TEST FIXTURE
V-22 MANUAL DRIVE UNIT

Laine Johnson

May 2013
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PHASE 1 REQUIREMENTS DEFINITION

EXECUTIVE SUMMARY

“The V-22’s leap-ahead technology revolutionizes military air transport capabilities in a manner not since the introduction of helicopters more than 50 years ago. No other aircraft can do what the V-22 does. The V-22’s ability to self deploy around the world dramatically reduces strategic lift requirements. It is the most flexible, capable, and revolutionary combat troop transport / SAR / MEDEVAC aircraft in the world. It is the weapon of choice for the full spectrum of combat. The ideal platform when the mission dictates high speeds and long ranges with a mid-mission hover requirement (i.e. airfield independence). Sea-based or in mountainous wilderness region, V-22 provides the answer.”[1]

Fleet Readiness Center East has been named the sole Depot Level Maintenance Facility for the V-22. This means that FRCE is in the process of becoming 100% “Stand Up Capable”. By July 2015 FRCE must have all Test Fixtures, Support Equipment, tools and materials for the overhaul and repair of the Manual Drive Unit (P/N 901-331-950-123). Designing the Test Fixture for this Manual Drive Unit is the topic of the 2012-2013 NCSU/Support Equipment Engineering Capstone Design Project.

The Manual Drive Unit is a critical component for the BF/WS (blade-fold/wing-stow) to happen successfully. The Manual Drive Unit is connected to the capstan drive assembly through a quill shaft. The hydraulic motor is attached to the Manual Drive Unit and engages the splines in the input shaft assembly. The Manual Drive Unit is used during maintenance to move the wing from deployed to stow positions, when hydraulic power is not available.

Figure 1: BF/WS
PROBLEM DEFINITION

The V-22 overhaul and repairs shops at Fleet Readiness Center East (FRC East), are currently in the process of “standing up” capability to perform re-work on most of the major assemblies and components of the V-22 aircraft. One of the next components to declare capability is on the V-22 Manual Drive Unit. In order to do this there is a need to be able to test the overhauled units. This will be accomplished by the Test Fixture which the North Carolina State University MES 401 Capstone Design group have been tasked to design.

PROJECT STAKEHOLDERS

Air 4.8.4.11 Support Equipment Management
   Decision Authority/Cost
Air 4.3 FST Sub-systems Engineers
   Procedures to Qualify Parts
Components Integrated Product Team (IPT)
   Maintainability
FRC Artisans
   Information
Manufacturing
   Ease of procurement/manufacturing
OSHA
   Safety Requirements

NEEDS STATEMENT

The North Carolina State University MES 401 Capstone Design group has been tasked to design and develop a Test Fixture for the Manual Drive Unit for the V22 Osprey Aircraft. The Test Fixture will comply with the requirements of the Acceptance Test Procedure (ATP) for the TY2031 Manual Drive Unit for the Boeing V22 Osprey Air Vehicle. The ATP is in the document Goodrich Actuation Systems Engineering Report number ED/1877/129/AP project V22 Osprey Air Vehicle Wing Rotation and Lockpin System dated 24 April 2010 Issue 08 so that The V-22 Program is 100% “stand up” capable.
Operational Scenarios

Motorized Configuration
The Test Fixture will be permanently attached to a 35 inch high table which is currently in the shop. First the Artisan needs to check the Planned Maintenance (PM) card to insure that the calibration is up to date. Then the Artisan will take the Manual Drive Unit (MDU), line up the 4 holes on the male output shaft side with the two aligning pins and two threaded studs that are attached to the vertical holding plate on the Test Fixture. To secure the MDU to the Test Fixture attach the two steel flange hex nuts onto the two threaded studs. The Artisan will then make sure that the motorized housing with the motorized configuration is in place, with the 3/8 inch shaft securely attached to the 5-C collet and the 13-involute male spline in-line with the 13-involute female spline on the MDU. The circular base of the holding plate can be rotated 45 degrees by unscrewing the two low profile knobs. Once the MDU is in-line with the motorized configuration the two knobs should be tighten down securely. The carriage with the cross-slide and holding plates can then be moved along the bed of the lathe until the 13-involute splines are engaged. Then the Artisan can secure the carriage by tightening the Gibb screws down. The Artisan should check to make sure that the cable for the torque transducer and its digital indicator is connected to both devices, while keeping the cable out of the way of the rotating shaft by placing the cable in the wire clamps. Once the MDU, the motorized configuration and the 5-C collet are all in-line and engaged the Artisan should slide the protective covering over the Test Fixture being careful to cover all rotating parts. Now the MDU is ready to begin completing Performance Tests 5.1 & 5.3 from the Acceptance Test Procedures (ATP).

Manual Configuration
The Test Fixture will be permanently attached to a 35 inch high table which is currently in the shop. First the Artisan needs to check the Planned Maintenance (PM) card to insure that the calibration is up to date. Then the Artisan will take the Manual Drive Unit (MDU), line up the 4 holes on the male output shaft side with the two aligning pins and two threaded studs that are attached to the vertical holding plate on the Test Fixture. To secure the MDU to the Test Fixture attach the two steel flange hex nuts onto the two threaded studs. The Artisan will then remove the motorized housing. To complete this, first unplug the cable from the torque transducer and remove the cable from the wire clamp. Loosen the 5-C collet so that the 3/8 inch shaft can be disengaged. Loosen the Gibb screws under the carriage so that the carriage, the cross-slide and the holding plates can be slide back so that the 13-involute splines will be disengaged. Place the motorized housing with motorized housing configuration on the table, safely out of the way. Pick up the motorized housing (3/4 inch shaft, 40 inch-lb shaft-to-shaft clutch, and the 3/4 inch shaft with a 3/8 inch square drive male end), insert and secure the 3/4 inch shaft into the 5-C collet. The circular base of the holding plate can be rotated 45 degrees by unscrewing the two low profile knobs. Once the MDU's 3/8 inch square drive female end is in-line with the manual
configuration the two knobs should be tighten down securely. Next place the gag plate (part of the backlash equipment P/N A660412) into the 13-involute female spline. The carriage with the cross-slide and holding plates can then be moved along the bed of the lathe until the 3/8 inch square drives are engaged. Then the Artisan can secure the carriage by tightening the Gibb screws down. Once the MDU, the manual configuration and the 5-C collet are all in-line and engaged the Artisan should slide the protective covering over the Test Fixture being careful to cover all rotating parts. Now the MDU is ready to begin completing Performance Tests 5.4 from the Acceptance Test Procedures (ATP).

**Maintenance Scenarios**

The maintenance shall include the vendor’s recommendations and the existing FRC East’s maintenance program. The Design Team will write up a maintenance plan which will be presented to FRC East for final approval. Upon approval from FRC East this maintenance plan will be incorporated into the FRC East’s maintenance schedule.

**Production Scenario**

![Production Plan](image)

*Figure 2: Production Plan*
SPECIFIC CUSTOMER NEEDS

1.0 The Test Fixture shall be able to compete the Running in Performance Test.
   • The Test Fixture shall be capable of driving the unit (configured for powered operation & output shaft free) through its splined drive shaft CW and CCW at a speed of 1000 +/- 300 RPM for at least one minute.
   • The Test Fixture shall be able to measure the rotation of the main and manual input shafts in RPM with a range of +/- 1000 RPM with 10% FSD accuracy and display on a digital readout. The Test Fixture shall measure RPM up to 2000 RPM.

2.0 The Test Fixture shall be able to complete the Smooth Running Check Performance Test.
   • The Test Fixture shall be configured so that the manual drive unit can be fitted to the Test Fixture so that the manual drive unit’s input is disengaged from the Test Fixture.
   • The Test Fixture shall allow the manual drive unit’s motor input shaft to be manually rotated while in manual mode.

3.0 The Test Fixture shall be able to complete the Dynamic Torque Performance Test.
   • When operating as described in 1.1 (configuration 1), the Test Fixture shall be capable of measuring and displaying torque on the main input shaft with a range of +/- 10 in-lb with 1% FSD accuracy.

4.0 The Test Fixture shall be able to complete the Torque Limiter Operation Performance Test.
   • The Test Fixture shall allow the gagging piece (A664642) to be secured to the unit.
   • The Test Fixture shall be capable of driving the manual drive unit (configured for manual operation & output shaft gagged) through its manual input shaft CW and CCW at a speed of 1000 +/- 300 RPM for at least one minute.
   • When the manual drive unit is configured for manual operation with the output shaft gagged, the test unit shall allow the manual input shaft to be manually rotated for at least 10 breakouts in a CW and CCW direction.
   • When manually operated as described in 4.3, the Test Fixture shall be capable of measuring and displaying maximum torque on the manual input shaft with a range of +/- 35 in-lb with 1% FSD accuracy.

5.0 The Test Fixture shall be able to complete the Backlash Test.
   • The bench test backlash equipment will be supplied by Support Equipment Engineers NAVAIR 4.8.4.11.
   • The Test Fixture shall utilize bench backlash equipment A660412 while allowing the gagging device to be installed on the Output Shaft without removing the Test Fixture from the fixture so that a Dial Test Indicator can measure the Manual Input Shaft backlash.
6.0 For the Test Fixture to comply with FRC East’s expectations the following shall apply.

- The Test Fixture dimensions should not be larger than 6’ x 3’ x 3’.
- The Test Fixture will operate in room conditions between 68 degrees F and 90 degrees F.
- The Test Fixture shall interface with existing services.
- The Test Fixture shall be able to reverse directions without disassembling the Test Fixture.
- The Test Fixture shall be configured so that the manual drive unit can complete all tests for the ATP by being engage and disengaged without being removed from the fixture.
- The Test Fixture shall comply with all applicable safety codes, OSHA and FRCE Instructions. The Test Fixture shall have a safety cover that will be used while the motor is running.
- The Test Fixture shall be able to measure and display RPM during all tests.
- All readings from the Test Fixture shall be digital.
- An approved corrosive preventative measure will be applied to the Test Fixture (4.8.4.11 Support Equipment Engineers will approve method).
- A ratio of 3:1 will be utilized for any strength analysis of Yield strength.
- A ratio of 5:1 will be utilized for any strength analysis of Ultimate Tensile strength.
- Working Test Fixture shall be delivered by 4/26/2013.
- The specifications for calibrating the Test Fixture shall be provided by 4/26/2013.

**DESIGN METHODOLOGY**

Systems Engineering is a very useful set of tools that helped guide the design process. Using Systems Engineering from the start of the project to the completion of the project helped the NCSU Design Team always remember what the focus was; A satisfied Customer. By constantly referring back to the Requirements each component was chosen due to a specific reason. By ensuring that each component met the overall need of the system and evaluating the component against the Measures of Effectiveness aided in the decision process. Documenting all decisions showing the correlation between the decision and the need or requirement that it satisfied encouraged the use of Systems Engineering.
PROJECT DELIVERABLES

Table 1: Deliverable Due Dates

<table>
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<td>Drawing Package (Appendix A)</td>
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<td>Maintenance Information (Appendix B)</td>
<td>May 2013</td>
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<tr>
<td>Calibration Requirements (Appendix C)</td>
<td>May 2013</td>
</tr>
</tbody>
</table>

PROJECT MANAGEMENT

Project Schedule

Figure 3 below is the Top Level Gant Chart for this project. During this time period the schedule was updated and revised many times.

![Top Level Project Schedule](image)

Figure 3: NSCU Design Team 2012-2013 Schedule
Technical Event Plan

Before each of the Technical Events listed below in Table 2 the NCSU Design Team was given a list of requirements specific to that Milestone. After each Review the NCSU Design Team would type of the minutes, and then electronically distribute them to all members for clarification of items that were discussed or items that needed to be changed. There are three dates listed for the Detailed Design Review due to changes made to the design after the first two Detailed Design Reviews. The Support Equipment Engineers (4.8.4.11 NAVAIR) worked very closely with the NSCU Design Team on these changes. There were many informal “mini-detailed design reviews” with the Support Equipment Engineers that are not documented in Table 2.

Table 2: Review Dates

<table>
<thead>
<tr>
<th>Date</th>
<th>Milestone (Technical Event)</th>
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<tr>
<td>19-September-2012</td>
<td>System Requirements Review</td>
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<tr>
<td>10-October-2012</td>
<td>Concept Design Review</td>
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<tr>
<td>7-November-2012</td>
<td>Preliminary Design Review</td>
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<tr>
<td>12/18/2013; 1/7/2013; 2/6/2013</td>
<td>Detailed Design Review</td>
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<tr>
<td>8-May-2013</td>
<td>Critical Design Review / Final Presentation</td>
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</table>

Risk Management Approach

Figure 4 is a template for the management of the risks associated with this project. During each review risks were discussed, noted, and tracked. A mitigation plan shall be presented to the project leaders.

Figure 4: Risk Cube
**Team Structure**

The NCSU Design Team consists of one, me, Laine Johnson. Dr. Bill Fortney and Jim Yankauskas served as members of the design team during the beginning process. This was especially helpful while brainstorming. After the Concept Design Review their involvement was greatly reduced. Their contribution was mainly acting as a resource for me to contact if I had a specific question.

While completing the drawing package many Support Equipment Engineers (4.8.4.11) were kind to answer questions pertaining to Solid Edge ST3 (the drawing software used by Support Equipment Engineers 4.8.4.11 at FRC East). Engineers from the V-22 Support Equipment Engineers attended my reviews.

I am not the typical NC State student. I graduated in 1990 from the University of North Carolina at Pembroke with a BS in Mathematics with a minor in Secondary Education. I taught high school math in North Carolina for 20 years. In 2010 NAVAIR at FRC East hired me as a Mechanical Engineering Technician Student Trainee. I have worked 40 hours a week over the past 3 years while taking classes through NCSU to earn my BSE in Mechanical Systems Engineering. Thanks to NAVAIR hiring me through the EDAP (Engineering Development Assistance Program) I was able to work having a flexible schedule around my classes. NAVAIR also paid the tuition for the classes that I took while employed at FRC East.
PRESENTATION OF REQUIREMENTS

Before the requirements could be written the NCSU Design Team utilized a few helpful diagrams from Systems Engineering. These diagrams gave the Team a better understanding of the system; the systems' interfaces and the systems' required functions.

Context Diagram

The Context Diagram shows who will have direct or indirect contact with the Test Fixture, as well as the physical environment that the Test Fixture will interact with. This is represented in Figure 5.

![Context Diagram](image)

Figure 5: System Context Diagram
Function Block Diagram

By constructing the Function Block Diagram the NCSU Design Team was able to decide upon and organize the functions that will be required of the overall system, the Test Fixture, in order for the ATP (Acceptance Test Procedures) to be completed. This can be seen in Figure 6.

Figure 6: Function Block Diagram for the System

System Requirements

1. The Test Fixture shall be capable of driving the MDU (motorized configuration) through its splined drive shaft CW and CCW at a speed of 1000 +/- 300 rpm for at least one minute.
2. The Test Fixture shall be able to measure the rotation of the main and manual input shafts in rpm with a range of +/- 1000 rpm with 10% FSD. [7]
3. The Test Fixture shall be configured so that the MDU can be fitted to the Test Fixture so that the MDU’s input is disengaged from the Test Fixture.
4. The Test Fixture shall allow the MDU’s motor input shaft to be manually rotated while in manual mode.
5. When operating as described in 1.1 (motorized configuration), the Test Fixture shall be capable of measuring and displaying torque on the main input shaft with a range of +/- 10 in-lb with 1% FSD (Full Scale Deflection) accuracy. [7]

6. The Test Fixture shall allow the gagging piece (A664642) to be secured to the MDU.

7. The Test Fixture shall be capable of driving the MDU (manual configuration & output shaft gagged) through its manual input shaft CW and CCW at a speed of 1000 +/- 300 rpm for at least one minute.

8. When the MDU is configured for manual operation with the output shaft gagged, the Test Fixture shall allow the manual input shaft to be manually rotated for at least 10 breakouts in a CW and CCW direction.

9. When manually operated as described in 4.3, the Test Fixture shall be capable of measuring and displaying maximum torque on the manual input shaft with a range of +/- 35 in-lb with 1% FSD accuracy. [7]

10. The bench test backlash equipment will be supplied by Support Equipment Engineers 4.8.4.11.

11. The Test Fixture shall utilize bench test backlash equipment A660412 while allowing the gagging device to be installed on the Output Shaft without removing the MDU from the Test Fixture so that a Dial Test Indicator can measure the Manual Input Shaft Backlash.

12. The Test Fixture dimensions should not be larger than 6’ x 3’ x 3’.

13. The Test Fixture will operate in room conditions between 68 degrees F and 90 degrees F.

14. The Test Fixture shall interface with existing services.

15. The Test Fixture shall be able to reverse directions without disassembling the Test Fixture.

16. The Test Fixture shall be configured so that the manual drive unit can complete all tests for the ATP by being engaged and disengaged without being removed from the Test Fixture.

17. The Test Fixture shall comply with all applicable safety codes, OSHA (29 CFR 1910 Subpart O, Machinery and Machine Guarding) and FRCE Instructions (NAVARDEPOTINST 5100.2H). The Test Fixture shall have a safety cover that will be used while the motor is running.

