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Design of a Standardized Sensor Platform
For a C-130 Aircraft

Zenovy S. Wowczuk

A thesis submitted to the College of Engineering and Mineral Resources at
West Virginia University
In partial fulfillment of the requirements for the degree of
Master of Science
in
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ABSTRACT

Design of a Standardized Sensor Platform For a C-130 Aircraft

Zenovy S. Wowczuk

The development of a standardized sensor pallet system for a C-130 aircraft was conceived by the National Guard to assist in counterdrug reconnaissance activities within the United States. Before development, the design parameters were established by the National Guard mission requirements and by the limitations of the C-130 aircraft. These limitations include using Commercial off the Shelf (COTS) and Government off the Shelf (GOTS) items when developing the system that must be universal on all C-130 aircraft variants B thru H. Further design criteria are delegated by the limitations of the C-130 aircraft. The following work describes the design process concentrating on engineering analysis and the selection process used to design and develop a prototype system to assist the National Guard in their reconnaissance activities. A comprehensive evaluation has been conducted on alternative configurations and approaches for achieving optimal tradeoffs between cost, performance and reliability criteria.

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1.0 Introduction

Throughout its long history, the National Guard (NG) has had to fulfill a dual mission for the United States. That mission is to provide the nation with units trained, equipped and ready to defend the United States and its interests all over the globe and to protect life and property here in the United States.

One of the biggest threats to life and property in the United States is the continuing presence of a large and often organized illicit drug trade, which supplies the United States with drugs sourced from home and abroad. The role of the National Guard in combating the drug trade is to support Counterdrug law enforcement efforts by providing personnel and equipment resources. For the case of aircraft, these resources are limited to what is already in inventory with no immediate plans for large additions to the fleet.

The National Guard provides irreplaceable support to the Department of Defense as well as civilian sectors. Within this context, the National Guard, to meet its needs, leverages programs, research, and developed technology from a wide variety of sources. This includes Government, University, Industry, and Non-profit organizations. With these and other groups, the National Guard focuses their efforts on the transferring and insertion of confirmed technologies and programs that will directly assist their missions.

Similar to military and law enforcement agencies, the missions of the NG necessitate the investigation and implementation of field deployable and often time's novel technologies to meet demanding and changing needs. The National Guard has a requirement to support Counterdrug law enforcement efforts through the National Guard Bureau Counterdrug Office (NGB-CD). In this role, the NG provides resources, technical

and personnel, to support civil authorities in Counterdrug activities. To supplement this effort, the National Guard uses technology to enhance and advance Counterdrug law enforcement agency efforts.

The National Guard has only recently begun investigating using other aircraft (other than the C-26) in assistance with counterdrug missions. One of the most available and versatile aircraft in the National Guard fleet is the C-130 Hercules. The abundance of C-130 aircraft available to National Guard units across the United States and around the world gives it the immediate access advantage over other aircraft in the National Guard fleet.

The C-130 aircraft is manufactured by Lockheed Martin and has been produced since the mid 1950's. The primary mission of the C-130 is as a medium range tactical airlift and as the prime transport for paratroop and equipment drops into hostile areas. The C-130 has also been modified into specialized platforms including gun ships and electronic warfare platforms (Smith). Figure 1 shows a C-130 aircraft in flight.

Figure 1 –C-130 aircraft during flight.

The C-130 aircraft encompasses a cargo floor approximately four feet above the ground, a roll on/roll off rear loading ramp, and an unhindered, fully pressurized cargo hold area. The C-130 is capable of holding more than 42,000 pounds of cargo distributed through four 463L pallet positions in addition to a rear cargo ramp pallet position. The 463L pallets are military standard pallets that are developed for use on the C-130 aircraft as well as other military aircraft. These pallets are easily maneuvered throughout the aircraft by a roller system integrated into the cargo hold and ramp (Bowman). Another important feature of the C-130 aircraft is that it has the capability of flying while the rear cargo door is down. This feature was developed for the use of parachute drops during flight.

West Virginia University (WVU) has been tasked with the needs assessment, design and fabrication of a sensor platform that is capable of operating remote sensors for use aboard the C-130 military aircraft. To this end WVU will propose the design and construction of a transportable roll-on roll-off sensor pallet(s) that will deploy via the rear cargo door of the aircraft while in flight. Criteria that must be met for this final design include immediate compatibility, universality for the C-130, transportability, reliability and durability.

The individual chosen sensors to be installed on the pallet determine, in part, the requirements for this sensor pallet design process. The pallet must provide the sensors with a useable field of view (FOV) so that the sensor can see ground targets unobstructed. The pallet must also be designed to operate the sensor within its designed limits for vibration and temperature. The pallet must have provisions for all the support equipment including, but not limited to, computers, communication links, instrument panels, and

displays. An additional preference for this proposed platform is that the sensors should be interfaced, where possible, so that a single workstation can control and will help view the information from all sensors. This system may also be required to have provisions for georectification of the collected imagery. Sensor and data fusion can make the operation of this pallet much simpler for the operator while the georectification allows maps to be made available to the operator on a near real-time basis.

The final design must be able to be deployed while the craft is in flight and it cannot interfere with other mission requirements. All features and functions of the pallet are determined by the physical limitations of the C-130 airframe and the minimum mission profile. This includes that no modifications be made to the C-130 airframe because the C-130's main roles must not be compromised. A second requirement for the final design is that the pallet system must be compatible with all C-130 aircraft. This is because the C-130 has been produced in A through H variants for almost fifty years in appreciable numbers. It is also important to consider that the final pallet must not exceed weight distribution restrictions because this can impair the safe operation of the aircraft. All safety and flight considerations for the aircraft must also be addressed, preferably before the final design is approved for the construction of the delivered product.

The pallet itself must be lightweight and weather tight so that it can be moved by truck and stored between deployments and the pallet should be flexible enough to allow hardware/software upgrades and sensor reconfiguration. The sensor interfaces must be standardized and the support equipment must be packaged in a modular design (i.e. plug and play).

Operator requirements pertain to the personnel that must install and remove the pallet and those that must operate the sensors on the pallet during a mission. This requires that the pallet must be simple enough to be installed and maintained by existing personnel, and the pallet must mount in the same fashion as standard cargo pallets and the tools and supplies used to maintain the physical pallet must be the same as for other DoD equipment. The operation of the platform must be executed with a simple PC-type interface so that enlisted, or drug enforcement personnel can be trained to operate the system easily.

The first assembly exists as an enclosure placed in the main cargo hold of the aircraft. This enclosure (Operator Station) houses the operators along with the control computers for the sensor array and the communications equipment. It also supports a power converter. WVU's intended design for the operator's station is to allow ease of access during operation and will not obstruct personnel passage through the aircraft. This station is built using the design of a standard cargo shelter upon a standardized flat pallet that will insure that it will be securable and transportable. This operator station will have provisions for all the support equipment including, but not limited to, computers, instrument panels, and displays. The palletized station is also designed to operate control equipment, data collection and, if found cost feasible, data storage within the limits of available power, vibration and temperature. Ideally, the pallet system can be stored long term, with adequate-supplied power; to run the airflow and fans protecting the computer systems within the weather sealed station. Figure 2 shows a computerized model of the operator station.

Figure 2 –Model of operator station.

The second smaller pallet (Sensor Platform) attaches to the rear ramp of the aircraft. This pallet supports an extendable arm upon which the sensor array is installed onto a modular attachment bar. In flight, the rear doors of the aircraft open and the sensor arm rotates the sensor array outside the rear of the aircraft to perform its mission. The sensor platform is the primary system that will be described (by means of design and analysis) in this document. Figure 3 shows a computer-generated model of the sensor platform system.

Figure 3 –Model of sensor platform system.

Both systems make up the entire standardized sensor pallet. A concept diagram of the complete system is shown in figure 4.

Figure 4 – Standardized sensor pallet system concept diagram

2.0 Sensor Pallet Review

With the development of sensor technology in the past decade much emphasis has been placed to integrate these sensors into aircraft reconnaissance systems. The military has committed to a lot a research into the development of fully operational sensor systems (primary called sensor pallets) to be used on the C-130 aircraft.

Currently, there are three Airlift Wings that have already completed prototypes of sensor pallets for Counterdrug use. These are the 137th National Guard Airlift Wing, the 146th National Guard Airlift Wing, and the 152nd National Guard Airlift Wing.

The 137th National Guard Airlift Wing is located in Oklahoma City, Oklahoma and was one of the first units to deploy a palletized sensor reconnaissance system on a C-130 aircraft. A view of the complete system is shown in Figure 5.

After succeeding on the C-130 aircraft another sensor pallet was developed by the 137th Airlift Wing. The 137th sensor pallet accommodates the KC-1B mapping camera, the KS-87 framing camera, and the KA-91A panoramic camera. The location of these cameras is shown in Figure 6. These wet-film cameras are able to take aerial photographs in daylight during reconnaissance missions. The platform itself is stabilized within the C-130 by two mounting connections to the rear cargo door of the C-130 aircraft. The location of the mounting position on the C-130 is shown in Figure 6.

Figure 5 - National Guard 137th Airlift Wing sensor pallet system.

Figure 6 – Location of camera's and mounting points on National Guard 137th Airlift Wing sensor pallet system.

Figure 7 shows the deployed sensor platform on board a C-130 aircraft during flight. The pallet is mounted to the rear ramp on the door of the aircraft, and the door has to be opened during flight. Any two of the three cameras are attached to two individual arms that are extended over the rear of the ramp. This arrangement allows the cameras to take images directly below the aircraft during flight. The retractable arms allow in-flight film and camera changes when the arms are retracted inside the C-130 rear door. The 137th Airlift Wing has discontinued the use of this pallet and halted the development of another palletized system.

Figure 7 - National Guard 137th Airlift Wing sensor pallet system deployed in flight.

The National Guard 146th Airlift Wing is located in Port Hueneme, CA. This sensor pallet is similar to the 137th Airlift Wing's sensor pallet. The 146th Airlift Wing sensor pallet has a KS-87 framing camera and a KS91 panoramic camera. The pallet is mounted to the rear ramp of the aircraft and is to be used with the ramp open during

flight. The cameras are attached in a position so they stuck out over the edge of the rear ramp. This position gives the pallet the capability of taking aerial photograph directly below the aircraft. The pallet has the capability of a three camera mounting system. No illustrations for this system are currently available.

The 146th Airlift Wing is currently investigating the incorporation of new sensors into their sensor pallet. These new sensors are Synthetic Aperture Radar (SAR) and Infrared (IR) and can be used for various missions. This updated system is intended to fly with the rear cargo door ramp closed during flight. Test for this new system are ongoing.

The National Guard 152nd Airlift Wing is located in Reno, Nevada and has developed a pallet similar to that of the 137th Airlift Wing. The 152nd's pallet was developed to accommodate the KS-87 and KS-91 cameras (along with the KS-87 long lens), and it also has them mounted on two retractable arms. Figure 8 shows the location of the three cameras on the sensor platform. The pallet is mounted to the rear ramp of the aircraft with the intention of being flown with the ramp open. Figure 9 shows the placement of the sensor platform on the C-130 aircraft. In addition to the common sensor pallet design, the 152nd Airlift Wing has developed a SCATHE view system to act as a surveillance system. The SCATHE view system provides a near-real-time imaging capability to support humanitarian relief and non-combatant evacuation operations. This system contains a Gimbal turret mounted underneath the nose of the aircraft, a palletized workstation in the cargo hold of the aircraft, and a satellite-linked ground station. Figure 10 highlights the two-operator workstation for the system. The Gimbal turret houses a

FLIR unit, color day TV, a spotter scope, and a laser rangefinder. These sensors give the C-130 an equivalent sensor platform to that of the C-26B. Presently, the 152nd Airlift Wing is working to develop SCATHE view technology further to incorporate newer sensors therefore updating and enhancing the entire sensor platform.

Figure 8 - National Guard 152nd Airlift Wing sensor platform camera arrangement.

Figure 9 - National Guard 152nd Airlift Wing sensor platform loaded on a C-130 aircraft.

Figure 10 - National Guard 152nd Airlift Wing operator station.

Each of these developed sensor pallet systems use a non-standard pallet system that translates linear outside of the rear cargo door of the C-130 aircraft into the air stream. This final position (parallel with the rear cargo door) limits the (FOV) of the system because of the geometry of the C-130 fuselage and cargo door components. No system developed has the capability of generating a full (FOV) underneath the aircraft. A system proposed that could allow the sensors to rest underneath the rear cargo door of the C-130 aircraft would maximize its (FOV) capabilities.

