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Technical Report

Selective Offload for Sea Basing

by

Anthony Blair, Robert Cullen, Miguel Quintero, and Kevan Shaw-Alley

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The United States Navy is currently looking at methods of supplying a Marine Expeditionary Brigade (MEB) in the event that there is not a friendly port available in the area of conflict. One solution that is being investigated is the use of a sea base to supply a MEB from offshore. An important characteristic of the sea base is to store enough supplies to support a MEB for a sustained amount of time while being 100 % selective, which is defined as the ability to select a specific container or vehicle from a storage area without having to rearrange the contents of the area. An equally important quality of any storage area is the ability to have 100 % selectability of materials while maintaining high storage efficiencies. The selective offload team has developed several concepts that satisfy these characteristics. The designs are based on traditional methods of storing goods in warehouses. However, these concepts incorporate innovative technologies to produce higher storage efficiencies than land base warehouses while maintaining 100% selectability of supplies.

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Abstract

The United States Navy is currently looking at methods of supplying a Marine Expeditionary Brigade (MEB) in the event that there is not a friendly port available in the area of conflict. One solution that is being investigated is the use of a sea base to supply a MEB from offshore. An important characteristic of the sea base is to store enough supplies to support a MEB for a sustained amount of time while being 100 % selective, which is defined as the ability to select a specific container or vehicle from a storage area without having to rearrange the contents of the area. An equally important quality of any storage area is the ability to have 100 % selectability of materials while maintaining high storage efficiencies. The selective offload team has developed several concepts that satisfy these characteristics. The designs are based on traditional methods of storing goods in warehouses. However, these concepts incorporate innovative technologies to produce higher storage efficiencies than land base warehouses while maintaining 100% selectability of supplies.

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1. Section I - INTRODUCTION

1.1. Mission Statement

The Selective Offload Concept Team was asked to develop effective systems that would allow for 100% selectivity of cargo including vehicles and dry stores from a sea base storage system. The system had to deliver its cargo in a time efficient manor, store the maximum amount of cargo possible, and also allow for 100% selectivity of any single piece of cargo at any time. The selective offload system must also deliver this cargo in sea state 4 and be able to survive, not necessarily operate, in sea state 8.

1.2. Background

1.2.1. Selective Offload Concept Team

The Selective Offloading Sea Base Concept Team is a group of four interns under the mentorship of Dr. Christopher Dicks and Dr. Colen Kennel. The four interns are as follows:

Name	School	Degree
Anthony Blair	Maine Maritime Academy	Marine System Engineer
Robert Cullen	University of Maryland	Mechanical Engineer
Miguel Quintero	Florida Atlantic University	Ocean Engineer
Kevan Shaw-Alley	University South Carolina	Mechanical Engineer

The interns worked under the Naval Research Enterprise Intern Program (NREIP), funded by the Office of Naval Research (ONR). The team is based at the Center for Innovative in Ship Design (CISD) at the Naval Surface Warfare Center Carderock Division. One focus area of CISD is preliminary design and concept generation for future naval ships. The following illustrates the teams research and conclusions with respect to a selective offloading system for a sea base.

1.2.2. Sea Basing

According to the Center of Naval Analysis, "sea basing is a deliberate, managed provision of all combat service support to forces ashore from ships offshore." Under sea power 21, the purpose of a sea base is to provide the support and base of operations for Sea Strike and Sea Shield ("SEA BASE"). Currently, the Navy utilizes friendly ports for the transfer and storage of sustainment materials required by military personal in a conflict zone. In the case where a friendly port is not available the Navy will utilize on-shore bases to store this sustainment material. The idea of a sea base is to limit the on shore presence of sustainment materials. There are many advantages to limiting the on shore presence of sustainment materials including safer storage of the materials and security because on shore materials are susceptible to sabotage and attacks. At sea storage of material in a sea base provides a buffer between the essential sustainment materials and the fighting. A sea base also offers a mobility aspect that is not available with on shore storage of materials. Once the materials required to sustain a fighting force are moved ashore, it is time intensive to relocate the materials should the need arise. A sea base, however, can relocate from conflict to conflict without having to package and relocate copious amounts of equipment.

Currently the Navy does not have a specific design for a sea base. The selective offload designs were based off of the assumption that a sea base would consist of multiple cargo ships. Each ship must carry a percentage of the supplies necessary to sustain a Marine Expeditionary Brigade (MEB), which consists of 4,585 troops ashore and 6,648 troops afloat. An essential aspect of the sea basing concept and the sustainment of an MEB is the selective offload system that is discussed in detail in this report. However, due to the current lack of definition of what a sea base will be composed of, any selective offload system must be adaptable to multiple situations.

1.3. Requirements

1.3.1. Cargo Requirements

The selective offload system is required to store enough dry stores to support 20 % of an MEB for 20 days. The following sections detail the amount of each type of cargo, both dry stores and vehicles, which are required to support 20 % of an MEB for 20 days.

Containers

Before a list of the different cargo types that will be required to sustain 20 % of an MEB for 20 days is described, the types of containers that will be used to transport the cargo must be established. The Navy and Merchant Marines use various different containers to transport dry stores. These containers include:

- TEUs
- SIXCONs
- Quadcons
- JMICs (Joint Modular Intermodal Container)
- Pallets

TEU containers are the largest containers used by the Navy for the transportation of supplies. This container measures 20ft long, 8 ft wide, and 8 ft high. A smaller version of the TEU is the SIXCON, which represents 20 % of a TEU container. A SIXCON can be assembled with other SIXCONS to form a standard TEU container. These containers are typically used to store fuel oil and water.

The Navy generally stores all of its dry stores on pallets. There are two standard pallets that the Navy uses, both of which are 40×48 in. However, the position of the forklift slots for the two standard pallets are different. In one configuration, the position of the forklift slots are on the 48 in. long side and in the other the forklift slots are on the 40 in. side.

The Navy also has Quadcons, which is a TEU that is subdivided into four sections. The Quadcon dimensions are 57.375 in. wide, 96 in. long, and 84 in. high. Quadcons are typically used by the Navy to store dry storage goods. The Navy is currently developing a new, standard dry storage container known as the Joint Modular Inter-Modal Container (JMIC). The JMIC is being developed to create a common container for shipping. The concept behind the JMIC is that sixteen JMICs can connect to form a standard TEU. Once the sixteen JMICs are connected together, they are locked on to a Joint Modular Intermodal Platform (JMIP), which fits inside a standard TEU. The larger container can then be shipped commercially and offloaded to a Navy vessel where they can be broken down and stored like a pallet. A current design of the JMIC has the dimensions 44 in. wide, 53.75 in. long, and 42 in. high. A diagram of the JMIC and Quadcon can be found in APPENDIX A.

For the selective offload concepts considered in this report, it was assumed that all of the dry storage materials would be transported to the selective offload system in either JMICs or standard pallets. The following section details the amount of each dry store required and the corresponding number of pallets that would be necessary to store the dry stores.

Dry Stores

The Navy has different classifications for types of dry storage items. The types of storage items are organized according to type: food, water, fuel oils, ammunition etc. The following are the class types for the Navy and Marines.

Classes	Types
Class I	Food/Water
Class II	Individual Equipment
Class III	petroleum, oil, and lubricants (POL)
Class IV	Construction Materials
Class V	Ammunition
Class VI	Personal Demand Items
Class VII	Principal End Items
Class VIII	Medical Supplies
Class IX	Repair Parts

In the design of the selective offload system, Individual Equipment, Personal Demand Items, and Principal End Items were not taken into consideration in the amount of cargo that was required to be stored. This assumption was made because these items do not require replenishment over the 20 days on station. The following tables show the amount of total dry storage items required to sustain 20% of an MEB for 20 days along with the amount and type of containers required to store the supplies.

Table 1: The following three tables detail the dry store requirements and corresponding number of pallets to satisfy 20% of an MEB for 20 days.