18. The Test Fixture shall be able to measure and display RPM during all tests.

19. All reading from the Test Fixture shall be digital.

20. An approved corrosive preventative measure will be applied to the Test Fixture. (4.8.4.11 support Equipment Engineers will approve method)

21. A ratio of 3:1 will be utilized for any strength analysis of Yield Strength.

22. A ratio of 5:1 will be utilized for any strength analysis of Ultimate Tensile Strength.

23. Working Test Fixture shall be delivered by 4/26/2013.

24. The specifications for calibrating the Test Fixture shall be provided by 4/26/2013.
Selection Criteria

During the Concept Design Review the NCSU Design Team passed out a paired comparison sheet to each member of SE Engineers that attended. The NCSU Design Team asked each SE Engineer to fill out the blank spaces as seen in Figure 7. The directions were first to choose between the column title and the row title based upon importance for this project. Then rank (1 lowest to 5 highest) the importance of the one you chose relative to the overall system.

![Paired Comparisons for the V-22's MDU Test Fixture](image)

**Figure 7: Blank Paired Comparison**

After the review the weighted percentage was calculated. This determined the ranking of the most important criteria down to the least important criteria. Table 3 has the totals for each person and the weighted percentages.

**Table 3: Weighted Percentages with Rankings**

![Paired Comparisons for the V-22's MDU Test Fixture](image)
SYSTEM VALIDATION / VERIFICATION PLAN

The System Validation/Verification plan for this project is mainly made up of inspection and demonstration. The analysis part was done for the workstation height, assemblies’ weights and for the critical speed of the rotating shaft. To verify that the Test Fixture is functioning properly the use of a Calibrated RPM Meter, a Calibrated Torque Meter for low torque ranges and a Calibrated Torque Meter for the higher torque ranges will be utilized. Figure 8 states the 3 types of verifications. The Systems Requirement Matrix is shown in Tables 4, 5 and 6.

Figure 8: System Verification
### Table 4: Systems Requirements 1-2

<table>
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<th>Sub System</th>
<th>Description</th>
<th>Tied To ATP</th>
<th>Verification Method</th>
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<tr>
<td>1 0</td>
<td>Need</td>
<td>The Test Fixture shall be able to complete the Running In performance test.</td>
<td>.5.1.</td>
<td></td>
</tr>
<tr>
<td>1 1</td>
<td>System</td>
<td>The Test Fixture shall be capable of driving the unit (motorized configuration) through its splined drive shaft CW and CCW at a speed of 1000 +/- 300 RPM for at least one minute.</td>
<td>.5.1.2</td>
<td>X</td>
</tr>
<tr>
<td>1 2</td>
<td>System</td>
<td>The test Fixture shall be able to measure the rotation of the main and manual input shafts in RPM with a range of +/- 1000 RPM with 10% FSD accuracy and display on a digital readout. The Test Fixture shall measure RPM up to 2000 RPM.</td>
<td>.2.1, .5.0</td>
<td>X</td>
</tr>
<tr>
<td>2 0</td>
<td>Need</td>
<td>The Test Fixture shall be able to complete the Smooth Running Check performance test.</td>
<td>.5.2.</td>
<td></td>
</tr>
<tr>
<td>2 1</td>
<td>System</td>
<td>The Test Fixture shall be configured so that the manual drive unit can be fitted to the Test Fixture so that the manual drive unit’s input is disengaged from the Test Fixture.</td>
<td>.5.2.1</td>
<td>X</td>
</tr>
<tr>
<td>2 2</td>
<td>System</td>
<td>The Test Fixture shall allow the manual drive unit’s motor input shaft to be manually rotated while in manual mode.</td>
<td>.5.2.2</td>
<td>X</td>
</tr>
<tr>
<td>Req. #</td>
<td>Sub System</td>
<td>Description</td>
<td>Tied To ATP</td>
<td>I</td>
</tr>
<tr>
<td>-------</td>
<td>------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------------</td>
<td>---</td>
</tr>
<tr>
<td>3 0</td>
<td>Need</td>
<td>The Test Fixture shall be able to complete the Dynamic Torque performance test.</td>
<td>5.3</td>
<td></td>
</tr>
<tr>
<td>3 1</td>
<td>System</td>
<td>When operating as described in 1.1 (motorized configuration), the test Fixture shall be capable of measuring and displaying torque on the main input shaft with a range of +/- 10 in-lb with 1% FSD accuracy.</td>
<td>5.3.2</td>
<td></td>
</tr>
<tr>
<td>4 0</td>
<td>Need</td>
<td>The Test Fixture shall be able to complete the Torque Limiter Operation performance test.</td>
<td>5.4</td>
<td></td>
</tr>
<tr>
<td>4 1</td>
<td>System</td>
<td>The Test Fixture shall allow the gagging piece (A664642) to be secured to the unit.</td>
<td>5.4.1.1</td>
<td></td>
</tr>
<tr>
<td>4 2</td>
<td>System</td>
<td>The Test Fixture shall be capable of driving the unit (manual configuration &amp; output shaft gagged) through its manual input shaft CW and CCW at a speed of 1000 +/- 300 RPM for at least one minute.</td>
<td>5.4.1.2</td>
<td></td>
</tr>
<tr>
<td>4 3</td>
<td>System</td>
<td>When the manual drive unit is configured for manual operation with the output shaft gagged, the test unit shall allow the manual input shaft to be manually rotated for at least 10 breakouts in a CW and CCW direction.</td>
<td>5.4.2.2, 5.4.3.2</td>
<td></td>
</tr>
<tr>
<td>4 4</td>
<td>System</td>
<td>When manually operated as described in 4.3, the test unit shall be capable of measuring and displaying maximum torque on the manual input shaft with a range of +/- 35 in-lb with 1% FSD accuracy.</td>
<td>5.4.3.2, 2.1</td>
<td></td>
</tr>
<tr>
<td>5 0</td>
<td>Need</td>
<td>The Test Fixture shall be able to complete the Backlash test.</td>
<td>4.3</td>
<td></td>
</tr>
<tr>
<td>5 1</td>
<td>System</td>
<td>The bench test backlash equipment will be supplied by Support Equipment Engineers 4.8.11.</td>
<td>4.3</td>
<td>X</td>
</tr>
<tr>
<td>5 2</td>
<td>System</td>
<td>The Test Fixture shall utilize bench test backlash equipment A660412 while allowing the gagging device to be installed on the Output Shaft without removing the Test Fixture from the fixture so that a Dial Test Indicator can measure the Manual Input Shaft backlash.</td>
<td>4.3</td>
<td>X</td>
</tr>
</tbody>
</table>
## Table 6: Systems Requirements

<table>
<thead>
<tr>
<th>Req. #</th>
<th>Sub System</th>
<th>Description</th>
<th>Tied To ATP</th>
<th>I</th>
<th>A</th>
<th>D</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td><strong>System Requirements</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 0</td>
<td>Need</td>
<td>For the Test Fixture to comply with FRC East’s expectations the following shall apply.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 1</td>
<td>System</td>
<td>The Test Fixture dimensions should not be larger than 6’ x 3’ x 3’.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 2</td>
<td>System</td>
<td>The Test Fixture will operate in room conditions between 66 degrees F and 90 degrees F.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 3</td>
<td>System</td>
<td>The Test Fixture shall interface with existing services.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 4</td>
<td>System</td>
<td>The Test Fixture shall be able to reverse directions without disassembling the Test Fixture.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 5</td>
<td>System</td>
<td>The Test Fixture shall be configured so that the manual drive unit can complete all tests for the ATP by being engaged and disengaged without being removed from the fixture.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 6</td>
<td>System</td>
<td>The Test Fixture shall comply with all applicable safety codes, OSHA (29 CFR 1910 Subpart Q, Machinery and Machine Guarding) and FRCE Instructions (NAVAIRDEPOTINST 5100.2H). The Test Fixture shall have a safety cover that will be used while motor is running.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 7</td>
<td>System</td>
<td>The Test Fixture shall be able to measure and display RPM during all tests.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 8</td>
<td>System</td>
<td>All readings from the Test Fixture shall be digital.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 9</td>
<td>System</td>
<td>An approved corrosive preventative measure will be applied to the Test Fixture. (4.8.11 Support Equipment Engineers will approve method.)</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 10</td>
<td>System</td>
<td>A ratio of 3:1 will be utilized for any strength analysis of Yield strength.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 11</td>
<td>System</td>
<td>A ratio of 5:1 will be utilized for any strength analysis of Ultimate Tensile strength.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 12</td>
<td>System</td>
<td>Working Test Fixture shall be delivered by 4/25/2013.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 13</td>
<td>System</td>
<td>The specifications for calibrating the Test Fixture shall be provided by 4/25/2013.</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
PHASE 2 SYSTEM ARCHITECTURE

LITERATURE REVIEW

There were many resources that were utilized from the beginning to the completion of the project. Topics that were researched ranged from definitions of terms in the ATP, material properties, critical speeds for shafts, torque transducers, lathes, machine guards, plastics (polycarbonate), slip clutches, shafts with keyways, keyways, set screws, 13 involute splined shafts, 3/8” square drives, phosphate coating (manganese or zinc base), AISI A2 cold work tool steel, torque wrenches, types of taps, welding electrodes, ASTM A36 steel, heights for standing workstations, manual lifting weight limits and many different topics about Solid Edge ST3. While completing the drawing package many pages were turned in the 10th Edition of the Drawing Requirements Manual ASME Y14.100-2000 MIL-DTL-31000B.

Technical Literature

The technical literature that was used served to reinforce concepts addressed in earlier classes. Most of the topics that were researched were touched upon in the Engineering classes as NC State but for this project a deeper knowledge was needed. The books listed below in Table 7 were utilized often while completing the drawing package. The Technical Drawing with Engineering Graphics 14th Edition was very helpful while learning how to construct my 3D modeling and then the actual technical drawing 18E10601 in Solid Edge.

Table 7: Technical Books

<table>
<thead>
<tr>
<th>AUTHOR</th>
<th>TITLE</th>
<th>PUBLISHER</th>
<th>YEAR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Theodor Baumeister</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Technical Papers came in very handy. Some of these resources were located at FRC East while others were located using the internet. Table 8 displays the list of the Technical papers that I utilized.

Table 8: Technical Papers

<table>
<thead>
<tr>
<th>TITLE</th>
<th>COMPANY</th>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>AISI A2 Cold work tool steel:</td>
<td>Uddeholm</td>
<td></td>
</tr>
<tr>
<td>Socket Set Screws ASME B18.3</td>
<td>Alloy Steel</td>
<td>2003</td>
</tr>
<tr>
<td>Product Application Notes Volume 56, No. 3 Shaft and Hub Keyway and Key Sizes</td>
<td>Gates</td>
<td>April 2009</td>
</tr>
<tr>
<td>Phosphate Coating, Heavy, Manganese or Zinc Base</td>
<td>MIL-DTL-16232G</td>
<td>7 January 2000</td>
</tr>
<tr>
<td>NAVAIRDEPOTINST 5100.2H CH 24 Equipment Specific Safety Requirements</td>
<td>DoN</td>
<td>3 November 2003</td>
</tr>
<tr>
<td>Gear Backlash</td>
<td>Neugart USA LP</td>
<td>2001</td>
</tr>
<tr>
<td>Motion Control Made Easy</td>
<td>Anaheim Automation, Inc</td>
<td>2011</td>
</tr>
<tr>
<td>AM Series Lubricated Air Motors</td>
<td>Gast</td>
<td>2003</td>
</tr>
<tr>
<td>Model 1800 In-Line Torque Sensor</td>
<td>Honeywell</td>
<td>2012</td>
</tr>
<tr>
<td>New or Rebuilt Engine Break-in Procedure</td>
<td>NTNOA</td>
<td>1995</td>
</tr>
<tr>
<td>Specifier Guide</td>
<td>Baldor Electric Company</td>
<td></td>
</tr>
</tbody>
</table>
Web Sites

When brainstorming and looking at alternatives the internet proved very useful. The system needed a motor to run at 1000 rpm but to have two different output torque values; one value < 3.5 in-lbs while and one value > 29 in-lbs or but < 40 in-lbs, this became a dilemma. To use one motor the system would need to have a more complicated gear box. The Internet was used to research information about motors that used compressed air. The web sites helped the NCSU Design Team to formulate questions that needed to be answered by Facilities Engineers at FRC East. Based upon the answers from the Facilities and Electrical Engineers air motors were ruled out. The information from these different web sites, shown in Table 9, helped to rule out some possible alternatives.

Table 9: Web Sites

<table>
<thead>
<tr>
<th>WEBSITES</th>
</tr>
</thead>
<tbody>
<tr>
<td><a href="http://www.rockfordsystems.com/online/safeguarding/transparent-thate-chuck-shields.cfm">http://www.rockfordsystems.com/online/safeguarding/transparent-thate-chuck-shields.cfm</a></td>
</tr>
<tr>
<td><a href="http://www.grainger.com/Grainger/WESTWARD-Medium-Lathe-Guard">http://www.grainger.com/Grainger/WESTWARD-Medium-Lathe-Guard</a></td>
</tr>
<tr>
<td><a href="http://mcmaster.com">http://mcmaster.com</a></td>
</tr>
<tr>
<td><a href="http://www.nowmantools.com/taps/taptech.htm">http://www.nowmantools.com/taps/taptech.htm</a></td>
</tr>
<tr>
<td><a href="http://www.osha.gov/pls/oshaweb/owadisp.show_document">http://www.osha.gov/pls/oshaweb/owadisp.show_document</a></td>
</tr>
<tr>
<td><a href="http://www.thefreedictionary.com/judder">http://www.thefreedictionary.com/judder</a></td>
</tr>
<tr>
<td><a href="http://www.igsdirectory.com/dynamometers/">http://www.igsdirectory.com/dynamometers/</a></td>
</tr>
<tr>
<td><a href="http://www.sensing-systems.com/services/torque_and_horsepower_measurements/default.html">http://www.sensing-systems.com/services/torque_and_horsepower_measurements/default.html</a></td>
</tr>
<tr>
<td><a href="http://en.wikipedia.org/wiki/Break-in">http://en.wikipedia.org/wiki/Break-in</a> (mechanical run-in)</td>
</tr>
<tr>
<td><a href="http://www.datum-electronics.co.uk/rs420-rotary-torque-transducers.aspx">http://www.datum-electronics.co.uk/rs420-rotary-torque-transducers.aspx</a></td>
</tr>
<tr>
<td><a href="http://www.sswhiteaerospace.com/flexible-shaft/fittings.asp">http://www.sswhiteaerospace.com/flexible-shaft/fittings.asp</a></td>
</tr>
<tr>
<td><a href="http://www.OSHA.gov">www.OSHA.gov</a></td>
</tr>
<tr>
<td><a href="http://www.technologiststudent.com/gears1/gears3.htm">http://www.technologiststudent.com/gears1/gears3.htm</a></td>
</tr>
</tbody>
</table>
Vendors

The most important decision was finding the lathe since this housed the motor, the gears, the spindle and the holding devices. The South Bend Lathe Company had the sturdiest lathe in the small footprint that was needed. Next the other major components were explored. All the vendors listed in Table 10 were very helpful answering questions that were posed to them by the NCSU Design Team.

Table 10: Vendors

<table>
<thead>
<tr>
<th>VENDORS</th>
<th>CONTACT</th>
<th>PRODUCT(S)</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Bend Lathe Company</td>
<td>Matt Washkow</td>
<td>8&quot; x 18&quot; Lathe</td>
</tr>
<tr>
<td>Grizzly Industries</td>
<td>Matt Washkow</td>
<td>5-C Collet, Back Plate</td>
</tr>
<tr>
<td>Interface Advanced Force</td>
<td>(800) 947-5598</td>
<td>Torque Transducer, Flexible Couplings, Digital Indicator</td>
</tr>
<tr>
<td>Measurement</td>
<td><a href="http://www.interfaceforce.com">www.interfaceforce.com</a></td>
<td></td>
</tr>
<tr>
<td>SDP-SI</td>
<td>(516) 328-3300</td>
<td>Shaft-to-Shaft Slip Clutches (15 in-lbs &amp; 40 in-lbs)</td>
</tr>
<tr>
<td><a href="http://www.sdp-si.com">www.sdp-si.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shimpo</td>
<td>1701 Glenlake Avenue</td>
<td>Handheld Laser</td>
</tr>
<tr>
<td>Itasca, IL 60143</td>
<td>(800) 237-7079</td>
<td>Tachometer</td>
</tr>
<tr>
<td>Shimpo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reid Supply</td>
<td>(800) 253-0421</td>
<td>Thermoplastic Six-Lobe Washer Knob</td>
</tr>
<tr>
<td><a href="http://www.ReidSupply.com">www.ReidSupply.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shimpo</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waytek Wire Company</td>
<td>(800) 328-2724</td>
<td>Adhesive Backed Wire Clamp</td>
</tr>
<tr>
<td><a href="http://www.waytekwire.com">www.waytekwire.com</a></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waytek Wire Company</td>
<td></td>
<td></td>
</tr>
<tr>
<td>McMaster-Carr Supply</td>
<td>(404) 346-7000</td>
<td>Hardware, Material</td>
</tr>
<tr>
<td>Company</td>
<td><a href="http://www.mcmaster.com">www.mcmaster.com</a></td>
<td></td>
</tr>
</tbody>
</table>
**Company Contacts at FRC East**

Everyone in Support Equipment 4.8.4.11 has been extremely helpful to the NCSU Design Team. The Design Engineers listed in Table 11 were the Engineers who were the go to people about questions dealing with the actual design while the Engineers listed as Solid Edge Guidance were the people who so graciously helped with the ins and outs of using Solid Edge correctly.