3.0 Motion Design

The sensor pallet is required to translate from inside the aircraft (“stow” position) to a location outside of the aircraft (final operational position) to allow for sensors to take data. Developing a system that could translate underneath the rear cargo door of the C-130 aircraft would generate a maximum (FOV) that was limited in previous sensor pallet designs. The mechanical arm system is designed to translate from a stationary “stow” position to a final operational position. There are many different ways the system can translate from the “stow” position to the final operational position. The three methods that were analyzed are: 1) a system that uses a rotational movement by means of a shaft, 2) a system that uses an elevator-type up and down translation, 3) and a system that uses a scissor method movement. All three methods were analyzed to ensure the most effective and efficient process was used for the translation of the mechanical arm system.

3.1 Shaft Rotation System

The initial method conceptualized was to translate the mechanical arm system using a rotational movement. The system would have two types of motion associated with it: a brief linear movement and a rotational movement. The general design would call for the system to translate linearly outside of the rear cargo door from a pallet-based stow position (1), then rotate the entire sensor pod system outside of the cargo door underneath the door (2), and finally linearly retract back to clamp against the bottom of the rear cargo door (3). The system would use a driven shaft that would be rotating from within the aircraft door to its final position underneath the door. Figure 11 shows a concept diagram of the rotational systems movement. The entire sensor system would lie on the rear cargo door of the C-130. The advantage of this type of system would be the

simplicity in movement design and position flexibility. The rotational movement allows the systems to be positioned at any point during the rotational translation of the mechanical arm system, thereby allowing for various FOV capabilities when deployed. The rotational system would need to be able to compensate for a large moment (during the rotational process) that would be generated during the deployment of the system outside of the aircraft. Note that this approach places the sensor pod near the rear of the pallet when in the stowed position this allowing for quick access to the sensor pod for quick change-outs or repairs.

Figure 11 – Process diagram of rotational translation.

3.2 Elevator Movement System

A second method that was investigated was using an elevator type system to translate the system by means of a vertical movement. The system would consist of two types of movement: a horizontal translation and a vertical translation. This system would initially translate outside of the rear cargo door from a raised stow position (1), then the system would translate down to a position below the cargo door (2), and finally the system would retract linearly against the rear cargo door (3). Figure 12 shows a concept diagram of the elevator type translation system. The elevator type system would vertically translate using a customized vertical translation apparatus that would be capable of locking in place at any desired position along the vertical track. The

advantage of this type of system would be simplicity in movement. Mechanically, a sole vertical movement is more efficient than a rotational translation which accumulates losses during rotation (Haugen). The vertical movement also cuts down on the moment created by a rotational movement of the mechanical arm system. This system also offers the capability of a variety of FOV positions created by positioning the system at different vertical locations on the elevator translation system.

Figure 12 – Process diagram of elevator type movement.

3.3 Scissor Movement System

The final system that was examined during the design concept phase was one that performed a scissor type movement to translate to the final operational position. This system would have one unique movement that would combine both a rotational movement and a vertical translation. The controlled movement was taken from the movement of a scissor tool and a four-bar mechanism. The basic concept of the four-bar mechanism is depicted in the diagram in Figure 13(a). The system would begin in the ground “stow” position on the rear cargo door and translate by the motion shown in Figure 13(b) until it has reached the final operational position underneath the rear cargo door (1). This system eliminates the need for a two step process by combining both a linear translation a rotational movement to translate from the “stow” to the final position.

This system introduces the complexity of a four bar mechanism and the addition of several mechanical systems working in unison. The system offers a comparable FOV adjustment capability available in the prior two design options.

Figure 13 – (a) Basic four-bar mechanism diagram. (b) Process diagram of scissor type movement.

3.4 Design Summary

This summary of the three systems shows that System 1 (Shaft Rotation System) is overwhelmingly the greater design in terms of mechanism simplicity, customization/cost, and flexibility. The system was the only one of the three capable of achieving the rotation needed to translate the system from inside the aircraft to the final position underneath the rear cargo door of the aircraft. The major factor contributing to this determination is that using Commercial Off The Shelf (COTS) and Government Off The Shelf (GOTS) items to design/build a system improves its simplicity, cost, and flexibility. An increase of specialized components increases the chances of a mechanical failure to occur during use. The first design allows for greater flexibility in sensor access while the third case proved to have complex stress problems and the potential for binding. The second case involved the greatest cost of the three systems because of the customization involved in designing and assembling the system.

4.0 Component Selection

The shaft rotational system was selected to perform the task of translating the mechanical arm system from the “stow” position to the final operating position. Once the overall design was selected, the components could be selected to make up the entire system. The components fall into four categories: the base platform, the rotational system, the linear system and the mechanical arms and pod. This section describes component selection and analysis used to develop the entire standardized sensor pallet system

4.1 Base Platform

Military Aircraft require that transport cargo use pallets as a base platform to prevent damage to the floor of the aircraft and for ease of loading and unloading. As discussed in the introduction the system must be a roll-on/roll-off C-130 accessible system used solely for a C-130 aircraft. Figure 14 shows a standard 463L Systems Cargo Pallet used by the United States Armed Forces. These pallets are loaded on C-130 aircraft by means of a series of roller systems on the floor of the rear cargo door and on the floor inside the C-130 fuselage.

Figure 14 – Standard 463L type cargo hauling pallet (AAR Mobility Systems).

In order for this standard sensor pallet to provide a suitable base for the standardized sensor pallet system some modifications needed to be implemented to the

current design. One modification made (for the application of the Standardized Sensor Pallet System) to the standard 463L Air Cargo Pallet was to replace the aluminum skin/balsa wood sheet with a $\frac{3}{4}$ " aluminum plate as the pallet surface. Figure 15 shows a corner view of the aluminum plate addition. This reinforced plate would provide ample structural support to build a complete rotational system on the surface. It would also provide a thick skin to support drilling and tapping modifications to securely attach components to the pallet. In addition to the $\frac{3}{4}$ " aluminum plate, a grid of "hard point" sections was installed to provide additional mounting support. The dashed lines in Figure 16 depict this "hard point" grid.

Figure 15 – Exploded view showing pallet aluminum plate thickness (AAR Mobility Systems).

Figure 16 – Diagram of Reinforced Air Cargo Pallet (AAR Mobility Systems).

The standard (but modified) pallet that will be used as the base component of the Standardized Sensor Pallet System will be called the Gen-X Pallet Base With $\frac{3}{4}$ " Plate. A picture of the Gen-X Pallet is shown in figure 17 (complete dimensional diagrams and solid model of the base pallet are available in Appendix I).

Figure 17 – Picture of a hoisted Gen-X Pallet Base With $\frac{3}{4}$ " Plate

4.2 Rotational System

The rotational system is the main component of the standardized C-130 sensor platform. The system dictates the more difficult of the two movements (linear and rotational) needed to translate from the “stow” position to the final operational position located underneath the rear cargo door of the C-130 aircraft. The components needed for proper translation of the rotational system are: gear reducer (with motor), output shafts, gear reducer to shaft couplings, shaft bearings (with supports), and shaft collars.

4.2.1 Gear Reducer (with motor)

The main component of the rotational system is the mechanism that will provide the system with the rotational movement. The mechanism selected to perform this movement is a rotational gear reducer. A gear reducer is capable of translating a large

torque by a low input motor because of large reductions by the internal gearing. There are many different types and manufacture of gear reducers but the one selected for this application was a double enveloping worm gear reducer manufactured by Textron Power Transmission. Figures and diagrams of the 30-60 Double Enveloping Gear Reducer are available in Appendix II.

Double-enveloping worm gearing provides several distinct advantages over cylindrical worm gearing, including increased torque throughput, improved accuracy, and extended life. Double-enveloping worm gearing possess several key advantages over other types of worm gearing. In a cylindrical worm gear set, only one to two gear teeth are in contact with the worm. In a double-enveloping worm gear set, three to eleven gear teeth are typically in contact with the worm, depending upon the ratio. The increased number of driven gear teeth that are in contact with the worm significantly increases torque capacity, and also raises shock load resistance.

In addition to increasing the number of driven gear teeth in contact with the worm, double-enveloping worm gearing also increases the contact area on each gear tooth. The actual areas of instantaneous contact between the worm threads and the driven gear tooth are lines. Figure 18 highlights the features of the double enveloping worm gear. These lines of contact move across the face of the gear tooth as it progresses through its total time of mesh with the worm. The lines of contact in double-enveloping worm gearing are configured to increase the power transmission capability and reduce the stress on each gear tooth. The Textron Power Transition double enveloping gear reducer

design can carry load's which would require cylindrical worm gearing much larger and heavier.

Figure 18 – Contact feature of double enveloping gear reducer (Textron power Transmission).

The first stage in selecting the optimal gear reducer is to properly lay out all loading involved in the rotational system. To analyze the forces a program was generated in Excel to calculate the maximum torque that will be seen by the gear reducer. The components of the loading come from the weight of the mechanical arms/pod and the estimated drag forces calculated at a maximum traveling speed of 150 knots. Moment equations were generated and solved for each angle during the translation of the system. The total rotational travel of the system spans from 33° to 270° beginning from the stow

position inside the aircraft and ending in the final operating position underneath the rear cargo door. It was found through an iterative approach that the worst-case angle for the mechanical arm/pod system occurs at 203° during the rotation of the mechanical arm/pod system. Figure 19 shows the mechanical arm/pod system at the position it receives the maximum aerodynamic drag forces. At this position it is estimated that the gear reducer system must be capable of handling a torque of **63,133 in-lbs**. These torque values calculated using the aerodynamic loads and the weight of the mechanical arm/pod system with a 1.5 safety factor. This torque is based on the weight of the mechanical arm/pod weigh, the drag force factor during 150 knots of travel and the distance of the mechanical arm/pod system from the gear reducer. All results are shown in the program output located in Appendix III.

Figure 19 – Mechanical arm/pod system at worst-case scenario (203°).

The aerodynamic forces used in calculating the torque needed from the gear reducer break down the axial and normal forces exerted on the mechanical arm/pod system (Serrano). The analysis calculates the two types of forces acting on the mechanical arm/pod system at each degree angle of rotation ranging from 33° to 270°.

The program and graphs found in Appendix III shows the maximum torque generated during rotation occurs at 203° during rotation to produce a torque of 63,133 in-lbs. With the found torque of 63,133 in-lbs the torque motor was sized to accommodate a torque greater than this. A known restraint in sizing the gear reducer is that a maximum 2 (hp) motor can be used to drive the system. This restraint is created by the limited amount of power supplied to the standardized sensor platform by means of the C-130 electrical capabilities. In order to minimize the gear reduction in the gear reducer the maximum horsepower motor should be used to drive the gear reducer.

The formulas used (Textron Power Transmission) to attain the gear reducer specifications are listed below. Two variables that can vary to find the appropriate torque are the gear ratio (m_G) and the rotational speed of the worm (n). It should be noted that with the increase in gear ratio (m_G) the efficiency (η) of the gear reducer drops significantly. The final specifications found are listed in Table 1.

$$\text{Formula 1: } P = \frac{T_w n}{63,000}$$

$$\text{Formula 2: } T_w = \frac{P \cdot 63,000}{n}$$

$$\text{Formula 3: } T_G = T_w \cdot m_G \cdot \eta$$

m_G	=	gear ratio
n	=	rotational speed of worm (rpm)
P	=	power input to worm (Horsepower)
T_w	=	input torque (inch pounds)
T_G	=	output torque (inch pounds)
η	=	efficiency (percent)

Table 1 – Specifications of 30-60 double enveloping type gear reducer.

Reduction Stage	1st	2nd	Overall
Center Dist.	3	6	
Ratio	30	20	600
Input Speeds	1750	58.3	
Output Speed			2.92
Running Eff.	0.8	0.75	0.6
Start. Eff.	0.47	0.56	0.26
Backdriving Eff.	0.37	0.38	0.14
Sliding Vel.	632.3	42.6	
Horsepower	4.28	3.47	4.28
Thermal HP (HO/HU)	2.19	2.22	2.19
Fan Thermal HP	0	2.22	0
OT (IN-LBS)	3680	56173	55188
100 RPM OT	6171	56173	56173
Input Torque	154	3746	154
WK ² (Solid) (LB-IN ²)	1.55	23.88	1.58
Backlash (Degrees)	0.311	0.168	0.184

Table 2 explains the service factor rating system. A service factor of 0.8 was selected for the gear reducer. This service factor was chosen because the system will experience a very low duty cycle (1/2 hours per day) and will not experience any shock during use.