Class	Individual Weight of Dry Store (st)	Individual Pallet Weight (lb)	# of Pallets (Total MEB)	# of Pallets (20% of MEB)
I	629	1,056	1,248	250
IV	339	1,200	565	113
V	6,000	1200*	10,000	2,000
VI and IX	x	x	10784	2,157
VIII	130	1,200	217	44

* assumed weight

Class I	gal/man/day	# of Days	# of Troops	20% of Troops	Total Gallons of Water	20% of Total Gallons of Water	SIXCON Storage Capacity (gal)	Total SIXCONS	20% of Total SIXCONS
Water	6.50	20.00	13000.00	2600.00	1690000.00	338000.00	4500.00	375.56	76.00

Class III	Rate (gal/day)	20% Rate (gal/day)	20% Total for 20 Days
(POL)	60,000	12,000	240,000

Vehicles

The following table lists the vehicles that will be accounted for in this selective offload system.

Table 2: This table lists the vehicles required to support 20% of an MEB for 20 day. The table includes the number, dimensions, and weight of each vehicle as well as the total weight of each type of vehicle for 20% of an MEB.

Vehicle	100%	20%	Length		Width		Height		Area		Weight		Total Payload	
			(m)	(ft)	(m)	(ft)	(m)	(ft)	(m^2)	(ft^2)	(MT)	(st)	(MT)	(st)
M1A1	14	3	7.93	26.01	3.66	12.00	2.63	8.63	29.02	312.30	57.22	62.94	171.66	188.83
AAAV	48	10	9.10	29.85	3.66	12.00	3.18	10.43	33.31	358.37	28.53	31.38	285.30	313.83
M88A1	1	1	8.21	26.93	3.38	11.09	3.40	11.15	27.75	298.59	48.93	53.82	48.93	53.82
HMWVV	99	20	5.01	16.43	2.18	7.15	2.59	8.50	10.92	117.52	3.86	4.25	77.20	84.92
M198	18	4	7.52	24.67	2.82	9.25	2.18	7.15	21.21	228.18	8.00	8.80	32.00	35.20
LVS Mk48	2	2	11.58	37.98	2.44	8.00	2.59	8.50	28.26	304.03	25.40	27.94	50.80	55.88
M101A2	20	4	3.73	12.23	1.91	6.26	2.13	6.99	7.12	76.66	0.63	0.69	2.52	2.77
M390	21	4	4.72	15.48	2.44	8.00	2.24	7.35	11.52	123.92	2.32	2.55	9.28	10.21
LAV	25	5	6.99	22.93	2.67	8.76	2.67	8.76	18.66	200.82	15.73	17.30	78.65	86.52
FRKLFT	7	2	8.86	29.06	2.57	8.43	2.72	8.92	22.77	245.01	15.02	16.52	30.04	33.04
AVLB	1	1	9.67	31.72	3.60	11.81	2.25	7.38	34.81	374.58	54.70	60.17	54.70	60.17
MEWSS	3	2	6.99	22.93	2.67	8.76	2.67	8.76	18.66	200.82	15.73	17.30	31.46	34.61
MTVR	133	25	8.70	28.54	2.46	8.07	3.53	11.58	21.40	230.29	11.79	12.97	294.75	324.23
MRC	33	6	4.85	15.91	2.31	7.58	1.83	6.00	11.20	120.55	4.67	5.14	28.02	30.82
M9293/ Q46	4	2	7.98	26.17	2.46	8.07	3.53	11.58	19.63	211.23	10.87	11.96	21.74	23.91
ABV	2	2	12.04	39.49	3.66	12.00	2.90	9.51	44.07	474.15	49.90	54.89	99.80	109.78
												Total:	1316.85	1448.54

As can be seen from Table 2, the length, number, and weight of each type of vehicle vary greatly. The longest vehicle is approximately 40 ft while the shortest vehicle is 12 ft long. An important aspect of the selective offload system is the system's ability to adapt to different supply requirements. The vehicle list and number of each vehicle listed in Table 2 may not be required for every situation. As a result, any storage and selective offload system will have to be designed to accommodate the maximum vehicle specifications.

1.4. Design Process

1.4.1. Brainstorming

The process of generating concepts began with defining the functional requirements of the selective offload concept. The main objective of the selective offload system is to store enough provisions and supplies to sustain an MEB (Marine Expeditionary Brigade) for twenty days while allowing for 100% selectability of the individual supplies in storage. In order to fulfill this objective, it was determined that the selective offload concept must perform the following functions:

- Store dry cargo with 100% selectability
- Store vehicles with 100% selectability
- Retrieve individual items from storage and repackage these items to fill requests from MEB units in the field
- Operate in sea state 4 and have safe storage in sea state 8

Once the functional requirements of the selective offload system were established, the team began brainstorming different methods to satisfy them. The initial brainstorming required researching existing systems that provided similar functions to those required by the selective offload design. The team focused the initial research on two systems, automated parking garages and automated warehouses, due to the fact that these systems fulfill a majority of the functional requirements of the selective offload system. Researching these two systems provided a general idea of how a selective offload system could be implemented on land. The team then researched the different methods of performing the functions required for a selective offload system which included researching technologies such as air pallets, lifts systems, cranes, containers, robotic arms, and automated palletizing. Once there was an understanding of how existing selective offload systems function, the team began to brainstorm methods to implement a selective offload system at sea in the hull of a ship.

The initial brainstorming of ideas included both group and individual brainstorming sessions. Individually, team members recorded as many different concepts for selective offload as possible. These ideas were generated without taking into account the evaluation criteria discussed in the next section. Initially neglecting the evaluation criteria was important in early brainstorming because it allowed for the generation of ideas that may not have been thought of due to the constraints of the evaluation criteria. Once the individual brainstorming was completed the team had a meeting to collect and organize all of the selective offload concepts. The meeting consisted of presenting and recording the individual ideas for selective offload concepts. A table of the different concepts that were generated is located in APPENDIX B.

1.4.2. Evaluation Criteria

In order to appropriately choose a selective offload system, there are certain evaluation criteria that must be considered. This evaluation criterion outlines the important characteristics that should be present in a 100% selective offload system. The evaluation criterion used for the selective offload system include:

- Maximize Storage Capacity
- Minimize Retrieval Time
- Minimize Complexity of Parts
- Ruggedness of Design
- Easy Accessibility/Serviceability
- Minimal Maintenance Required
- Minimal Reliance on Machines
- Fail Safe/Redundancy

- Operation in Sea State 4
- Safe Storage in Sea State 8
- Minimize Man Power
- Easily Adaptable to Different Size Containers/Pallets
- Easily Identifiable Containers/Pallets
- Maximize Selectability

The following is a detailed description of the evaluation criteria used to evaluate the selective offload concepts.

Maximize Storage Capacity

Employing selective offload will require sacrificing storage space in order to implement automated designs. This criterion is important because each concept should be designed to keep storage at a maximum while still having the capability of selecting a specific piece of cargo.

Minimize Retrieval Time

The goal of automating the selective offload process is to make the selection of cargo more efficient and ideally less time consuming. With an inefficient design, the time to retrieve an item can be very long. This criterion was set to keep designs as practical as possible, so that cargo can be moved and retrieved in a timely manner.

Minimize Complexity of Parts

A complex design requires many mechanical parts in order to operate. When so many mechanical parts are integrated into one system, this leads to more objects that could fail or malfunction. It is not desirable to have the whole selective offload system fail because one mechanical part failed. The fewer parts a system uses and the less complex a system is, the easier it is to maintain and fix when a problem arises.

Rugged Design

A desirable system would be one that could withstand many extreme conditions while still being operable. Little to no maintenance should be required to support the system in order to prevent problems from occurring while at sea. Also, the system should be built to last a reasonable amount of time without requiring significant maintenance.

Easy Accessibility/Service

In the event of a mechanical malfunction, the ability to access and service the system is another desirable aspect of the design. If there is a possibility of malfunctioning parts, the ability to reach the part and work on the part is important to fully correct the system to prevent extended downtime.

Minimal Maintenance Required

Using different mechanical systems would require a certain amount of routine planned maintenance. This differs from the Rugged Design criteria because a rugged design requires little corrective maintenance as a result of mechanical failure where as this criteria requires little routine maintenance. An example of routine maintenance would be lubrication of a hydraulic system. It is desirable to choose a mechanical system that could operate without significant routine maintenance.

Minimal Reliance on Machines

Using a very complex system utilizes many different components, which in turn rely heavily on machines. An ideal situation would have a simple system that is fully automated with the fewest possible machines.