**Table 11: Support Equipment 4.8.4.11**

<table>
<thead>
<tr>
<th>NAME</th>
<th>TITLE</th>
<th>ROLE as it pertains to the NCSU Design Team</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scott Fisher</td>
<td>Support Equipment Department Head 4.8.4.11</td>
<td>SE Design Lead</td>
</tr>
<tr>
<td>Lee Alan</td>
<td>Support Equipment Senior Engineer</td>
<td>SE Designer</td>
</tr>
<tr>
<td>Robbie Puett</td>
<td>Support Equipment Senior Engineer V-22</td>
<td>SE Designer</td>
</tr>
<tr>
<td>Kevan Dover</td>
<td>Support Equipment Engineer V-22</td>
<td>SE Designer</td>
</tr>
<tr>
<td>David Daniels</td>
<td>Support Equipment Engineering V-22</td>
<td>Solid Edge Guidance</td>
</tr>
<tr>
<td>David Toler</td>
<td>Support Equipment Engineering V-22</td>
<td>Solid Edge Guidance</td>
</tr>
<tr>
<td>Josh Corbett</td>
<td>Support Equipment Engineer</td>
<td>Solid Edge Guidance</td>
</tr>
<tr>
<td>Patrick Townsend</td>
<td>Support Equipment Engineer</td>
<td>Solid Edge Guidance</td>
</tr>
<tr>
<td>Ken Szommer</td>
<td>Support Equipment Engineer</td>
<td>Solid Edge Guidance</td>
</tr>
</tbody>
</table>

**ALTERNATIVES CONSIDERED**

Once the NCSU Design Team had brainstormed and written the system requirements it was time to begin figuring out how to successfully meet the system requirements. Research was done on electrical motors and air motors. Information from facilities personnel was gathered about the available compressed air and available power sources. Due to the air motors requiring a higher psi than the shop floor has available the air motors were ruled out of the design.

Scott Fisher, Support Equipment Department Head, requested that if possible he would prefer that the design utilized single phase power. Baldor Electric was a company that the NCSU Design Team contacted with questions about their electric motors. Since there were two different torque ranges with the same rpm values Baldor Electric suggested a 1 horsepower motor to accomplish this, but added that the gear box would need to be more complicated. Having the requirement for two different torque values would increase the price of the gear box.

Next decision was how to hold the Manual Drive Unit (MDU) in place without removing it so that all the ATP tests could be completed. A type of “lazy Susan” or a
type of “turn table” was our best idea. Deciding whether the MDU should rotate horizontally or vertically was part of the next decisions. Figure 9 shows the Top View of the two Alternate Designs. While Figure 10 shows the front views (elevated views) of the two Alternate Designs.
When the NCSU Design Team began with the hand sketches we joked about how it looked like we were drawing a lathe. Then based on that and with the help of Jim Yankauskas, the “silly idea” of using a lathe for the motor/gear box was researched.

**PROPOSED DESIGN**

The idea of using a lathe was sprung on Dr. Fortney two days before the Concept Design Review. He was very skeptical. During the Concept Design Review the Alternate Designs were discussed first, and then the idea of purchasing a “mini-lathe” and modifying it to fit our needs was introduced. When the costs of the 3 proposed designs were discussed along with the modifications that would need to be done on the lathe everyone was convinced that the idea of a lathe was not too farfetched. Due to time constraints for the procurement process at FRC East it was decided to proceed forward with the design using the “mini-lathe” as the main component.
PHASE 3 DETAILED DESIGN

FINAL DESIGN

The Manual Drive Unit Test Fixture for the V-22 Osprey will fulfill all the system requirements, which is representative of all the customer’s needs. This design has a much lower dollar value associated with it than the cost of FRC East purchasing the Test Fixture from the OEM. Figure 11 is a picture of the actual lathe marking indicating which parts would be removed/discarded, possibly be removed/discarded and parts which will be removed but replaced with a different part.

Purchased Part  SB1001 8”x 18” Lathe

Motorized Configuration

To complete half of the ATP the Test Fixture would be in the Motorized Configuration. This is when the (external) 13 involute splined shaft will be mated with the motorized female input (internal) 13 involute spline of the MDU. The torque values are required to be < 3.5 in-lbs while the shaft will be rotating 1000 rpm CW and CCW.
Figure 12 displays this configuration. This configuration includes the low torque transducer, double flexible couplings and a 15 in-lb shaft-to-shaft-mounted slip clutch. The pedestal torque transducer is mounted to a base which is mounted to the bottom of the motorized housing. The Motorized housing can be lifted off of the bed of the lathe and placed on the workstation behind the lathe with protective covering so that the parts of the ATP that do not require the torque transducer can be performed. The MDU is attached to a holding devise that can be moved left to right along the bed of the lathe. This will enable the alignment of the shaft with the lathe’s collet and the shaft with the motorized input of the MDU.

![Test Fixture V-22 MDU Motorized Configuration](image)

**Figure 12: 18E10601 View A Motorized Configuration**

**Manual configuration**

To complete the other half of the ATP the Test Fixture would be in the Manual Configuration. This is when the 3/8” square male drive will be mated to with the manual female 3/8” square drive manual input of the MDU. The torque values required to “breakout” should be between 24 in-lbs and 27 in-lbs. This value will be taken by a hand held LCD Laser Tachometer. Then the manual input will be rotated at 1000 rpm
CW and CCW, since the torque values are not required to be taken while rotating the motorized housing will be removed from the Test Fixture to prevent damage to the torque transducer (17.7 in-lb maximum torque). Figure 13 displays this configuration. The manual configuration assembly consists of a ¾" shaft with a .188" x .094" keyway, a Shaft-to-Shaft 40 in-lb Slip Clutch and a ¾" shaft with a .188" x .094" keyway on one end and a 3/8” square drive on the other end.

Figure 13: 18E10601 View B Manual Configuration
DESIGN COMPONENTS

Lathe Assembly

The main component of the Test Fixture is the purchased South Bend 8” x 18” Lathe. The Lathe will be modified to fit our needs. Figure 13 is a 3D model of the modified Lathe 18E10601-2. First the tailstock assembly (quill ball handle, quill lock lever and tailstock) will be removed and discarded. Next the 4-way tool rest, the compound rest ball handle and maybe the cross-slide ball handle will be removed and discarded. Parts that will be added to the lathe will be the end plate, the t-slots nuts, the rectangular bottom plate and one of the adhesive back wire clamps.

The end plate serves two purposes; first to keep the saddle & cross-slide from sliding off the back of the lathe bed and second for the overall assembly number to be engraved for identification purposes. To keep the cable that connects the torque transducer to the digital indicator needs to be kept out of the way of the rotating shafts and off the lathe’s bed. The adhesive backed wire clamp will serve that function.

Figure 14: 18E10601-2 Lathe Assembly
Holding Plate Assembly

The requirements stated that the MDU will remain in the Test Fixture from the beginning of the ATP until it is completed. The decision was made that the best way to accomplish the movement of the MDU was to mount it on a rotating device. This component is the “lazy Susan”. This circular plate can rotate; the retractable spring plunger will be the locating pin so that the rotation will be 45 degrees. On the rectangular plate beneath it there are holes already at the 45 degree location. The steel butt weld is there for a safety reason. It covers the output shaft of the MDU. It will be welded to the vertical plate. No strength analysis was performed since there is no stress applied. The assembly is shown in Figure 15.

Figure 15: 18E10601-3 Holding Plate Assembly

Protective Covering Assembly

Since the lathe is actually a “mini-lathe” it does not come with a machine guard. Therefore the NCSU Design Team needed to design some type of protective covering. Extensive research was done trying to find a machine guard that would fit with the smaller dimensions of this lathe plus the height of the motorized housing. Due to the
small dimensions of the lathe and the height of the side plates of the motorized housing made the use of a pre-manufactured machine guard impossible.

While designing the protective covering ergonomics was a main criterion. A simple design was desired, but weighting less than 35 pounds. The key component with the protective covering is the U-Channel Teflon track. Since Teflon is a self-lubricating material it allows the polycarbonate plates to slide or glide inside the U-Channel. Figure 16 below shows the protective covering.

![Sub-Assembly Protective Covering](image)

**Figure 16: 18E10601-4 Protective Covering**

**Motorized Configuration Assembly**

The Motorized Configuration Assembly is the most complicated assembly of the design. The most critical part of the component is the height. The next concern was maintaining the overall weight of this assembly to be less than 35 pounds so that one artisan could lift it off the lathe’s bed.

For stability a pedestal torque transducer was chosen over using a floating torque transducer. Based on this torque transducer the company recommends using double flexible couplings to account for any mis-alignment. To protect the torque transducer (17.7 in-lb maximum torque value) from being damaged a shaft-to-shaft mounted 40 in-lb slip clutch was utilized between the connection of the collet and the couplings. The diameters of the shafts are 3/8”. The shafts that are interfacing with
the slip clutch have flatways because the clutch has setscrews. The motorized input shaft has a 13 involute spline on one end of the shaft.

There is a base that the torque transducer is mounted on. The height of this part may need to be altered if the current measurements for the lathe are incorrect. Until the lathe is procured and delivered to FRC East these measurements cannot be verified. The 3D model and the drawing can be modified once all exact values are known. The assembly is shown in Figure 17 below.

Figure 17: 18E10601-5 Motorized Configuration Assembly

Manual Configuration Assembly

Since the torque values are not required when the manual input is being rotated by the motor the torque transducer is removed. Also the torque required to initially turn the manual 3/8" square drive input is a higher torque (between 24-27 in-lbs). This high of torque would damage the T5 2nm (17.7 in-lbs) torque transducer. A shaft-to-shaft mounted slip clutch of 40in-lbs is utilized to prevent damage to the MDU.
One shaft has a diameter of ¾” with a keyway of .188” x .094”. The other shaft has a diameter of ¾” with a keyway of .188” x .094” on one end while the other end is a 3/8” square drive. Figure 18 shows this configuration.

**Figure 18: 18E10601-6 Manual Configuration Assembly**

**Vertical Plate Weldment**

The steel butt cap is welded to the vertical plate. The purpose is to cover the MDU’s output shaft. Since there is no force or stress acting on this weld no stress analysis was performed. This is shown in Figure 19.

**Figure 19: 18E10601-7 Vertical Plate Weldment**
End Plate

The function of the end plate is to keep the saddle/cross-slide with the holding plates from being able to slide off the end of the lathe. The identification plate for the overall assembly will be placed on the end plate. The plate is shown in Figure 20.

Figure 20: 18E10601-8 End Plate

Cross-Slide

Figure 21 shows the cross-slide from the lathe. Again the exact dimensions have not been verified yet. They will be verified once the lathe or the drawing package from the South Bend Lathe Company arrives. The center hole is for the ½” diameter dowel pin that is press fit into this part and the rectangular bottom plate. This is the dowel that the circular holding plate assembly with rotate around.

Figure 21: 18E10601-9 Cross-Slide
Rectangular Bottom Plate

There will be 4 T-Slot nuts that will attach this plate to the cross-slide (4 countersunk holes). The center hole is for the \( \frac{1}{2} \)" dowel pin that will be press fitted into this plate and the cross-slide. The 2 outer holes are for two threaded studs that will be there so that after the circular holding assembly has been aligned it can be held in place by the 2 six-lobed washer knobs. The smaller hole on the right is for aligning this plate with the cross-slide underneath it. The 45 degree angle is marking the two holes for the retractable spring plunger that is the locating device when the MDU will be rotated to a different configuration. These details are shown in Figure 22. Correct location is very important for the alignment of the shafts to the input of the MDU.

![Rectangular Bottom Plate](image)

Figure 22: 18E10601-10 Rectangular Bottom Plate

Circular Plate

The circular plate is the main part of the Holding Plate Assembly. This plate has the two slots so that it can be rotated 45 degrees to enable both configurations. To help with wear from the two threaded studs and the 6-lobe washer knobs there is radius to round out the slots. The center hole is slightly larger than the center \( \frac{1}{2} \)" dowel
pin which used as the pivot point. As shown in Figure 23 the other 4 holes are to attach the vertical plate weldment.

Figure 23: 18E10601-11 Circular Plate

**Manufactured Part** Circular Plate

**Vertical Plate**

This plate is thick so that it can hold the MDU. The center large hole is to allow the MDU to fit flush with the vertical plate while its output shaft extends out the other side. The top edges are rounded to protect the artisans from sharp edges. On the
front two holes are threaded and 2 are not. This is due to using 2 threaded studs and 2 dowel pins to attach the MDU. Figure 24 shows all these details.

![Manufactured Part](image)

**Figure 24: 18E10601-12 Vertical Plate**

---

**DESIGN OPTIMIZATION**

**Height/Horizontal Reach Evaluation**

Since Ergonomics was the number one Measure of Effectiveness, based upon results from the Support Equipment Engineering input, making sure that the height of the Test Fixture was within the suggested range was important. First the type of work needed to be decided: precision work, light or normal work, or heavy work. Lining the center of the collet with the shafts and then lining the shafts to the appropriate input for the manual drive unit would be considered precision work. Based on the recommendations from OSHA 29CFR Part 1910 Docket No. S-777 RIN No. 1218AB36 Ergonomics Program the workstation height should be between 45.5” and 49.5” for precision work. Figure 18 has an Artisan whose height is about 5’ 8.25” along with the table height, the height from floor to centers and the height from the floor to the Motorized Configuration handles (location for lifting). [4]
Horizontal Reach dimensions also were needed. Table 12 displays the recommended dimensions. Figure 19 verifies that our workstation is in compliance. [4]

**Table 12: Recommended Dimensions for Reaching**

<table>
<thead>
<tr>
<th>Horizontal Reach and Grasp Dimension</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Frequent reaches should be within normal range or within 14-18”</td>
</tr>
<tr>
<td>- Reaches between 22-26” should be made occasionally</td>
</tr>
<tr>
<td>- Avoid reaches over 26”</td>
</tr>
</tbody>
</table>
Finding the exact values for the fixed workstation height and horizontal reaching dimensions were very difficult to find on the OSHA website. I was able to find some information in the FRC East Safety Manual NAVAIRDEPOTINST 5100.2 on the CPWeb (Cherry Point Wingspan, FRC East homepage). [5]
**Hand Calculations for Critical Speed**

The Rayleigh-Ritz method was used for calculating an approximation of the first natural frequency of vibration, which is assumed to be nearly equal to the critical speed of rotation \[^{[3]}\]

\[
\text{Critical Speed, } N_c = \frac{30}{\pi} \sqrt{\frac{g}{\delta_{ST}}}
\]

Where:
- \(g\) = gravity acceleration \((32.2 \text{ ft/s}^2)\)
- \(\delta_{ST}\) = total maximum static deflection

![Diagram of shaft with labeled parts: W, A, B, L, and cross-sectional area.

\[
\delta_{ST2} = \frac{WB(L^2 - B^2)^{2/3}}{9\sqrt{3EI}L}
\]

Where:
- \(w\) = weight of shaft, lbm
- \(\rho\) = density of A36 Steel, lbm/\(in^3\)
- \(V\) = volume of shaft, \(in^3\)
- \(W\) = weight of clutch, lbm
- \(E\) = modulus of elasticity, psi
- \(I\) = moment of inertia, inch\(^4\) \[I = \frac{\pi D^4}{64}\]
- \(L\) = length of shaft, inches
- \(D\) = diameter of shaft, inches
- \(B\) = shorter length of shafts, inches

39
Figure 27: 18E10601-6 Manual Configuration

\[ \delta_{str} = \frac{WB(L^2 - B^2)^{2/3}}{9\sqrt{3}EIL} \]

Where:
\[ \rho = .284 \text{ lbm/in}^3 \]

\[ V_1 = (4 \text{ in})(\frac{\pi}{4})(.750 \text{ in})^2 = 1.767145868 \text{ in}^3 \]

\[ V_2 = (3 \text{ in})(\frac{\pi}{4})(.750 \text{ in})^2 + (3\text{ in})(.375\text{ in})^2 = 1.747234401\text{ in}^3 \]

\[ w_1 = \rho \times V = (.284 \text{ lbm/in}^3)(1.767145868 \text{ in}^3)(32.2 \frac{ft}{s^2})(\frac{12 \text{ in}}{1 \text{ ft}}) \]

\[ w_1 = 193.9223464 \text{ lbf} \]

\[ w_2 = \rho \times V = (.284 \text{ lbm/in}^3)(1.747234401 \text{ in}^3)(32.2 \frac{ft}{s^2})(\frac{12 \text{ in}}{1 \text{ ft}}) \]

\[ w_2 = 191.7373098 \text{ lbf} \]

\[ w_{total} = 385.6596562 \text{ lbf} \]

\[ B = 4\text{ in} \]

\[ L = 10.035\text{ in} \]

\[ W = (2.25\text{ lbs}_m)(32.2 \frac{ft}{s^2})(\frac{12\text{ in}}{1\text{ ft}}) = 869.4 \text{ lbf} \]

\[ E = 2.9 \times 10^7 \frac{\text{lbf}}{\text{in}^2} \]

\[ D = .750\text{ in} \]
\[ I = \frac{\pi D^4}{64} \quad I = \frac{\pi \times (.75\text{in})^4}{64} = .015531555\text{in}^4 \]

\[ \delta_{ST2} = \frac{(869.4\text{lbf})(4\text{in})((10.035\text{in})^2 - (4\text{in})^2)^{2/3}}{9\sqrt{3} \left(2.9 \times 10^2 \text{lbf/}in^2\right) (.015531555\text{in}^4)(10.035\text{in})} = \frac{67071.71658\text{in}}{70458509.29} = \]

\[ \delta_{ST2} = .000951932\text{in} \]

\[
\text{Critical Speed, } N_c = \frac{30}{\pi} \sqrt{\frac{g}{\delta_{ST}}} \\
N_c = \frac{30}{\pi} \sqrt{\left(32.2 \frac{\text{ft}}{s^2}\right) \left(\frac{12 \text{ in}}{1 \text{ ft}}\right) \times .000951932\text{in}} = 6083.97 \text{ rpm} \\
\]

