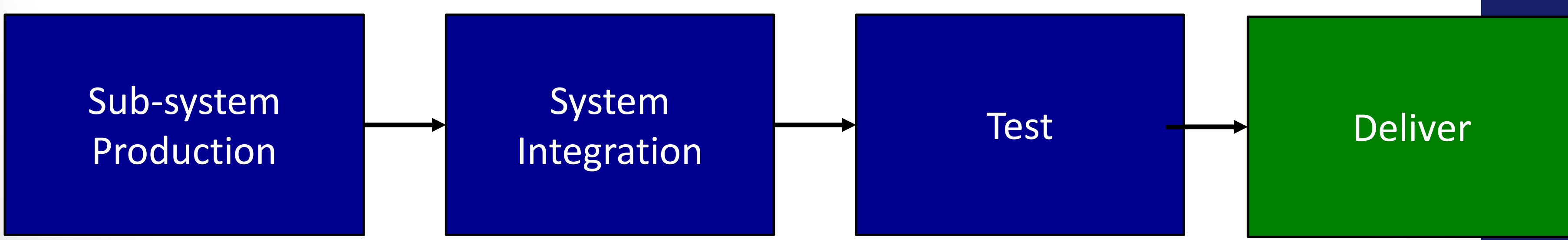
Pre Production Run Data

Manufacturing Process Flow and Plans

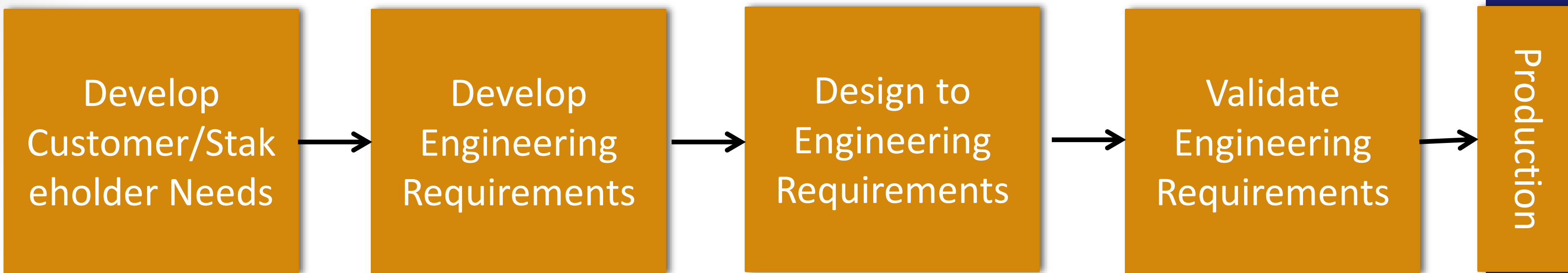
Schedule

Production and Deployment:





Design Cycle: Capstone



- Stakeholder analysis
- Market research
- House of Quality

- House of Quality
- Spec sheet
- Regulations
- Analysis

- Ideation
- Function tree & Morph charts
- Trade studies
- Industrial Design
- Human Factors
- CAD/Modeling
- Mock ups
- Analysis

- Analysis
- Test
- Inspect
- Prototype

Analysis and test starts early and continues through production.

Analysis and Testing

Life as an analyst

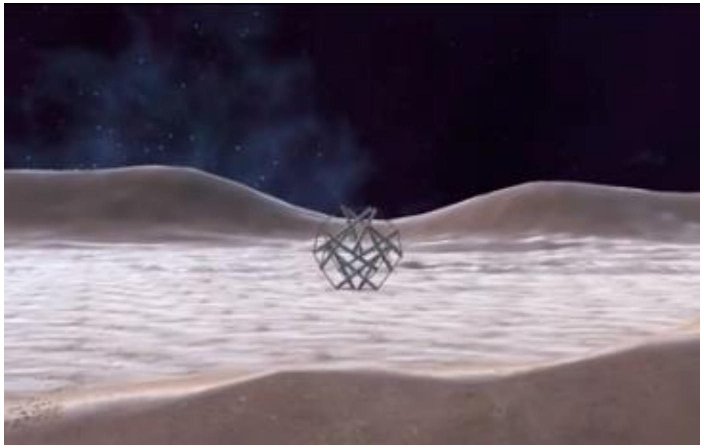
- https://www.youtube.com/watch?v=BKorP55Aqvg

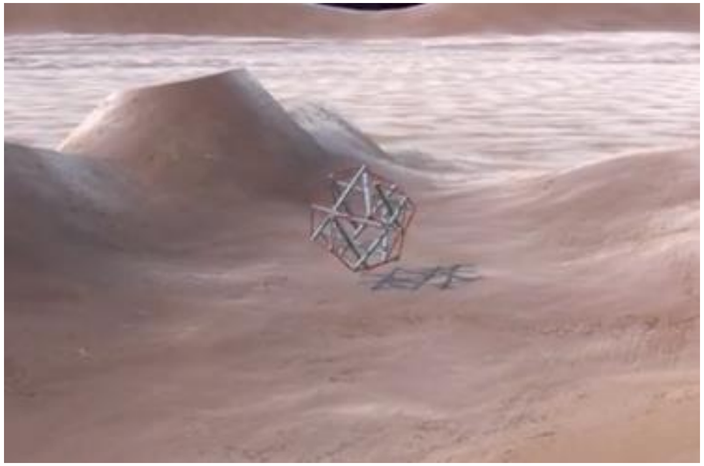
- Specifications matter!

Why do we do analysis?

Why do we do analysis?

- Selection: Analysis can improve design!
  - Wall thickness
  - Fastener selection
  - Number of fasteners
  - Weight reduction
  - Material selection
  - Structural geometry
  - Component selection
  - Gear train design