Table 2 – Service factor chart for double enveloping gear reducers

Duty Cycle	Hours / Day	Uniform	Moderate Shock	Heavy Shock	Extreme Shock
	1/2	.8	.9	1.0	1.2
	2	.9	1.0	1.2	1.3
	10	1.0	1.3	1.5	1.7
	24	1.3	1.5	1.7	2.0

As a gear reducer transmits power from the input to output shaft, it also increases torque and reduces speed. The power and torque delivered depends on gearbox efficiency. Some power is lost because of component friction within the gearbox. The gear reducer efficiency is defined by (Avallone):

$$\text{Efficiency} = (\text{output power}) / (\text{input power})$$

As seen in table 1 the overall running efficiency of the gear reducer is 60%. This efficiency is based on optimal working conditions that include constant running speed, optimal working temperature and minimal vibration.

Figure 20 shows the locations of the gear reducer on the base pallet. The location is centered along the long side of the pallet (108 inches) to generate a maximum area for the rotational shaft and the sensor pod and to disperse the load equally along the entire rotational shaft.

Figure 20 – Model of the double-enveloping gear reducer positioned on the base pallet.

4.2.2 Shaft to Gear Reducer Design

The output shafts of the gear reducer must be able to handle the high torque loading distributed through the mechanical arms. The output shaft will serve as the main torque carrier during the rotational translation of the mechanical arm/pod system. The analysis to size the rotational shaft was performed using a torque (T) of 65,000 in-lbs in addition to a safety factor of 1.5. For the analysis it should be assumed that the four mechanical arms would distribute the load evenly. Figure 21 shows this even torque distribution represented by T1 and T2.

Figure 21– Block diagram of gear reducer with output shaft and applied torques.

The first step in analyzing the torque-carrying shaft is to determine how much load each mechanical arm (represented by $T1$ and $T2$) will take. Once this torque (24,375 in-lbs) is found (using a dynamic load factor (F_{DL}) of 1.5) the shaft stress can be calculated using a selected diameter for the shaft. The shaft diameter (d) for this equation was selected to be 2 inches. This diameter was selected because it is a standard size output for the gear reducer selected in Section 4.2.1. The torque and shaft stress equations used are shown below (Bedford).

$$\text{Torque Distribution,} \quad 2(T1) + 2(T2) = T(F_{DL}); \quad T1 = T2$$

$$\text{Shaft Stress,} \quad \tau = Tc / J ;$$

$$\text{Using,} \quad J = \pi d^4 / 32$$

$$c = 1$$

$$\text{Maximum Stress} \quad \tau = 31,035 \text{ psi.}$$

The analysis of these equations shows that a 2-inch diameter (d) shaft needs to be made of a material able to withstand 31,035 psi of stress (τ). By selecting a 1045 Carbon Steel Shaft (yield strength of 77,000 psi) a factor of safety of two is implemented into the design. This safety factor will serve as a precautionary measure if at one point the torques on the shaft are not distributed evenly.

Next, the key way connecting the shaft to the coupler must be designed to withstand the forces seen by the rotational shaft. The selection of the key also depends heavily on the standard size key ways used on the flex coupler (explained later in this section). For this analysis the torque used in the shaft equations (24,375 psi) and a 1-inch radius are used. Two iterations are run using two common key sizes ($\frac{3}{8}$ " x $\frac{3}{8}$ " and $\frac{3}{4}$ " x $\frac{3}{4}$ ") to determine the key length (Oberg). The equations used for sizing the key way are shown below. Key way diagrams are available in Appendix IV (10.0).

$$\begin{aligned} F &= T / r \\ \tau &= F / (l * w) \\ \sigma_b &= F_b / A_b \\ F.S. &= \sigma_{alt} / \sigma_b \end{aligned}$$

Keyway Equations

The iteration performed using the $\frac{3}{8}$ " x $\frac{3}{8}$ " size requires the length of the keyway to be 4.8 inches. The $\frac{3}{4}$ " x $\frac{3}{4}$ " size requires a 2.4 inch length keyway. The $\frac{3}{4}$ " x $\frac{3}{4}$ " keyway increases the factor of safety from 1.23 to 4.73. This high factor of safety is needed if the loading is not distributed equally on each shaft.

The 2 in. diameter shaft will be attached to the extended shaft of the gear reducer and provide the length needed for the mechanical arm(s) to attach. Textron Power Transmission suggests the use of a flexible coupling to attach the gear reducer's extended

shaft and the output shaft and to compensate for misalignment between the output shaft and the extended shaft of the gear reducer. The steelflex coupling selected is shown in Figure 22. Additional diagrams of the flex coupler are shown in Appendix V.

Figure 22 – Gear Reducer extended shaft to output shaft flex coupler (Falk Corporation).

A mechanical attachment hub must be used to attach the mechanical arm(s) to the rotational shaft. The hub should lock together the mechanical arm and the hub by bolts and then lock the mechanical arm/hub system to the shaft by means of a key way. The equations used for calculating the keyway size for the hubs is the same as used for the shaft keyways earlier in this section.

Bearing shaft supports are designed to support the gear reducer, coupling, rotational shaft, hub, and mechanical arm assembly. The bearings shaft supports will provide placement support for the rotating shaft during its use. For symmetry and support two shaft support bearings will be used on each output shaft of the rotational system. Each shaft support bearing selected has a dynamic load capability of 9,800 lbs. Figure 23 (left) shows an isometric view and diagram of the cast iron shaft support bearing. The dimensions coinciding with Figure 23 (right) are $A = 2 \frac{1}{2}''$, $B = 8 \frac{55}{64}''$, $C =$

$6 \frac{59}{64}$ ", $D = 4 \frac{53}{64}$ ", $E = 2 \frac{15}{32}$ ", $F = \frac{23}{32}$ ". Each bearing is capable of supporting up to 1,575 shaft rpm.

Figure 23 – (left) Isometric view of cast iron support bearing. (right) Diagram of cast iron support bearing support.

Nearly the entire rotational shaft is covered with components that align, support, or join each component of the system together. Additional shaft collars are inserted outside the mechanical arm/hub assembly to provide additional reinforcement to prevent movement in the horizontal direction along the shaft. A picture (left) and diagram (right) of the shaft collar are located in figure 24. The dimensions coinciding with Figure 24 (right) are Bore = 2", O.D = 3", and Wd. $\frac{11}{16}$ ".

Figure 24 – (left) Isometric view of shaft collar. (right) Diagram of shaft collar.

A top and front view diagram of the entire rotational shaft system is shown in Figure 25 and Figure 26.

Figure 25 – Top view of rotational system.

Figure 26 – Front view of rotational system.

Figure 27 shows a model of the complete rotational system positioned on the base pallet.

Figure 27 – Complete rotational system attached to gear reducer.

4.3 Linear System

The linear system performs the second type of movement for the system to translate it from the “stow” position to the final operational position. This system performs the translation moving outside of the rear cargo door and the translation retracting in against the rear cargo door. The linear system is also the base platform for the entire rotational system. Whenever the linear system translates it is also translating the rotational system with it. The major components of the linear system are the linear actuator (with motor), a base rail plate, linear guide/bearing assembly, and stiffening supports/diamond plate surface.

4.3.1 Linear Actuator (with motor)

The main component of the linear system must be able to translate the entire rail platform (including the weight of the rotational system and mechanical arm/pod system) outside into the air stream located outside of the rear cargo door of the C-130 aircraft. A motor driven linear actuator was selected to perform this translation because of their simplicity of design and capability of precision positioning. The linear actuator must also have a double extended input to accommodate for manual translation (in the event power is lost).

The main features required of the linear actuator (generated by the design of the base pallet and rotational system) are located in Table 3.

Table 3 – Linear Actuator design requirements.

Linear Actuator Requirements	
Stroke Length (in)	24
Load Capacity (lbs)	3000
Motor Type	AC
Motor Power (hp)	1/3

The stroke length of the linear actuator was determined by the size requirements of the mechanical arm/pod system. The mechanical arm/pod system must have a proper amount of distance outside of the rear cargo door in order to rotate completely without coming in contact with the door itself. This translation needs a stroke length of 19 inches in order to complete the cycle without coming in contact with the airframe body. A stroke distance of 24 inches was selected to provide an ample amount of clearance for the system and to provide sufficient room for future modification (if they should arise).

The load capacity of the linear actuator must be able to support the maximum amount of weight supplied by the linear system, the rotational system and the mechanical arm/pod system. This value will only vary because of the mechanical arm/pod system. The sensor pod will have a maximum load capacity that is limited by the gear reducer's load carrying capability and the overall size of the pod. The maximum load capacity for the mechanical arm/pod system is 700 lbs. It should be noted that another safety factor was provided to allow for future design improvements.

An AC motor must control the linear actuator. The type of power supplied by the C-130 determines this constraint. The linear actuator must also be capable of running on a minimum horsepower motor in order to leave sufficient power for various types of sensors used in the sensor pod.

Figure 28 shows the selected ball screw actuator made by Motion Systems Corporation. The attachment on the end of the actuator will be the only connection to the rail plate, which will translate (by means of the translating tube) the entire linear, rotational, and mechanical arm/pod system. The translating tube is protected by an aluminum housing to prevent any contamination of the system. Figure 28 shows the right angle mounting design of the 1/3 hp motor.

Figure 28 – Linear actuator system

Figure 29 shows an internal view of the gearing component of the linear actuator. The screw drive system shown generates the torque needed to translate a platform system that can be populated with 3000 lbs of mechanical components and sensor equipment.

Figure 29 – Ball screw gearing component of linear actuator.

Figure 30 shows the placement of the linear actuator on the sensor platform. The linear actuator will attach to the rail plate system explained in section 4.3.2.

Figure 30 – Model showing location of linear actuator.

4.3.2 Base Rail Plate

The entire rotational and linear systems are connected to the base rail plate of the linear system. The plate is attached to linear guide/bearing system (shown in Figure 36) that controls the linear translation of the rotation, linear and mechanical arm/pod systems. This shows that the ½” piece of 6061 T6 aluminum is a significant component of the entire sensor platform. Figure 31 shows a model of the rail plate in location on the base pallet. The gear reducer and linear actuator are both connected to the rail plate.

Figure 31 – Rail plate in place on base pallet.

4.3.3 Linear Guide/bearing Assembly

The entire rotational, linear and mechanical arm/pod system translates by means of a linear guide and bearing system. The rail plate, explained in section 4.3.2, is bolted to a set of eight linear bearings (explained below) that are attached to the shafting of the linear guides. The linear guides are drilled and tapped into the $\frac{3}{4}$ " aluminum plate of the Base Pallet. The base pallet provides the support structure for the entire linear guide/bearing assembly system.

The shafting and bearing components were selected using moment (M) and force (F) equations with loading generated by aerodynamic drag outside the rear cargo door of the C-130 and by mechanical arm/pod system weight during worst-case situations. In Figure 32 (B1) and (B2) represent sets of four bearings used to translate the entire linear and rotational system. The distances (D1) and (D2) are the distances from (O) to (B1) and from (O) to (B2) respectively. The moment (M) is generated by the weight (W) of the mechanical arm/pod system and the aerodynamic forces acting on them while deployed. The equations below are used to solve for B1 and B2.

Figure 32 – Diagram used to determine bearing loading.

Linear Bearing Force Equations $\sum F_y = -B1 + B2 - W = 0$

$$\sum M_o = D1B1 - D2B2 = M$$

When using the estimated moment (M) of 63,132 in/lbs the rear (4) bearings will see 767 lbs of pulling force each. Each front bearing will be subjected to 917 lbs of compressive force. It should be reminded that the 63,132.98 in/lbs of torque is already factoring in a 1.5 safety factor to ensure a stable design.

With the known force values that the bearings will be subjected (during worst case scenarios) a bearing selection can be made. Because this will be a one of a kind sensor platform and it will be flown on an aircraft we want to increase the safety factor to a reasonable maximum. When sizing the bearings a comfortable over design can be used (greater than the 917 lb force needed) to prepare for overloading and misuse.

Standard bearings come with a Nominal-Hole diameter (column two in Figure 33) that range in increments of 0.25 inches and begin with a minimum diameter of 0.5 inches.

Figure 33 shows the load ratings and dimensions for standard bearings. The dynamic load rating (C) is the maximum force rating the bearings are capable of being subjected too before a failure occurs (Danaher). Columns 3, 4, 5 and 6 in Figure 33 give the dimensions of the bearings.

Dimensions in Inches						
Part Number	Nominal Diameter	L1	H	Br	B9	Dynamic Load Rating, C(lb _f) (Even Distribution)
1CA-08-FAO	0.50	1.50	1.812	1.50	2.00	290
1CA-12-FAO	0.75	1.88	2.437	1.75	2.75	1800
1CA-16-FAO	1.00	2.63	2.937	2.13	3.25	3000
1CA-20-FAO	1.25	3.38	3.625	2.50	4.00	3730
1CA-24-FAO	1.50	3.75	4.250	3.00	4.75	6160

Figure 33 – Standard bearing sizes and load ratings (McMaster-Carr Distributor).

