Complex System Design Cycle, Analysis and Test, Fabrication Package

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

User Needs

Pre-Syscon Acquisition
- Concept Decision
- Pre-Systems Acquisition

Technology Development
- Concept Refinement
- Technology Development

System Development & Demonstration
- System Development & Demonstration
- Critical Design Review

Production & Deployment
- Production & Deployment
- LRIP/IOT&E
- ERP Decision Review

Operations & Support
- Operations & Support
- Sustainment
- IOC
- FOC
- Preliminary Design Review
Develop and acquire Advanced Extremely High Frequency (AEHF) Military Satellite Communications (MILSATCOM) satellites, mission control segment and cryptography for survivable, anti-jam, worldwide, secure communications for the strategic and tactical warfighters.

AEHF satellites will replenish the existing EHF system (Milstar) providing much higher capacity and data rate (5x increase over Milstar II) capabilities.

Satellites must be fully backward compatible with existing ground infrastructure, to include fielded Low Data Rate (LDR) and Medium Data Rate (MDR) terminals; in-development extended data rate (XDR) terminals

Launch of the SV5 satellite is required within seven years of the initial authorization for full funding expected in 2012. SV6 launch will follow one year after launch of SV5. The period of performance for this procurement is for 9 years and will begin in 2012.
Complex Design: Subsystems

AEHF SATELLITE

- Pointing Control
- Power
- Structures
- Thermal Control

- Mission Payload
- Comm
- Command & Data
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

- Preliminary Design Review
- System Development & Demonstration
- Critical Design Review
- Engineering Requirements/Specification Sheet
- Analysis
- Testing: Accelerated Life, Qual
- Production Test Build

Detailed Final Design

Pre-Systems Acquisition

Systems Acquisition

Sustainment
Why do we go through this prior to production?
Design <-> Cost

- Failures in production -> major cost.

F-22: 67 billion

- 37.6 Billion Sunk cost
- 30 Billion Fly away cost
System Development and Demonstration: Manufacturing Readiness Review
Production and Deployment:

- Preliminary Design Review
- Critical Design Review
- LRIP/IOT&E
- ERP Decision Review
- Operations & Support
- Sustainment

Sub-system Production → System Integration → Test → Deliver
Design Cycle: Capstone

1. Develop Customer/Stakeholder Needs
   - Stakeholder analysis
   - Market research
   - House of Quality

2. Develop Engineering Requirements
   - House of Quality
   - Spec sheet
   - Regulations
   - Analysis

3. Design to Engineering Requirements
   - Ideation
   - Function tree & Morph charts
   - Trade studies
   - Industrial Design
   - Human Factors
   - CAD/Modeling
   - Mock ups
   - Analysis

4. Validate Engineering Requirements
   - Analysis
   - Test
   - Inspect
   - Prototype

Production
Analysis and test starts early and continues through production.
Analysis and Testing
Life as an analyst

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

- Structural
- GD&T
- Dynamics
- Thermal/Fluids
- Materials
- Controls
- System Optimization
- Power/Energy
- DFMA
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](http://www.youtube.com/watch?v=Ai2HmvAXcU0)
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
  - 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 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
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: $4.2 \times 10^9$ repetitions
- Promote laminar blood flow
- Biocompatible
Testing

Class S (Space Flight) Microelectronic Circuit

- MIL STD 883:
  - Open electrical test
  - -100x (high power) visual inspection of semiconductor and package
  - Thermal Cycle (-65 C to 165 C)
  - Centrifuge (30,000 g)
  - Particle Impact Noise Detection (mini-vibration test)
  - Gross Leak Testing
  - Fine Leak Testing
  - External Visual Inspection
  - Electronic ‘Burn in’ test

- Destructive Tests: (Done on small percent of packages for qual)
  - Residual Gas Analysis
  - Drop Test
  - Accelerated life tests
    * Internal visual inspection
    * Cross section
    * X-Ray
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

• Model analysis (Vibration, natural frequency), Shock
• “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