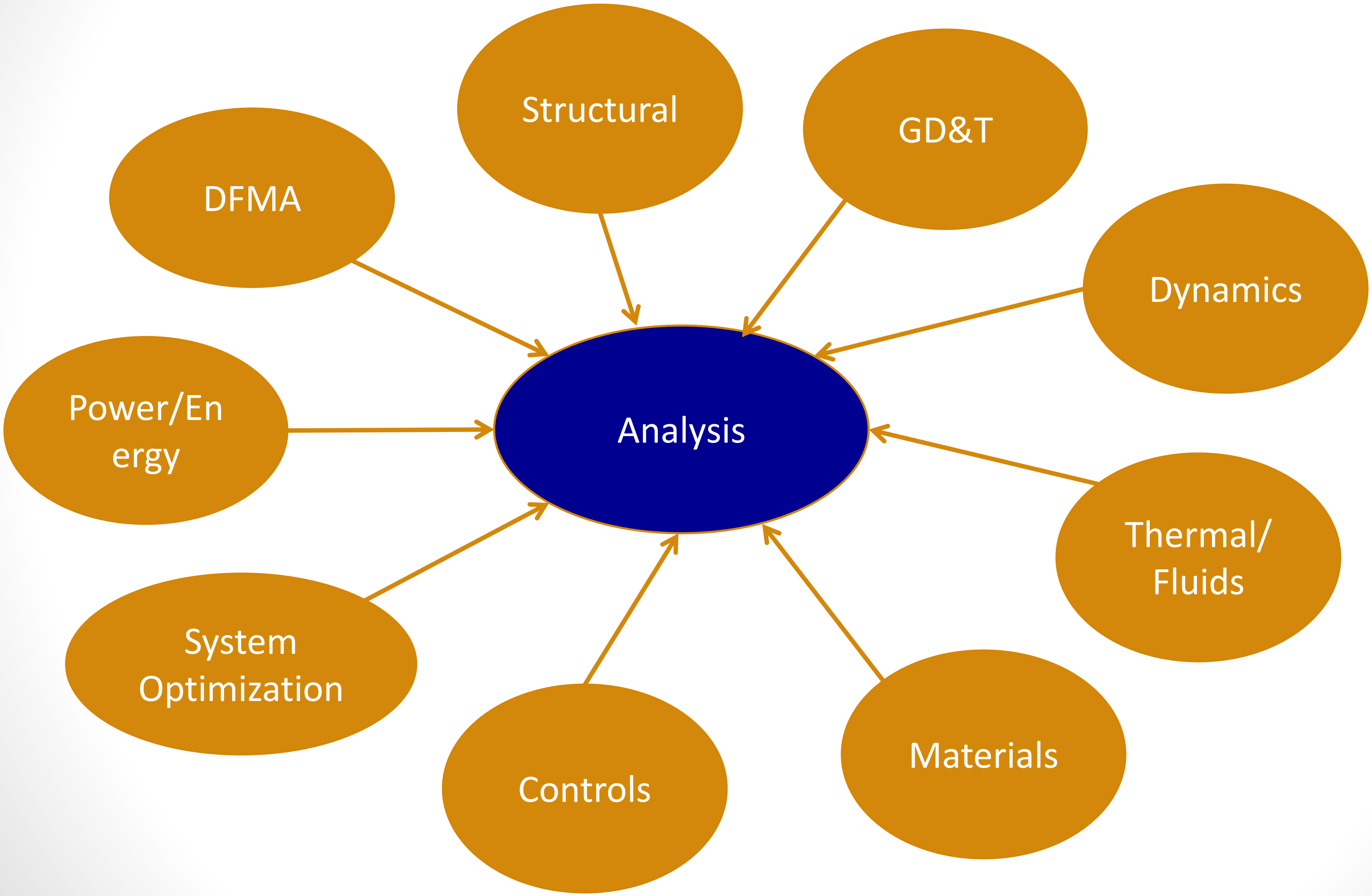


Dr. Julian Rimoli
http://www.magicalrobot.org/BeingHuman/2016/01/related-projects-by-collaborators

Why do we do analysis?

- Validation: Analysis demonstrates design meets engineering requirements!
  - Life
  - Load
  - Weight
  - Geometry
  - Gain/Phase
  - Power
  - Thermal
  - Failure modes

Types of Analysis



You learned analysis in….

- ME 1770
- MSE 2001
- ME 2016
- ME 2202
- COE 3001
- ME 3322
- ME 3340
- ME 3017
- ME 3345
- ME 3210
- ME 3180
- ME 4315

… Now, how do you decide what to analyze?

What to Analyze/Test

- Choosing requirements to design to/validate with analysis:
  - System critical requirements
  - Design for function (operational loads)
  - Design for failure (limit loads)
    - Failure Modes and Effects Analysis (FMEA)
  - Life, load, and weight
  - Choose your components/dimensions from analysis!

When to Analyze

- Can be validated by analysis
  - Does your team have the capability to complete this analysis?
    - Outsource analysis with technical consulting firms!
  - Will good results validate the problem with the correct level of confidence?

- Time efficient

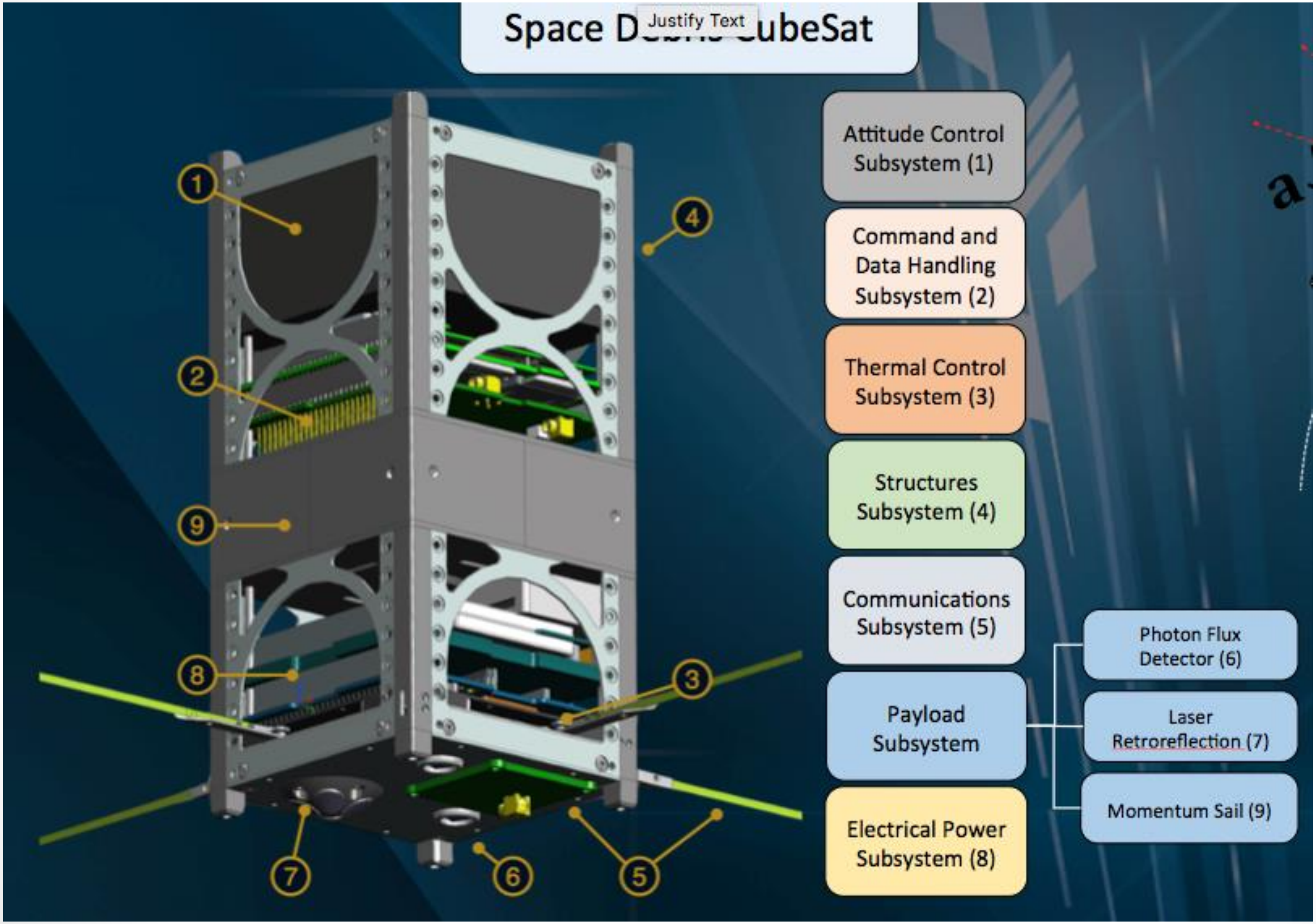
- Expensive test setup

- Need both testing and analysis
  - FMEA indicates high risk (high probability and severity)
  - http://www.youtube.com/watch?v=Ai2HmvAXcU0