The explanation of the dimensions from Figure 33 is seen in Figure 34 and 35. Figure 34 shows a front view of the assembled on the linear guide. The variable (H) gives the overall height of the linear guide/bearing assembly. (B9) represents the width of the pillow block housing surround the linear bearing. The variable (Br) represents the width of the linear guide base structure. Figure 35 shows a top view of the bearing assembled on the linear guide. For a visual understanding, Figure 36 shows an isometric view of the complete linear guide/bearing assembly. Figure 37 shows the linear guide/bearing system placement on the base pallet. Each set of linear guide/bearing system comes with one linear guide and two pillow block linear bearings.

Figure 34 – Variables coinciding with dimension in columns 4, 5 and 6 of figure 33.

Figure 35– Variable coinciding with dimensions in column 3 of figure 33.

Figure 36 – Isometric view of linear guide/bearing assembly.

Figure 37 – Model showing placement of linear guide/bearing system.

4.4 Mechanical Arm/Pod System

The mechanical arm/pod system is the module that translates outside the rear cargo door of the C-130 aircraft. The mechanical arm(s) sole objective it to transfer the sensor pod from the “stow” position inside the aircraft, to the final operating position underneath the rear cargo door of the C-130 aircraft. The mechanical arms are directly connected to the rotational shaft (by way of the connection hubs explained in Section 4.2.2) of the rotational system. The sensor pod must be able to withstand the forces generated by the aerodynamic drag outside of the aircraft and create a stable environment (minimal vibration) for data collection. The sensor pod directly connects to the mechanical arm(s) and houses the sensors that will be used during the flight mission.

4.4.1 Mechanical Arm Design

The design of the mechanical arms initially looked at using two mechanical arms on both ends of the sensor pod. This design was quickly rejected because of the great distance (5 feet) the arms would be separated from one another. With the expectancy of holding 500 pounds of sensor weight in the sensor pod, such a large separation between

the arms would create a high instability with horizontal forces. The solution to this problem is the addition of a third and fourth mechanical arm to minimize the separation between each mechanical arm.

The design of the four-part mechanical arm system involved positioning along the rotational shaft of the rotational system, determining geometry to contour the face of the rear cargo door of the C-130 aircraft, material selection and material thickness selection determined by Finite Element Analysis Methods using simulated loading calculated in Section 4.2.1. These four design characteristics will determine the positioning (on the rotational shaft), size, shape, and material makeup of the four-part mechanical arm system.

The positioning of the four mechanical arms was designed simultaneously with the positioning of the components on the rotational shaft. As shown in Figures 25 and 26 (from Section 4.2.2) both output shafts are heavily populated with mechanical components (support bearings, hubs, collars, flex couplings), this makeup predetermines the positioning of the mechanical arms. The ideal positioning of the mechanical arms would be to equally separate them along the output shafts, but the width of the gear reducer does not allow for this design. Figure 38 shows the positioning of the mechanical arms along the rotational shaft.

Figure 38 – Mechanical arms positioned on rotational shaft.

The geometry of the mechanical arms is determined by the location of the rotational shaft on the sensor platform and the geometry of the rear cargo door of the C-130 aircraft. The position of the rotational shaft was determined with the design of the linear and rotational systems. The position of the rotational shaft with respect to the rear cargo door of the C-130 aircraft is shown in Figure 39.

Figure 39 – Location of gear reducer with respect to edge of rear cargo door.

Ideally the mechanical arms would like to have a shape that would perfectly mold to the contours of the rear cargo door of the C-130 aircraft, but because acquiring such precise geometry's and tolerances are unreasonable, the mechanical arm geometry was simplified. Figure 40 shows a diagram of the rear cargo door of the C-130 aircraft. The rear cargo door has two locations that the mechanical arm can use for contact points to provide stability for the mechanical arm/pod system when it is in its final operational position. The red arrows in Figure 40 show these contact locations. Molding the mechanical arms to nearly meet these contact points and having the sensor pod provide contact with the bottom of the rear cargo door this would provide a wedge to stabilize the system. Figure 41 shows a model of the mechanical arm (all dimensions of the arm are located in Appendix VI). Figure 41 shows the location of the rear cargo door and the contact points with respect to the mechanical arm.

Figure 40 – Rear cargo door of C-130 with contact points highlighted.

Figure 41 - Model of mechanical arm.

With the geometry set by the structure of the linear and rotational system (as well as the contour shape of the rear cargo door) the mechanical arm system can be analyzed to determine if the structure can support the loading during deployment. The complete analysis was performed using ProEngineer and ProMechanica software packages. The analysis shows the critical stress concentration points on the structure and the stress concentrations values that will cause the arm to fail. An analysis of the complete mechanical arm/pod system is explained in Section 4.4.3.

4.4.2 Sensor Pod Design

The sensor pod is the component that houses all of the sensors used on the sensor platform. The sensor pod must be able to withstand the impact of the aerodynamic drag force explained in Section 4.2.1. It must also be easily altered (machined, welded, tapped, etc.) to allow for the use of various types of sensors with their respectable connection procedures. The system should be as lightweight as possible but not to compromise the strength needed for the rugged application.

With the mechanical arm structure already determined the sensor pod must adjust to mesh properly with them. The pod will have four mounting locations (each arm) and must be shaped to provide a wedge structure for stability and vibration dampening reasons. The height and width of the sensor pod are predetermined by the location and geometry of the mechanical arm system. A maximum height for the pod would be from bottom of the rear cargo door to the end of the mechanical arms during the operational final position. This maximum height will be slightly minimized from the bottom of the rear cargo door to ensure no contact is made between the pod and the rear cargo door during the deployment. The width of the sensor pod is set at 60 inches (plus the outside

framing of the pod) by the overall distance between arms one and four along the rotational shaft. The depth of the sensor pod must be designed to accommodate various sensor sizes but must not increase beyond an unreasonable size as if to produce a second wing in the rear of the C-130 aircraft. This would directly affect one of the major design requirements of not interfering with the pilot's flight by causing a "nose down" force to the aircraft which causes a flight course obstruction to the pilot.

Two sensor pod pallet systems have been built from the work in this thesis. The first sensor pod was designed to allow for mounting along the entire body of the pod. The sensor pod body was designed using $\frac{1}{4}$ " aluminum plate for the sides, $\frac{3}{8}$ " aluminum plate for the bottom, and $\frac{1}{2}$ " aluminum plate for the top to create a surface to bolt sensors. Figure 42 shows a model of the first sensor pod design. The surface was attached to a framing system to structurally stabilize the sensor pod body. The framing system was attached directly to all four mechanical arms to create the mechanical arm/pod system. The system was high in weight and decreased the amount of total weight to accommodate the sensors.

Figure 42 – Initial sensor pod model.

The revised second pod minimized sensor pod weight and allowed for increased sensor weight within the pod. Most aerial sensor manufacturers request their units be operated within a housing to prevent damage from weather and high drag forces seen during flight. These new design requirements helped develop a frame with aluminum skin structure that could only support sensors inside the pod. The new pod has a support skeleton bracing the structure in place. The top plate would remain at $\frac{1}{2}$ " thickness to provide a base to mount various sensors. Figure 43 shows a model of the revised pod design. Figure 44 shows the complete mechanical arm/pod system attached to the rotational shaft. Additional drawings of the sensor pod are shown in Appendix VII.

Figure 43 – Revised model of sensor pod.

Figure 44 – Mechanical arm/pod system attached to rotational shaft.

4.4.3 Analysis of Mechanical Arm/Pod System

With the design of the mechanical arm/pod system finalized an analysis is performed to ensure the system will not fail when subjected to the simulated loading. The Finite Element Analysis on the mechanical arm/pod system is performed using Pro Mechanical analysis package found within the Pro Engineer Software package. Finite Element Analysis is a mathematical representation of a physical system comprising a part/assembly (model), material properties, and applicable boundary conditions {collectively referred to as *pre-processing*}, the solution of that mathematical representation {*solving*}, and the study of results of that solution {*post-processing*}.

The analysis consists of modeling the entire system, assigning material properties to the system components, applying boundary conditions and restraints to the model, running the analysis with the simulated loading generated from the aerodynamic drag and weight of the sensor pod (with expected sensor weight capacity), and finally reading the result's and interpreting the data (Gagnon).

Modeling - A solid model was created in Pro Engineer using the current arm/pod design. This design includes all new modifications made with arm dimensions and new pod skin. The frame of the pod is made of L-channel aluminum (2.5"x 2.5"x 0.25") and is joined together by welds. The mechanical arm is made of $\frac{3}{4}$ " aluminum plate cut to the specified dimensions shown in the appendix. For simplicity in running a FEA only one of the 4 arm/pod connections were modeled. It should be noted that when running the analysis only $\frac{1}{4}$ of the estimated loading should be applied to the model to simulate equal distribution throughout the four-arm structure. This simplified modeling will analyze the high stress concentration regions located at the high point connection between the arm

and pod and the location of the hub connection on the arm. These locations are shown in Figure 45.

Figure 45 – Mechanical arm/pod system with maximum stress location circled.

Restraints/Boundary Conditions - This simulation was run to analyze the response of the system at the loading specified in Section 4.2.1. This analysis with the extreme load applied will determine what the maximum stress is and also give suggestion as to where reinforcements should be applied. To represent the aerodynamic drag of the system in the C-130 during flight a force was applied to the surface of the frame that is in contact with the rear cargo door of the C-130 aircraft. A force equivalent to a 4-G loading was applied as a worst-case scenario to analyze how the mechanical arm/pod system would react. A system restraint was applied to the shaft-connecting hole located on the top of the mechanical arm. Figure 46 shows the restraints and boundary conditions applied to the mechanical arm/pod system.

Figure 46 – Mechanical arm/pod system with loads and boundary conditions applied.

Results - The results shown in Figure 47 indicate that the mechanical arm/pod system can handle a simulated worst-case 4-G loading. The mechanical arm/pod system on the right in Figure 47 shows a maximum stress level of 32,134 psi. This value is below the rated yield strength of Aluminum 6061-T6 material (37,000 psi). The left side of Figure 47 shows the displacement of the system when subjected to the 4-G loading. The maximum displacement seen on the bottom of the frame is 0.0048 inches.

Figure 47 – Von mises stress results of the FEA performed on the mechanical arm/pod system.

With the conclusion of the FEA on the most critical component of the Standardized Sensor Platform System the design is complete. A complete modal analysis and shock loading analysis is to be performed in a later work stemming from this project (Naternicola). All final drawings and pictures of the completed sensor pallet system are available in Appendix VIII. Appendix VIII also shows pictures of the system inside and loaded in a C-130 Aircraft. Appendix IX shows a table with the safety factors of the critical components of the rotational and mechanical arm/pod systems.

5.0 Conclusions

The design and prototype of a Standardized Sensor Pallet Systems was developed in parallel with this document. The system shows that through engineering analysis and creativity a highly technical, versatile and useful system can be produced using standard off the shelf components. The system developed is a self supporting mechanical system that can be used on any C-130 aircraft variants B thru J. The system is capable of providing law enforcement (National Guard , DoD, etc.) officials with a tool that can assist in the counterdrug mission of the United States.

6.0 Future Work

The next phase in development of the Standardized Sensor Pallet System involves gaining FAA certification for the system to allow for it to fly on military aircraft as a certified system and to enhance the current design to allow for the system to fly above 10,000 feet. An FAA certification of the Standardized Sensor Pallet System would ease the process of gaining mission flight time on a military aircraft. Military personnel in charge of allowing non-standard system on aircraft are instructed to not allow non-certified systems on mobile aircraft. An increase in mission flight time would directly increase the efforts and results of the counterdrug and homeland security agencies. A Standardized Sensor Pallet Systems capable of flying above 10,000 feet would add stealth and safety to the original system. Flying above 10,000 feet would allow for law enforcement officials to go nearly undetected when performing missions. This high altitude would also provide safety to officials who can expect response actions from perpetrators during low altitude missions.

Both enhancements to the original system would provide increased safety and success for law enforcement agencies.

7.0 References

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Appendix I – Base Pallet

This section shows the dimensions of a standard sized aircraft cargo pallet with a reinforced $\frac{3}{4}$ " aluminum plate on top. Figures 48-50 show the dimensions of the internal grid structure of the pallet. This grid structure provides the pallet with forklift capabilities used for transport. Figure 51 shows a solid model of the pallet for visualization purposes.

Figure 48 – Dimensioned top view of base pallet.