Fail Safe / Redundancy

This criterion describes the ability to operate the system in alternate ways if the system were to malfunction. This can be powered either by manpower or an alternate mechanical mechanism. Redundancy is important because if the selective offload system is dependent on one machine, and that machine fails, then the system is rendered ineffective because the stored cargo cannot be accessed.

Operation in Sea State 4

The ocean often has numerous variables that need to be accounted for, including inclement weather and high seas. To make an efficient system, it must operate at higher sea states to prevent idle times until offload can be possible.

Safe Storage in Sea State 8

The selective offload system must be able to survive through different conditions and be safe without damaging any cargo or people. This criteria does not mean that the selective offload system should be operable in Sea State 8, rather that it will remain safe so that offload can resume when sea conditions improve.

Minimize Man Power

The system should be able to operate with very minimal human interaction while still being fully functional.

Easily Adaptable to Different Size Containers/Pallets

The ability to accommodate different size cargo items without making serious adjustments to the system is an important attribute of the selective offload concept. The Navy currently uses different size pallets and containers when transporting goods to maintain a Marine Expeditionary Brigade. Therefore, ideally one single system could store all the different cargo items.

Easily Identifiable Containers/Pallets

This criterion entails locating different items of cargo in the hold without having to search a container to discover its contents.

Maximize Selectability

Maximizing selectability is important because some situations require only certain pieces of cargo or vehicles to be retrieved from storage. If selecting these pieces of cargo or vehicles requires removing all of the cargo from the sea base, then the system is very inefficient. Therefore, any selective offload system should be able to remove a desired piece of cargo in a time and space efficient manner without rearranging cargo.

1.4.3. Decision Process

Once the initial concepts for the selective offload system were compiled, the next step required evaluating the concepts and identifying the optimal designs. The evaluation criteria identified in SECTION 1.4.2 were used to identify the optimal designs. However, before the evaluation criteria could be applied to the generated concepts, the relative importance of each evaluation criteria with respect to each other needed to be determined. In order to accomplish this task, a pair wise comparison was utilized. Through this process, the evaluation criteria were weighted so that the more important criteria would have a larger effect on the decision process. The pair wise comparison used for the selective offload concepts is located in APPENDIX C. The following is a list of the evaluation criteria in order from most important to least important:

1. Operation in Sea State 4
2. Safe Storage in Sea State 8
3. Easily Adaptable to Different Size Containers/Pallets
4. Ruggedness of Design
5. Maximize Selectability
6. Fail Safe/Redundancy
7. Minimize Retrieval Time
8. Maximize Storage Capacity
9. Easy Accessibility/Serviceability
10. Minimize Complexity of Parts
11. Minimal Maintenance Required
12. Minimize Man Power
13. Minimal Reliance on Machines
14. Easily Identifiable Containers/Pallets

The weighted evaluation criteria were then used in a weighted decision matrix in order to evaluate each design concept. The weighted decision matrix provided an organized way to determine which design concepts were better than others. In the weighted decision matrix, each design concept was compared to each individual evaluation criteria and given a score based on how well the concept satisfied the individual criterion. Then, each score was multiplied by the weighting factor of the individual evaluation criterion determined by the pair wise comparison. The resulting number for the evaluation criteria was then totaled to give an overall score for the design concept. This process was repeated for each of the designs located in APPENDIX C.

Once the weighted decision matrix was created for each of the large subsystems (dry storage, vehicle storage, and distribution system), the team began the processes of identifying the total systems that would be developed in further detail. Based on the scores from the weighted decision matrix, the following conceptual designs were chosen for each large subsystem:

- Dry Storage
    - Branched
    - Library Shelf
    - Plus Sign Configuration
- Vehicle Storage
    - Single Level with Air Pallets
- Distribution System
    - Vertical Dispenser
    - Horizontal Dispenser
    - On-Demand Dispenser

A more detailed design of each total system design as well as an analysis of each design is located in the following sections.

2. Dry Storage Design Concepts

2.1. Introduction to Dry Stores

One of the three major components of the design concept is the dry stores or long term storage of containers. For this system it was assumed that in order to maximize storage efficiency, minimize retrieval time, and have the ability to selectively offload that a small container was necessary. Several storage containers looked at were the quadcon, JMIC, and standard wooden pallets. The quadcon was still fairly large, thus the final choice of storage containers was the JMIC or wooden pallets. Since the JMIC is small it has some advantages and disadvantages. The advantages of being small mean that it is easier to selectively offload cargo in a timely manner and also the storage cells within which the cargo is stored can be smaller. The main disadvantages are that if the container is small, then the transport onto the ship is a much more lengthy process. The wooden pallets offer a similar set of advantages and disadvantages, but there is also the added disadvantage of not being a closed container as in with the JMIC or quadcon.

From the brainstorming process, three main ideas arose. The first and most basic design was the branched layout. This layout is similar to that of a traditional warehouse with a main aisle and side aisles between shelf units or storage cells. The main difference in this design is that traditionally on land, when a forklift is used, the aisle must be 1.5-2 times wider then the storage shelf in order for the forklift to be able to turn in the aisle and load or unload items. In order to be more space efficient, various transfer units can be used that have the ability to load and unload items from opposing shelves without turning in place. This mean that the aisles do not need to be much wider than the item being stored, and amounts to a large saving of space throughout the storage system. This design is very basic, however it is an easy design to implement, and could be done all with technology that exists today.

The branched design along with other brainstorming led to other design concepts that attempted to remain simple yet increase the overall stowage factor. Many designs were considered, and eliminated through an orderly thought process. The other two final designs were the library shelf design, which is similar to that of a standard library shelf that is currently in use today to store books and files, as well as in some automated warehouse storage facilities. The final design that was considered was a new concept using a vertical storage method. This system is unique from any other designs currently in existence today, and comes with several distinctive advantages and disadvantages as well. The following sections will discuss these two designs in further detail.

2.2. Library Shelves

2.2.1. Introduction

Background of Concept

Many libraries around the country have been converting to movable shelving systems to increase their storage capacity without sacrificing room. Seeing these systems operate is very impressive, because it does not take much human work to move the shelving system. Using a system that can maximize space efficiency and maximize selectability is exactly what the project entailed and that is exactly what is prevalent with this system.

General Description and Assumptions

The library shelf concept evolved from the branched aisle concept and is designed to store JMICs and pallets containing dry store goods. The team was looking for a system similar to the branched aisle concept that would have a higher storage density. The higher storage density is achieved by using moveable shelving units. The moveable shelving units stay packed together until a specific piece of cargo is requested, and then move apart to form an aisle to that allows for the retrieval of a specific piece of cargo. The movement of the shelves is accomplished by using a system of linear synchronous motors (LSM), which is explained in more detail in later sections. A transfer unit with a forklift will be used to retrieve the desired JMIC or pallet from the shelves and will be powered by a separate system of LSMs. The system will also have various locking systems to ensure that the JMICs or pallets are secured while the ship is in motion.

In order to make this design as efficient as possible, using a standard storage container is desirable. A JMIC is a new container being proposed as the military's next standardized container. This is the container that the design will be incorporating. and the shelving unit was designed to accommodate as many JMICs as possible with out sacrificing selectability. As a result, the JMICs will be stacked two wide within the shelving unit to allow access to one container from either side of the shelf. One shelving unit that measures 19×17×9 ft would be able to hold 32 JMICs. These JMICs have the capability of being transported by forklift and are also collapsible allowing for easy storage when they are not in use.

2.2.2. Process Description

Once cargo is loaded onto the ship it will either already come packed in JMICs or it will come in pallets. All cargo that arrives on pallets will be sorted and placed in a JMIC that will consist of similar items to make storing goods a little more efficient than just placing anything anywhere. When all similar items are placed in a JMIC, radio frequency identification tags (RFID) will be placed on them in order to identify the containers once they are spread out about the ship. The contents of the container and the location of the container in the storage area will also be stored in a computer database to allow for quick and easy retrieval of specific containers. When each container is ready to be stored, the automated forklift will retrieve the container, lock the container and make its way to the designated storage location.

While the cart is in transit, the library shelves will move to form an aisle where there is an empty storage space. Once the aisle is formed, the cart will travel down the aisle to an empty storage space. The transfer unit will then use a forklift to place the container in the correct storage space. Once in the storage space, the locks from the forklift will disengage and the locks in the storage space will engage.