<table>
<thead>
<tr>
<th>Operating Conditions for Stress Analysis</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cases</td>
<td>Pb, psi</td>
<td>Pd, psi</td>
</tr>
<tr>
<td>1: DAT Proof</td>
<td>860</td>
<td>860</td>
</tr>
<tr>
<td>2a: DAT Cyclic #1</td>
<td>520</td>
<td>520</td>
</tr>
</tbody>
</table>

| Material Yield Strength | 35 |
| Material Ultimate Strength | 42 |

<table>
<thead>
<tr>
<th>Location</th>
<th>Stress @ 860psi ksi</th>
<th>Limit Margin of Safety</th>
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</thead>
<tbody>
<tr>
<td>Loc#1</td>
<td>28.15</td>
<td>0.24</td>
</tr>
<tr>
<td>Loc#2</td>
<td>22.85</td>
<td>0.53</td>
</tr>
<tr>
<td>Loc#3</td>
<td>16.45</td>
<td>1.13</td>
</tr>
</tbody>
</table>

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 – Drawings (as Appendix within report). This section should focus solely on the details of the fabrication, assembly of, and manufacture of your design, as if this section, as a stand-alone document, would be provided to a manufacturer. It should NOT be introducing or describing functions, specifications, etc.
  - Provide assembly view drawing(s), exploded views, etc.
  - Provide fully dimensioned working drawings for the custom parts of your design
  - Provide a detailed Bill or Materials and/or parts list, including vendors, part numbers and price
Fabrication Package:
# Fabrication Package

![Fabrication Package Diagram]

## ISOMETRIC VIEW

### Overall Assembly

<table>
<thead>
<tr>
<th>ITEM NO.</th>
<th>PART NUMBER</th>
<th>VENDOR</th>
<th>DESCRIPTION</th>
<th>Defective/Qty</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>SYMA0002</td>
<td>--</td>
<td>OVERALL FRAME ASSEMBLY</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>SYMA0005</td>
<td>--</td>
<td>FISH TANK ASSEMBLY</td>
<td>1</td>
</tr>
<tr>
<td>3</td>
<td>SYMA0007</td>
<td>--</td>
<td>SLUDGE TANK ASSEMBLY</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>SYMA0006</td>
<td>--</td>
<td>FILTER TANK ASSEMBLY</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>SYMA0008</td>
<td>--</td>
<td>MEDIA TANK ASSEMBLY</td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>V_4544153</td>
<td>MCMASTER-CARR</td>
<td>SUMP TANK</td>
<td>1</td>
</tr>
<tr>
<td>7</td>
<td>SYMA0012</td>
<td>--</td>
<td>FILTER STAND</td>
<td>1</td>
</tr>
<tr>
<td>8</td>
<td>SYMA0010</td>
<td>--</td>
<td>SUMP TANK FRAME ASSEMBLY</td>
<td>1</td>
</tr>
<tr>
<td>9</td>
<td>SYMA0011</td>
<td>--</td>
<td>GROW BED ASSEMBLY</td>
<td>1</td>
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<tr>
<td>10</td>
<td>V_5311194</td>
<td>HOME DEPOT</td>
<td>1 1/2” PVC PIPE: 18’ LENGTH</td>
<td>1</td>
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<tr>
<td>11</td>
<td>4880534</td>
<td>HOME DEPOT</td>
<td>1 1/2” PVC PIPE: 8’ LENGTH</td>
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<tr>
<td>12</td>
<td>V_PVC072000200</td>
<td>HOME DEPOT</td>
<td>1 1/2” PVC PIPE: 8” LENGTH</td>
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<tr>
<td>13</td>
<td>V_C4811HD112</td>
<td>HOME DEPOT</td>
<td>1 1/2” PVC DWV 4-X MIP REDUCER MALE ADAPTER</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>V_PVC072000200</td>
<td>HOME DEPOT</td>
<td>1 1/2” PVC PIPE: 4” LENGTH</td>
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<tr>
<td>15</td>
<td>V_PVC02101101</td>
<td>HOME DEPOT</td>
<td>1 1/4” X 1 1/2” PVC MPT X S REDUCER MALE ADAPTER</td>
<td>5</td>
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<tr>
<td>16</td>
<td>V_407-015</td>
<td>PVC FITTINGS ONLINE</td>
<td>1 1/2” PVC ELBOW 90-DEGREE FPT X S</td>
<td>3</td>
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<tr>
<td>17</td>
<td>V_PVC072000200</td>
<td>HOME DEPOT</td>
<td>1 1/2” PVC PIPE: 3” LENGTH</td>
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<tr>
<td>18</td>
<td>V_3-600</td>
<td>HOME DEPOT</td>
<td>1 1/2” PVC Threaded FPT X FPT BALL VALVE</td>
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<tr>
<td>19</td>
<td>V_PVC072000200</td>
<td>HOME DEPOT</td>
<td>1 1/2” PVC PIPE: 5” LENGTH</td>
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<td>20</td>
<td>V_C4807HD112</td>
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<td>1 1/2” PVC DWV 90 DEGREE HUB X HUB ELBOW</td>
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<td>21</td>
<td>V_VBWH4276</td>
<td>HOME DEPOT</td>
<td>1 1/2” PVC SLIP X SUP VALVE</td>
<td>3</td>
</tr>
</tbody>
</table>