Developing an Analysis Plan

- What is the requirement?
- What is your factor of safety?
  - How well do you know the design/material (heritage?)
  - How confident are you in the material properties?
  - How confident are you in the analysis predicting the failure mode?
  - Is this requirement system critical?
- Design for function: Simulate the operating environment!
  - What are your knowns?
  - What assumptions are you making?
    - Point load?
    - Thermal environment?
    - k_f = is there anything special about this environment? Corrosion? Plating?
    - Constrained? Boundary conditions?
- Design for failure: worst case scenario
- Determine analysis based off of:
  - Textbooks (Shigley's, Roarks, CRC handbooks)
  - Standards: ASME, MIL STD, ect.
  - Literature (Google scholar), Experts in the field

Analysis Example: Cube Sat



Common Analyses (Mechanical)

- GD&T: Tolerance Stack Up (Worst Case Scenario)
- Static Loading: Von Mises: (bending, axial, torsion, shear)
- Fatigue: (Goodman)
- Coefficient of Thermal Expansion:
  - Geometry
  - CTE mismatch
- Fasteners: Preload, Shear
- Components: life/load
- Gear Trains: torque, HP, gear ratios
- Modal analysis (Vibration, natural frequency), Shock

When to Test

- Analysis is not a good predictor of failure mode
  - Fatigue failures
  - Shock failures
  - Fracture propagation
  - Corrosion, environmental tests
  - https://www.youtube.com/watch?v=_jfXX7qppbc

- Easier to test than to run analysis (but no substitute for proper design and selection)
  - Time consuming simulation

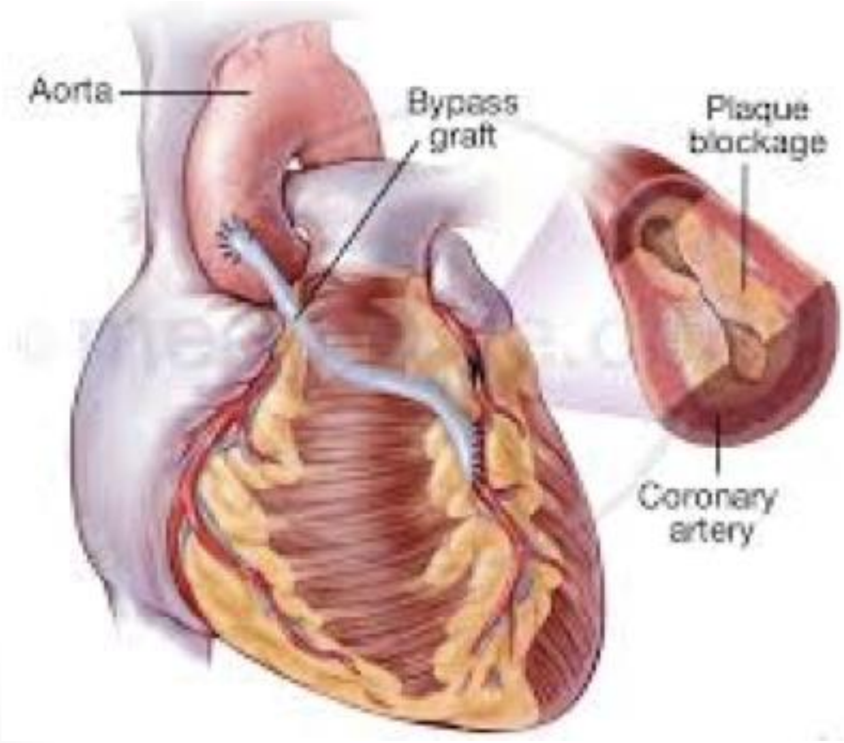
- Failure dependent on manufacturing process or material
  - Material lot screening
  - Manufacturability screening

- Need both testing and analysis
    - FMEA indicates high risk (high probability and severity)

Developing a Test Plan

- What is the requirement?
- What is the operating condition?
  - Thermal?
  - Mechanical?
  - Geometry?
  - Environmental?
- What tests are already done for these requirements/conditions?
  - MIL HNDBK J, ASTM, MIL STD 883
  - NIST
- What are the pass criteria?
  - Visual inspection at 20x: no visual cracking or fracture
  - CT scan/X-ray: no internal fracture
  - Dye penetrant check for fracture
  - Yield at > 50 ksi
  - Electrical performance
- What is your plan for each possible outcome of the test?

Vascular Graft (Bypass)



- Liquid tight
- Suture retention: 1.20±0.23 N
- Withstand static pressure: 200 mmHg (systolic)
- Withstand diastolic/systolic cycle for patient life: $4.2X10^9$ repetitions
- Promote laminar blood flow
- Biocompatiable

- “It doesn’t matter how smart you are if you can’t explain your analysis to the program manager and the customer.”