Once the container is locked down, the forklift will make its way back to the entrance of the storage area and the process will begin again with a new container or pallet. The three images below provide a general visualization of the library shelf system in operation.

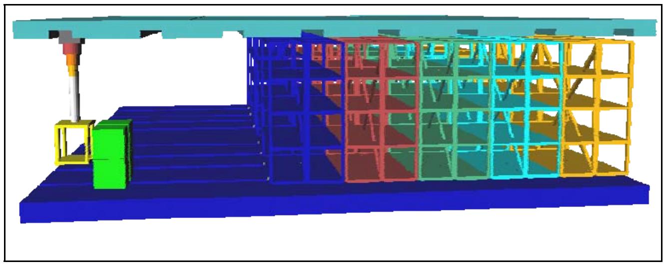


Figure 1: The transfer unit retrieves container from the loading area.

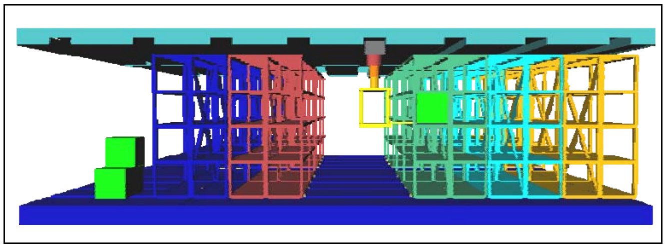


Figure 2: The library shelves move, opening an aisle for the transfer unit to travel down.

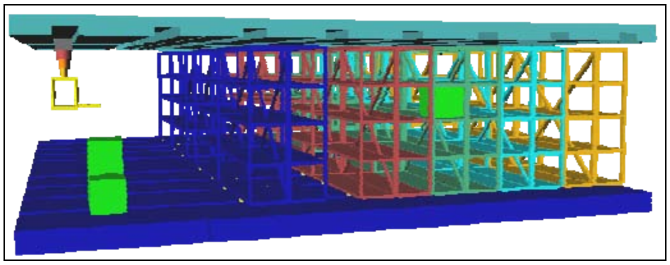


Figure 3: The JMIC is placed in the storage space and the transfer unit returns to the entrance of the storage area to retrieve another JMIC.

2.2.3. Detailed Component Description

Transfer unit

Storage and retrieval of JMIC's from the storage shelves is an integral component of the library shelf system. In order to accomplish this task, it was decided that an transfer unit that is powered by a system of linear synchronous motors would be used. An transfer unit that is powered by LSMs was chosen for the storage and retrieval of dry stores for several reasons. First, the transfer unit will be more stable during higher sea state conditions because it will be running along an LSM track. An transfer unit would also rely less on human interaction and could prove to be more time efficient than using a human operated cart.

There are two different possible configurations for the transfer unit. The first configuration involves running the cart along LSM tracks on the floor of the storage level and the second involves running the LSM tracks along the ceiling of the level. The two transfer unit designs can be seen below in FIGURE 4 and FIGURE 5.

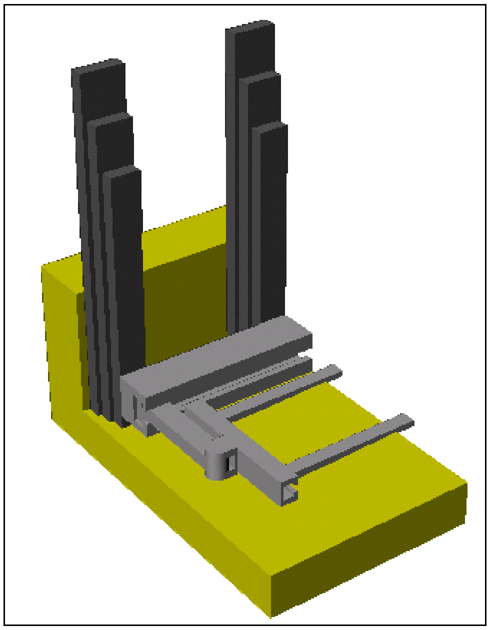


Figure 4: Floor mounted transfer unit with 180 degree rotating forklift blades.

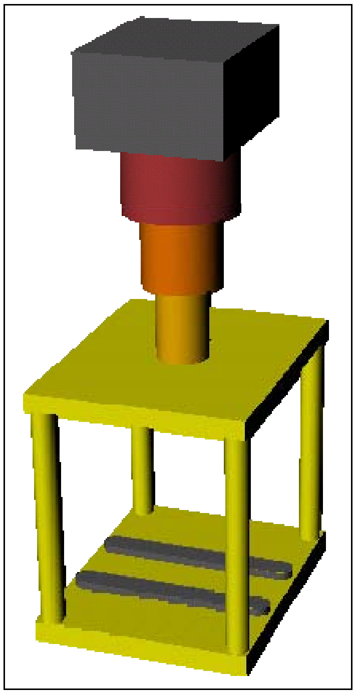


Figure 5: Ceiling mounted transfer unit with 180 degree rotating forklift blades.

The only difference between the two transfer units is the placement of the LSM tracks that they will use to travel around the storage area. Also, the transfer unit that rides along the ceiling tracks will utilize a telescoping arm to travel up and down the storage shelf. The cart that utilizes the floor LSM tracks will use two vertical lifts to move the JMIC in the vertical direction.

Both carts will utilize side-facing forklifts to retrieve JMICs from the storage shelf. The advantage of using a side-facing forklift is that it requires less aisle space then a front facing forklift design. If a front facing forklift design were used, the aisles would have to be wide enough for the cart to turn 90 degrees in order to place the JMIC in the storage space. As a result of the smaller aisles, there will be a greater amount of storage space to accommodate more JMICs. These forklifts will also be able to rotate 180° so the transfer unit can access the shelves on both sides of the storage aisle.

Motion of Library Shelves

The movement of the library shelves will be controlled by a system of LSM tracks located above and below the shelving units. The tracks will be located above and below the shelves so there is not a large moment created on the shelving units. A description of how LSMs operate can be found Appendix D. Each shelf will be able to move independently of the other shelves or with a group of other shelves. In order to save time when moving shelves to create an aisle, the ideal situation would involve moving multiple shelves at once rather than one at a time. Each shelving unit will also have heavy-duty wheels at the bottom to allow movement across the deck.

Locking Systems

When at sea it is vital that the cargo not be loose, therefore all cargo and machinery must be locked down. As a result, several systems needed to be developed to ensure that all of the cargo and machinery within the storage area is secure at all times. These systems include:

- Securing JMICs to the transfer unit
- Securing JMICs to the storage shelf
- Securing the transfer unit to the ship
- Securing the library shelves within the ship