Recommended Maximum Speed
\[ 75\% \times N_c = (.75)(6083.97 \text{ rpm}) = 4562.97 \text{ rpm} \]

Maximum Speed for ATP requirements, 1300 rpm

\[
\text{Factor of Safety} = \frac{4562.97}{1300} = 3.5 
\]
Figure 28: 18E10601-5 Motorized Configuration

\[ \delta_{ST2} = \frac{WB(L^2 - B^2)^{2/3}}{9\sqrt{3EI}L} \]

Where:
\[ \rho = .284 \text{ lbm/in}^3 \]

\[ V_1 = (5 \text{ in}) \left( \frac{\pi}{4} \right)(.375 \text{ in})^2 = 0.552233084 \text{ in}^3 \]

\[ V_2 = (3 \text{ in}) \left( \frac{\pi}{4} \right)(.375 \text{ in})^2 = 0.33133985 \text{ in}^3 \]

\[ V_{TOTAL\ LEFT} = V_1 + V_2 = .883572934\text{in}^3 \]

\[ w_1 = \rho \cdot V = (0.284 \text{ lbm/in}^3)(0.552233084 \text{ in}^3) \left(32.2 \text{ ft/s}^2\right) \left(\frac{12 \text{ in}}{1 \text{ ft}}\right) \]

\[ w_1 = 60.60073328 \text{lbf} \]

\[ w_2 = \rho \cdot V = (0.284 \text{ lbm/in}^3)(0.33133985 \text{ in}^3) \left(32.2 \text{ ft/s}^2\right) \left(\frac{12 \text{ in}}{1 \text{ ft}}\right) \]

\[ w_2 = 36.36043992 \text{lbf} \]
\( w_{TOTAL\ LEFT} = 96.9611732 \text{lbf} \)

\( B = 3 \text{in} \)

\( L_{LEFT} = 8.125 \text{in} \)

\[
W = (0.50 \text{lbs}_m)(32.2 \text{ ft/s}^2)\left(\frac{12 \text{in}}{1 \text{ft}}\right) = 193.2 \text{lbf}
\]

\( E = 2.9 \times 10^7 \text{lbf/in}^2 \)

\( D = .375 \text{in} \)

\[
I = \frac{\pi D^4}{64} \quad I = \frac{\pi \times (.375 \text{in})^4}{64} = .000970722 \text{in}^4
\]

\[
\delta_{ST2} = \frac{(193.2 \text{lbf})(3 \text{in})((8.125 \text{in})^2 - (3 \text{in})^2)^{2/3}}{9\sqrt{3} \left(2.9 \times 10^7 \text{lbf/in}^2\right) (.000970722 \text{in}^4)(8.125 \text{in})} = \frac{8586.001692 \text{ in}}{3565491.264} =
\]

\( \delta_{ST2\ LEFT} = .002408084 \text{ in} \)

\[
\text{Critical Speed, } N_c = \frac{30}{\pi} \sqrt{\frac{g}{\delta_{ST}}}
\]

\[
N_{c\ LEFT} = \frac{30}{\pi} \sqrt{\left(\frac{32.2 \text{ ft}}{\text{s}^2}\right)\left(\frac{12 \text{ in}}{1 \text{ft}}\right) .002408084 \text{ in}} = 3825.20 \text{ rpm}
\]

**Recommended Maximum Speed**

75\% * \( N_c = (.75)(3825.20 \text{ rpm}) = 2868.90 \text{ rpm} \)

**Maximum Speed for ATP requirements**, 1300 \text{ rpm}

**Factor of Safety** \( \frac{2868.90}{1300} = 2.2 \)
\[
\delta_{ST} = \frac{5wL^3}{384EI}
\]

Where:

\[
\rho = 0.284 \ \text{lbm/in}^3
\]

\[
V_{RIGHT} = (5 \text{ in}) \left(\frac{\pi}{4}\right) (.375 \text{ in})^2 = 0.552233084 \text{ in}^3
\]

\[
w_{RIGHT} = \rho * V = (0.284 \text{ lbm/in}^3) (.552233084 \text{ in}^3) \left(32.2 \text{ ft/s}^2\right) \left(12 \text{ in/1 ft}\right)
\]

\[
w_{RIGHT} = 60.60073328 \text{ lbf}
\]

\[
E = 2.9 * 10^7 \text{ lbf/in}^2
\]

\[
D = 0.375 \text{ in}
\]

\[
l = \frac{\pi D^4}{64} = \frac{\pi * (0.375 \text{ in})^4}{64} = 0.00970722 \text{ in}^4
\]

\[
\delta_{ST \ RIGHT} = \frac{(5)(60.60073328 \text{ lbf})(5 \text{ in})^3}{384 \left(2.9 * 10^7 \text{ lbf/in}^2\right) (.00970722 \text{ in}^4)} = \frac{37875.46 \text{ in}}{10809960.19}
\]

\[
\delta_{ST \ LEFT} = 0.003503756 \text{ in}
\]
Weight Calculations

Solid Edge has the capability to include the material properties for the components so that the weight of the component can be calculated. Solid Edge has a drop down menu with standard types of materials used to machine parts with their densities stored into the program. Figure 22 is an example of one of the calculations for the components in Solid Edge ST3.

Critical Speed,
\[ N_c = \frac{30}{\pi} \sqrt{\frac{g}{\delta_{ST}}} \]

\[ N_{c\,\text{RIGHT}} = \frac{30}{\pi} \sqrt{\frac{32.2}{5^2} \left(\frac{12\,\text{in}}{1\,\text{ft}}\right) \left(\frac{1\,\text{ft}}{0.003503713\,\text{in}}\right)} = 3171.20\,\text{rpm} \]

Recommended Maximum Speed
\[ 75\% \times N_c = (0.75)(3171.20\,\text{rpm}) = 2378.40\,\text{rpm} \]

Maximum Speed for ATP requirements, 1300 rpm

\[ \text{Factor of Safety} = \frac{2378.40}{1300} = 1.83 \]
Figure 29: Example of calculating the weight of a component

This function was used to calculate the weight of the components which made up the assemblies that will be manually lifted or manually moved. Table 13 and Table 14 display these results. OSHA recommends that employees should not manually lift anything > 35 pounds without assistance. [6] Both assemblies that will be manually moved or lifted are less than the recommended weight of 35 pounds.
Table 13: Weight of assembly 18E10601-4 Protective Covering

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Weight (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18E10601-13</td>
<td>6.589</td>
</tr>
<tr>
<td>18E10601-13</td>
<td>6.589</td>
</tr>
<tr>
<td>18E10601-14</td>
<td>4.269</td>
</tr>
<tr>
<td>1556A36 L-BRACKET (X8)</td>
<td>3.496</td>
</tr>
<tr>
<td>96640A137 SCREW (X48)</td>
<td>0.25392</td>
</tr>
<tr>
<td>91581A335 HEX NUTS (X48)</td>
<td>0.19536</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>21.392</strong></td>
</tr>
</tbody>
</table>

Table 14: Weight of assembly 18E10601-5 Motorized Configuration

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Weight (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18E10601-16</td>
<td>12.536</td>
</tr>
<tr>
<td>18E10601-17</td>
<td>3.019</td>
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</tr>
<tr>
<td>18E10601-18</td>
<td>0.687</td>
</tr>
<tr>
<td>18E10601-18</td>
<td>0.687</td>
</tr>
<tr>
<td>T5-2-A1A &amp; MST-32-M8-038</td>
<td>2</td>
</tr>
<tr>
<td>S9946Y-1X6X6015</td>
<td>0.5</td>
</tr>
<tr>
<td>18E10601-20</td>
<td>0.150</td>
</tr>
<tr>
<td>18E10601-21</td>
<td>0.092</td>
</tr>
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<td>18E10601-22</td>
<td>0.153</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>22.843</strong></td>
</tr>
</tbody>
</table>
## COST ESTIMATE

### Table 15: Hardware Cost

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Qty</th>
<th>Unit</th>
<th>Unit Cost</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/4&quot;-20 x 3/4&quot; Locknut</td>
<td>2</td>
<td>Ea</td>
<td>$0.10</td>
<td>$0.20</td>
</tr>
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<td>1/4&quot;-20 x 3/4&quot; Flatwasher Nut</td>
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<td>Ea</td>
<td>$0.93</td>
<td>$1.86</td>
</tr>
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<td>$0.10</td>
<td>$2.05</td>
</tr>
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<td>$0.95</td>
<td>$1.90</td>
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<td>$0.50</td>
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<tr>
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<td>pack</td>
<td>$0.50</td>
<td>$1.00</td>
</tr>
<tr>
<td>1/4&quot;-20 x 3/4&quot; Black-Oxide Nut</td>
<td>1</td>
<td>pack</td>
<td>$0.50</td>
<td>$0.50</td>
</tr>
<tr>
<td>1/4&quot;-20 x 3/4&quot; Locknut</td>
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<td>1/4&quot;-20 x 3/4&quot; Black-Oxide Nut</td>
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<td>2</td>
<td>pack</td>
<td>$0.50</td>
<td>$1.00</td>
</tr>
<tr>
<td>1/4&quot;-20 x 3/4&quot; Black-Oxide Nut</td>
<td>1</td>
<td>pack</td>
<td>$0.50</td>
<td>$0.50</td>
</tr>
<tr>
<td>1/4&quot;-20 x 3/4&quot; Locknut</td>
<td>2</td>
<td>pack</td>
<td>$0.50</td>
<td>$1.00</td>
</tr>
<tr>
<td>1/4&quot;-20 x 3/4&quot; Black-Oxide Nut</td>
<td>1</td>
<td>pack</td>
<td>$0.50</td>
<td>$0.50</td>
</tr>
<tr>
<td>1/4&quot;-20 x 3/4&quot; Locknut</td>
<td>2</td>
<td>pack</td>
<td>$0.50</td>
<td>$1.00</td>
</tr>
<tr>
<td>1/4&quot;-20 x 3/4&quot; Black-Oxide Nut</td>
<td>1</td>
<td>pack</td>
<td>$0.50</td>
<td>$0.50</td>
</tr>
<tr>
<td>1/4&quot;-20 x 3/4&quot; Locknut</td>
<td>2</td>
<td>pack</td>
<td>$0.50</td>
<td>$1.00</td>
</tr>
<tr>
<td>1/4&quot;-20 x 3/4&quot; Black-Oxide Nut</td>
<td>1</td>
<td>pack</td>
<td>$0.50</td>
<td>$0.50</td>
</tr>
</tbody>
</table>

**Subtotal: $255.14**
Table 16: Material Cost

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>RND NUMBER [M]</th>
<th>QUANTITY</th>
<th>MATERIAL</th>
<th>LABOR</th>
<th>TOTAL</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material (Purchased)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Super-Adhesive Hotfix 6&quot; x 1/2&quot; x 5-Ft</td>
<td>1 Ea</td>
<td>$58.76</td>
<td>$58.76</td>
<td>$58.76</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teflon U-Channel 1/2&quot; x 1/4&quot; x 1/8&quot; x 5-Ft</td>
<td>1 Ea</td>
<td>$74.50</td>
<td>$74.50</td>
<td>$74.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact-Resistant Polycarbonate 12&quot; x 12&quot; x 1/4&quot;</td>
<td>2 Ea</td>
<td>$15.58</td>
<td>$31.16</td>
<td>$31.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact-Resistant Polycarbonate 24&quot; x 24&quot; x 1/4&quot;</td>
<td>1 Ea</td>
<td>$45.70</td>
<td>$45.70</td>
<td>$45.70</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Impact-Resistant Polycarbonate 24&quot; x 24&quot; x 3/8&quot;</td>
<td>2 Ea</td>
<td>$72.10</td>
<td>$144.20</td>
<td>$144.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SUBTOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$302.40</td>
<td></td>
</tr>
<tr>
<td>Material (Manufactured) ($125 PER HOUR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12&quot; x 11&quot; x 3/8&quot; Carbon Steel A36 Plate</td>
<td>1</td>
<td>$101.72</td>
<td>$101.72</td>
<td>$101.72</td>
<td>$125.00</td>
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<tr>
<td>10&quot; x 10&quot; x 1/4&quot; Carbon Steel A36 Plate</td>
<td>1</td>
<td>$63.84</td>
<td>$63.84</td>
<td>$63.84</td>
<td>$125.00</td>
<td>$188.84</td>
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<tr>
<td>8&quot; x 8&quot; x 1/4&quot; Carbon Steel A36 Plate</td>
<td>1</td>
<td>$87.70</td>
<td>$87.70</td>
<td>$87.70</td>
<td>$125.00</td>
<td>$182.70</td>
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<tr>
<td>6&quot; x 12&quot; x 1/2&quot; Carbon Steel A36 Plate</td>
<td>1</td>
<td>$74.00</td>
<td>$74.00</td>
<td>$74.00</td>
<td>$125.00</td>
<td>$199.00</td>
</tr>
<tr>
<td>6&quot; x 12&quot; x 1/4&quot; Carbon Steel A36 Plate</td>
<td>2</td>
<td>$62.00</td>
<td>$124.00</td>
<td>$124.00</td>
<td>$125.00</td>
<td>$250.00</td>
</tr>
<tr>
<td>6&quot; x 12&quot; x 1&quot; Carbon Steel A36 Plate</td>
<td>1</td>
<td>$175.00</td>
<td>$175.00</td>
<td>$175.00</td>
<td>$125.00</td>
<td>$300.00</td>
</tr>
<tr>
<td>12&quot; x 11&quot; x 1/2&quot; Polycarbonate</td>
<td>2</td>
<td>$31.43</td>
<td>$62.86</td>
<td>$62.86</td>
<td>$125.00</td>
<td>$187.86</td>
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<tr>
<td>24&quot; x 24&quot; x 1/4&quot; Polycarbonate</td>
<td>1</td>
<td>$45.04</td>
<td>$90.08</td>
<td>$90.08</td>
<td>$125.00</td>
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<tr>
<td>24&quot; x 24&quot; x 3/8&quot; Polycarbonate</td>
<td>2</td>
<td>$74.32</td>
<td>$148.64</td>
<td>$148.64</td>
<td>$125.00</td>
<td>$273.64</td>
</tr>
<tr>
<td>3/8&quot; x 5&quot; Steel Shaft With 13-Involute Spur Male End</td>
<td>1</td>
<td>$11.91</td>
<td>$11.91</td>
<td>$11.91</td>
<td>$500.00</td>
<td>$511.91</td>
</tr>
<tr>
<td>3/8&quot; x 5&quot; Steel Shaft With A Flat on One End</td>
<td>1</td>
<td>$7.56</td>
<td>$7.56</td>
<td>$7.56</td>
<td>$250.00</td>
<td>$257.56</td>
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<tr>
<td>3/8&quot; x 5&quot; Steel Shaft With A Flat on One End</td>
<td>1</td>
<td>$11.91</td>
<td>$11.91</td>
<td>$11.91</td>
<td>$250.00</td>
<td>$261.91</td>
</tr>
<tr>
<td>3/4&quot; x 6&quot; Steel Shaft With A 188&quot; x .044&quot; Keyway</td>
<td>1</td>
<td>$10.71</td>
<td>$10.71</td>
<td>$10.71</td>
<td>$250.00</td>
<td>$260.71</td>
</tr>
<tr>
<td>3/4&quot; x 6&quot; Steel Shaft/188&quot; x .044&quot; Keyway/3/8&quot; Square Drive</td>
<td>1</td>
<td>$10.71</td>
<td>$10.71</td>
<td>$10.71</td>
<td>$8,000.00</td>
<td>$10,010.71</td>
</tr>
<tr>
<td>1.88&quot; x 0.94&quot; x 3/8&quot; Keyway</td>
<td>1</td>
<td>$10.00</td>
<td>$10.00</td>
<td>$10.00</td>
<td>$125.00</td>
<td>$135.00</td>
</tr>
<tr>
<td><strong>SUBTOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$4,552.63</td>
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</table>