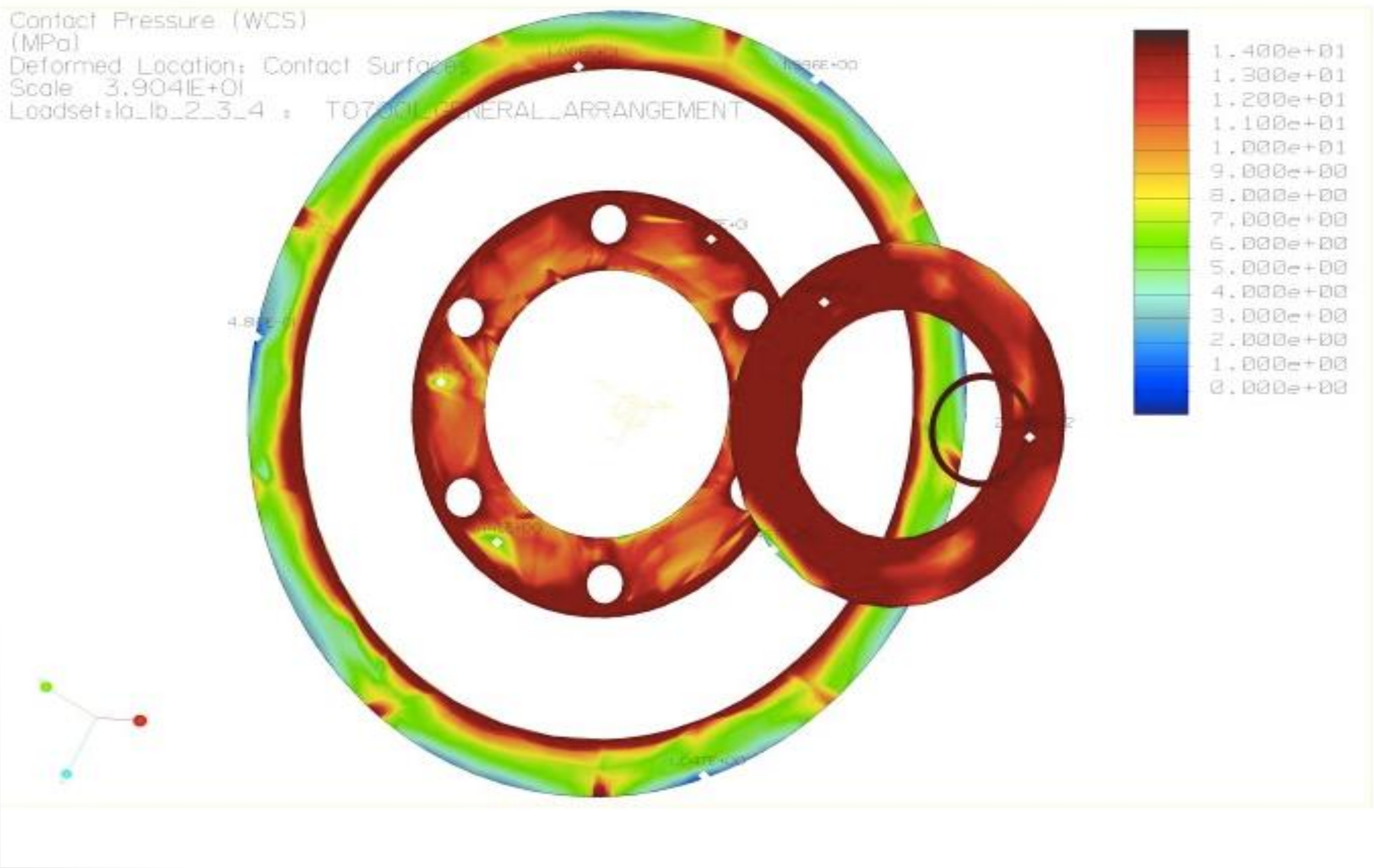
  - Chief Engineer, Hamilton Sundstrand

Presenting/Reporting Analysis

- **What was the requirement that drove this analysis?**
- **What is the mode of failure your concerned about?**
  What type of analysis did you complete?
  - Shear pull out?
  - Goodman fatigue?
- **What are the key assumptions in the analysis?**
  - Boundary conditions?
  - Material properties?
  - Loading?
  - Nodes and elements?
- **How does your analysis show this requirement has been validated?**
  - Factor of safety?
  - Gain and phase margin?

Just… No.

FEA: Contact Analysis of Gasket

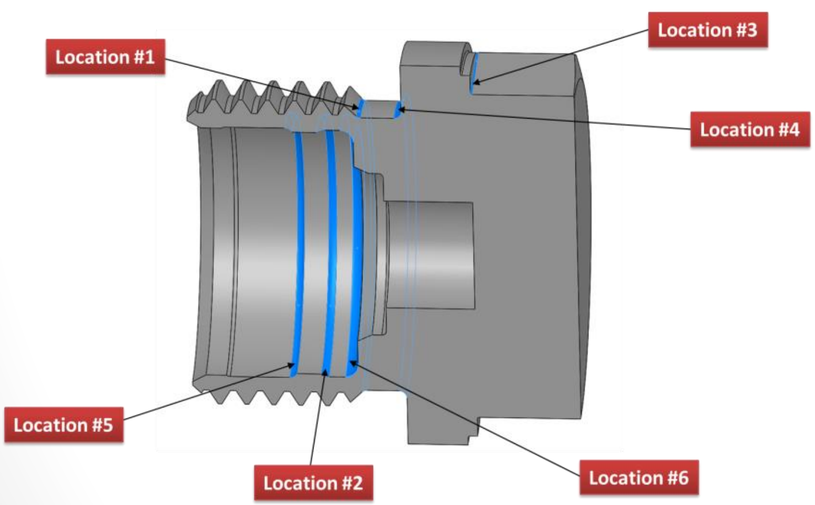


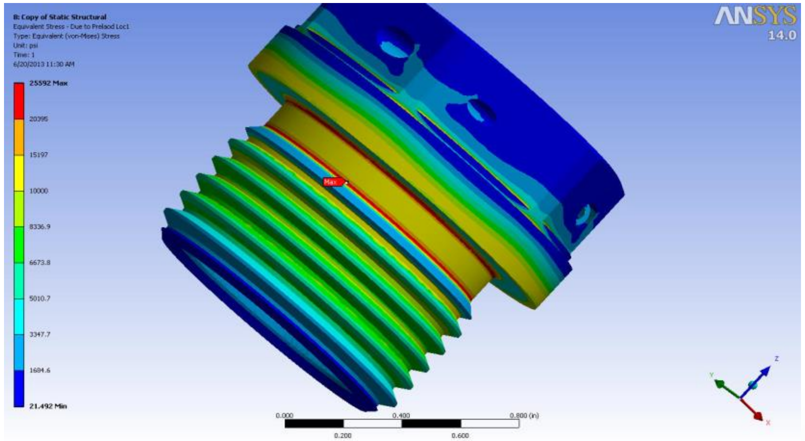
Analysis: Check Valve Assembly

- Withstand pressure loading due to preload per source: X114283-D002 Rev. 2

Operating Conditions for Stress Analysis		
Cases	Pb, psi	Pd, psi
1: DAT Proof	860	860
2a: DAT Cyclic #1	520	520

Material Yield Strength		35
Material Ultimate Strentgth		42
Loacation	Stress @ 860psi ksi	Limit Margin of Safety
Loc#1	28.15	0.24
Loc#2	22.85	0.53
Loc#3	16.45	1.13





FE Model Results - VonMises Stress at Loc1 Due to Preload

Location 1-3 margin of safety acceptable per program requirements.

Presenting/Reporting Test Results

- **What was the requirement that drove this test?**
  - Satellite must withstand thermal variations in GEO orbit and launch of -65 C to 125 C.