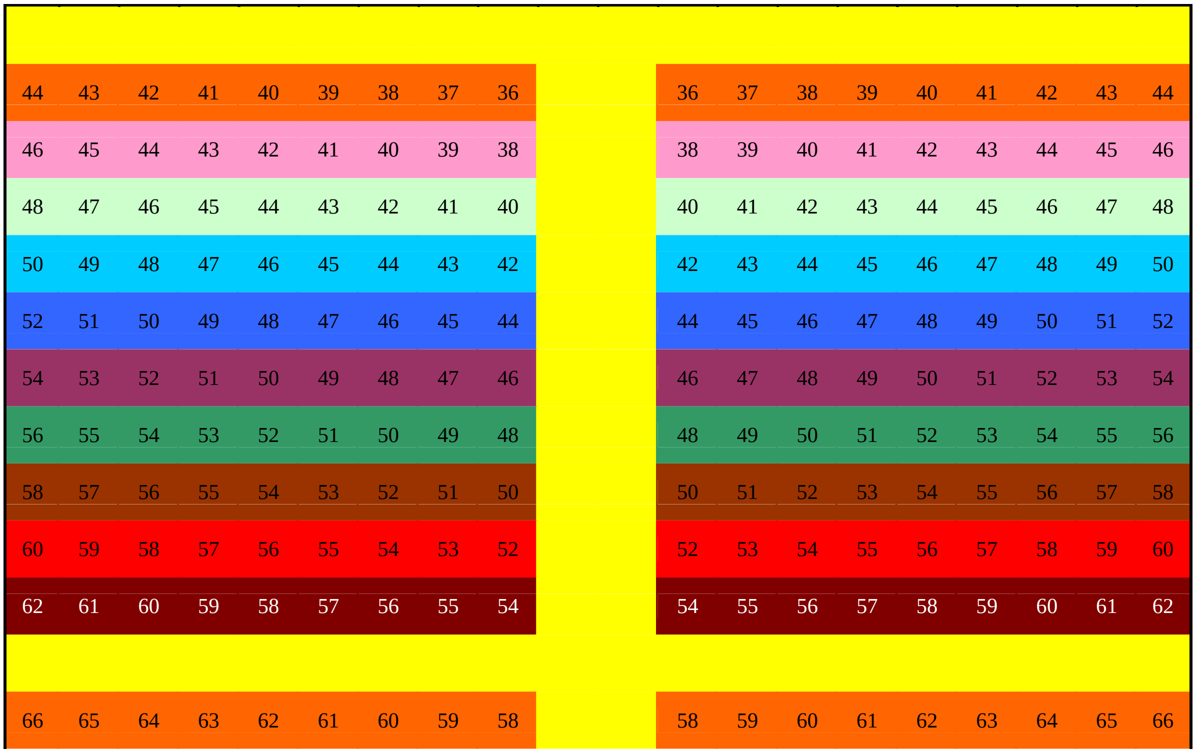
The most important component of the storage system that needs to be secured is the shelving unit. Due to the shear size of the shelves, if one of them were to move while the ship was in motion it would severely damage both the ship and the contents of the shelf. The only direction with which the shelves will be able to freely move is along the axis of the LSM tracks and therefore the motion of the shelves needs to be constrained along this axis. This constraint will be accomplished using the LSM tracks themselves. The operation of the LSM tracks allows for the object that is running along the track to remain constrained in a single position as the track pitches forward and backward. This is accomplished by increasing the power to the LSM tracks. As a result, by increasing the power to the LSM track, the position of the library shelving units can be maintained even when the ship is experiencing large pitch and roll characteristics. Similarly, this mode of constraint can be used for the transfer unit that is traveling throughout the deck because of its use of LSM tracks. However, there will also be a mechanical locking mechanism so that the LSM system does not have to operate continuously.

The methods for securing containers to the transfer unit and to the shelving units will be discussed in detail in SECTION 2.4. These ideas include scissor jack pressure locks and pin locks.

2.2.4. Analysis of Design

Calculations were performed in order to see the performance of the design. This can be accomplished by analyzing the library shelves time, energy, and storage efficiency.

First the time analysis will be reviewed to try to grasp how long it would take to get to any piece of cargo within the system. The factors that were implemented into these calculations were the time it takes the forklift to travel, how long it takes the forklift to raise and lower the forks, and how long it takes for each shelf to move. The forklift speed was estimated to be 5 ft/sec horizontally, 2 ft/sec vertically, and the shelves were estimated to take 30 seconds to move one space over. Along with all these considerations a few factors were neglected including the locking time, deceleration times, and time it takes for the forks to extend. Below is a chart that shows how long it would take to retrieve any one piece of cargo from the system. The yellow segments are the access aisles while the other colored segments are different movable shelves.



44	43	42	41	40	39	38	37	36		36	37	38	39	40	41	42	43	44
46	45	44	43	42	41	40	39	38		38	39	40	41	42	43	44	45	46
48	47	46	45	44	43	42	41	40		40	41	42	43	44	45	46	47	48
50	49	48	47	46	45	44	43	42		42	43	44	45	46	47	48	49	50
52	51	50	49	48	47	46	45	44		44	45	46	47	48	49	50	51	52
54	53	52	51	50	49	48	47	46		46	47	48	49	50	51	52	53	54
56	55	54	53	52	51	50	49	48		48	49	50	51	52	53	54	55	56
58	57	56	55	54	53	52	51	50		50	51	52	53	54	55	56	57	58
60	59	58	57	56	55	54	53	52		52	53	54	55	56	57	58	59	60
62	61	60	59	58	57	56	55	54		54	55	56	57	58	59	60	61	62
66	65	64	63	62	61	60	59	58		58	59	60	61	62	63	64	65	66

Figure 6: The retrieval times for different cells in the library shelf system

From the chart above it is noticeable that the times to retrieve a piece of cargo increases as the number of shelves that need to be moved to make an aisle increases. This system has the longest retrieval time due to the fact that not only is there a forklift that has to move, but also the shelves have to move. This can be time consuming when compared to a regular branched layout where all aisles are accessible and stationary.

Even with this system taking the longest time to retrieve cargo, it is the most efficient when it comes to volume. This system had the highest stowage factor of 81%. The stowage factor was calculated by dividing the usable storage area by the amount of space used to store containers. For the calculation it was assumed there would be one aisle to allow a cart to travel down for every ten aisles used for storage. However, it does not take into account space lost within individual storage shelves due to locking systems or loss of space due to the structure of the library shelves themselves. However, these two variables should not contribute significantly to the overall stowage factor of the system.

The energy required to make this system fully functional was also analyzed. Table 3 shows how much energy is needed to move a shelf that is loaded to its maximum load capacity. These energy calculations were performed assuming the ship was experiencing a five-degree pitch upward, which will cause more energy to be used since it is not traveling along flat ground. These calculations do not take into consideration the energy required to move the forklift or elevators. Since this calculation is only to move one shelf, to operate the whole system would require a lot more energy than any of the other systems.

Table 3: Energy requirements of the library shelf system.

Layout	Object Weight (lb)	Maximum Instantaneous Power Required (kW)	Total Energy Required to Move Maximum Distance (W*hr)
Library Shelf	251,683	10.7	117.9

2.2.5. Future Considerations

To make this system worthy of installation on a U.S. Navy ship, sea keeping and further energy analysis should be explored. There will be a lot of energy used in order to prevent the large storage shelves from moving while the ship is at sea. The question to ask is if it is worth having such a high storage factor while having such a large amount of energy consumption.

Another component of the library shelf system that requires further development is the interaction between the LSM tracks for the library shelving units and the transfer unit. The way the system is designed now, the transfer unit will have to have some way to move past the large LSM tracks that will be present when in a storage aisle. A possible solution to this problem would be to have the LSM tracks for the library shelving units on the units themselves and have recessions in the deck for the rare earth magnets. As a result, the transfer unit would have to traverse a gap rather than be impeded by a raised LSM track. However, this solution would still require further development.

Another important factor that needs to be taken into account when designing the movable shelving units is the large deflections a ship at sea experiences. Depending on the sea state, the hull of a ship can deflect as much as 8 in. There appear to be two practical solutions to alleviate the problems caused by large deflections in the hull of the ship. The first possible solution is to isolate the frame from the hull, making the system its own entity therefore it will not experience the deflections that the rest of the ship will experience. The second solution would be to increase the strength of the ship's hull to minimize the deflection it experiences.

2.3. Plus-Sign Configuration

2.3.1. Background of Concept

The plus sign layout was derived after considering many different dry stores configurations. It was thought that using a vertical storage system could possibly maximize the stowage factor while still having a simple design. Many different vertical configurations were considered, some of which are shown below Figure 7. It can be seen that all of the layouts are in such a way that they overlap and that there is no wasted space within the storage area with a few exceptions that will be discussed in further detail. The more complex layouts were eliminated because they would require a more complex transfer unit system. The final design chosen was five cells arranged in the shape of a plus sign, which is shown in Figure 8. This was chosen because of the simplicity of the design of the transfer unit.