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**NOTICE:**
- The diagram shows an overview of the assembly with various components and their quantities.
- The table lists each component with its vendor and description, along with the defective quantity.
- The overall assembly includes multiple parts, such as pipes, fittings, and valves.

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**Scale:** 1/144

**Sheet:** 1 of 3
Fabrication Package
Fabrication Package
Fabrication Package
# Fabrication Package

<table>
<thead>
<tr>
<th>Assembly</th>
<th>Item</th>
<th>Part Number</th>
<th>QTY</th>
<th>Vendor</th>
<th>Unit Price</th>
<th>Per Unit</th>
<th>Total Price</th>
<th>Prototype Material</th>
<th>Final Material</th>
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</thead>
<tbody>
<tr>
<td><strong>Nail Assembly</strong></td>
<td>1 Nail Body</td>
<td>8905SK53</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$10.70</td>
<td>0.5ft</td>
<td>$5.35</td>
<td>Ti-6Al-4V</td>
<td>Ti-6Al-4V</td>
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<tr>
<td></td>
<td>2 Nail Shuttle</td>
<td>8885SK1</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$3.32</td>
<td>0.5ft</td>
<td>$3.32</td>
<td>Stainless Steel 17-4PH</td>
<td>Stainless Steel 17-4PH</td>
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<tr>
<td></td>
<td>3 Nail Dynamic Element</td>
<td>SSMO50X0300D</td>
<td>1</td>
<td>NDC</td>
<td>$1,176.00</td>
<td>1 ft</td>
<td>$23.52</td>
<td>Nitinol</td>
<td>Nitinol</td>
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<td></td>
<td>4 Nail Sliding Element</td>
<td>8905SK53</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$10.70</td>
<td>0.5ft</td>
<td>$1.07</td>
<td>Titanium Ti-6Al-4V</td>
<td>Ti-6Al-4V</td>
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<tr>
<td><strong>Compression</strong></td>
<td>5 Metal-Backed Sleeve Bearings (Shaft 6mm OD 8mm, Length 10mm)</td>
<td>6679K11</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$2.00</td>
<td>10c</td>
<td>$2.00</td>
<td>Steel-Backed PTFE-Coated Bronze</td>
<td>Steel-Backed PTFE-Coated Bronze</td>
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<td><strong>Assembly</strong></td>
<td>6 Compressor Piece</td>
<td>8974K28</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$2.30</td>
<td>.5ft</td>
<td>$0.29</td>
<td>8061 Aluminum</td>
<td>Ti-6Al-4V</td>
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<td>7 Thrust Bearing (Shaft 5/8” OD 1”)</td>
<td>5906SK15</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$1.01</td>
<td>1 pc</td>
<td>$1.01</td>
<td>SAE 841 Solid Bronze</td>
<td>Plastic</td>
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<td></td>
<td>8 5/8” Thumb Nut</td>
<td>9172SA150</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$8.94</td>
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<td>18-8 Stainless Steel</td>
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<td></td>
<td>9 Manual Compression Rod</td>
<td>9057SA818</td>
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<td>10 M4 x 25mm Bolts</td>
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<td>McMaster-Carr</td>
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<td>11 Guide Rod</td>
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<td>12 Targeting Arm</td>
<td>8503K444</td>
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<td>McMaster-Carr</td>
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<td>13 Press Fit Metric Drill Bushing</td>
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<td>McMaster-Carr</td>