Figure 49 – Dimensioned front view of base pallet.

Figure 50 – Dimensioned side view of base pallet.

Figure 51 – Base pallet solid model.

Appendix II – Gear Reducer

This section includes an illustration of the Textron 30-60 Gear Reducer as well as a dimensional drawing of the unit. Figure 52 shows the housing structure for all Double Enveloping gear reducers made by Textron Power Transmission. Figure 53 shows the dimensional drawing of the unit and also shows the size and location of the internal components.

Figure 52 – Picture of the Textron 30-60 Double Enveloping Gear Reducer (Textron).

NOTE #1: CAUTION: IT IS THE PURCHASERS OR USERS RESPONSIBILITY TO GUARD ALL SHAFTING IN ACCORDANCE WITH OSHA REQUIREMENTS.

NOTE #2: FOR ADDITIONAL MOUNTING POSITIONS SEE DRAWING QU30-60-A348W1.

Figure 53 – Dimensional view of Textron gear reducer (Textron).

Appendix III – Torque Analysis Program and Results

Note: The Different Weight Values for the 3 Components (FLIR Ball, General Area for other Sensors and the Rotational part of the Mechanical Arm) may be varied and entered accordingly.

Calculation of Center of Gravity for Mechanical System and Sensors

Moment of Area for Specified Components

<u>Component</u>	<u>Area, A (in²)</u>	<u>X Bar (in)</u>	<u>Y Bar (in)</u>	<u>X Bar * A (in³)</u>	<u>Y Bar * A (in³)</u>
#1 FLIR BALL SENSOR					
1. (Round Area)	226	21	-65.75	4746	-14859.5
2. (Rectangular Area)	255	21	-54	5355	-13770.0
Sum of Columns	481			10101	-28629.5
X bar and Y bar ; Respectively				21	-59.5
#2 Adjacent Sensors					
X Bar and Y Bar ; Respectively	1	13.21	-42.75	13.21	-42.75
#3 Mechanical Arm					
1. Section 1	53.5	0	-6.6875	0	-357.8
2. Section 2	32	3.5	-15.5	112	-496.0
3. Section 3	27	10	-17	270	-459.0
4. Section 4	138	20	-30	2760	-4140.0
Sum of Columns	250.5			3142	-5452.8
X bar and Y bar ; Respectively				12.5	-21.8

#4 Base Plate, Sensor Plate and Front Plate	<u>Area, A</u> <u>(in^2)</u>	<u>X Bar</u> <u>(in)</u>	<u>Y Bar (in)</u>	<u>X Bar * A (in^3)</u>	<u>Y Bar * A (in^3)</u>
1. Base Plate (3/4 in thickness)	17.1	6.5	-32.1	111.0	-547.9
2. Sensor Plate (3/4 in thickness)	27.0	13.1	-46.1	354.8	-1245.5
3. Front Plate (3/8 in Thick)	4.8	-5.1	-40.1	-24.1	-191.1
Sum of Columns	48.8			441.6	-1984.5
X bar and Y bar ; Respectively				9.0	-40.6

(inches)	<u>Weight of Mehcanical Arm without Sensors</u>				
0.375					
<u>Wall Thickness</u>	<u>Density of</u> <u>Material</u>	<u>Width of Extrusion</u>	<u>Width of</u> <u>Extrusion</u>	<u>Width of</u> <u>Extrusion</u>	<u>Width of</u> <u>Extrusion</u>
(feet)	(lb / ft^3)	(Arm) (in)	(Arm) (ft)	(Plate) (in)	(Plate) (ft)
0.03125	168.2	0.75	0.0625	60	5
<u>Component</u>	<u>Length (ft)</u>	<u>Heigth (ft)</u>	<u>Area (ft^2)</u>	<u>Volume (ft^3)</u>	<u>Weight (lb)</u>
Arm 1 (Solid)	5.3	0.3	1.7	0.1	18.4
Arm 2 (Solid)	5.3	0.3	1.7	0.1	18.4
Arm 3 (Solid)	5.3	0.3	1.7	0.1	18.4
Arm 4 (Solid)	5.3	0.3	1.7	0.1	18.4
Plate "BASE" (3/4 in)	1.9	0.1	0.1	0.6	99.7
Plate "SENSOR" (3/4 in)	3.0	0.1	0.2	0.9	157.7
Plate "Front" (3/8 in)	1.1	0.0	0.0	0.2	27.9
Plate "Side" (3.8 in)	Odd Shape	Odd Shape	2.08	0.06	10.91
Plate "Side" (3.8 in)	Odd Shape	Odd Shape	2.08	0.06	10.91
Interior Arm Side Plate	Odd Shape	Odd Shape	0.45	0.01	2.38
Interior Arm Side Plate	Odd Shape	Odd Shape	0.45	0.01	2.38
Totals				2.29	385.43

#5 Side Plate & Interior Supporting Plate	Area, A (in²)	X Bar (in)	Y Bar (in)	X Bar * A (in³)	Y Bar * A (in³)
1. Section 5 (side plate 3/8 in thick)	374.0	13.1	-38.0	4899.4	-14212.0
2. "minus" Section 6	-48.0	-0.1	-31.0	4.8	1488.0
3. "minus" Section 7	-27.0	29.5	-30.5	-796.5	823.5
4. Section 5b Int Arm (side plate 3/8 in thick)	65.0	17.5	-32.0	1137.5	-2080.0
Sum of Columns	364.0			5245.2	-13980.5
X bar and Y bar ; Respectively				14.4	-38.4

Center of Gravity

Component	Weight (lb)	X Bar (in)	Y Bar (in)	X Bar * W (lb)	Y Bar * W (lb)
#1 FLIR BALL Sensors	96.9	21.0	-59.5	2034.9	-5767.6
#2 Adjacent Sensors	50.0	13.2	-42.8	660.5	-2137.5
#3 Mechanical Arm (4 Arms)	73.6	12.5	-21.8	922.9	-1601.7
#4 <u>Base Plate, Sensor Plate and Front Plate</u>	285.3	9.0	-40.6	2580.0	-11593.3
#5 <u>Side Plate & Interior Supporting Plates</u>	26.6	14.4	-38.4	383.2	-1021.4

Totals	532.3	6581.6	-22121.4
<u>Center of Gravity</u>		<u>12.4</u>	<u>-41.6</u>

					<u>Moment Arm for</u>				
					<u>Weight</u>				
					<u>Inches</u>		<u>Feet</u>		
<u>Distance of Moment Arm</u>					44.37		<u>3.6975</u>		
					Safety		Weight		
					Factor		(lbs)		
<u>Delta</u>					<u>1.5</u>		<u>532.3303</u>		
					Force		Force in		
					perpendicular to		plane of door		
<u>(Theta)</u>					door		lbs		
<u>Degrees</u>					lbs				
	270	4.4	-1.0	-542.5		88.6	502.4	270	4.54
	269	4.4	-1.1	-575.5		73.7	465.3	269	4.52

268	4.4	-1.1	-608.2	60.1	427.7	268	4.50
267	4.4	-1.2	-640.8	47.8	389.6	267	4.49
266	4.4	-1.3	-673.2	36.9	351.1	266	4.47
265	4.3	-1.3	-705.4	27.3	312.3	265	4.45
264	4.3	-1.4	-737.3	19.1	273.1	264	4.43
263	4.3	-1.4	-769.1	12.2	233.7	263	4.42
262	4.3	-1.5	-800.6	6.8	194.1	262	4.40
261	4.3	-1.6	-831.8	2.7	154.3	261	4.38
260	4.3	-1.6	-862.8	0.0	146.2	260	4.36
259	4.2	-1.7	-893.6	-2.7	154.3	259	4.35
258	4.2	-1.7	-924.1	-6.8	194.1	258	4.33
257	4.2	-1.8	-954.2	-12.2	233.7	257	4.31
256	4.2	-1.8	-984.1	-19.1	273.1	256	4.29
255	4.2	-1.9	-1013.7	-27.3	312.3	255	4.28
254	4.2	-2.0	-1043.0	-36.9	351.1	254	4.26
253	4.1	-2.0	-1072.0	-47.8	389.6	253	4.24
252	4.1	-2.1	-1100.7	-59.5	423.6	252	4.22
251	4.1	-2.1	-1129.0	-72.2	455.7	251	4.21
250	4.1	-2.2	-1156.9	-85.7	486.2	250	4.19
249	4.1	-2.2	-1184.5	-100.1	515.1	249	4.17
248	4.0	-2.3	-1211.8	-115.3	542.4	248	4.15
247	4.0	-2.3	-1238.7	-131.2	568.1	247	4.14
246	4.0	-2.4	-1265.2	-147.6	592.1	246	4.12
245	4.0	-2.4	-1291.3	-164.6	614.5	245	4.10
244	4.0	-2.5	-1317.0	-182.1	635.2	244	4.08
243	4.0	-2.5	-1342.4	-200.0	654.2	243	4.07
242	3.9	-2.6	-1367.3	-218.2	671.6	242	4.05
241	3.9	-2.6	-1391.8	-236.6	687.2	241	4.03
240	3.9	-2.7	-1415.9	-255.2	701.3	240	4.01
239	3.9	-2.7	-1439.5	-273.9	713.6	239	4.00
238	3.9	-2.7	-1462.7	-292.7	724.3	238	3.98
237	3.9	-2.8	-1485.5	-311.3	733.4	237	3.96

236	3.8	-2.8	-1507.8	-329.9	740.9	236	3.94
235	3.8	-2.9	-1529.6	-348.2	746.8	235	3.93
234	3.8	-2.9	-1551.0	-366.3	751.1	234	3.91
233	3.8	-3.0	-1571.9	-384.1	753.8	233	3.89
232	3.8	-3.0	-1592.4	-401.5	755.1	232	3.87
231	3.8	-3.0	-1612.3	-418.4	754.8	231	3.86
230	3.7	-3.1	-1631.8	-434.8	753.1	230	3.84
229	3.7	-3.1	-1650.7	-450.6	750.0	229	3.82
228	3.7	-3.1	-1669.2	-465.8	745.5	228	3.80
227	3.7	-3.2	-1687.2	-480.3	739.6	227	3.79
226	3.7	-3.2	-1704.6	-494.1	732.5	226	3.77
225	3.6	-3.2	-1721.5	-507.0	724.1	225	3.75
224	3.6	-3.3	-1737.9	-519.1	714.5	224	3.74
223	3.6	-3.3	-1753.8	-530.3	703.8	223	3.72
222	3.6	-3.3	-1769.1	-540.6	691.9	222	3.70
221	3.6	-3.4	-1783.9	-549.9	679.1	221	3.68
220	3.6	-3.4	-1798.1	-558.1	665.2	220	3.67
219	3.5	-3.4	-1811.8	-565.3	650.3	219	3.65
218	3.5	-3.4	-1825.0	-571.4	634.6	218	3.63
217	3.5	-3.5	-1837.6	-576.4	618.1	217	3.61
216	3.5	-3.5	-1849.6	-580.2	600.8	216	3.60
215	3.5	-3.5	-1861.1	-582.8	582.8	215	3.58
214	3.5	-3.5	-1872.0	-584.2	564.2	214	3.56
213	3.4	-3.5	-1882.3	-584.4	545.0	213	3.54
212	3.4	-3.6	-1892.0	-583.4	525.3	212	3.53
211	3.4	-3.6	-1901.2	-581.0	505.1	211	3.51
210	3.4	-3.6	-1909.8	-577.4	484.5	210	3.49
209	3.4	-3.6	-1917.8	-572.5	463.6	209	3.47
208	3.4	-3.6	-1925.3	-566.4	442.5	208	3.46
207	3.3	-3.6	-1932.1	-558.9	421.1	207	3.44
206	3.3	-3.6	-1938.4	-550.1	399.7	206	3.42
205	3.3	-3.7	-1944.1	-540.0	378.1	205	3.40
204	3.3	-3.7	-1949.1	-528.7	356.6	204	3.39