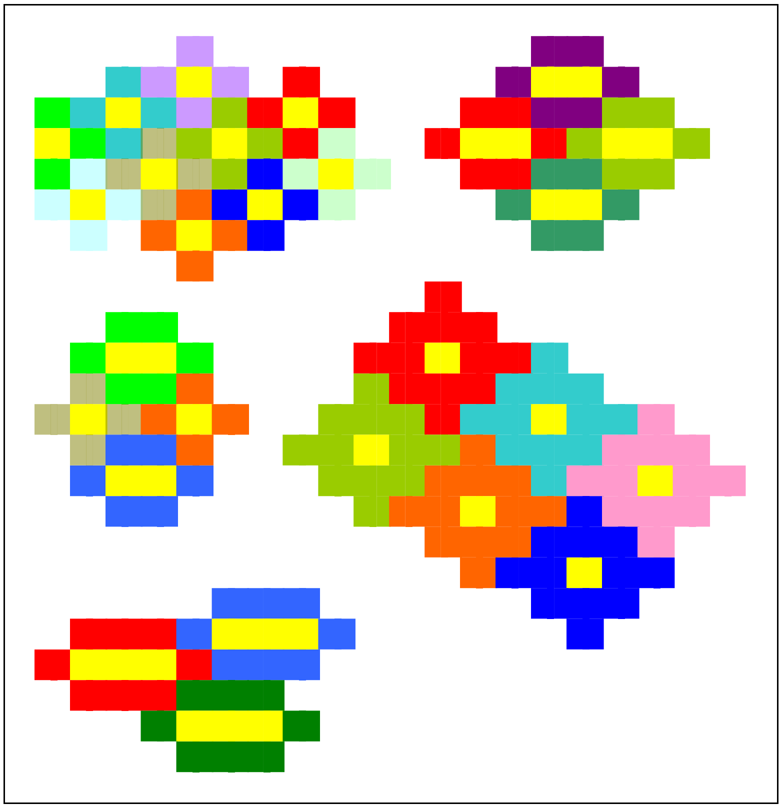


Figure 7: Various layouts considered for a vertical layout, where yellow represents a vertical shaft.

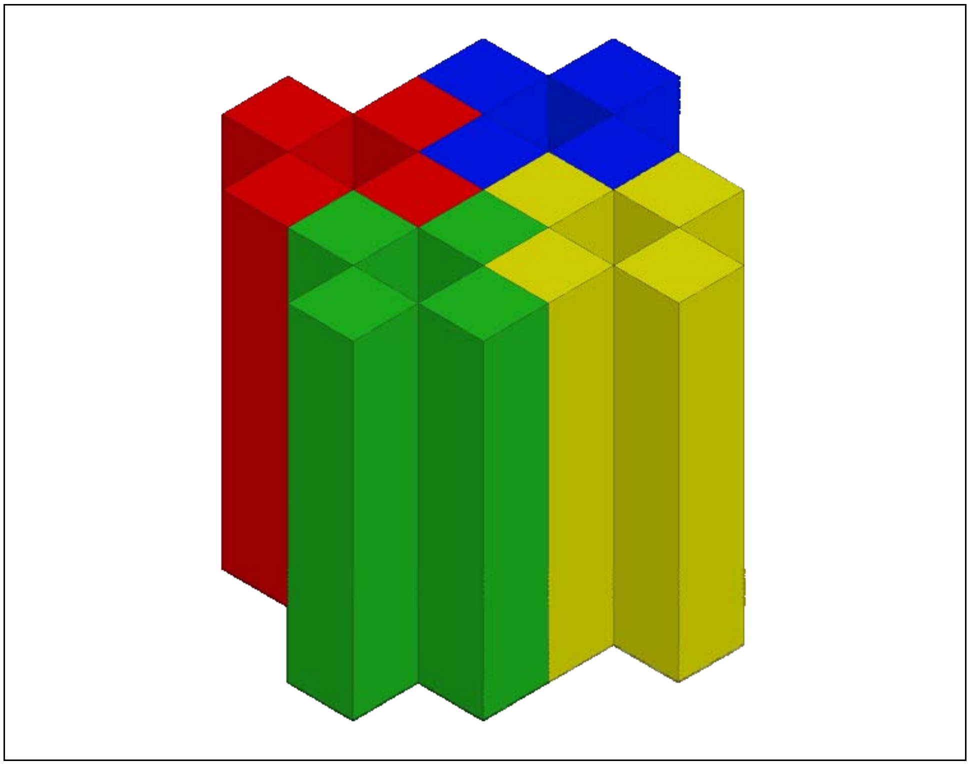


Figure 8: Final layout chosen – similar to that of a plus sign.

Using a vertical storage system arrangement poses several specific challenges to be overcome. In a vertical storage system there is a plane in which the transfer unit will move in the x (transverse) and y (longitudinal) directions of the ship, as well as vertical shafts that the transfer unit moves up and down in order to reach the destination cell. This design would use a rail system that the transfer unit moves on in the x, y, and z directions. There are several different options that could be used for powering the transfer units for this design as well as several types of tracks that could be used. For the final design, LSMs were used in order to move the transfer units efficiently.

2.3.2. Process Description

Show below is a representative set of images showing the sequence of events that would take place from when the container is loaded onto the ship until it is locked in the storage cell.

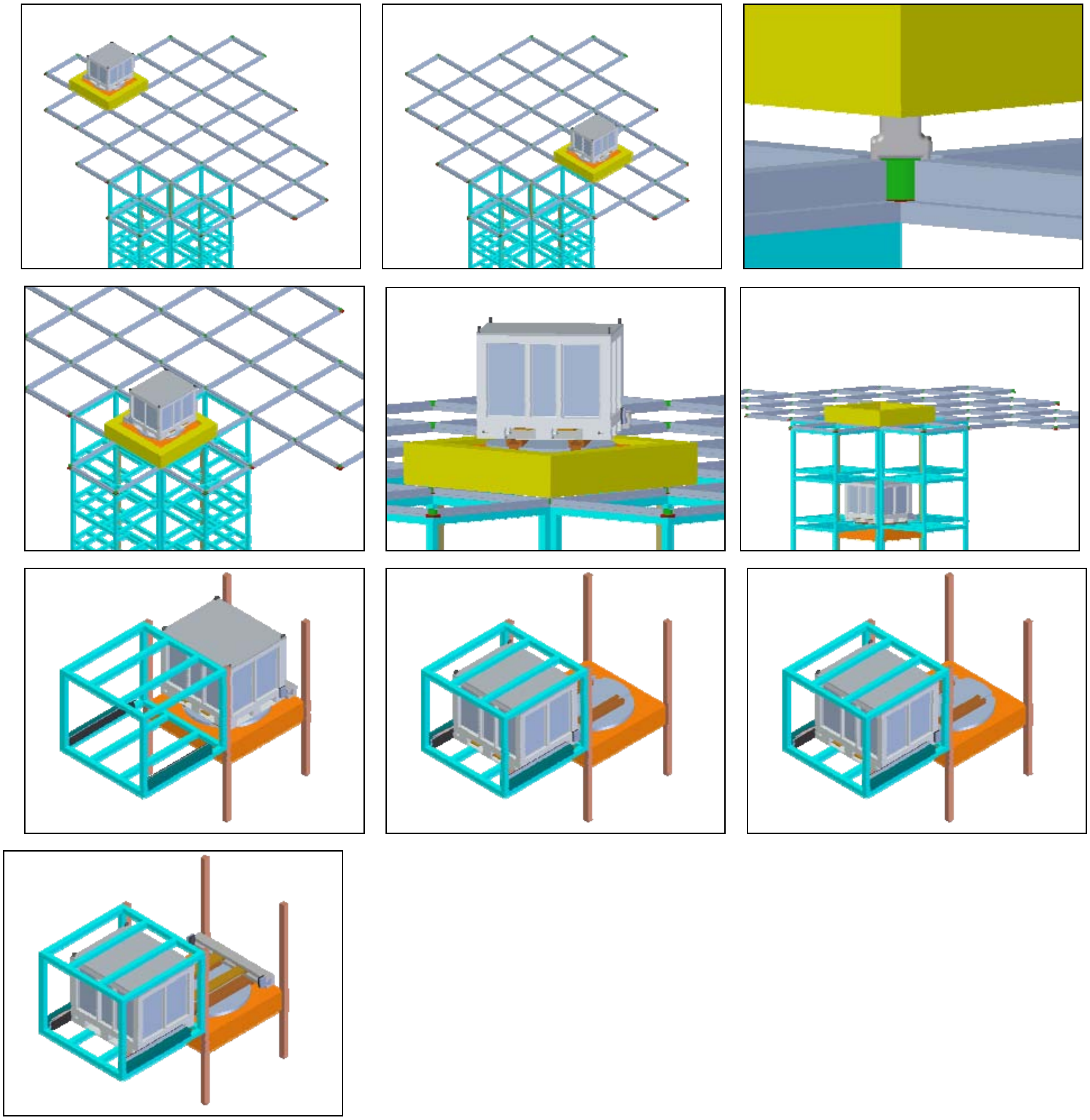


Figure 9: Event model for plus sign layout.