- **What type of test did you complete?**
  What documentation or spec outlined test requirements?
  - Thermal cycling per MIL STD 883 method 2050 program class K

- **What are the key variables in the test?**
  - 50 cycles each with 10 minutes at -65 C and 20 minutes at 120 C

- **How does your analysis show this requirement has been validated**?
  - Visual inspection before and after test to ensure no cracks or delamination in electronic circuits per MIL STD 883 method 2010 program class K
  - Electronic burn out test before and after thermal cycling to ensure electrical performance meets program specs per class K

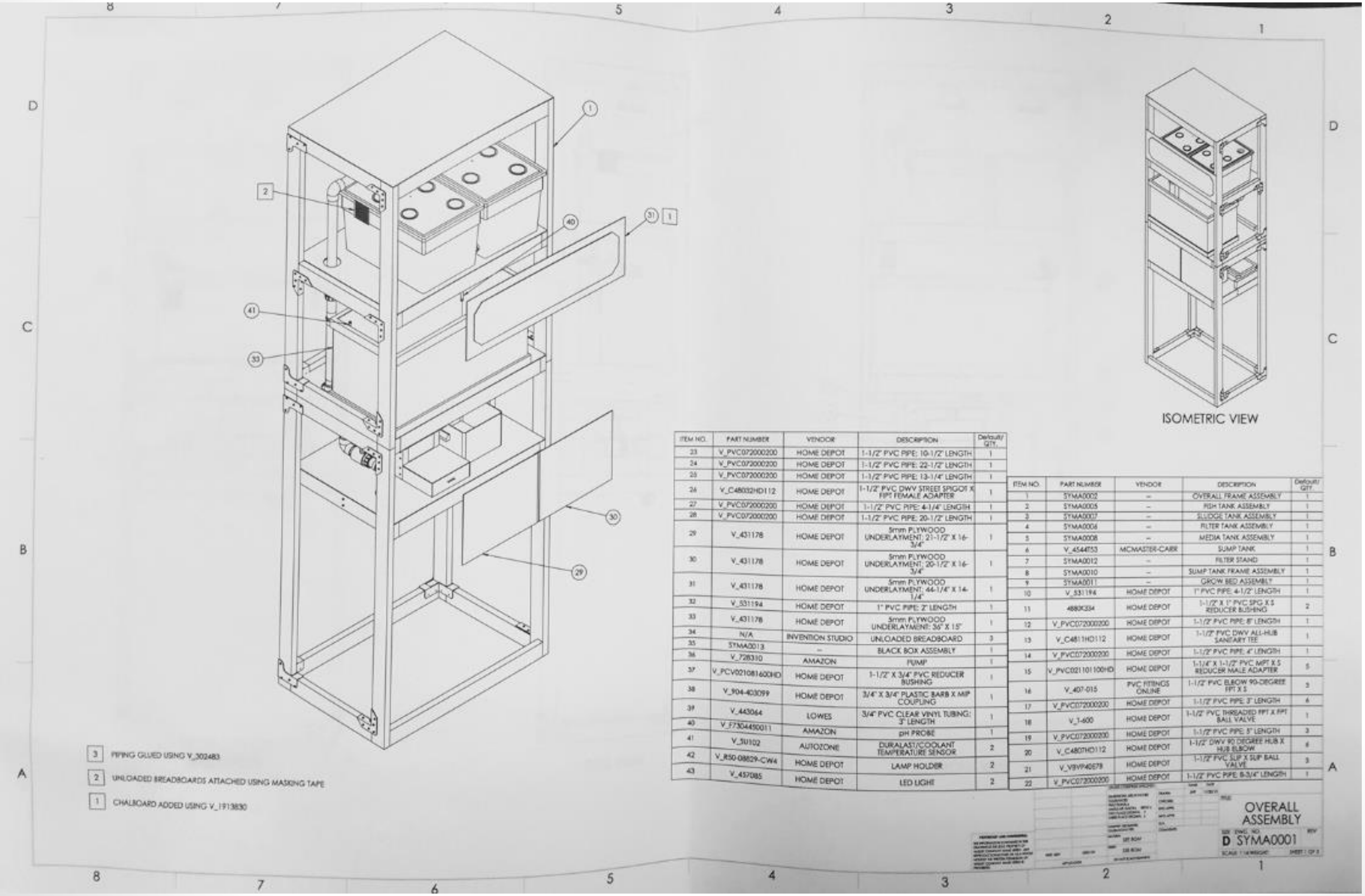
Fabrication Package

- Fabrication Package – Drawing Set
- Should focus solely on the details of the fabrication, assembly of, and manufacture of your design, as if this package, as a stand-alone document, would be provided to a manufacturer.
- It should NOT be introducing or describing functions, specifications, etc.

Fabrication Package

- Provide assembly view drawing(s), exploded views, etc. (typically 1st page of set)
- Provide drawing index referenced to assembly
- Provide a detailed Bill or Materials and/or parts list, including vendors, part numbers (and price if known)
- Provide fully dimensioned working drawings for the custom parts of your design
- Identify principle designer in title block for each custom component
- Fully specify parts; material, tolerances, finishes, etc.

Fabrication Package:



ITEM NO.	PART NUMBER	VENDOR	DESCRIPTION	Default/ QTY.
23	V_PVC072000200	HOME DEPOT	1-1/2" PVC PIPE: 10-1/2" LENGTH	1
24	V_PVC072000200	HOME DEPOT	1-1/2" PVC PIPE: 22-1/2" LENGTH	1
25	V_PVC072000200	HOME DEPOT	1-1/2" PVC PIPE: 13-1/4" LENGTH	1
26	V_C48032HD112	HOME DEPOT	1-1/2" PVC DWV STREET SPIGOT X FIPT FEMALE ADAPTER	1
27	V_PVC072000200	HOME DEPOT	1-1/2" PVC PIPE: 4-1/4" LENGTH	1
28	V_PVC072000200	HOME DEPOT	1-1/2" PVC PIPE: 20-1/2" LENGTH	1
29	V_431178	HOME DEPOT	5mm PLYWOOD UNDERLAYMENT: 21-1/2" X 16-3/4"	1
30	V_431178	HOME DEPOT	5mm PLYWOOD UNDERLAYMENT: 20-1/2" X 16-3/4"	1
31	V_431178	HOME DEPOT	5mm PLYWOOD UNDERLAYMENT: 44-1/4" X 14-1/4"	1
32	V_531194	HOME DEPOT	1" PVC PIPE: 2" LENGTH	1
33	V_431178	HOME DEPOT	5mm PLYWOOD UNDERLAYMENT: 36" X 15"	1
34	N/A	INVENTION STUDIO	UNLOADED BREADBOARD	3
35	SYMA0013	–	BLACK BOX ASSEMBLY	1
36	V_728310	AMAZON	PUMP	1
37	V_PCV021081600HD	HOME DEPOT	1-1/2" X 3/4" PVC REDUCER BUSHING	1
38	V_904-403099	HOME DEPOT	3/4" X 3/4" PLASTIC BARB X MIP COUPLING	1
39	V_443064	LOWES	3/4" PVC CLEAR VINYL TUBING: 3" LENGTH	1
40	V_F7304450011	AMAZON	pH PROBE	1
41	V_SU102	AUTOZONE	DURALAST/COOLANT TEMPERATURE SENSOR	2
42	V_R50-08829-CW4	HOME DEPOT	LAMP HOLDER	2
43	V_457085	HOME DEPOT	LED LIGHT	2