203	3.3	-3.7	-1953.6	-516.1	335.1	<u>203</u>	3.37
202	3.2	-3.7	-1957.5	-502.2	313.8	202	3.35
201	3.2	-3.7	-1960.8	-487.0	292.6	201	3.33
200	3.2	-3.7	-1963.5	-470.6	271.7	200	3.32
199	3.2	-3.7	-1965.6	-453.0	251.1	199	3.30
198	3.2	-3.7	-1967.1	-434.2	230.9	198	3.28
<u>197</u>	3.2	-3.7	-1968.0	-414.2	211.1	197	3.26
196	3.1	-3.7	-1968.3	-393.1	191.7	196	3.25
195	3.1	-3.7	-1968.0	-370.9	172.9	195	3.23
194	3.1	-3.7	-1967.1	0.0	0.0	194	3.21
193	3.1	-3.7	-1965.6	0.0	0.0	193	3.19
192	3.1	-3.7	-1963.5	0.0	0.0	192	3.18
191	3.1	-3.7	-1960.8	0.0	0.0	191	3.16
190	3.0	-3.7	-1957.5	0.0	0.0	190	3.14
189	3.0	-3.7	-1953.6	0.0	0.0	189	3.12
188	3.0	-3.7	-1949.1	0.0	0.0	188	3.11
187	3.0	-3.7	-1944.1	0.0	0.0	187	3.09
186	3.0	-3.6	-1938.4	0.0	0.0	186	3.07
185	2.9	-3.6	-1932.1	0.0	0.0	185	3.05
184	2.9	-3.6	-1925.3	0.0	0.0	184	3.04
183	2.9	-3.6	-1917.8	0.0	0.0	183	3.02
182	2.9	-3.6	-1909.8	0.0	0.0	182	3.00
181	2.9	-3.6	-1901.2	0.0	0.0	181	2.98
180	2.9	-3.6	-1892.0	0.0	0.0	180	2.97
179	2.8	-3.5	-1882.3	0.0	0.0	179	2.95
178	2.8	-3.5	-1872.0	0.0	0.0	178	2.93
177	2.8	-3.5	-1861.1	0.0	0.0	177	2.91
176	2.8	-3.5	-1849.6	0.0	0.0	176	2.90
175	2.8	-3.5	-1837.6	0.0	0.0	175	2.88
174	2.8	-3.4	-1825.0	0.0	0.0	174	2.86
173	2.7	-3.4	-1811.8	0.0	0.0	173	2.84
172	2.7	-3.4	-1798.1	0.0	0.0	172	2.83
171	2.7	-3.4	-1783.9	0.0	0.0	171	2.81

170	2.7	-3.3	-1769.1	0.0	0.0	170	2.79
169	2.7	-3.3	-1753.8	0.0	0.0	169	2.78
168	2.7	-3.3	-1737.9	0.0	0.0	168	2.76
167	2.6	-3.2	-1721.5	0.0	0.0	167	2.74
166	2.6	-3.2	-1704.6	0.0	0.0	166	2.72
165	2.6	-3.2	-1687.2	0.0	0.0	165	2.71
164	2.6	-3.1	-1669.2	0.0	0.0	164	2.69
163	2.6	-3.1	-1650.7	0.0	0.0	163	2.67
162	2.5	-3.1	-1631.8	0.0	0.0	162	2.65
161	2.5	-3.0	-1612.3	0.0	0.0	161	2.64
160	2.5	-3.0	-1592.4	0.0	0.0	160	2.62
159	2.5	-3.0	-1571.9	0.0	0.0	159	2.60
158	2.5	-2.9	-1551.0	0.0	0.0	158	2.58
157	2.5	-2.9	-1529.6	0.0	0.0	157	2.57
156	2.4	-2.8	-1507.8	0.0	0.0	156	2.55
155	2.4	-2.8	-1485.5	0.0	0.0	155	2.53
154	2.4	-2.7	-1462.7	0.0	0.0	154	2.51
153	2.4	-2.7	-1439.5	0.0	0.0	153	2.50
152	2.4	-2.7	-1415.9	0.0	0.0	152	2.48
151	2.4	-2.6	-1391.8	0.0	0.0	151	2.46
150	2.3	-2.6	-1367.3	0.0	0.0	150	2.44
149	2.3	-2.5	-1342.4	0.0	0.0	149	2.43
148	2.3	-2.5	-1317.0	0.0	0.0	148	2.41
147	2.3	-2.4	-1291.3	0.0	0.0	147	2.39
146	2.3	-2.4	-1265.2	0.0	0.0	146	2.37
145	2.3	-2.3	-1238.7	0.0	0.0	145	2.36
144	2.2	-2.3	-1211.8	0.0	0.0	144	2.34
143	2.2	-2.2	-1184.5	0.0	0.0	143	2.32
142	2.2	-2.2	-1156.9	0.0	0.0	142	2.30
141	2.2	-2.1	-1129.0	0.0	0.0	141	2.29
140	2.2	-2.1	-1100.7	0.0	0.0	140	2.27
139	2.1	-2.0	-1072.0	0.0	0.0	139	2.25
138	2.1	-2.0	-1043.0	0.0	0.0	138	2.23

137	2.1	-1.9	-1013.7	0.0	0.0	137	2.22
136	2.1	-1.8	-984.1	0.0	0.0	136	2.20
135	2.1	-1.8	-954.2	0.0	0.0	135	2.18
134	2.1	-1.7	-924.1	0.0	0.0	134	2.16
133	2.0	-1.7	-893.6	0.0	0.0	133	2.15
132	2.0	-1.6	-862.8	0.0	0.0	132	2.13
131	2.0	-1.6	-831.8	0.0	0.0	131	2.11
130	2.0	-1.5	-800.6	0.0	0.0	130	2.09
129	2.0	-1.4	-769.1	0.0	0.0	129	2.08
128	2.0	-1.4	-737.3	0.0	0.0	128	2.06
127	1.9	-1.3	-705.4	0.0	0.0	127	2.04
126	1.9	-1.3	-673.2	0.0	0.0	126	2.02
125	1.9	-1.2	-640.8	0.0	0.0	125	2.01
124	1.9	-1.1	-608.2	0.0	0.0	124	1.99
123	1.9	-1.1	-575.5	0.0	0.0	123	1.97
122	1.9	-1.0	-542.5	0.0	0.0	122	1.95
121	1.8	-1.0	-509.4	0.0	0.0	121	1.94
120	1.8	-0.9	-476.2	0.0	0.0	120	1.92
119	1.8	-0.8	-442.8	0.0	0.0	119	1.90
118	1.8	-0.8	-409.2	0.0	0.0	118	1.88
117	1.8	-0.7	-375.6	0.0	0.0	117	1.87
116	1.7	-0.6	-341.8	0.0	0.0	116	1.85
115	1.7	-0.6	-307.9	0.0	0.0	115	1.83
114	1.7	-0.5	-273.9	0.0	0.0	114	1.82
113	1.7	-0.5	-239.9	0.0	0.0	113	1.80
112	1.7	-0.4	-205.7	0.0	0.0	112	1.78
111	1.7	-0.3	-171.5	0.0	0.0	111	1.76
110	1.6	-0.3	-137.3	0.0	0.0	110	1.75
109	1.6	-0.2	-103.0	0.0	0.0	109	1.73
108	1.6	-0.1	-68.7	0.0	0.0	108	1.71
107	1.6	-0.1	-34.4	0.0	0.0	107	1.69
106	1.6	0.0	0.0	0.0	0.0	106	1.68
105	1.6	0.1	34.4	0.0	0.0	105	1.66

104	1.5	0.1	68.7	0.0	0.0	104	1.64
103	1.5	0.2	103.0	0.0	0.0	103	1.62
102	1.5	0.3	137.3	0.0	0.0	102	1.61
101	1.5	0.3	171.5	0.0	0.0	101	1.59
100	1.5	0.4	205.7	0.0	0.0	100	1.57
99	1.4	<u>0.5</u>	239.9	0.0	0.0	99	1.55
98	1.4	0.5	273.9	0.0	0.0	98	1.54
97	1.4	0.6	307.9	0.0	0.0	97	1.52
96	1.4	0.6	341.8	0.0	0.0	96	1.50
95	1.4	0.7	375.6	0.0	0.0	95	1.48
94	1.4	0.8	409.2	0.0	0.0	94	1.47
93	1.3	0.8	442.8	0.0	0.0	93	1.45
92	1.3	0.9	476.2	0.0	0.0	92	1.43
91	1.3	1.0	509.4	0.0	0.0	91	1.41
90	1.3	1.0	542.5	0.0	0.0	90	1.40
89	1.3	1.1	575.5	0.0	0.0	89	1.38
88	1.3	1.1	608.2	0.0	0.0	88	1.36
87	1.2	1.2	640.8	0.0	0.0	87	1.34
86	1.2	1.3	673.2	0.0	0.0	86	1.33
85	1.2	1.3	705.4	0.0	0.0	85	1.31
84	1.2	1.4	737.3	0.0	0.0	84	1.29
83	1.2	1.4	769.1	0.0	0.0	83	1.27
82	1.2	1.5	800.6	0.0	0.0	82	1.26
81	1.1	1.6	831.8	0.0	0.0	81	1.24
80	1.1	1.6	862.8	0.0	0.0	80	1.22
79	1.1	1.7	893.6	0.0	0.0	79	1.20
78	1.1	1.7	924.1	0.0	0.0	78	1.19
77	1.1	1.8	954.2	0.0	0.0	77	1.17
76	1.0	1.8	984.1	0.0	0.0	76	1.15
75	1.0	1.9	1013.7	0.0	0.0	75	1.13
74	1.0	2.0	1043.0	0.0	0.0	74	1.12
73	1.0	2.0	1072.0	0.0	0.0	73	1.10
72	1.0	2.1	1100.7	0.0	0.0	72	1.08

71	1.0	2.1	1129.0	0.0	0.0	71	1.06
70	0.9	2.2	1156.9	0.0	0.0	70	1.05
69	0.9	2.2	1184.5	0.0	0.0	69	1.03
68	0.9	2.3	1211.8	0.0	0.0	68	1.01
67	0.9	2.3	1238.7	0.0	0.0	67	0.99
66	0.9	2.4	1265.2	0.0	0.0	66	0.98
65	0.9	2.4	1291.3	0.0	0.0	65	0.96
64	0.8	2.5	1317.0	0.0	0.0	64	0.94
63	0.8	2.5	1342.4	0.0	0.0	63	0.93
62	0.8	2.6	1367.3	0.0	0.0	62	0.91
61	0.8	2.6	1391.8	0.0	0.0	61	0.89
60	0.8	2.7	1415.9	0.0	0.0	60	0.87
59	0.8	2.7	1439.5	0.0	0.0	59	0.86
58	0.7	2.7	1462.7	0.0	0.0	58	0.84
57	0.7	2.8	1485.5	0.0	0.0	57	0.82
56	0.7	2.8	1507.8	0.0	0.0	56	0.80
55	0.7	2.9	1529.6	0.0	0.0	55	0.79
54	0.7	2.9	1551.0	0.0	0.0	54	0.77
53	0.6	3.0	1571.9	0.0	0.0	53	0.75
52	0.6	3.0	1592.4	0.0	0.0	52	0.73
51	0.6	3.0	1612.3	0.0	0.0	51	0.72
50	0.6	3.1	1631.8	0.0	0.0	50	0.70
49	0.6	3.1	1650.7	0.0	0.0	49	0.68
48	0.6	3.1	1669.2	0.0	0.0	48	0.66
47	0.5	3.2	1687.2	0.0	0.0	47	0.65
46	0.5	3.2	1704.6	0.0	0.0	46	0.63
45	0.5	3.2	1721.5	0.0	0.0	45	0.61
44	0.5	3.3	1737.9	0.0	0.0	44	0.59
43	0.5	3.3	1753.8	0.0	0.0	43	0.58
42	0.5	3.3	1769.1	0.0	0.0	42	0.56
41	0.4	3.4	1783.9	0.0	0.0	41	0.54
40	0.4	3.4	1798.1	0.0	0.0	40	0.52
39	0.4	3.4	1811.8	0.0	0.0	39	0.51

38	0.4	3.4	1825.0	0.0	0.0	38	0.49
37	0.4	3.5	1837.6	0.0	0.0	37	0.47
36	0.3	3.5	1849.6	0.0	0.0	36	0.45
35	0.3	3.5	1861.1	0.0	0.0	35	0.44
34	0.3	3.5	1872.0	0.0	0.0	34	0.42
33	0.3	3.5	1882.3	0.0	0.0	33	0.40