The upper transfer unit moves the lower transfer unit to the destination stack by moving in the x and y directions. At intersections, the rail guides on the upper transfer unit turn with the green turntables to change direction. Once at the destination stack, the upper transfer unit lowers down to connect the vertical track and lock in place. Also, while the upper transfer unit lowers into place, the lower transfer unit rotates the container to the correct direction. The lower transfer unit then moves down the shaft to the destination cell. The lower transfer unit then places the container into the storage cell. Next the locks in the storage cell engage and lock the container into place. The locks on the lower transfer unit then disengage, and the transfer unit moves on to another task.

2.3.3. Detailed Component Description

Layout

The layout for the design is such that the shape of the plus sign or stack overlaps with other stacks to form a completely filled grid. When considering the layout, there are only two possible ways in which the stacks can overlap each other as shown in Figure 10. The two different configurations are actually identical; when one configuration is rotated ninety degrees it becomes the other configuration. It is important that each cell or block of the overlapping shape is the same size. The main reason for needing this uniformity is due to the placement of the track system for the transfer unit. If the cells are not the same size in the x-y plane then the rails would eventually cross over one of the vertical shaft causing it to be inaccessible. With any layout it is possible to use a square or rectangular shape, as shown in Figure 11. A rectangular shape can be used as long that the rectangles are oriented all in the same direction and this does not limit the use of the transfer unit.

In this design either the top or bottom plane would be used to move the transfer unit in the x-y plane. This movement would position the transfer unit at the shaft, then the transfer unit would be able to proceed down the shaft to the destination cell. In this design it was concluded that having the x-y plane on the top of the stacks rather than under the stacks would be best. This would be more efficient due to the placement of the distribution center and on/offload points at the top of the ship, as well as not interfering with the supporting structure of the overall grid if the transfer unit were under the stacks. There are some limitations to this design, one of which is that at the edges of the boundary for the dry stores area there are certain cells that can not be accessed because there is not a vertical shaft that connects to them as shown in Figure 12. These spaces are wasted for the dry stores area, but could be used for other systems needed by the ship. Also the stacks are affected by the tapering of the hull of the ship. As the hull tapers in and cuts into a storage cell, it must be removed from that level of the stack. As long as the hull does not interfere with the cell of the vertical shaft, it is possible to still access other storage cells at that level that are not affected by the hull, this can be seen in Figure 13.

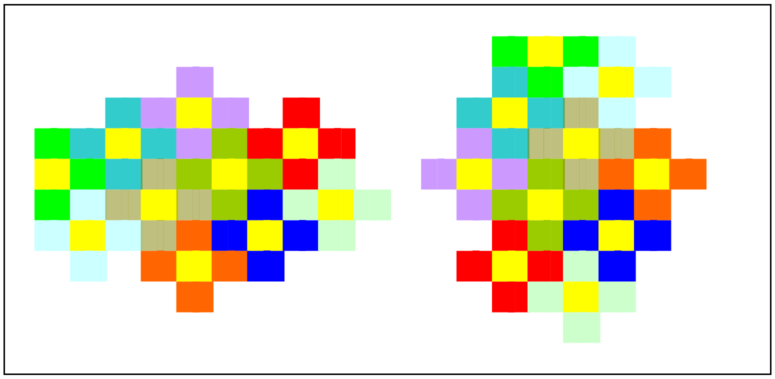


Figure 10: Two different layouts for the final design.

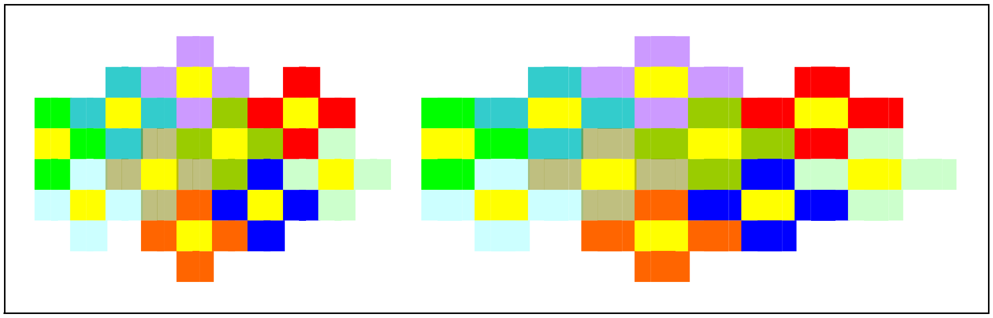


Figure 11: A square or rectangular pattern will overlap with no lost space.

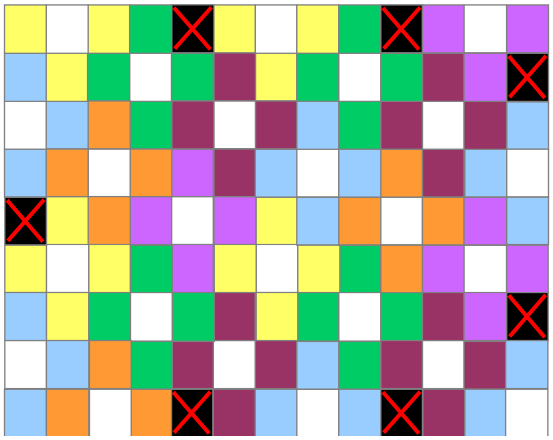


Figure 12: Lost spaces in storage - shown black with a red X.

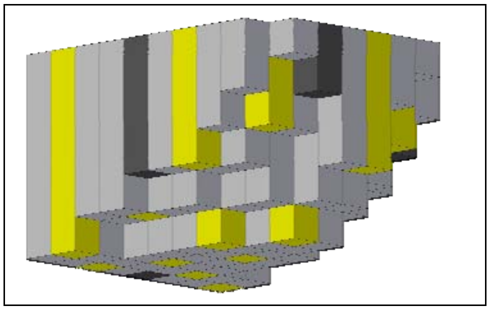
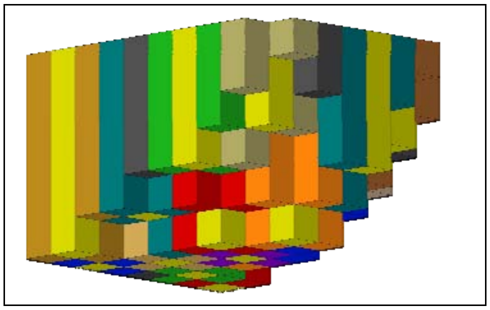


Figure 13: Images of plus sign layout tapered to fit inside hull are shown above and below. Yellow and black are representative of shafts and wasted space respectively.



Rail System

For the rail system that the transfer unit moves on, there are several options that can be implemented. There would be a grid on top of the stacks to facilitate the movement of the transfer unit in the x-y plane. At the intersections of the grid as shown in Figure 14 there would be small turn tables on which parts of the transfer unit will rotate with in order to change direction. Using a system of rails and turntables it may be possible to make the transfer unit move in directions that are not perpendicular to each other, this is shown in Figure 15. Also using four rail guides on the transfer unit may make it possible for the transfer unit to move along curved rails in a similar fashion to that of a railroad car with rotating bodies as shown in Figure 16. If the LSM is used as main method of power for the transfer unit then the rails would be flat. However, it must have groves for the wheels or rollers of the transfer unit to support the weight of the transfer unit and completely constrain the movement of the transfer unit except in the direction of travel.

Another option for the rail system is a rack and pinion style track, in which the transfer unit would be self-propelled. One important limitation of this system is when using an LSM track it is important to keep the grid of rails in the x-y plane extremely flat. The specifics of tolerances are not known, however it would be possible to have large variations in the track, but over long distances. One reason for the possible uneven level of the rail system would be due to the loading of different stacks, and how they are connected. If a stack is fully loaded with containers, the top of the stack is going to deflect down in the vertical direction. If an adjacent stack is completely empty, the stack would not be deflected downward thus the tracks would be at different levels. There are ways in which this could be solved; if the stacks were rigidly connected or constructed as one piece, then the loads and thus deflections would be distributed more evenly. Also there could be an inert device such as a dampener that separates the track from the top of the stacks such that the track maintains a flat surface.