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<td>1 pc</td>
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<td>Hardened Steel 17-4PH</td>
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<td>- 1/8”, 1/2” Length Dowel Pin</td>
<td>9739SA454</td>
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<td>1 pc</td>
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<td><strong>Nail Holder</strong></td>
<td>14 Nail Holder Sleeve</td>
<td>5041SK24</td>
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<td>0.5m</td>
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<td><strong>Assembly</strong></td>
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<td>1</td>
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<td>16 M3 x 8mm Bolts</td>
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<td>$0.08</td>
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<td>Stainless Steel 17-4PH</td>
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<td>17 Support Block</td>
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<td>1</td>
<td>McMaster-Carr</td>
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<td>Delrin</td>
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<td>18 Plastic Plates</td>
<td>8662K111</td>
<td>2</td>
<td>McMaster-Carr</td>
<td>$2.20</td>
<td>1 ft</td>
<td>$0.44</td>
<td>Stainless Steel 316</td>
<td>Stainless Steel 316</td>
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<td>19 Stretching Rod</td>
<td>8932SK99</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$1.96</td>
<td>0.5ft</td>
<td>$0.98</td>
<td>Stainless Steel 17-4PH with .4140 Steel Pins</td>
<td>316 Stainless Steel</td>
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<tr>
<td></td>
<td>20 Bushing</td>
<td>8885SK55</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$8.24</td>
<td>0.5ft</td>
<td>$8.24</td>
<td>Stainless Steel 17-4PH with .4140 Steel Pins</td>
<td>Stainless Steel 17-4PH</td>
</tr>
<tr>
<td><strong>Cam Lever</strong></td>
<td>21 Sleeve Bearing</td>
<td>6679K11</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$2.00</td>
<td>1 pc</td>
<td>$2.00</td>
<td>Steel-Backed PTFE-Coated Bronze</td>
<td>UHMWPE</td>
</tr>
<tr>
<td><strong>Assembly</strong></td>
<td>22 Cam Lever</td>
<td>9008K14</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$4.40</td>
<td>0.5ft</td>
<td>$2.20</td>
<td>Aluminum 6062, Radel</td>
<td>Aluminum 6062, Radel</td>
</tr>
<tr>
<td></td>
<td>23 M4 Nut</td>
<td>92497A250</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$14.07</td>
<td>100 pc</td>
<td>$0.14</td>
<td>Class 10 Steel</td>
<td>Stainless Steel 17-4PH</td>
</tr>
<tr>
<td></td>
<td>24 Acorn Nut</td>
<td>9400G035</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$3.90</td>
<td>25 pc</td>
<td>$0.16</td>
<td>304 Stainless Steel</td>
<td>Stainless Steel 17-4PH</td>
</tr>
<tr>
<td></td>
<td>- 1/8”, 1/2” Length Dowel Pin</td>
<td>9739SA441</td>
<td>2</td>
<td>McMaster-Carr</td>
<td>$0.69</td>
<td>1 pc</td>
<td>$1.38</td>
<td>316 Stainless Steel</td>
<td>316 Stainless Steel</td>
</tr>
<tr>
<td><strong>Miscellaneous</strong></td>
<td>- Collet Nut Wrench</td>
<td>6975A12</td>
<td>1</td>
<td>McMaster-Carr</td>
<td>$16.05</td>
<td>1 pc</td>
<td>$16.05</td>
<td>Forged Steel</td>
<td>Steel</td>
</tr>
</tbody>
</table>

- UHMWPE: Ultra High Molecular Weight Polyethylene
- Aluminum 6062: Aluminum alloy for applications requiring high corrosion resistance and strength.
- Radel: A type of high performance engineering thermoplastic material.
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