Negative

Negative

Angle deg	Moment Arm in (Perp)	Moment Aero ft-lbs (Perp)	Moment Arm in (Plane)	Moment Aero ft-lbs (Plane)	Required Ft-lbs	Required Inch-lbs	Required Inch-lbs
270	-0.63	55.9	-3.6	1798.4	1311.8	15741.6	23612.4
269	-0.69	51.1	-3.6	1660.2	1135.8	13629.7	20444.5
268	-0.76	45.4	-3.6	1520.5	957.7	11492.7	17239.1
267	-0.82	39.1	-3.5	1379.8	778.1	9337.8	14006.6
266	-0.88	32.5	-3.5	1238.4	597.6	7171.7	10757.6
265	-0.94	25.7	-3.5	1096.5	416.8	5001.7	7502.5
264	-1.00	19.1	-3.5	954.4	236.2	2834.7	4252.0
263	-1.06	13.0	-3.5	812.5	56.5	677.7	1016.5
262	-1.12	7.6	-3.5	671.1	-121.9	-1462.3	-2193.4
261	-1.18	3.2	-3.4	530.5	-298.2	-3578.3	-5367.4
260	-1.24	0.0	-3.4	499.5	-363.4	-4360.4	-6540.7
259	-1.30	-3.5	-3.4	523.8	-373.3	-4480.0	-6720.0
258	-1.36	-9.2	-3.4	654.3	-279.0	-3348.3	-5022.5
257	-1.42	-17.4	-3.3	782.1	-189.5	-2274.4	-3411.6
256	-1.48	-28.2	-3.3	907.0	-105.3	-1264.1	-1896.1
255	-1.54	-42.0	-3.3	1028.8	-26.9	-323.0	-484.5

254	-1.59	-58.8	-3.3	1147.1	45.3	543.5	815.2
253	-1.65	-78.9	-3.2	1261.8	110.8	1330.1	1995.2
252	-1.71	-101.6	-3.2	1359.6	157.3	1887.7	2831.6
251	-1.76	-127.2	-3.2	1448.7	192.6	2310.8	3466.2
250	-1.82	-155.8	-3.1	1530.5	217.8	2613.5	3920.2
249	-1.87	-187.5	-3.1	1605.0	233.0	2795.7	4193.6
248	-1.93	-222.1	-3.1	1672.1	238.2	2858.2	4287.3
247	-1.98	-259.6	-3.0	1731.8	233.5	2802.0	4203.0
246	-2.03	-300.1	-3.0	1784.3	219.1	2628.8	3943.2
245	-2.08	-343.3	-3.0	1829.7	195.1	2340.7	3511.1
244	-2.14	-389.1	-2.9	1867.9	161.7	1940.5	2910.7
243	-2.19	-437.5	-2.9	1899.2	119.3	1431.1	2146.6
242	-2.24	-488.3	-2.9	1923.6	68.0	816.1	1224.1
241	-2.29	-541.3	-2.8	1941.4	8.3	99.5	149.2
240	-2.34	-596.4	-2.8	1952.7	-59.5	-714.3	-1071.5
239	-2.38	-653.3	-2.7	1957.7	-135.0	-1620.6	-2430.9
238	-2.43	-711.8	-2.7	1956.7	-217.9	-2614.2	-3921.3
237	-2.48	-771.8	-2.7	1949.8	-307.5	-3689.7	-5534.6
236	-2.53	-832.9	-2.6	1937.3	-403.4	-4841.4	-7262.0
235	-2.57	-895.1	-2.6	1919.4	-505.3	-6063.1	-9094.6
234	-2.61	-957.9	-2.5	1896.5	-612.4	-7348.5	-11022.8
233	-2.66	-1021.1	-2.5	1868.8	-724.3	-8691.2	-13036.8
232	-2.70	-1084.5	-2.4	1836.5	-840.4	-10084.4	-15126.6
231	-2.74	-1147.8	-2.4	1800.0	-960.1	-11521.2	-17281.8
230	-2.78	-1210.7	-2.3	1759.6	-1082.9	-12994.6	-19491.9
229	-2.82	-1273.0	-2.3	1715.6	-1208.1	-14497.4	-21746.1
228	-2.86	-1334.3	-2.2	1668.3	-1335.2	-16022.4	-24033.6
227	-2.90	-1394.4	-2.2	1618.0	-1463.5	-17562.4	-26343.6
226	-2.94	-1453.0	-2.1	1565.1	-1592.5	-19110.0	-28665.0
225	-2.98	-1509.7	-2.1	1509.7	-1721.5	-20658.1	-30987.1
224	-3.01	-1564.4	-2.0	1452.4	-1849.9	-22199.3	-33298.9
223	-3.05	-1616.8	-2.0	1393.3	-1977.2	-23726.5	-35589.8
222	-3.08	-1666.5	-1.9	1332.9	-2102.7	-25232.7	-37849.1

221	-3.12	-1713.3	-1.9	1271.3	-2225.9	-26711.0	-40066.5
220	-3.15	-1757.0	-1.8	1208.9	-2346.2	-28154.6	-42231.9
219	-3.18	-1797.3	-1.8	1146.1	-2463.1	-29556.8	-44335.3
218	-3.21	-1834.0	-1.7	1083.0	-2576.0	-30911.5	-46367.2
217	-3.24	-1866.8	-1.7	1020.0	-2684.4	-32212.3	-48318.5
216	-3.27	-1895.6	-1.6	957.4	-2787.8	-33453.5	-50180.3
215	-3.29	-1920.1	-1.5	895.3	-2885.8	-34629.5	-51944.2
214	-3.32	-1940.1	-1.5	834.2	-2977.9	-35734.9	-53602.3
213	-3.35	-1955.5	-1.4	774.0	-3063.7	-36764.9	-55147.3
212	-3.37	-1966.1	-1.4	715.2	-3142.9	-37714.7	-56572.1
211	-3.39	-1971.8	-1.3	657.9	-3215.0	-38580.3	-57870.4
210	-3.42	-1972.3	-1.2	602.4	-3279.8	-39357.6	-59036.4
209	-3.44	-1967.8	-1.2	548.7	-3336.9	-40043.3	-60064.9
208	-3.46	-1957.9	-1.1	497.0	-3386.2	-40634.1	-60951.2
207	-3.48	-1942.7	-1.1	447.6	-3427.3	-41127.5	-61691.3
206	-3.49	-1922.2	-1.0	400.5	-3460.1	-41521.3	-62281.9
205	-3.51	-1896.2	-0.9	355.8	-3484.5	-41813.6	-62720.3
204	-3.53	-1864.7	-0.9	313.6	-3500.2	-42003.0	-63004.5
203	-3.54	-1827.8	-0.8	274.0	-3507.4	-42088.7	-63133.0
202	-3.56	-1785.5	-0.8	237.1	-3505.8	-42070.1	-63105.1
201	-3.57	-1737.8	-0.7	203.0	-3495.6	-41947.2	-62920.8
200	-3.58	-1684.7	-0.6	171.5	-3476.7	-41720.5	-62580.8
199	-3.59	-1626.4	-0.6	142.8	-3449.2	-41390.9	-62086.3
198	-3.60	-1563.0	-0.5	116.8	-3413.3	-40959.5	-61439.2
197	-3.61	-1494.5	-0.4	93.5	-3369.0	-40428.2	-60642.2
196	-3.62	-1421.1	-0.4	72.9	-3316.6	-39799.0	-59698.5
195	-3.62	-1343.0	-0.3	54.8	-3256.2	-39074.7	-58612.0
194	-3.63	0.0	-0.3	0.0	-1967.1	-23605.1	-35407.7
193	-3.63	0.0	-0.2	0.0	-1965.6	-23587.1	-35380.7
192	-3.63	0.0	-0.1	0.0	-1963.5	-23562.0	-35342.9
191	-3.63	0.0	-0.1	0.0	-1960.8	-23529.6	-35294.4
190	-3.64	0.0	0.0	0.0	-1957.5	-23490.1	-35235.2
189	-3.63	0.0	0.1	0.0	-1953.6	-23443.4	-35165.2

188	-3.63	0.0	0.1	0.0	-1949.1	-23389.6	-35084.4
187	-3.63	0.0	0.2	0.0	-1944.1	-23328.7	-34993.1
186	-3.63	0.0	0.3	0.0	-1938.4	-23260.7	-34891.0
185	-3.62	0.0	0.3	0.0	-1932.1	-23185.5	-34778.3
184	-3.62	0.0	0.4	0.0	-1925.3	-23103.4	-34655.0
183	-3.61	0.0	0.4	0.0	-1917.8	-23014.1	-34521.2
182	-3.60	0.0	0.5	0.0	-1909.8	-22917.9	-34376.8
181	-3.59	0.0	0.6	0.0	-1901.2	-22814.7	-34222.0
180	-3.58	0.0	0.6	0.0	-1892.0	-22704.5	-34056.8
179	-3.57	0.0	0.7	0.0	-1882.3	-22587.4	-33881.2
178	-3.56	0.0	0.8	0.0	-1872.0	-22463.5	-33695.2
177	-3.54	0.0	0.8	0.0	-1861.1	-22332.7	-33499.0
176	-3.53	0.0	0.9	0.0	-1849.6	-22195.1	-33292.6
175	-3.51	0.0	0.9	0.0	-1837.6	-22050.7	-33076.0
174	-3.49	0.0	1.0	0.0	-1825.0	-21899.6	-32849.4
173	-3.48	0.0	1.1	0.0	-1811.8	-21741.9	-32612.8
172	-3.46	0.0	1.1	0.0	-1798.1	-21577.5	-32366.2
171	-3.44	0.0	1.2	0.0	-1783.9	-21406.5	-32109.8
170	-3.42	0.0	1.2	0.0	-1769.1	-21229.1	-31843.6
169	-3.39	0.0	1.3	0.0	-1753.8	-21045.1	-31567.7
168	-3.37	0.0	1.4	0.0	-1737.9	-20854.8	-31282.2
167	-3.35	0.0	1.4	0.0	-1721.5	-20658.1	-30987.1
166	-3.32	0.0	1.5	0.0	-1704.6	-20455.1	-30682.6
165	-3.29	0.0	1.5	0.0	-1687.2	-20245.9	-30368.8
164	-3.27	0.0	1.6	0.0	-1669.2	-20030.5	-30045.7
163	-3.24	0.0	1.7	0.0	-1650.7	-19809.0	-29713.5
162	-3.21	0.0	1.7	0.0	-1631.8	-19581.4	-29372.2
161	-3.18	0.0	1.8	0.0	-1612.3	-19348.0	-29021.9
160	-3.15	0.0	1.8	0.0	-1592.4	-19108.6	-28662.9
159	-3.12	0.0	1.9	0.0	-1571.9	-18863.4	-28295.1
158	-3.08	0.0	1.9	0.0	-1551.0	-18612.4	-27918.6
157	-3.05	0.0	2.0	0.0	-1529.6	-18355.8	-27533.7
156	-3.01	0.0	2.0	0.0	-1507.8	-18093.6	-27140.4

155	-2.98	0.0	2.1	0.0	-1485.5	-17825.9	-26738.8
154	-2.94	0.0	2.1	0.0	-1462.7	-17552.7	-26329.1
153	-2.90	0.0	2.2	0.0	-1439.5	-17274.2	-25911.3
152	-2.86	0.0	2.2	0.0	-1415.9	-16990.4	-25485.7
151	-2.82	0.0	2.3	0.0	-1391.8	-16701.5	-25052.3
150	-2.78	0.0	2.3	0.0	-1367.3	-16407.5	-24611.2
149	-2.74	0.0	2.4	0.0	-1342.4	-16108.5	-24162.7
148	-2.70	0.0	2.4	0.0	-1317.0	-15804.5	-23706.8
147	-2.66	0.0	2.5	0.0	-1291.3	-15495.8	-23243.7
146	-2.61	0.0	2.5	0.0	-1265.2	-15182.3	-22773.5
145	-2.57	0.0	2.6	0.0	-1238.7	-14864.2	-22296.3
144	-2.53	0.0	2.6	0.0	-1211.8	-14541.6	-21812.4
143	-2.48	0.0	2.7	0.0	-1184.5	-14214.6	-21321.9
142	-2.43	0.0	2.7	0.0	-1156.9	-13883.2	-20824.8
141	-2.38	0.0	2.7	0.0	-1129.0	-13547.6	-20321.4
140	-2.34	0.0	2.8	0.0	-1100.7	-13207.9	-19811.8
139	-2.29	0.0	2.8	0.0	-1072.0	-12864.1	-19296.1
138	-2.24	0.0	2.9	0.0	-1043.0	-12516.4	-18774.6
137	-2.19	0.0	2.9	0.0	-1013.7	-12164.9	-18247.4
136	-2.14	0.0	2.9	0.0	-984.1	-11809.7	-17714.6
135	-2.08	0.0	3.0	0.0	-954.2	-11451.0	-17176.4
134	-2.03	0.0	3.0	0.0	-924.1	-11088.7	-16633.0
133	-1.98	0.0	3.0	0.0	-893.6	-10723.0	-16084.5
132	-1.93	0.0	3.1	0.0	-862.8	-10354.1	-15531.2
131	-1.87	0.0	3.1	0.0	-831.8	-9982.0	-14973.0
130	-1.82	0.0	3.1	0.0	-800.6	-9606.9	-14410.4
129	-1.76	0.0	3.2	0.0	-769.1	-9228.9	-13843.3
128	-1.71	0.0	3.2	0.0	-737.3	-8848.0	-13272.0
127	-1.65	0.0	3.2	0.0	-705.4	-8464.5	-12696.7
126	-1.59	0.0	3.3	0.0	-673.2	-8078.3	-12117.5
125	-1.54	0.0	3.3	0.0	-640.8	-7689.8	-11534.6
124	-1.48	0.0	3.3	0.0	-608.2	-7298.8	-10948.2
123	-1.42	0.0	3.3	0.0	-575.5	-6905.7	-10358.5