Table 17: Equipment Cost

<table>
<thead>
<tr>
<th>ITEM DESCRIPTION</th>
<th>RND NUMBER [M]</th>
<th>QUANTITY</th>
<th>MATERIAL</th>
<th>LABOR</th>
<th>TOTAL</th>
<th>TOTAL COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8&quot; x 18&quot; 40 TIP BEND LATHE</td>
<td>1 Ea</td>
<td>$2,265.00</td>
<td>$2,265.00</td>
<td>$2,265.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3-COOLT CHUCK平 ENDCUT</td>
<td>1 Ea</td>
<td>$395.00</td>
<td>$395.00</td>
<td>$395.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D-1-2 BACK PLATE FOR SERT-TRU</td>
<td>1 Ea</td>
<td>$225.00</td>
<td>$225.00</td>
<td>$225.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shaft-Tongue-1.25Holes Slp Clutch</td>
<td>1 Ea</td>
<td>$229.74</td>
<td>$229.74</td>
<td>$229.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS ROTARY TORQUE TRANSUDER</td>
<td>1 Ea</td>
<td>$3,042.00</td>
<td>$3,042.00</td>
<td>$3,042.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DOUBLE FLEXIBLE COUPLINGS</td>
<td>2 Ea</td>
<td>$118.00</td>
<td>$118.00</td>
<td>$118.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HIGH SPEED DIGITAL INDICATOR</td>
<td>1 Ea</td>
<td>$800.00</td>
<td>$800.00</td>
<td>$800.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCREW WIPER CONNECTOR CABLE LOFT</td>
<td>1 Ea</td>
<td>$210.00</td>
<td>$210.00</td>
<td>$210.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>HANDHELD LCD DIGITAL LASER TACHOMETER</td>
<td>1 Ea</td>
<td>$335.00</td>
<td>$335.00</td>
<td>$335.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>SUBTOTAL</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$7,619.74</td>
<td></td>
</tr>
</tbody>
</table>
### Table 18: Total Cost Estimate

<table>
<thead>
<tr>
<th>Item Description</th>
<th>Quantity</th>
<th>Material</th>
<th>Labor</th>
<th>Total Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardware</td>
<td></td>
<td></td>
<td></td>
<td>$255.14</td>
</tr>
<tr>
<td>Material (Purchased)</td>
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<td></td>
<td></td>
<td>$302.40</td>
</tr>
<tr>
<td>Material (Manufactured) ($125 PER HOUR)</td>
<td></td>
<td></td>
<td></td>
<td>$4,552.63</td>
</tr>
<tr>
<td>Equipment</td>
<td></td>
<td></td>
<td></td>
<td>$7,619.74</td>
</tr>
<tr>
<td><strong>SUB-TOTAL ESTIMATED CONSTRUCTION COST</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$12,729.91</strong></td>
</tr>
<tr>
<td><strong>TOTAL ESTIMATED CONSTRUCTION COST WITH TAXES</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>$13,621.00</strong></td>
</tr>
</tbody>
</table>
PHASE 4 PRODUCTION

The NCSU Design Team will model the design using the software that FRC East utilizes, Solid Edge ST3. Once the design has been approved by Support Equipment Engineers the NCSU Design Team will provide a complete drawing package which consists of all assembly drawings, bill of materials, part details and machine processing notes. The NCSU Design Team will deliver this package to FRC East Support Equipment 4.8.4.11. When testing begins the NCSU Design Team will be members of the Testing Team, along with FRC East.

The procurement of parts, using the drawing package to manufacture the parts, assembling the system and testing the Test Fixture are all the responsibilities of FRC East. Once the tests have been validated the Test Fixture will be integrated with the FRC East production floor.

Figure 30: Production Plan
CONCLUSIONS

IMPACT ON SOCIETY

The biggest impact on society is a huge cost reduction. By having the NCSU Design Team design the Test Fixture and then having it manufactured at FRC East is a reduction of the cost. The price that was quoted from Bell/Boeing was at least 10 times more than the cost that we incurred. Another large impact on the local communities around FRC East is if FRC East does not learn how to be flexible and continue to change then the work load for FRC East may dwindle. Carteret County, Craven County, Pitt County and Onslow County would be devastated if FRC East shut down. The V-22 overhaul/repair work for this component is scheduled to begin July 2015. When FRC East cannot handle a particular problem then we are also letting the Fleet (Marines, Navy) down.

ETHICS

When Ethics were discussed in our college classes the “Code of Ethics” seemed very straight forward. But as you begin your senior Capstone design you realize how difficult it is to interpret some of these guidelines. Fundamental Canon 2 “Perform services only in the areas of their competence” was very important to the NCSU Design Team since this was our first attempt at designing a Test Fixture. The key is to research the topic first. Then develop a proposed solution then contact Engineers that are experts in that field. By doing this you are educating yourself so that this particular topic can become part of your area of competency.

Canon 1 “Hold paramount the safety, health, and welfare of the public” was always considered while completing the project. For the NCSU Design Team it is especially important since this Test Fixture will test an aircraft component that will be installed on an aircraft that will be full of service men and women protecting the United States of America. Those service men and women have already put their life on the line by serving in a hostile environment; they need to be able to trust that the engineers had designed the best possible parts and components for their safety.

By putting my name on this project I am staking my reputation on the line, so I have done everything to honor Fundamental Canon 6 “Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.”

OVERALL RESULTS

The NCSU Design Team has done their very best to use their newly acquired knowledge, mechanical knowledge and systems engineering knowledge, to design the best working Test Fixture possible based upon the selection criteria and measures of
effectiveness. The importance of TEAMWORK in the work place, not just the academic world became very apparent. Without the many Engineers that answered questions for the NCSU Design Team this project would not have been completed.

Applying the tools from Systems Engineering was a necessity for success. Tools like using the context diagram, function block diagrams, gant charts for scheduling, writing up the requirements matrix, paired comparison and the many other types of organizational skills that were taught in the Systems Engineering Classes. Always remembering that what the customer wants is the most important concept, because you may design a great product but if it was not what the customer was asking for then you failed to deliver the end item.

After completing the project the NCSU Design Team has a much greater appreciation of all the Design Engineers of the past. Until you have personally gone through all the steps from talking to the customer then designing and delivering a working product you don’t have a clue how much time and research that goes into an efficiently designed product.

BIBLIOGRAPHY


APPENDIX B – MAINTENANCE INFORMATION

18E10601-2 South Bend Lathe SB1001
http://www.southbendlathe.com/products/lathes/SB1001
Maintenance pg 48

Model SB1001 8K™ Lathe

MAINTENANCE
For Machines Mfg. Since 8/11

Maintenance Schedule

WARNING
Always disconnect machine from power before performing maintenance or serious personal injury may result.

Ongoing
To maintain a low risk of injury and proper machine operation, if you ever observe any of the items below, shut down the machine immediately and fix the problem before continuing operations.

- Loose mounting bolts or fasteners.
- Worn, frayed, cracked, or damaged wires.
- Emergency STOP button not working correctly or not requiring you to reset it before starting the machine again.
- Loose, worn, or damaged drive belts or timing belts.
- Damaged or malfunctioning components.

Daily, Before Operations

- Lubricate the spindle bearings (Page 49).
- Lubricate feed direction gears (Page 50).
- Lubricate grease fittings (Page 51).
- Clean/lubricate the longitudinal leadscrew (Page 51).
- Lubricate 3-jaw chuck (Page 52).
- Clean/lubricate the bedways and slides (Page 52).
- Check condition and tension of drive belts (Page 55) and timing belts.
- Check for loose or damaged timing-belt pulleys.
- Turn the spindle speed dial all the way counterclockwise (to prevent high-speed startup).
- Disengage the half nut lever on the apron (to prevent crashes upon startup).
- Ensure the carriage lock is loose.

Cleaning & Protecting

Regular cleaning is one of the most important steps in taking care of this lathe. We recommend that the cleaning routine be planned into the workflow schedule, so that adequate time is set aside to do the job right.

Typically, the easiest way to clean swarf from the bedways and chip drawer is to use a wet/dry shop vacuum that is dedicated for this purpose. The small chips left over after vacuuming can be wiped up with a lightly-oiled rag. Avoid using compressed air to blow off chips, as it may drive them deeper into moving surfaces and could cause sharp chips to fly into your face or hands.

In addition to the ways, all other unpainted and machined surfaces should be wiped down daily to keep them rust-free and in top condition. This includes any surface that is vulnerable to rust (especially any part exposed to water soluble cutting fluid). Typically, a thin film of good quality way oil is all that is necessary for protection. (Refer to Accessories on Page 46 for an option from South Bend.)

NOTICE
The timing belts and pulleys should remain free from grease and grime. Clean the pulleys with mineral spirits when changing configurations, then allow them to dry. Wipe the timing belts with a clean, dry shop rag at the same time.
### 7.1 Maintenance Schedule

<table>
<thead>
<tr>
<th>Action</th>
<th>Frequency</th>
<th>Date</th>
<th>Date</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control of cables and connectors</td>
<td>1x p.a.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calibration</td>
<td>&lt; 26 months</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control of fixation (flanges, shafts)</td>
<td>1x p.a.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have bearings exchanged by Interface, Inc.</td>
<td>20,000 hrs operating time</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MODEL 9834 Digital Indicator
PDF/Downloads

S9946Y-1X6X6015 Slip Clutch 15in-lbs & S9946Y-2XCX040 Slip Clutch 40 in-lbs

MODEL DT-205LR-S12 Handheld LCD Digital Laser Tachometer
## APPENDIX C – CALIBRATION REQUIREMENTS

<table>
<thead>
<tr>
<th>EQUIPMENT</th>
<th>CALIBRATION SCHEDULE</th>
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</thead>
<tbody>
<tr>
<td>18E10601-2 South Bend Lathe SB1001</td>
<td>Every 12 months</td>
</tr>
<tr>
<td>MODEL DT-205LR-S12 Handheld LCD Digital Laser Tachometer</td>
<td>Every 12 months</td>
</tr>
</tbody>
</table>
APPENDIX D – SUPPORT EQUIPMENT BRIEF

BRIEF TO:
NCSU Mechanical Engineering
Capstone Project
Scott Fisher
Kevan Dover

V-22 Manual Drive Test Fixture

Kevan Dover
BS Mechanical Engineering
December 2009
University of North Carolina
at Charlotte

Scott Fisher
BS Mechanical Engineering
May 2002
University of Missouri-
Columbia
Personal Background

- **Kevan Dover**
  - 4.8.4.11 Mechanical Engineer
  - (252) 464-6360
  - kevan.dover@navy.mil

- **Scott Fisher, P.E.**
  - 4.8.4.11 Branch Head
  - (252) 464-7133
  - scott.j.fisher1@navy.mil

- **J. Brantley Garner**
  - AIR-4.8 Department Head
  - jonathan.garner@navy.mil

Naval Air Systems Command

Under the **Department of Defense (DOD)**, NAVAIR is a **United States Navy** command with military and **civilian employees** stationed at eight sites throughout the United States. NAVAIR engineers provide acquisition, research, development, test and evaluation, and in-service support capabilities to deliver advance warfare technologies: aircraft, sensors, weapons systems, training systems, and communications technologies.

**Locations**

- **Patuxent River, Maryland**
  - Headquarters
  - Aircraft and Systems Development Test Ranges

- **Lakehurst, New Jersey**
  - Support Equipment
  - Aircraft Launch and Recovery

- **Orlando, Florida**
  - Training and Instructional Systems

- **China Lake, California**
  - Weapons and Systems Development
  - Energetics, and Test Ranges

- **Point Mugu, California**
  - Weapons Test and Evaluation
  - Targets, and Test Ranges

- **Cherry Point, North Carolina**
  - Jacksonville, Florida
  - San Diego, California
  - In-Service Engineering
  - Repair and Modification Services
The Fleet Readiness Center (FRC) East at Cherry Point, N.C., provides extensive maintenance and engineering support to Navy and Marine Corps aviation, as well as other armed services, federal agencies and foreign governments. Our skilled workforce uses state-of-the-art technology to ensure that FRC East is without equal in providing quality, cost-effective support.

http://www.navair.navy.mil/frce/
NAVAIR Cherry Point

Research and Engineering

Systems Engineering

Air Vehicle (Airframes, Rotor blades, gearboxes, etc)

Propulsion and Power (Engines)

Avionics

Crew Systems (Ejection seats)

Support Systems (Support equipment, Automated test equipment, etc)

http://www.navair.navy.mil/frce/

What is Support Equipment?

• Slings
• Workstands
• Fixtures
• Tooling
• Dollies
Slings

Workstands
Fixtures

Tooling
Project Statement

The shops at FRC-East, are currently in the process of “standing up” capability to perform re-work on most of the major assemblies and components of the V-22 aircraft. One of the next components to declare capability on is the V-22 Manual Drive Unit. In order to do this there is a need to be able to test the overhauled units.

V-22 Wing Stow System

• The wing/nacelles rotate 90°. Until they are directly on top of the fuselage.
• The wing stow system allows shipboard capability through reduced footprint of the aircraft.
• This is done via the flex ring, which is rotated by the Capstan Drive (a hydraulically powered radial actuator).
• The Capstan Drive is driven through the Manual Drive Unit by a hydraulic motor.
• The Manual Drive Unit allows the use of hand-held wrenching to manually stow the wing in the event of electrical and/or hydraulic failure.
V-22 Wing Stow System

Complete Wing Stow
Technical Requirements

The requirements are driven by the Production Acceptance Test Procedure or ATP that is given to Bell/Boeing by the OEM of the specific component(s).

The requirements include but are not limited to:

- Product “Run-In” (motor input run at 3000 rpm for 1 minute) in both directions, CW and CCW.
- Static Breakout Torque (measure the max torque at motor input required for input to rotate at 10 rpm) in both directions.
- Dynamic Torque (max torque at motor input when ramping speed from 10 to 2400 rpm in 10 seconds in both directions).
- Test setup size limitation: 6’ x 3’ x 3’ max

Design Objectives

- Design for ease of manufacture
- Design for simple disassembly/re-assembly of unit the for inspection purposes
- Design for minimal floor footprint of the unit
- Design to minimize the likelihood of damage to the aircraft component
- Design for the safety and ease of operation by the operator
- Minimize the costs associated with materials, machining, and assembly
Components

Figure 1: Capstan Drive, Manual Drive Unit, and Hydraulic Motor

Figure 2: Manual Drive Unit

QUESTIONS?
APPENDIX E – SYSTEMS REQUIREMENTS REVIEW

NC STATE MECHANICAL ENGINEERING SYSTEMS BSE PROGRAM

TEST RIG
FOR THE MANUAL DRIVE UNIT ON THE V-22 OSPREY

SYSTEM REQUIREMENTS REVIEW

PREPARED BY
LAINE JOHNSON
9/19/2012

Overview

- Background/Problem Statement
- Requirements
- Project Deliverables
- Project Management
- Clarifications
The V-22 overhaul and repair shops at FRCE are currently in the process of “standing up” capability to perform re-work on most of the major assemblies and components of the V-22 aircraft. One of the next components to declare capability is on the V-22 Manual Drive Unit. In order to do this there is a need to be able to test the overhauled units. This will be accomplished by the Test Rig which the NC State University MES 401 Capstone Design group have been tasked to design.

The NC State MES 401 Capstone Design group has been tasked to design and develop a Test Rig for the Manual Drive Unit (MDU) for the V-22 Osprey Aircraft.

The Test Rig will allow the MDU to be tested as specified in the Goodrich Actuation Systems Acceptance Test Procedure (ATP) document number ED/1877/129/AP.
Context Diagram

Stakeholders

<table>
<thead>
<tr>
<th>Stakeholder</th>
<th>Description</th>
<th>Role</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRCE 4.8.11 Support Equipment Engineers</td>
<td>Responsible for financing project.</td>
<td>Decision</td>
</tr>
<tr>
<td>Artisans</td>
<td>Directly responsible for running the Test Rig to perform the ATP for the Manual Drive Unit on the V-22. Recording the results from the performance tests on the ATP. Based upon the results they decide whether the Manual Drive Unit is functioning correctly.</td>
<td>Information</td>
</tr>
<tr>
<td>Component Integrated Product Team</td>
<td>Held accountable for stand-up capability of the V-22 program.</td>
<td>Decision</td>
</tr>
<tr>
<td>V-22 FST</td>
<td>Held accountable for engineering support to the Fleet.</td>
<td>Decision</td>
</tr>
</tbody>
</table>
Operating Scenario

- One or two Artisans get the Test Rig out of cabinet or off of shelf.
- Artisan(s) check the maintenance card and calibration date.
- Artisan(s) place the Test Rig on the workbench/table and connect it to the required utilities.
- Artisan attaches the Manual Drive Unit to the Test Rig following the instructions in the technical publications (tech pubs) then run the Acceptance Test Procedures according to the instructions, recording results on the ATP data sheet.
- For each test, the Test Rig will allow the proper conditions to be set (RPM, load, ...) and will display the necessary value (RPM, Torque, ...).
- At the end of the ATP, the artisan will decide whether the overhauled Manual Drive Unit passes the ATP based upon given maximum/minimum values on the data sheet provided to them.
- Artisan will notify Engineering if the manual drive unit fails the ATP.
- Artisan will route manual drive unit per the work order if it passes the ATP.