ITEM NO.	PART NUMBER	VENDOR	DESCRIPTION	Default/ QTY.
1	SYMA0002	–	OVERALL FRAME ASSEMBLY	1
2	SYMA0005	–	FISH TANK ASSEMBLY	1
3	SYMA0007	–	SLUDGE TANK ASSEMBLY	1
4	SYMA0006	–	FILTER TANK ASSEMBLY	1
5	SYMA0008	–	MEDIA TANK ASSEMBLY	1
6	V_4544T53	MCMASTER-CARR	SUMP TANK	1
7	SYMA0012	–	FILTER STAND	1
8	SYMA0010	–	SUMP TANK FRAME ASSEMBLY	1
9	SYMA0011	–	GROW BED ASSEMBLY	1
10	V_531194	HOME DEPOT	1" PVC PIPE: 4-1/2" LENGTH	1
11	4880K334	HOME DEPOT	1-1/2" X 1" PVC SPG X S REDUCER BUSHING	2
12	V_PVC072000200	HOME DEPOT	1-1/2" PVC PIPE: 8" LENGTH	1
13	V_C4811HD112	HOME DEPOT	1-1/2" PVC DWV ALL-HUB SANITARY TEE	1
14	V_PVC072000200	HOME DEPOT	1-1/2" PVC PIPE: 4" LENGTH	1
15	V_PVC021101100HD	HOME DEPOT	1-1/4" X 1-1/2" PVC MPT X S REDUCER MALE ADAPTER	5
16	V_407-015	PVC FITTINGS ONLINE	1-1/2" PVC ELBOW 90-DEGREE FPT X S	3
17	V_PVC072000200	HOME DEPOT	1-1/2" PVC PIPE: 3" LENGTH	6
18	V_1-600	HOME DEPOT	1-1/2" PVC THREADED FPT X FPT BALL VALVE	1
19	V_PVC072000200	HOME DEPOT	1-1/2" PVC PIPE: 5" LENGTH	3
20	V_C4807HD112	HOME DEPOT	1-1/2" DWV 90 DEGREE HUB X HUB ELBOW	6
21	V_V8VP40678	HOME DEPOT	1-1/2" PVC SLIP X SLIP BALL VALVE	3
22	V_PVC072000200	HOME DEPOT	1-1/2" PVC PIPE: 8-3/4" LENGTH	1

Fabrication Package

ISOMETRIC VIEW

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19	V_PVC072000200	HOME DEPOT	1-1/2" PVC PIPE: 5" LENGTH	3
20	V_C4807HD112	HOME DEPOT	1-1/2" DWV 90 DEGREE HUB X HUB ELBOW	6
21	V_VBVP4DE7B	HOME DEPOT	1-1/2" PVC SLIP X SLIP BALL VALVE	3
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43	V_457085	HOME DEPOT	LED LIGHT	2