122	-1.36	0.0	3.4	0.0	-542.5	-6510.4	-9765.6
121	-1.30	0.0	3.4	0.0	-509.4	-6113.2	-9169.8
120	-1.24	0.0	3.4	0.0	-476.2	-5714.1	-8571.1
119	-1.18	0.0	3.4	0.0	-442.8	-5313.2	-7969.8
118	-1.12	0.0	3.5	0.0	-409.2	-4910.8	-7366.2
117	-1.06	0.0	3.5	0.0	-375.6	-4506.8	-6760.2
116	-1.00	0.0	3.5	0.0	-341.8	-4101.5	-6152.2
115	-0.94	0.0	3.5	0.0	-307.9	-3694.9	-5542.4
114	-0.88	0.0	3.5	0.0	-273.9	-3287.2	-4930.8
113	-0.82	0.0	3.5	0.0	-239.9	-2878.5	-4317.7
112	-0.76	0.0	3.6	0.0	-205.7	-2468.9	-3703.4
111	-0.69	0.0	3.6	0.0	-171.5	-2058.6	-3087.9
110	-0.63	0.0	3.6	0.0	-137.3	-1647.6	-2471.4
109	-0.57	0.0	3.6	0.0	-103.0	-1236.1	-1854.2
108	-0.51	0.0	3.6	0.0	-68.7	-824.3	-1236.5
107	-0.44	0.0	3.6	0.0	-34.4	-412.2	-618.3
106	-0.38	0.0	3.6	0.0	0.0	0.0	0.0
105	-0.32	0.0	3.6	0.0	34.4	412.2	618.3
104	-0.25	0.0	3.6	0.0	68.7	824.3	1236.5
103	-0.19	0.0	3.6	0.0	103.0	1236.1	1854.2
102	-0.13	0.0	3.6	0.0	137.3	1647.6	2471.4
101	-0.06	0.0	3.6	0.0	171.5	2058.6	3087.9
100	0.00	0.0	3.6	0.0	205.7	2468.9	3703.4
99	0.06	0.0	3.6	0.0	239.9	2878.5	4317.7
98	0.13	0.0	3.6	0.0	273.9	3287.2	4930.8
97	0.19	0.0	3.6	0.0	307.9	3694.9	5542.4
96	0.25	0.0	3.6	0.0	341.8	4101.5	6152.2
95	0.32	0.0	3.6	0.0	375.6	4506.8	6760.2
94	0.38	0.0	3.6	0.0	409.2	4910.8	7366.2
93	0.44	0.0	3.6	0.0	442.8	5313.2	7969.8
92	0.51	0.0	3.6	0.0	476.2	5714.1	8571.1
91	0.57	0.0	3.6	0.0	509.4	6113.2	9169.8
90	0.63	0.0	3.6	0.0	542.5	6510.4	9765.6

89	0.69	0.0	3.6	0.0	575.5	6905.7	10358.5
88	0.76	0.0	3.6	0.0	608.2	7298.8	10948.2
87	0.82	0.0	3.5	0.0	640.8	7689.8	11534.6
86	0.88	0.0	3.5	0.0	673.2	8078.3	12117.5
85	0.94	0.0	3.5	0.0	705.4	8464.5	12696.7
84	1.00	0.0	3.5	0.0	737.3	8848.0	13272.0
83	1.06	0.0	3.5	0.0	769.1	9228.9	13843.3
82	1.12	0.0	3.5	0.0	800.6	9606.9	14410.4
81	1.18	0.0	3.4	0.0	831.8	9982.0	14973.0
80	1.24	0.0	3.4	0.0	862.8	10354.1	15531.2
79	1.30	0.0	3.4	0.0	893.6	10723.0	16084.5
78	1.36	0.0	3.4	0.0	924.1	11088.7	16633.0
77	1.42	0.0	3.3	0.0	954.2	11451.0	17176.4
76	1.48	0.0	3.3	0.0	984.1	11809.7	17714.6
75	1.54	0.0	3.3	0.0	1013.7	12164.9	18247.4
74	1.59	0.0	3.3	0.0	1043.0	12516.4	18774.6
73	1.65	0.0	3.2	0.0	1072.0	12864.1	19296.1
72	1.71	0.0	3.2	0.0	1100.7	13207.9	19811.8
71	1.76	0.0	3.2	0.0	1129.0	13547.6	20321.4
70	1.82	0.0	3.1	0.0	1156.9	13883.2	20824.8
69	1.87	0.0	3.1	0.0	1184.5	14214.6	21321.9
68	1.93	0.0	3.1	0.0	1211.8	14541.6	21812.4
67	1.98	0.0	3.0	0.0	1238.7	14864.2	22296.3
66	2.03	0.0	3.0	0.0	1265.2	15182.3	22773.5
65	2.08	0.0	3.0	0.0	1291.3	15495.8	23243.7
64	2.14	0.0	2.9	0.0	1317.0	15804.5	23706.8
63	2.19	0.0	2.9	0.0	1342.4	16108.5	24162.7
62	2.24	0.0	2.9	0.0	1367.3	16407.5	24611.2
61	2.29	0.0	2.8	0.0	1391.8	16701.5	25052.3
60	2.34	0.0	2.8	0.0	1415.9	16990.4	25485.7
59	2.38	0.0	2.7	0.0	1439.5	17274.2	25911.3
58	2.43	0.0	2.7	0.0	1462.7	17552.7	26329.1
57	2.48	0.0	2.7	0.0	1485.5	17825.9	26738.8

56	2.53	0.0	2.6	0.0	1507.8	18093.6	27140.4
55	2.57	0.0	2.6	0.0	1529.6	18355.8	27533.7
54	2.61	0.0	2.5	0.0	1551.0	18612.4	27918.6
53	2.66	0.0	2.5	0.0	1571.9	18863.4	28295.1
52	2.70	0.0	2.4	0.0	1592.4	19108.6	28662.9
51	2.74	0.0	2.4	0.0	1612.3	19348.0	29021.9
50	2.78	0.0	2.3	0.0	1631.8	19581.4	29372.2
49	2.82	0.0	2.3	0.0	1650.7	19809.0	29713.5
48	2.86	0.0	2.2	0.0	1669.2	20030.5	30045.7
47	2.90	0.0	2.2	0.0	1687.2	20245.9	30368.8
46	2.94	0.0	2.1	0.0	1704.6	20455.1	30682.6
45	2.98	0.0	2.1	0.0	1721.5	20658.1	30987.1
44	3.01	0.0	2.0	0.0	1737.9	20854.8	31282.2
43	3.05	0.0	2.0	0.0	1753.8	21045.1	31567.7
42	3.08	0.0	1.9	0.0	1769.1	21229.1	31843.6
41	3.12	0.0	1.9	0.0	1783.9	21406.5	32109.8
40	3.15	0.0	1.8	0.0	1798.1	21577.5	32366.2
39	3.18	0.0	1.8	0.0	1811.8	21741.9	32612.8
38	3.21	0.0	1.7	0.0	1825.0	21899.6	32849.4
37	3.24	0.0	1.7	0.0	1837.6	22050.7	33076.0
36	3.27	0.0	1.6	0.0	1849.6	22195.1	33292.6
35	3.29	0.0	1.5	0.0	1861.1	22332.7	33499.0
34	3.32	0.0	1.5	0.0	1872.0	22463.5	33695.2
33	3.35	0.0	1.4	0.0	1882.3	22587.4	33881.2

Figure 54 – Required torque graph for gear reducer.

Figure 55 – Graph of moments acting on Mechanical arms.

Appendix IV - Shaft and Key Way Diagrams

This section shows dimensional diagrams of the shaft concentrating mainly on the key way. Figure 56 shows that a $\frac{3}{4}$ " x $\frac{3}{8}$ " keyway was designed to take the loading. The length of the key way (3 inches) is needed to take the anticipated loading. This length is shown in Figure 57. Both output shaft from the gear reducer have these key ways and are intended to take the loading simultaneously and distribute it equally.

Figure 56 – Face view of shaft with key way.

Figure 57 – Top view of key way on shaft.

Appendix V - Steelflex Coupling Diagrams

This section shows dimensional and solid model views of the Steelflex coupler made by Falk Corporation. The Steelflex coupling is able to compensate for shaft misalignment. The steel grid is able to rock and pivot within the couplings hub teeth. This allows for significant misalignment that will not cause bearing side loads. It also provides torsional flexibility when subjected to shock or vibratory loads. The couplings acts like a shock dampener during rotary motion. Figure 58 shows the three views of the flex coupling. Figure 59 shows a solid model of the Steelflex coupling. Figures 60-62 show the three views in Figure 58 with dimensions.

Figure 58 - Three views of Steelflex Coupling.

Figure 59 – Solid model of Steelflex Coupling.

TYPE: ASSEMB NAME: COUPLING SIZE: A0

Figure 60 – Dimensioned top view of Steelflex Coupling.

Figure 61 – Dimensioned front view of Steelflex Coupling.

Figure 62 – Dimensioned side view of Steelflex Coupling.

Appendix VI - Mechanical Arm Dimensional Drawings

This section provides dimensioned views of the mechanical arm/pod system to go along with the solid model in Section 4.4.3. The following models show one arm instead of the four arm system for simplicity in describing the dimensions. Figure 63 shows a side view of one mechanical arm with frame attached. Figure 64 shows the connection of the mechanical arm to the frame of the sensor pod.

Figure 63 – Dimensioned side view of mechanical arm.

Figure 64 – Dimensioned front view of mechanical arm.

Appendix VII - Sensor Pod Dimensional Drawings

This section shows the frame layout of the sensor pod system for the Standardized Sensor Pallet. Figure 65 shows a solid model of the internal frame structure that will house the sensors during use. The frame structure will have aluminum skin attached to it to prevent moisture from entering the pod and harming the equipment inside. Figures 66-68 show drawings of the pod with dimensions. All components of the frame structure are welded together and are attached to the mechanical arms by a series of bolts (location shown in Figure 67).

Figure 65 – Solid model of sensor pod frame.

Figure 66 – Top view of sensor pod (with frame), mechanical arm and rotational shaft.

Figure 67 – Side view of sensor pod (with frame), mechanical arm and rotational shaft.

Figure 68 – Front view of sensor pod (with frame), mechanical arm and rotational shaft.

Appendix VIII – Complete System Diagram and Pictures

This section shows illustrations and dimensional drawings of the complete Standardized Sensor Pallet System. Some additional features included in these illustrations and drawings (that are not explained in this document) are the electrical control system. The location of the electrical system is shown in Figure 69. Figure 70-72 show the dimensions of the entire pallet and the location of the key components. Figures 73 and 74 show the actual prototype system on the rear cargo door of a C-130 aircraft. The actual system was cycled several times while the aircraft was on the ground.

Figure 69 – Top, front and side views of complete sensor pallet system.

Figure 70 – Top view of sensor pallet system.

Figure 71 – Side view of sensor pallet system.

Figure 72 – Front view of sensor pallet system.

Figure 73 – Picture of sensor pallet system on a C-130 aircraft (stow position).

Figure 74 – Picture of sensor pallet system deployed on a C-130 aircraft.

Appendix IX – Safety Factors for Critical Components

This section shows the allowable safety factors for the critical components of the sensor platform system. Table 4 illustrates the safety factors at the three critical components of the system: the gear reducer, the connecting hubs, and the mechanical arms. This table shows that with the lowest factor of safety the mechanical arms are most susceptible to failure caused by over loading. This concludes that further analysis and optimization should be done to analyze the mechanical arm and pod system. This optimization analysis has been performed but has yet to be implemented into the current design (Ferragotti).

Table 4 – Safety factor analysis of critical components.

Component	Safety Factor
Gear Reducer	1.5
Hub Key Way (1)	1.8
Hub Key Way (2)	1.8
Hub Key Way (3)	1.8
Hub Key Way (4)	1.8
Steel Shaft Key Way	1.23
Mechanical Arm (1)	1.15
Mechanical Arm (2)	1.15
Mechanical Arm (3)	1.15
Mechanical Arm (4)	1.15