Requirements
Specific Customer Need #1

1.0 The Test Rig shall be able to complete the Running In performance test. (5.1)

1. The Test Rig shall be capable of driving the MDU (configured for powered operation & output shaft free) through its splined drive shaft CW and CCW at a speed of 1000+/−300 rpm for at least one minute. (5.1.2) – Configuration 1.

2. The Test Rig shall be able to measure the rotation of the main and manual input shafts in rpm with a range of +/-1000 rpm with a 10% FSD accuracy and display on a digital readout (2.1)

Request For Clarification

1) How can 1000 rpm be accurately measured with a meter that only goes to 1000 rpm as specified in 2.1?

2) Is input speed checked during tests with rpm requirement or just checked on the drive motor and then assume it stays when a test is going on? ATP says to check rpm of drive motor before test 5.2 and does not say to check rpm again.
Specific Customer Need #2

2.0 The Test Rig shall be able to complete the Smooth Running Check performance test. (5.2)

1. The Test Rig shall be configured so that the MDU can be fitted to the Test Rig so that the manual drive unit's input is disengaged from the Test Rig. (5.2.1)

2. The Test Rig shall allow the MDU’s motor input shaft to be manually rotated while in manual mode. (5.2.2)

Specific Customer Need #3

3.0 The Test Rig shall be able to complete the Dynamic Torque performance test. (5.3)

1. When operating as described in 1.1 (configuration 1), the test rig shall be capable of measuring and displaying torque on the main input shaft with a range of +/-10 lb/in with 1% FSD accuracy. (5.3.2)
Specific Customer Need #4

4.0 The Test Rig shall be able to complete the Torque Limiter Operation performance test. (5.4)

1. The Test Rig shall allow the gagging piece (A664642) to be secured to the unit. (5.4.1.1)

2. The Test Rig shall be capable of driving the MDU (configured for manual operation & output shaft gagged) through its manual input shaft CW and CCW at a speed of 1000 +/-300 rpm for at least one minute. (5.4.1.2) – Configuration 2.

4.0 Torque Limiter (Continued)

3. When the MDU is configured for manual operation with the output shaft gagged, the test unit shall allow the manual input shaft to be manually rotated for at least 10 breakouts in a CW and CCW direction. (5.4.2.2 & 5.4.3.2) – Configuration 3

4. When manually operated as described in 4.3 (Configuration 3), the test unit shall be capable of measuring and displaying peak torque on the manual input shaft with a range of +/-35 lb/in with 1% FSD accuracy. (2.1 & 5.4.1.2)
Specific Customer Need #5

5. For the Test Rig to comply with FRC East’s expectations, the following shall apply.

1. The Test Rig dimensions should not be larger than 6’ x 3’ x 3’.
2. The Test Rig will operate at normal ambient room conditions.
3. The Test Rig shall interface with existing services.
4. The Test Rig shall comply with all applicable safety codes, OSHA and FRC East Instructions.
5. Working Test Rig shall be delivered by 4/26/2013.
6. The specifications for calibrating the Test Rig shall be provided by 4/26/2013.

Measures of Effectiveness

• Cost
• Assembled Footprint
• Ease of Use (Safety, Ergonomics)
• Ease of Manufacturing
• Ease of Maintainability
Project Deliverables

Production Plan

Perform Design

Obtain Parts

Assemble / Verify

Drawing Package
Parts List
Mfg. Parts
Support Eq.
Purchased Parts

NCSU

NCSU

NCSU

Test Rig
# Project Management

![Image of a project diagram]

## Top Level Project Schedule

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>SRR</td>
<td>1 day</td>
<td>9/19/12</td>
<td>9/19/12</td>
</tr>
<tr>
<td>Concept/Prototype Design</td>
<td>29 days</td>
<td>9/20/12</td>
<td>10/10/12</td>
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<tr>
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<td>Wed 10/11/12</td>
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<tr>
<td>Detailed Design</td>
<td>29 days</td>
<td>Thu 11/1/12</td>
<td>Thu 11/1/12</td>
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<tr>
<td>DFR</td>
<td>1 day</td>
<td>Wed 12/12/12</td>
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<tr>
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<td>Fri 1/22/13</td>
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<tr>
<td>Assemble / Test</td>
<td>25 days</td>
<td>Mon 2/12/13</td>
<td>Fri 2/12/13</td>
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<tr>
<td>System Testing</td>
<td>1 days</td>
<td>Fri 4/13/13</td>
<td>Fri 4/13/13</td>
</tr>
<tr>
<td>Final Prep</td>
<td>1 day</td>
<td>Fri 4/26/13</td>
<td>Fri 4/26/13</td>
</tr>
</tbody>
</table>

Note: Uses Workweek M-F

Required Deadlines in MES
- Concept Design: 9/19/2012
- Prototype Design: 9/30/2012

9/19/2012 NC State Capstone Design MES 401
Project Deliverables

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Description</th>
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<tbody>
<tr>
<td>Drawing Package / Parts List</td>
<td>Drawing package will be sufficient to allow unit to be manufactured by an outside machine shop. Level of conformance to all internal Support Equipment requirements must be decided.</td>
</tr>
<tr>
<td>Properly Working Test Rig</td>
<td>Test procedure, data collection sheets,..</td>
</tr>
<tr>
<td>Operator Information</td>
<td>Scope of maintenance manual need to be decided. At least collection of all mfg data.</td>
</tr>
<tr>
<td>Maintenance Information</td>
<td>Calibration requirements for test rig will be clearly documented. Exact requirements must be decided.</td>
</tr>
</tbody>
</table>

Verification

**Physical Attributes**
- Demonstration

**Speed**
- Formal replicated test using Calibrated RPM Meter

**Torque**
- Formal replicated test using Calibrated Torque Meter or known load.
Clarifications

- Input Speed Requirement
- Drawing Package Expectations
- Operator Information Expectations
- Maintenance Package Expectations
- Test Rig Calibration Expectations
- Calibrated Equipment Available for Verification
- Strength Analysis of Support Equipment
TEST RIG
FOR THE MANUAL DRIVE UNIT ON THE V-22 OSPREY

SYSTEM REQUIREMENTS REVIEW

PREPARED BY
LAINÉ JOHNSON
9/19/2012
MEMORANDUM

TO: NAVAIR ISSC 4.8.11 Support Equipment Engineers and NC State’s BSE Capstone Design Team
FROM: Laine Johnson
DATE: 9/30/2012
SUBJECT: Minutes from 9/19/2012 Capstone Design SRR

Members Present: Scott Fisher, Kevan Dover, Bill Fortney, Jim Yankauskas, Laine Johnson

Meeting Summary
Laine Johnson presented the Systems Requirements Review for the MES 401 Capstone Design senior class. Specific changes to the requirements matrix were discussed (attachment 1 has been revised). The timeframe for the project was discussed and will be re-arranged so that there is more time to acquire components that have a long lead time. New Dates are listed in the last subheading Review Dates.

Requirements
- Scott stated that they did want the Test Fixture to be permanently mounted to the workstation, not portable.
- Support Equipment’s desire is that the Manual Drive Unit (MDU) would not be moved once installed into the Test Fixture until all the tests are completed.
- Scott stated the ratios that should be applied for any strength analysis. Ratio of 5:1 for Ultimate Tensile strength and a ration of 3:1 for Yield strength.
- Scott brought up the need for corrosion protection for the Test Fixture. An approved corrosive preventative measure will be applied to the Test Fixture (4.8.11 Support Equipment Engineers will approve the method).
- The environmental conditions need to be more specific. This will be updated once the type of motor is decided upon.
- A requirement for motor ramp up speed is needed. This will be updated once the type of motor is decided upon.
- Scott and Kevan explained that having one fixture for both the backlash and the ATP is preferable. Therefore requirements will need to be written for the backlash test.
• The Capstone Design Team will utilize / accommodate purchased bench test backlash equipment A660412 (per Goodrich Engineering Report for the ATP). The gag plate, spline shaft and backlash tool set will be available for use.
• Clarification was made due to the wording being ambiguous, so the RPM should be measured during each test.
• The Test Fixture shall be able to reverse directions without disassembling the Test Fixture.
• The Test Fixture shall have a timing device attached to it.
• It was decided that all readings from the Test Fixture shall be digital.
• The Test Fixture shall have a safety cover that will be used while the motor is running.

Project Deliverables
• The working Test Fixture will be delivered 26-April-2013. This date is dependent on the needed components being delivered the first week in April so that it can be assembled and tested prior to the Final Presentation scheduled for 26-April-2013.
• A Tech document will be produced with the listed information. The Tech document will not be in FRCE format. A department at FRCE will format the document.
  o Operator pre-op checks
  o PM items –unique to the Test Fixture
  o Unique calibration needs
  o “Test Procedures” –this will explain how the operator will use the Test Fixture to complete the ATP. This will not re-write the ATP.
• Drawings that use of the SE templates and Solid Edge following standard drawing conventions ASME Y14.1 will be delivered. The drawings should be complete enough for a machine shop to manufacture.

Project Management
• The timeframe for the first semester will be shortened to allow for the long lead times on some of the purchased components and machined components. Laine suggested having the motor and other long lead time components approved at an earlier date than initially planned.
• Scott suggested scheduling at least a 3 month minimum for ordering/machining parts.
• A revised scheduled will be sent out to account for the longer lead times needed to procure materials and components.
Discussion / Clarification

- The list of stakeholders should not include the V22 IPT but should include the Components IPT. The FST Subsystems need to be added to the list of stakeholders.
- Clarification was made for the test parameters. The device to measure the input speed should be able to measure up to 2000 RPM. This will be added to the requirements.
- The wording will be changed for one of the Measures of Effectiveness: change Ease of Assembly to Ease of Maintainability.
- Calibration procedures will not need to be performed for the components of the Test Fixture that come from the manufacture already calibrated.
- Drawing format was discussed and decided that for this project the use of the SE templates and Solid Edge following standard drawing conventions ASME Y14.1 will be required. The drawings should be complete enough for a machine shop to manufacture.

Action Items

- Laine: Research the environmental conditions needed for the Test Fixture.
- Laine: Verify the services (utilities) available in the shop once the location is defined.
- Laine: Research ramp-up speed for the particular motor that is chosen.
- Laine: Look up safety codes pertaining to containment.
- Laine: Update the requirements matrix.
- Laine: Modify the wording in the Measure of Effectiveness based on recommendations given at the SRR.
- Kevan: Find out the location where the Test Fixture will be installed.
- Dr. Fortney: Revise the schedule to account for the longer lead times needed to procure materials and components. Allow 3 months for the purchased parts and machined parts to be completed.

Review Dates

- Concept Review 10-October-2012 Wednesday
- Preliminary Design Review 2-November-2012 Friday
• Detailed Design Review 14-December-2012 Friday
• Critical Design Review 2-January-2013 Wednesday
• Final Presentation/Demonstration 26-April-2013 Friday

APPENDIX G – CONCEPT DESIGN REVIEW

Concept Design Review
Wednesday October 10, 2010 @ 2:00

I. Updated Requirements (go over the changes make sure there aren’t any more changes)

II. Hand out the MDU Test Fixture Functions Block Diagram
   a. Read / Display Torque
      i. High Torque (+/-35 in-Lbs 1% FSD (+/- 0.35) 24 – 27 in-Lbs)
         1. Hand-held Torque wrench
         2. Manual Input in the MDU
      ii. Low Torque (+/-10 in-Lbs 1% FSD (+/- 0.1) < 3.5 in-Lbs)
         1. Stationary Torque meter
         2. Motorized Input in the MDU

b. Turn
   i. Target RPM 1000 +/- 300
   ii. Target Power 110VAC
   iii. Size motor for 50 in-Lbs ¾ to 1 Hp

c. Read / Display RPM
   i. +/- 10% FSD @ 1000 RPM (+/-100 RPM)
   ii. +/- 2000 RPM
   iii. Want this built in to the motor since RPM are measured at all 4 interfaces.

d. Protect Operator
   i. Emergency stop button.
ii. Design for the safety shields will be done once more details of the design are finalized.

e. Holding the MDU
   i. During the Backlash Test (INTERFACE)
      1. Utilize the backlash equipment A660412
      2. Measure the Manual Input Shaft backlash with a Dial Test Indicator
   ii. Gag On
      1. Turn Manual Input MDU with Motor (INTERFACE)
         a. Only performed on NEW Test Fixtures
         b. Read RPM
      2. Turn Manual Input MDU with Hand Crank (INTERFACE)
         a. Read Hi Torque with Hand Held Torque Wrench
         b. Need to make sure the Manual Input MDU is easily accessed
   iii. Gag Off
      1. Turn Motor Input MDU Manually (INTERFACE)
         a. Checking to make sure the Motor Input MDU turns easily (Judder)
         b. Need to make sure there is enough room for the Artisan’s hand
      2. Turn Motor Input MDU with Motor (INTERFACE)
         a. Read RPM
         b. Read Low Torque

III. Show design option 1 (Stationary Motor with MDU sliding and rotating either horizontally or vertically)

IV. Show design option 2 (Metal Mini-Lathe)

V. Hand out Paired Comparison Sheet
Figure 9. Clearances.
MEMORANDUM

TO:  NAVAIR ISSC 4.8.11 Support Equipment Engineers and NC State’s BSE Capstone Design Team
FROM: Laine Johnson
DATE:  10/11/2012
SUBJECT: Minutes from 10/10/2012 Capstone Design Concept Review

Members Present: Scott Fisher NAVAIR), Lee Allen (NAVAIR), Robert Fiedler (FRC East), Robert Puett (NAVAIR), Bill Fortney (NCSU), Jim Yankauskas (NCSU) and Laine Johnson (NCSU and NAVAIR)
Kevan Dover (NAVAIR—Invited but was out of town due to work).

Meeting Summary
A Revised Requirements Matrix was handed out and discussed showing revisions from the SRR. Minutes from the SRR were handed out. Laine Johnson presented the Conceptual Design for the MES 401 Capstone Design senior class.

Discussion
Revisions to Requirements
- Requirement 6.2 “The Test Fixture will operate in room conditions between 42° F and 120°F” needs to be rewritten with a more specific description of the working conditions and stored conditions.
- Discussion about requirement 4.2 since this would only be performed on “New Manual Drive Units”. Scott will discuss this with their Sub-Systems group. The outcome of this question will impact the design of the Test Fixture greatly.

The basic functions that the test Fixture must perform were reviewed and comments follow:
- Torque Measurement
  - The low and high range torque measurements will be performed on two different devices.
  - If possible, the high range torque reading will be made using an existing device from the tool room. It is even possible tool room has a device that can be used for low range reading. Laine will research availability and capabilities.
  - Scott said the handheld tachometer which is used to measure the breakout torque would not necessarily have to have a digital readout as long as the tool marks the maximum torque value.
RPM Measurements
- Initial thought was to have some type of measurement tied to motor.
- If measurement is built in to motor, must consider how this impacts the calibration of RPM.
- Idea was brought up to use hand-help laser tachometers available from tool shop. Laine will research availability and capabilities.

Turning
- Discussed the proper way to size a motor. They question was brought up if approximately 27 in-Lbs would be needed to turn the MDU then what is the correct torque value that the motor should be sized for? Everyone was in agreement that 50 in-Lbs was an acceptable value.
- Some type of electric motor will be used in test Fixture.
- During the breakout for the manual input of the MDU the question of how much rotation does this require was discussed. Clearance for the artisan to complete the rotation was the reason for the question. Laine will research and determine for design.

Holding
- Two options were presented for the configuration of the MDU and drive system. Both require that the relative position of the drive to the MDU slide to enable engagement of the drive shaft.
- Due to the weight of the motor, it was decided that the MDU will move relative to the motor.
- The MDU also needs to rotate to allow alignment of the motor with either the spline shaft connection or hand torque connection.

Overall Approach

Two approaches for the test Fixture were presented:

- Approach 1: Engineer and build it from new design drawings with OEM hardware, such as the electric motor, bearing blocks, torque meter and shaft couplings.

- Approach 2: Procure and modify a new engine lathe that meets the speed and torque requirements.
  - Sample lathe was presented with a cost of approximately $3500.
  - Lathe would be modified to eliminate unnecessary items.
  - Adaptor plate to hold MDU would be mounted in place of tool rest.

Discussion of two approaches was as follows:
  - NAVAIR favors lathe option, as it best meets their objectives of buy vs. custom fabricate.
  - Must consider timeline impact of lathe option since cost of lathe will mean going through contracting.
o Need to discuss idea with shop and see if lathe can set on existing table (weight as well as working height). Also explore idea of having a stand-alone unit and see if it is a problem in terms of floor space. Laine will talk with shop.

o Need to confirm there is enough room between top of tool base and center of lathe to add fixture that will properly align both inputs with center of lathe. Laine will contact company.

o Need to confirm lathe can deliver required torque at the 1000 rpm. Laine will contact company.

o RPM reading on lathe may not be able to be used due to accuracy and issue of calibration. Laine will research with company.

o Laine should have informal meeting with Scott next week to discuss answers to above issues so project direction can be determined.