B

A

SEE BOM

SEE BOM

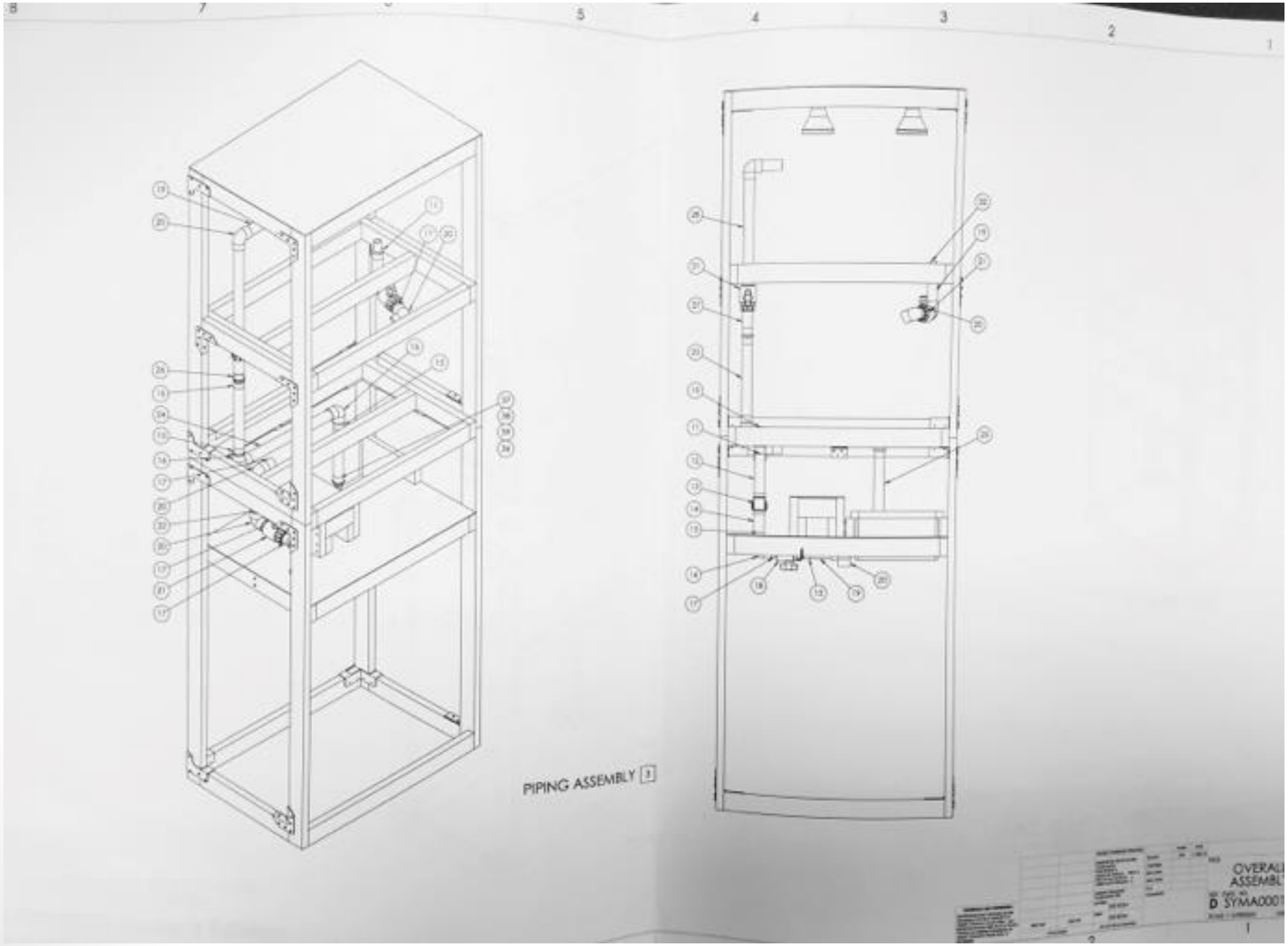
TITLE: OVERALL ASSEMBLY

SIZE D DWG. NO. SYMA0001 REV

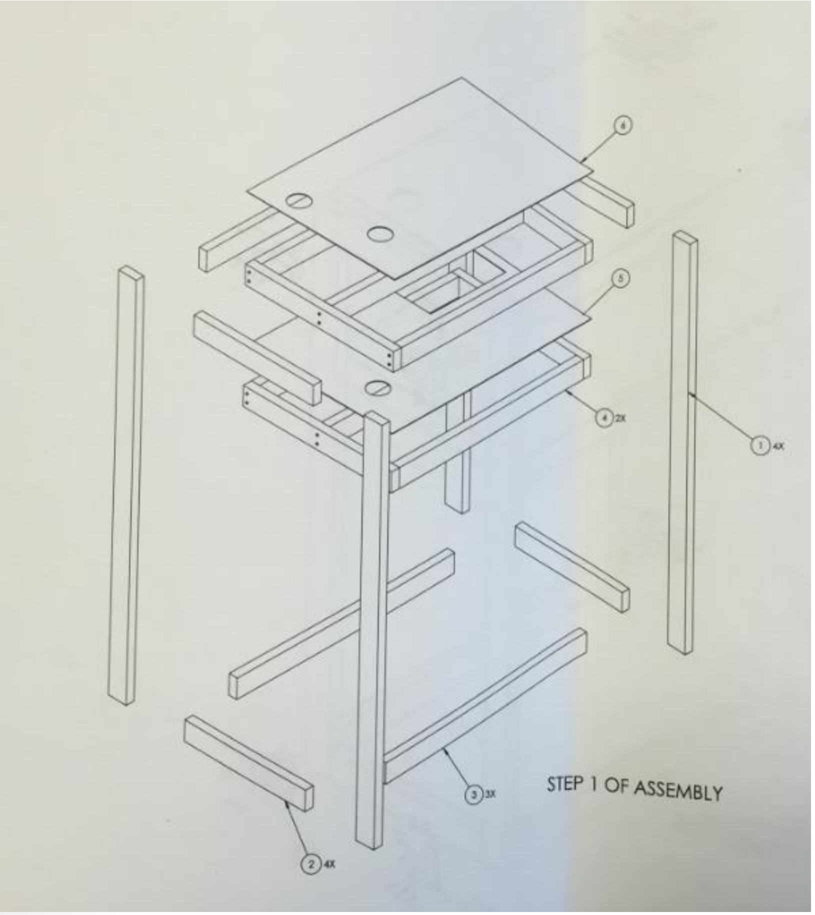
SCALE: 1:16 SHEET 1 OF 3

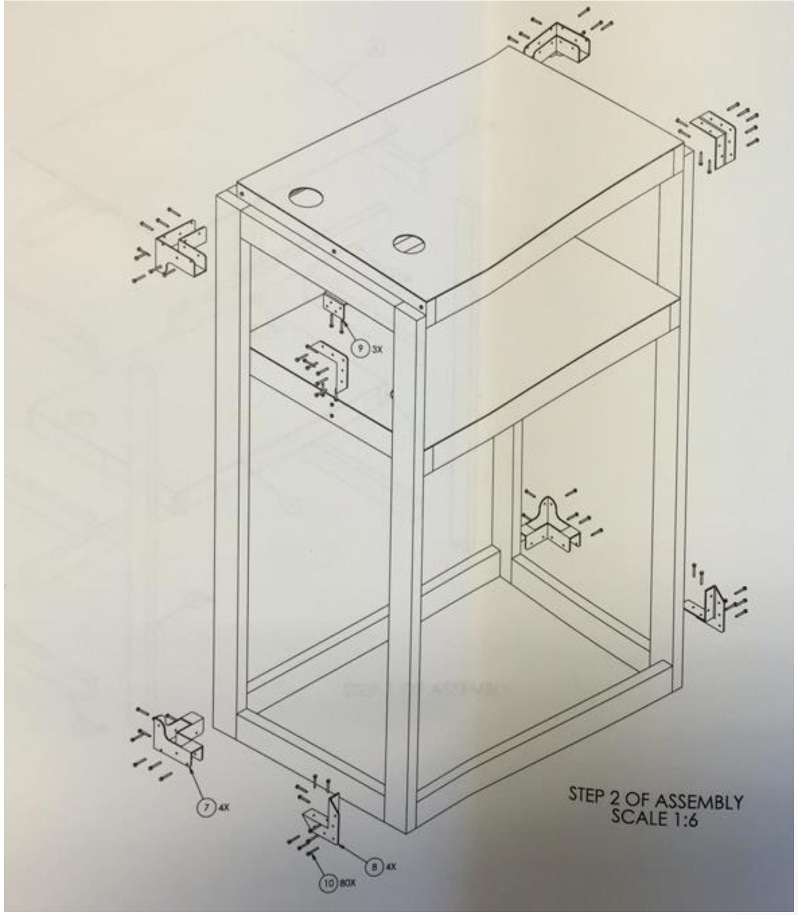
2 1

Fabrication Package

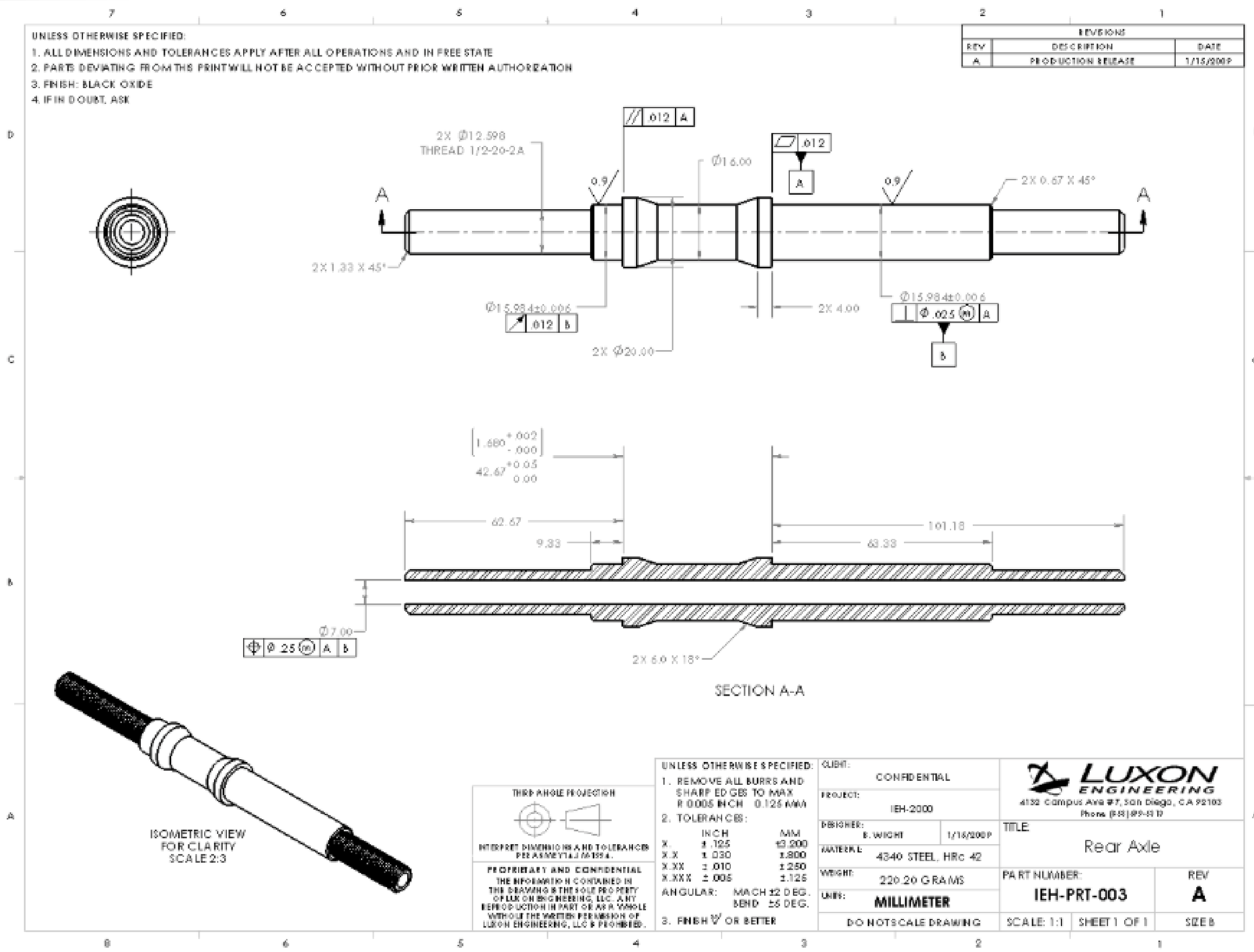


Fabrication Package





Fabrication Package



Fabrication Package

Assembly	Item	Part Name	Part Number	QTY	Vendor	Unit Price	Per Unit	Total Price	Prototype Material	Final Material
Nail Assembly	1	Nail Body	89055K53	1	McMaster-Carr	$ 10.70	0.5ft	$ 5.35	Ti-6Al-4V	Ti-6Al-4V
	2	Nail Shuttle	88855K1	1	McMaster-Carr	$ 3.32	0.5ft	$ 3.32	Stainless Steel 17-4PH	Stainless Steel 17-4 PH
	3	Nail Dynamic Element	SSM050X0300D	1	NDC	$ 1,176.00	1ft	$ 23.52	Nitinol	Nitinol
	4	Nail Sliding Element	89055K53	1	McMaster-Carr	$ 10.70	0.5ft	$ 1.07	Titanium Ti-6Al-4V	Ti-6Al-4V
Compression Assembly	5	Metal-Backed Sleeve Bearings (Shaft 6mm OD 8mm, Length 10mm)	6679K11	1	McMaster-Carr	$ 2.00	1pc	$ 2.00	Steel-Backed PTFE-Coated Bronze	Steel-Backed PTFE-Coated Bronze
	6	Compressor Piece	8974K28	1	McMaster-Carr	$ 2.30	.5ft	$ 0.29	6061 Aluminum	Ti-6Al-4V
	7	Thrust Bearing (Shaft 5/8" OD 1")	5906K515	1	McMaster-Carr	$ 1.01	1pc	$ 1.01	SAE 841 Solid Bronze	Plastic
	8	5/8" Thumb Nut	91725A150	1	McMaster-Carr	$ 8.94	1pc	$ 8.94	18-8 Stainless Steel	Stainless Steel
Targeting Arm Assembly	9	Manual Compression Rod	90575A818	1	McMaster-Carr	$ 10.52	0.5ft	$ 5.26	316 Stainless Steel	Stainless Steel 17-4PH
	10	M4 x 25mm Bolts	90278A375	2	McMaster-Carr	$ 2.39	1pc	$ 4.78	304 Stainless Steel	304 Stainless Steel
	11	Guide Rod	8974K18	1	McMaster-Carr	$ 11.28	0.5ft	$ 11.28	6061 Aluminum	Carbon-filled PEEK
	12	Targeting Arm	8503K444	1	McMaster-Carr	$ 61.46	1ft	$ 41.18	Delrin/PEEK	Carbon-filled PEEK
	13	Press Fit Metric Drill Bushing	8486A25	2	McMaster-Carr	$ 12.33	1pc	$ 24.66	Hardened Steel	Hardened 17-4PH