Action Items

- Scott: Talk to their Sub-System Group to see if they say we need to have the capability of testing “New MDU”.
- Laine: Contact the South Bend representative. Verify torque at the required speed of the lathe and clearance to mount MDU. Ask for detailed drawings of the lathe and ask about calibration of the tachometer.
- Laine: Get the measurements and weight limits of the table in the shop where the Test Fixture will be mounted. Research Ergonomics for the correct heights for working with machines on top of tables.
- Laine: Talk to the shop to see which they would prefer; the current table or a stand with locking casters.
- Laine: Go to the Tool room in building 137 to see what kind of tachometers that we currently have. Also research the types of torque readers that we already have. Optimal would be a combination tachometer and torque reader that FRC East already has here. This would save money and time concerning writing up calibration standard operations procedures (SOP).
- Laine: Research the environmental conditions needed for the Test Fixture while it is running and while it is being stored.
APPENDIX I – PRELIMINARY DESIGN REVIEW

TEST RIG
FOR THE MANUAL DRIVE UNIT ON THE V-22 OSPREY

PRELIMINARY DESIGN REVIEW

PREPARED BY
LAINE JOHNSON
11/07/2012
Overview

- Needs Statement / Requirements
- Functions / 2 Configurations
- Recap of CDR
- Details of Design Configurations
- Preliminary Cost Estimate
- Discussion of Project Risks
- Project Plan

Need Statement

The NC State MES 401 Capstone Design group has been tasked to design and develop a Test Rig for the Manual Drive Unit (MDU) for the V-22 Osprey Aircraft.

The Test Rig will allow the MDU to be tested as specified in the Goodrich Actuation Systems Acceptance Test Procedure (ATP) document number ED/1877/129/AP.
### MDU Test Rig Functions

- **Read / Display Torque**
  - **Low**
    - +/- 10 inLbs
    - 1% FSD (+/- 0.1)
    - < 3.5 inLbs
  - **High**
    - +/- 35 inLbs
    - 1% FSD (+/- 0.35)
    - 24-27 inLbs

- **Turn**
  - Target RPM: 1,000 +/- 300 @ 30 inLbs
  - Target Ramp up ???
  - Target Power 110VAC if elec
  - +/- 2000 RPM
  - +/- 10% FSD @ 1,000 RPM
  - +/- 100RPM

- **Read / Display RPM**
  - Turn Manual Input With Motor
  - Gag On
  - Gag Off

- **Protect**
  - Turn Manual Input With Motor
  - Read RPM Interface
  - Turn Manual Input With Crank
  - Read Hi Torque Interface

- **Hold MDU**
  - Turn Motor Input With Motor
  - Gag Off
  - Manually Turn Motor Input

### Functional Block Diagram – Configuration 1

- **Read RPM & Low Torque Interface**
- **Read RPM Interface**
- **Read / Display RPM Interface**
- **Turn Motor Input With Motor**
- **Manually Turn Motor Input**
 Recap of Concept Design Review

MDU Test Rig

Functions

Read / Display

Torque

High

+/− 35 in.lbs
1% FSD
+/− 0.35
24-27 in.lbs

Target RPM:
1,000 +/- 300
@ 30 in.lbs
Target Ramp up
???
Target Power
110VAC if elec

+/− 2000 RPM
+/− 10% FSD @
1,000 RPM
+/− 100 RPM

Turn Manual
Input With
Motor

Gag On

Turn Manual
Input With
Torque Wrench

Read RPM
Interface

Read Hi Torque
Interface

Protect

Hold MDU

Turn

Read / Display

RPM

Recap of Concept Design Review

11/07/2012
**Action Items from CDR**

Get clarification from Sub-System Group as to whether they want the requirement for "NEW" Manual Drive Units.-- Scott

Obtain measurements for the table in the shop where the Test Rig will be mounted. Research Ergonomics for the correct heights for working machines on top of tables.-- Laine

Talk to the shop (supervisor) to see which they prefer; the current table or a stand with locking casters.-- Laine

Go to the room in building 137 (main tool room) to see what kinds of tachometers that FRCE currently has available. Research types of torque readers that we already have available. Optimal would be a combination of tachometer and torque reader that FRCE already has, this would save money and time concerning writing up calibration standard operations procedures (SOP).-- Laine

Research the environmental conditions needed for the Test Rig while it is running and while it is being stored.-- Laine

---

**Research Performed for Alternatives**

• Web based Research

• Contacted FRCE Plant Engineers

• Contacted Company Representatives (via phone and email)

• Discussed Issues with Support Equipment 4.8.11

• Discussed Issues with NC State Professors / TAs
Presentation of Design Alternatives

- Electric Motor: 1HP Baldor Reliance L1407
- Air Motor: Gast Non-lubricated Air Motor NL42

Selection Criteria Including Weighting

Paired Comparisons for the V-22’s MDU Test Rig

<table>
<thead>
<tr>
<th>OPTION</th>
<th>Footprint</th>
<th>Cost</th>
<th>Ergonomics / Usability</th>
<th>Manufacturability</th>
<th>Maintainability</th>
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<tr>
<td>Footprint</td>
<td>1 C-5</td>
<td>3 C-3</td>
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<tr>
<td>Maintainability</td>
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</table>

Slightly Prefer       | Highly Prefer

1/07/2012 NC STATE CAPSTONE DESIGN ME 401
Description of Overall Design

- **Mini-Lathe**
  - Remove Tailstock & Quill Lock lever & Quill Ball Handle
  - Remove Tool Post & Compound Rest Ball Handle
  - Remove Longitudinal Lead screw & Thread Dial
  - Remove 3-Jaw Chuck use a Collette
  - Attach the MDU to a holding plate on the carriage of the lathe
  - Digital displays & timing device attached on head of mini-lathe
Description of Overall Design

• **Torque Transducer**: Interface Advanced Force Measurement Model T2 General Purpose Rotary Torque Transducer
• **Model 9834 High Speed Digital Indicator**

Description of Overall Design

• **Couplings**: Interface Advanced Force Measurement Model T2 with single flex coupling type MWS for 0.03 to 2 Nm

Flexible coupling: composite disc coupling CD® Single Flex
Description of Overall Design

• **Clutch**: Checking into a few different brands (will need 2—one for each configuration)
  • SDP/SI Magnetic Clutches & Couplings
  • Mechanical Clutches (shaft to shaft)

Description of Overall Design

• **Handheld Tachometer** (Digital torque wrench)
Description of Overall Design

**Handheld LCD Digital Laser Tachometer**

**Manufactured Components**

- 13 Involute Spline Shaft (configuration 1– motorized input into motorized MDU)
- 2 Keyed Shafts (configuration 1– both sides of the clutch)
- 1 Keyed Shaft (configuration 2– Collette and clutch interface)
- 1 Keyed Shaft with other end a male 3/8” square socket (configuration 2– clutch and Manual Input interface with the MDU– NEW Units only)
### Current Cost Approximations

<table>
<thead>
<tr>
<th>COMPONENTS</th>
<th>COST</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINI-LATHE</td>
<td>$3,364</td>
</tr>
<tr>
<td>TORQUE TRANSDUCER</td>
<td>$3,000</td>
</tr>
<tr>
<td>DIGITAL METER</td>
<td>$2,100</td>
</tr>
<tr>
<td>HANDHELD TACHOMETER</td>
<td>$300</td>
</tr>
<tr>
<td>2 COUPLINGS</td>
<td>?</td>
</tr>
<tr>
<td>LOW TORQUE CLUTCH</td>
<td>$300</td>
</tr>
<tr>
<td>HIGHER TORQUE CLUTCH</td>
<td>$270</td>
</tr>
<tr>
<td>HANDHELD TORQUE METER</td>
<td>$2,100 / $1,100</td>
</tr>
<tr>
<td>TIMING DEVICE</td>
<td>&lt; $100</td>
</tr>
<tr>
<td>ESTIMATED TOTAL</td>
<td>$11,434</td>
</tr>
</tbody>
</table>

#### Manufactured/Purchased Components
- 13 INVOLUTE SPLINE SHAFT
- 2 KEYED SHAFTS (CONFIGURATION 1)
- 1 KEYED SHAFTS (CONFIGURATION 2)
- 1 KEYED SHAFT with other end a MALE 3/8” SQUARE SOCKET

### Height Requirement

![Height Requirement Diagram](image-url)

- 12”
- 36”
Configuration 1

Shaft for configuration 1
  1 sided keyed shaft, clutch, 1 sided keyed shaft, flex coupling, torque transducer, flex coupling, 13 involute spline shaft
Project Deliverables

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drawing Package / Parts List</td>
<td>Drawing package will be sufficient to allow unit to be manufactured by an outside machine shop. Level of conformance to all internal Support Equipment requirements must be decided.</td>
</tr>
<tr>
<td>Properly Working Test Rig</td>
<td>Test procedure, data collection sheets,..</td>
</tr>
<tr>
<td>Operator Information</td>
<td>Scope of maintenance manual need to be decided. At least collection of all mfg data.</td>
</tr>
<tr>
<td>Maintenance Information</td>
<td>Calibration requirements for test rig will be clearly documented. Exact requirements must be decided.</td>
</tr>
</tbody>
</table>

Verification

**Physical Attributes**
- **Demonstration**

**Speed**
- Formal replicated test using Calibrated RPM Meter

**Torque**
- Formal replicated test using Calibrated Torque Meter or known load.
TEST RIG
FOR THE MANUAL DRIVE
UNIT ON THE V-22 OSPREY

PRELIMINARY DESIGN
REVIEW

PREPARED BY
LAINE JOHNSON
11/07/2012

BACK UP SLIDES
# Mini-Lathe

## Main Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swing Over Bed</td>
<td>12.00 in</td>
</tr>
<tr>
<td>Distance Between Centers</td>
<td>10.00 in</td>
</tr>
<tr>
<td>Swing Over Cross Slide</td>
<td>8.00 in</td>
</tr>
<tr>
<td>Maximum Tool Dia.</td>
<td>5.50 in</td>
</tr>
<tr>
<td>Compound Slide</td>
<td>2.50 in</td>
</tr>
<tr>
<td>Carriage Travel</td>
<td>71.95 in</td>
</tr>
<tr>
<td>Gradual Taper</td>
<td>4.94 in</td>
</tr>
</tbody>
</table>

## Headstock Info

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spindle Rpm</td>
<td>1000 rpm</td>
</tr>
<tr>
<td>Spindle Speed</td>
<td>Variable</td>
</tr>
<tr>
<td>Spindle Type</td>
<td>D1-3</td>
</tr>
<tr>
<td>Spindle Bearings</td>
<td>Cylindrical Roller Bearing (6000 SF)</td>
</tr>
</tbody>
</table>

## Dimensions

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bed Width</td>
<td>9.00 in</td>
</tr>
<tr>
<td>Lead Screw Diameter</td>
<td>8.00 in</td>
</tr>
<tr>
<td>Lead Screw Length</td>
<td>56.38 in</td>
</tr>
<tr>
<td>Low Center Height</td>
<td>23.62 in</td>
</tr>
</tbody>
</table>

---

## Basic Controls & Components

**Control Panel**

![Control Panel Diagram](image)

- **Master Power Switch**: The switch shown in Figure 1(a) is a toggle meaning power ON and OFF to the lathe controls.
- **Spindle Switch**: Controls the variable spindle speed.
- **Emergency Stop Button**: Cuts off power to the motor and control panel. Do not push until it is unavoidable.
- **Spindle Switch**: Turn this master power switch on/off, start, stop, and reverse the spindle rotation.
- **Tachometer Display**: Displays a Stroboscopic readout of the spindle speed.

**Features**

- 1500 RPM & 3000 RPM Signature Smith Tools & 3 Way Tool Post
- Electronic Variable Speed Controls
- 4 Way Tool Post
- Threading Capabilities
- Emergency Stop Button
- Tach and Warn Mode Controls on Tailstock, on Lathes.
## Torque Transducer

- Capacities from 0.1 to 1K Nm (0.88 to 8.85K lb-in)
- ±5 VDC output
- Digital electronics
- Stainless steel shaft
- 12 to 28 VDC supply
- Contactless
- 10 KHz sample rate
- 12-bit resolution

### OPTIONS

- Speed & Angle Output: 360 Pulse TTL, 2-tracks 90° offset, available on capacities up to 1,000 Nm only
- Speed Output: 60 Pulse TTL, 1-track, available on capacities 2,000 Nm & above
- +10 V torque output
- RS485
- Keyed shafts - per DIN 5885.1

### SPECIFICATIONS

<table>
<thead>
<tr>
<th>Accuracy (Max Error)</th>
<th>±0.2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-repeatability 5%</td>
<td>±0.04</td>
</tr>
<tr>
<td>Temperature Effect ±0.02°C</td>
<td>±0.015</td>
</tr>
<tr>
<td>Rated Range ±5°C</td>
<td>±0.01</td>
</tr>
<tr>
<td>Operating Range 0 to 100</td>
<td></td>
</tr>
</tbody>
</table>

#### ELECTRICAL

| Output ±VDC | ±5 |
| Calibration Signal | 3 kHz-600 |
| Supply Voltage ±VDC | 12 to 28 |
| Supply Current ±mA | 50 |
| Electrical Connection | 8 or 12-pin |
| Resolution | 12-bit |

#### MECHANICAL

| Safe Overload % R0 | 200 |
| Cycle Load Rating % R0 | ≤10 peak |
| Max Speed (rpm) | Values with capacity. See Table |
| Shaft | Stainless Steel |
| Housing | Aluminum |

### NOMINAL TORQUE

<table>
<thead>
<tr>
<th>Capacity (Nm)</th>
<th>0.1, 0.2, 0.5</th>
<th>1, 2.5</th>
<th>10, 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equivalent (lb-in)</td>
<td>0.88, 1.77, 4.43, 8.85, 17.7, 44.3</td>
<td>88.5, 133</td>
<td></td>
</tr>
</tbody>
</table>

| (1) | 3.35 | 3.36 | 3.36 | 85 |
| (2) | 0.71 | 0.71 | 0.71 | 18 |
| (3) | 0.3144 | 0.3016 | 0.3016 | 10g |
| (4) | 0.67 | 0.67 | 0.67 | 17 |
### Torque Transducer

#### DIMENSIONS

<table>
<thead>
<tr>
<th>Nominal Torque</th>
<th>Capacity (Nm)</th>
<th>Equivalent (lb-in)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1, 0.2, 0.5</td>
<td>88.5, 133</td>
</tr>
<tr>
<td></td>
<td>1, 2, 5</td>
<td>88.5, 133</td>
</tr>
<tr>
<td>inch</td>
<td>mm</td>
<td>inch</td>
</tr>
<tr>
<td>(1)</td>
<td>3.35</td>
<td>85</td>
</tr>
<tr>
<td>(2)</td>
<td>0.71</td>
<td>18</td>
</tr>
<tr>
<td>(3)</td>
<td>0.3144</td>
<td>18</td>
</tr>
<tr>
<td>(4)</td>
<td>0.67</td>
<td>17</td>
</tr>
</tbody>
</table>

#### Model 9834 High Speed Digital Indicator

- Works with +5 VDC, +10 VDC, 0-20 mA and 4-20 mA inputs
- Sample rate 129 readings per second
- Programmable analog output, +10 VDC and 4-20 mA, 2000 Hz bandwidth
- 5 digit bipolar LED display
- Nonlinearity < ±0.01%
- Front panel calibration
- Peak and valley monitoring
- Remote and front panel tare
- 4 limit setpoints
- Designed for CE compliance
- Bidirectional RS232

#### SPECIFICATIONS

- **Excitation**: +10 VDC
- **Current**: 100 mA

#### PERFORMANCE

- **Maximum Display Range**: ±9999
- **Display Update**: 100 ms
- **Internal Resolution**: ±32,768 counts
- **Signal Input Range**: ±0 to ±100 mV
- **Input Range**: ±10 VDC max for +10 VDC or 4-20 mA
- **Resolution**: ±20 mA
- **Limit Error**: ±0.01% of reading

#### ENVIROMENT

- **Operating Temperature**: 4 to 120°F
- **Humidity**: ±10% RH non-condensing
- **Power**: AC: 115 or 230 VAC

#### OPTIONS

- **Beach top enclosure**: 7/80 WAD power
Couplings

<table>
<thead>
<tr>
<th>nominal torque [Nm]</th>
<th>type MWS, size [mm]</th>
<th>max. speed [U/min]</th>
<th>dimensions [mm]</th>
<th>MA [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.03 0.05</td>
<td>12</td>
<td>12000</td>
<td>A 82.5 B 17 C 14 D 4 E 6 F 12</td>
<td>2 x M2.5 92 0.5</td>
</tr>
<tr>
<td>0.1 0.2</td>
<td>16</td>
<td>12000</td>
<td>107.5 29 C 18 D 4 E 8 16</td>
<td>2 x M3 94 0.7</td>
</tr>
<tr>
<td>0.5 1</td>
<td>25</td>
<td>12000</td>
<td>116 33.5 25 C 5 D 12 E 25</td>
<td>2 x M4 96.5 1.7</td>
</tr>
<tr>
<td>2</td>
<td>32</td>
<td>12000</td>
<td>124 37.5 32 C 8 D 14 E 32</td>
<td>2 x M4 98.5 1.7</td>
</tr>
</tbody>
</table>

Please specify requested bore D at order.

Flexible coupling: composite disc coupling CD® Single flex.

11/07/2012 NC STATE CAPSTONE DESIGN MES 401
### Clutches – Configuration 1

**Diagram: Clutch Assembly**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Hole Diameter</th>
<th>Overall Length</th>
<th>Length Of Body</th>
<th>Dia. Of Body</th>
<th>Dia. Over Bore</th>
<th>Torque Range</th>
<th>Weight</th>
<th>Key Slot</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

One part found.

### Clutches – Configuration 2

**Diagram: Clutch Assembly**

<table>
<thead>
<tr>
<th>Part Number</th>
<th>Hole Diameter</th>
<th>Bore Dia.</th>
<th>Hub Dia.</th>
<th>Overall Length</th>
<th>Actuating Pin</th>
<th>Hub Project</th>
<th>Material (Choose):</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

12 parts found.

11/07/2012  NC STATE  CAPSTONE DESIGN ME 401
Handheld Torque Reader

Specifications:

- **Model**: DO-9296-512
- **Measuring Range**: 0 - 9999 RPM
- **Accuracy**: ± 0.1% of reading ± 0.1% of full scale
- **Display**: 5 digit 0.4" (10 mm) high LCD
- **Display Units**: RPM (or contact using adapter included) for rate: RPM, r/min, r/min and Length, ft, in.
- **Display Update Time**: 1 second (typical)
- **Selector**: Lever
- **System Control**: Single-click C4005 microprocessor
- **Over Range Indicator**: Flashing numbers
- **Low Battery Indicator**: Flashing "00 BATT" display, "B" display
- **Auto Power Shut-Off**: Yes
- **Battery Life**: 40 hrs approx.
- **Operating Temperature Range**: 32°F to 122°F (0° to 50° C)
- **Design**: All-case aluminum housing
- **Weight**: 0.8 lbs (360 g)
- **Dimensions**: 6.0" L x 2.9" W x 3.8" H (152 x 74 x 97 mm)
- **Warranty**: 1 year
- **Standard Accessories**: Nondetect tape, cone adapter, carrying case, RST contributors, 1 master wheel (2.75") and 200L adapter

**COMPUTORQ II ELECTRONIC TORQUE WRENCHES**

<table>
<thead>
<tr>
<th>Product Code</th>
<th>Drive</th>
<th>Torque Range</th>
<th>In.</th>
<th>Lb. Ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>25075-8</td>
<td>1&quot;</td>
<td>20 - 250 in.</td>
<td>12</td>
<td>14.5</td>
</tr>
</tbody>
</table>

**COMPUTORQ III ELECTRONIC TORQUE WRENCHES**

- Up to 4,000 torque values can be stored in memory
- Screwdriver capability for torque/unidirectional
- Torque range: 0 to 4,000 lbf-ft
- Selectable units of operation: "peak hold" and "track"
- Torque values are easily programmed and stored through touchpad
- Available torque range: 0 to 1000 lbs-ft
- A 200 lb-in battery is standard for 150 hours of operation
- Accuracy: ± 0.1% of indicated value. CDI & COR from 20% to 100% of full scale, ± 0.15% of range
- All calibrations data is stored in the microprocessor
- Selectable load rate for downloading to a printer/computer/bridge printer
- Optional in-line RST-1000 adapter

Handheld Digital Tachometer

Specifications:

- **Model**: DO-9296-512
- **Measuring Range**: 0 - 9999 RPM
- **Accuracy**: ± 0.1% of reading ± 0.1% of full scale
- **Display**: 5 digit 0.4" (10 mm) high LCD
- **Display Update Time**: 1 second (typical)
- **Selector**: Lever
- **System Control**: Single-click C4005 microprocessor
- **Over Range Indicator**: Flashing numbers
- **Low Battery Indicator**: Flashing "00 BATT" display, "B" display
- **Auto Power Shut-Off**: Yes
- **Battery Life**: 40 hrs approx.
- **Operating Temperature Range**: 32°F to 122°F (0° to 50° C)
- **Design**: All-case aluminum housing
- **Weight**: 0.8 lbs (360 g)
- **Dimensions**: 6.0" L x 2.9" W x 3.8" H (152 x 74 x 97 mm)
- **Warranty**: 1 year
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**COMPUTORQ II ELECTRONIC TORQUE WRENCHES**

<table>
<thead>
<tr>
<th>Product Code</th>
<th>Drive</th>
<th>Torque Range</th>
<th>In.</th>
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<tbody>
<tr>
<td>25075-8</td>
<td>1&quot;</td>
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</tbody>
</table>

**COMPUTORQ III ELECTRONIC TORQUE WRENCHES**

- Up to 4,000 torque values can be stored in memory
- Screwdriver capability for torque/unidirectional
- Torque range: 0 to 4,000 lbf-ft
- Selectable units of operation: "peak hold" and "track"
- Torque values are easily programmed and stored through touchpad
- Available torque range: 0 to 1000 lbs-ft
- A 200 lb-in battery is standard for 150 hours of operation
- Accuracy: ± 0.1% of indicated value. CDI & COR from 20% to 100% of full scale, ± 0.15% of range
- All calibrations data is stored in the microprocessor
- Selectable load rate for downloading to a printer/computer/bridge printer
- Optional in-line RST-1000 adapter
APPENDIX J – PRELIMINARY DESIGN
MINUTES

MEMORANDUM
TO: NAVAIR ISSC 4.8.4.11 Support Equipment Engineers and NC State’s BSE Capstone Design Team
FROM: Laine Johnson
DATE: 11/13/2012
SUBJECT: Minutes from 11/07/2012 Capstone Preliminary Design Review

Members Present: Scott Fisher (NAVAIR), Kevin Dover (NAVAIR), Robert Fiedler (FRC East), Robert Puett (NAVAIR), Susan Lloyd (NCSU) and Laine Johnson (NCSU and NAVAIR)
Invited but did not attend: Lee Allen (NAVAIR), Bill Fortney (NCSU), Jim Yankauskas (NCSU)

Meeting Summary
A Requirements Matrix was handed out along with the Preliminary Design Review PowerPoint (printed 3 slides to a page with lines for notes).

Discussion
The basic functions that the test Fixture must perform were reviewed and comments follow:

- **Torque Measurement**
  - Kevan mentioned that the shop may have a new handheld torque wrench with the tattle-tale marker which might meet the requirements for the “breakout” part of the ATP.
  - Discussed the low range torque transducer from Interface and its digital meter. Due to the price the question was brought up if there was another digital meter that would work with the Interface torque transducer but manufactured by a different company.
  - Nelson Dale, FRC East’s calibration has looked over the low range torque transducer from Interface. He stated that there should not be a problem calibrating this equipment.
  - The flexible couplings chosen were approved by the 4.8.4.11 Support Equipment Representatives.
  - The 2 types of clutches were introduced, magnetic and mechanical; no one saw any problems with these choices.

- **RPM Measurements**
  - The handheld LCD Digital Laser Tachometer was introduced. Nelson Dale, FRC East’s calibration recommended this brand and style. He has had positive results using this brand and style.

- **Turning**
  - The Mini-Lathe has a variable speed motor which is manually set. The instructions can be written so that there is a ramp up for the motor and spindle.
  - Robert suggested contacting South Bend Lathe Company and ask if the price could be lowered since the tailstock, quill ball handle, quill lock lever, 4-way tool post and compound rest ball handle will all be removed.

- **Holding**
  - The plate designed to hold the MDU will need to be redesigned. The MDU must be held on its output shaft interface. This is due to the gag plate interfacing with the motorized input of the MDU.
  - Most of the discussion was on the details of how to attach the plate to the carriage of the mini-lathe and how to rotate the plate and MDU the 45 degrees so that the motorized shaft can interface with the manual input of the MDU. The best suggestion was using a 45 degree slotted plate with fasteners that tighten down to prevent the MDU from moving.

**Overall discussion**
- I am having trouble finding the BS 3550 Table 36 so that the 13 involute spline male shaft can be drawn and manufactured.
In the PowerPoint I left off the plates, brackets and fasteners when estimating the cost as well as reporting the manufactured components. Scott was not concerned with the estimation of the costs as much as the details of the design.

Scott and Robert both agreed that the revised schedule will need refinement. The drawings will be more complicated than first thought. Separate drawings will be needed to show the removal of parts from the lathe and a drawing showing the assembly and installation of the new hardware onto the lathe. All parts that will be machined will also need drawings.

Action Items

- Laine: Contact the South Bend representative to ask for a reduced price.
- Laine: Research other low torque transducer digital meters from other companies, not Interface Advanced Force Measurement.
- Laine: Take all the mini-lathe information to Nelson Dale, FRC East’s calibration to see if the lathe will need to be calibrated and if so how difficult will is it.
- Laine: Set up a time for Dr. Fortney, Scott Fisher and Laine to meet so that the schedule can be modified and updated.
- Kevan: Try to contact someone to get the BS 3550 Table 36 for the 13 involute spline.

APPENDIX K – DETAILED DESIGN REVIEW
AGENDA

- Design Overview
  - MDU Motorized Interface
  - MDU Manual Interface
- Discussion of Project Risks
  - Long Lead time for parts
  - Time for Drawings to be completed
- Discuss Schedule / Project Plan
System Design

MOTORIZED INTERFACE

MDU Motorized Interface
Components for Motorized Interface

PURCHASED PRODUCTS

- MODEL T4 GENERAL PURPOSE ROTARY TORQUE TRANSDUCER
- MODEL T2/T4 SINGLE FLEX COUPLING TYPE MWS FOR 0.03 TO 2 Nm
- MODEL 9834 HIGH SPEED DIGITAL INDICATOR FOR HIGH LEVEL INPUT DEVICES
- MODEL DT-205LR-S12 HANDHELD DIGITAL LASER TACHOMETER
- 47SS SHOULDER SCREW FROM CARR LANE
- 8478A400 SPRING PIN FROM MCMASTER-CARR (Quantity 3)
- S90MCC-MTL37510 NON ELECTRIC MAGNETIC CLUTCH COUPLING FROM SDP/SI
- ¼" BOLTS TO MOUNT MDU TO HOLDING PLATE (4)
- SLEEVE BEARINGS (4)
SHOULDER SCREW

SPRING PIN (McMASTER-CARR)

PART 8478A4

Plate-Mount Retractable Spring Plungers

Two countersunk holes in the plate make these plungers easy to mount to a flat surface. To lock plungers with locking nose, pull knob to retract, then rotate 90°. Maximum temperature is 230°F. Fasteners are not included.

Steel plungers have a pre-plated mounting plate and black plastic knob.

Stainless steel plungers are corrosion-resistant 18-8 stainless steel with a black plastic knob.

For technical drawings and 3D models, click on a part number.
NON ELECTRIC MAGNETIC CLUTCH COUPLING

FLANGED SLEEVE BEARING
Components for Motorized Interface

MANUFACTORED PRODUCTS

- BOTTOM PLATE ATTACHING MDU TO CARRIAGE
- PLATE HOLDING MDU WITH TURNING CAPABILITIES
- HOUSING FOR TORQUE TRANSDUCER, CLUTCH, COUPLINGS AND SHAFT

BOTTOM PLATE

THIS PLATE ATTACHED TO THE CARRIAGE BY 2 ½” BOLTS.
MDU Manual Interface (Top view)

MDU Manual Interface
COMPONENTS FOR MANUAL

SHAFT TO SHAFT SLIP CLUTCH

Description:
Shaft to Shaft Slip clutch with a slip torque rating of 40 in-lb with Actuator Pin

<table>
<thead>
<tr>
<th>Description</th>
<th>Product Details</th>
</tr>
</thead>
</table>
| Shaft to Shaft Slip clutch with a slip torque rating of 40 in-lb with Actuator Pin | Part Number 599485-0254CH0AP
Unit Inch
Slip Torque 40 in-lb
Bore Size 0.375" Hub Dia. (D) 1.775" Hub Dia. (C) 1.550" Overall Length (L) 2.422" Outside Dia. (O.D.) 2.165" Actuating Pin "es Material (housing) Pre-Treated 5215 Steel Hub Proj. (Short) 0.265" (G) 0.205" Hub Proj. (Long) 0.735" |

12/18/2012 NC STATE CAPSTONE DESIGN MES 401 23

12/18/2012 NC STATE CAPSTONE DESIGN MES 401 24
FLANGED SLEEVE BEARING

Top Level Project Schedule
Top Level Project Schedule

QUESTIONS
TEST RIG
FOR THE MANUAL DRIVE UNIT ON THE V-22 OSPREY
DETAILED DESIGN REVIEW
PREPARED BY
LAINE JOHNSON
11/07/2012

Top Level Project Schedule
### Top Level Project Schedule

<table>
<thead>
<tr>
<th>Task Name</th>
<th>Duration</th>
<th>Start</th>
<th>Finish</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronics / Wire Routing</td>
<td>2 days</td>
<td>Mon 11/7/12</td>
<td>Tue 12/6/12</td>
</tr>
<tr>
<td>Review/Modify Design</td>
<td>3 days</td>
<td>Wed 11/7/12</td>
<td>Fri 12/7/12</td>
</tr>
<tr>
<td>Prepare Drawings for Detailed Design</td>
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APPENDIX L – DETAILED DESIGN MINUTES

MEMORANDUM

TO: NAVAIR ISSC 4.8.4.11 Support Equipment Engineers and NC State’s BSE Capstone Design Team
FROM: Laine Johnson
DATE: 1/02/2013
SUBJECT: Minutes from 12/18/2012 Capstone Detailed Design Review

Members Present: Scott Fisher (NAVAIR), Robert Puett (NAVAIR), Kevan Dover (NAVAIR), Robert Fiedler (NAVAIR), Bill Fortney (NCSU), Jim Yankauskas (NCSU) and Laine Johnson (NCSU and NAVAIR).

Meeting Summary
Details were presented for the two different configurations for the Manual Drive Unit (MDU). The group asked questions, discussed and offered suggestions to change particular details of the overall design. Most of the suggestions were given to improve the design so that the holding plate, protective cover and other parts could be machined more easily.

The type of torque transducer was changed from a free-floating to a pillow-block type to improve stability.

Discussion

- Suggested Improvements for the MDU holding plate, bottom plate and cross-slide
  - The Oval shape of the holding plate should be a circular shape
  - The “Butt” shape of the MDU holding plate should be redesigned so that it does not have the curves, since they are difficult to machine. Radius top corners. Also have the plate thinner.
  - There needs to be 4 countersunk screws to attach the bottom plate to the cross-slide carriage. This is to prevent movement.
  - Change the shoulder screw at the pivot point on the holding plate to the bottom plate with a dowel pin.
  - To help mounting the MDU to the holding plate use 2 studs as guides to hold the MDU in place while mounting.
  - Use threaded plate/hanger nut instead of through hole with bolt & nut or threaded insert.
  - The bottom plate needs to be fixed mounted to the cross slide. The cross slide needs to be held stationary.
  - Need a way to determine alignment of mounting plate and how to locate holes/pins to set MDU mounting positions. Currently the plan has spring alignment pins with pre-drilled holes for alignment (90 degrees and 45 degrees). One suggestion is to have a 45 degree curved slot in the bottom plate with a screw/pin in the
holding plate that has a handle that allows the artisan to screw the holding plate tightly to the bottom plate.

- The MDU needs to be mounted so that the manual input “spout” is toward the artisan (the front of the lathe). This will allow the artisans better access to the manual input so that the breakout torque test can be completed.

- **Suggested Improvements for the Manual Input Shaft Configuration (45 degrees)**
  - Have the shafts as short as possible.
  - Use the 3/8” shaft attached to the shaft to shaft clutch with a slip torque rating of 40 in-lb with an actuator pin attached to a 3/8” shaft with a universal joint for an impact socket at the 3/8” square manual input.
  - Check information about the shaft to shaft clutch. Make sure it does not have any centerline flexibility and does it have the ability to have shaft couplings.

- **Suggested Improvements for the Motorized Input Shaft Configuration (90 degrees)**
  - Use a pillow block torque transducer instead of the floating type.
  - If a pillow block torque transducer is used then 2 double couplings must be used.
  - See if it is possible to use the tailstock base as the support to attach the motorized input configuration. Relocate the tailstock base to the center between the headstock and carriage.
  - Remove the Teflon sleeves at the shaft entry points into the holding box used for resting shaft when unattached. Instead use oversized holes through holding box.

- **Suggested Improvements for the Safety Features**
  - Design 1 protective covering that can be used for both the Motorized Configuration and the Manual Configuration.
  - Make sure that there is a cover or guard over the male spline output end of the MDU.
  - Use a solid metal box instead of Plexiglas for the protective covering.

**Action Items**
- **Laine:** Check the speed range on the lathe to reach 1000 RPM.
- **Laine:** Find out what is the angle of rotation to “break-out” using the handheld torque wrench. How far does it need to be turned?
Laine: Check on clutch, make sure it doesn’t have any centerline flexibility. Does it have the ability to have shaft couplings?
Laine: Update the 3-D model using the suggestions and changes from this review.
Kevan: Find the gage plate so that the dimensions can be measured.

Updated Dates

- Support Equipment will order the lathe the first week in January 2013.
- A second Detailed Design Review will be held in building 163 at FRCE on Wednesday January 9th so that the suggestions and improvements from the DDR on 12/18/2012 can be explained and reviewed by Support Equipment 4.8.4.11
- NAVAIR, Support Equipment, will accept risk of Critical Design Review being moved to January 30th from January 2nd. The Critical Design Review will be held at Craven Community College on Wednesday January 30, 2013.