	-	1/8", 1 1/2" Length Dowel Pin	97395A454	1	McMaster-Carr	$ 1.19	1pc	$ 1.19	Hardened Steel	Hardened 17-4PH
Nail Holder Assembly	14	Nail Holder Sleeve	50415K24	1	McMaster-Carr	$ 13.90	0.5m	$ 2.78	316 Stainless Steel	Ti-6Al-4V
	15	Nail Holder	9811T13	1	McMaster-Carr	$ 56.19	0.5m	$ 11.24	Stainless Steel	Ti-6Al-4V
	16	M3 x 8mm Bolts	91292A112	2	McMaster-Carr	$ 0.04	1pc	$ 0.08	18-8 Stainless Steel	Stainless Steel
	17	Support Block	9008K14	1	McMaster-Carr	$ 4.40	0.5ft	$ 1.32	6061 Aluminum	Stainless Steel 17-4PH
	18	Plastic Plates	8662K11	2	McMaster-Carr	$ 2.20	1ft	$ 0.15	Delrin	Delrin
Cam Lever Assembly	19	Stretching Rod	89325K89	1	McMaster-Carr	$ 1.96	0.5ft	$ 0.75	Stainless Steel 316	316 Stainless Steel
	20	Bushing	88855K55	1	McMaster-Carr	$ 8.24	0.5ft	$ 8.24	Stainless Steel 17-4PH with 4140 Steel Pins	Stainless Steel 17-4PH with Hardened 17-4 Stainless Steel Pins
	21	Sleeve Bearing	6679K11	1	McMaster-Carr	$ 2.00	1pc	$ 2.00	Steel-Backed PTFE-Coated Bronze	UHMWPE
	22	Cam Lever	9008K14	1	McMaster-Carr	$ 4.40	0.5ft	$ 2.20	Alumiumum 6062, Radel PPSU	Alumiumum 6061, Radel PPSU
	23	M4 Nut	92497A250	1	McMaster-Carr	$ 14.07	100 pc	$ 0.14	Class 10 Steel	Stainless Steel 17-4PH
	24	Acorn Nut	94000A035	1	McMaster-Carr	$ 3.90	25 pc	$ 0.16	304 Stainless Steel	Stainless Steel 17-4PH
	-	1/8", 1/2" Length Dowel Pin	97395A441	2	McMaster-Carr	$ 0.69	1pc	$ 1.38	316 Stainless Steel	316 Stainless Steel
Miscellaneous	-	Collet Nut Wrench	6975A12	1	McMaster-Carr	$ 16.05	1pc	$ 16.05	Forged Steel	Steel

Top Mistakes New Grads Make

- Chief Engineers and Directors for Hamilton Sundstrand UTC
  - Turn in work for grading instead of completion
  - Presentation and report clarity
    - It doesn't matter how smart you are if you cannot explain it
  - Work hard
    - Stress Analysts
      - FBD is wrong
      - Understanding the difference between principal and effective stresses
      - Boundary conditions are wrong
      - Material properties are not from the correct source