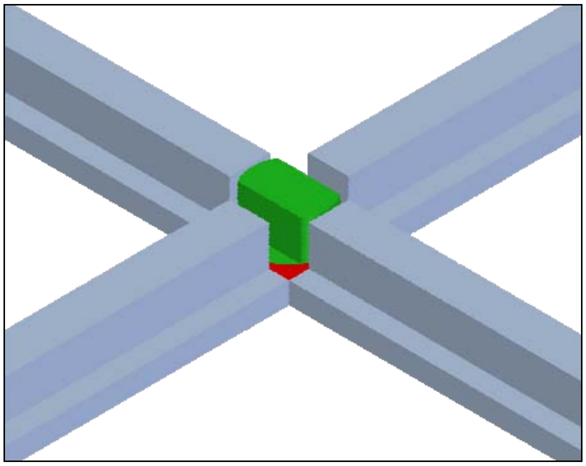


Figure 14: Small rotating turntable at intersections of LSM track.

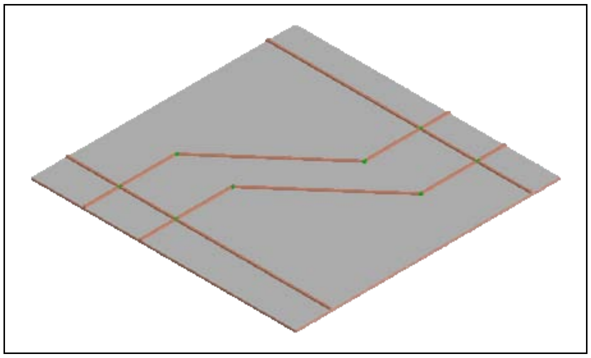


Figure 15: Possible layout of track that is not perpendicular.

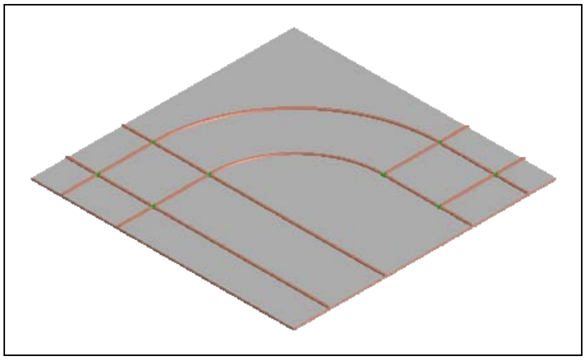


Figure 16: Possible layout of track that turns.

Frame Structure

The frame structure of the individual stacks would be fairly simple. Only one possible design used as our model for our stress analysis and images. However, there are other possible ways of laying out the structure. For the analysis and images of the structure, only one stack was considered, and it was considered to not share any structural members with other stacks. The overall structure could be manufactured as vertical stacks and then assembled in the ship, or could be assembled in large grids of stacks and then assembled. The specific design of the structure does not matter as long as the stacks line up as intended. A representation of the frame structure can be seen below in FIGURE 17.

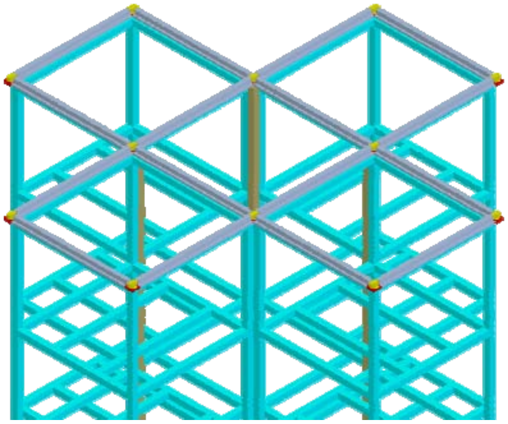


Figure 17: Frame structure of plus sign design.

Transfer Unit

The transfer unit that would be used by this system would be different from that of the branched or library shelf designs. The transfer unit was originally intended to be a one piece unit that would have the ability to traverse across the top of the stacks in the x-y plane as well as be able to move down the vertical shafts. However during the design process, it was decided that in order for the transfer unit to move on all three axes there would have to be a complex set of moving parts such that some rail guides/rollers would retract so that the transfer unit would be able to transition from horizontal to vertical movement. It was concluded that using a two piece transfer unit system would best accomplish the facilitation of movement on all three axes while keeping the complexity of the design to a minimum. Using a two-piece transfer unit, the upper transfer unit would move across the top of the stacks on the horizontal rail grid. It would also contain the rail sliders and it would house the lower transfer unit. Inside the upper transfer unit there would be a set of rails oriented vertically that the lower transfer unit would use to move into the shaft. The rails in the upper transfer unit would line up with the rails inside the shaft such that when the upper transfer unit is positioned over the stack, it would simple lower itself down thus lining up the rails as well as locking the cart into place with a pin system. The detail of the transfer unit can be seen in Figures 18-20. Once the lower transfer unit had moved down into the stack, the upper transfer unit could move on to another task, or wait for the lower transfer unit to return. The lower transfer unit would then be able to move up and down vertically inside the shaft and load or unload containers into the storage cells.

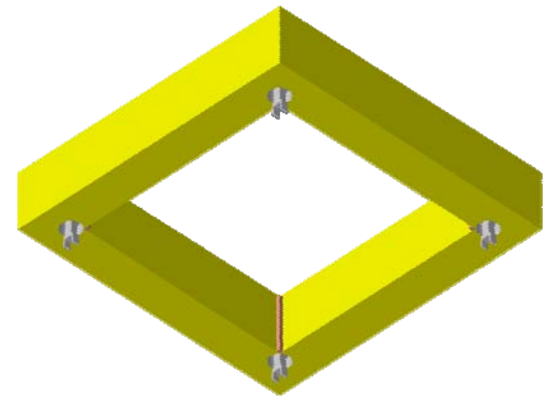


Figure 18: Detail of upper transfer unit – view from underneath.

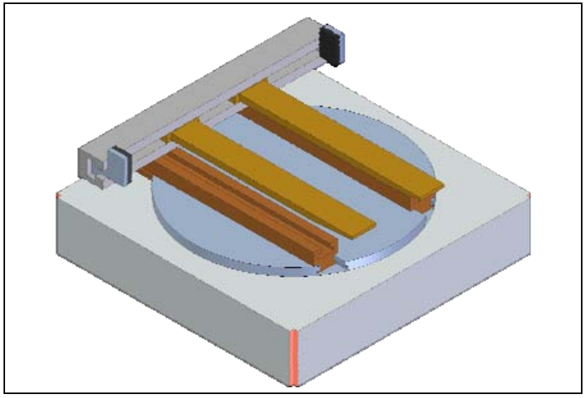


Figure 19: Detail of lower transfer unit.

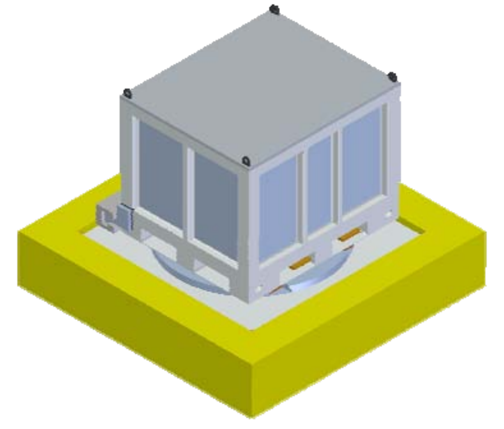


Figure 20: Detail of transfer unit together in x-y transfer configuration.

Storage Cell

In order to have the smallest possible storage cell and waste the least amount of space, several different configurations were considered. Shown below in Figures 21-23 are several different size configurations based on the size of a JMIC and a standard Pallet. In Figure 21 all of the containers face inwards, and the lower transfer unit prepositions the container at the top of the stack before descending into the shaft. This is because in order to save space, the lower transfer unit does not have the ability to rotate inside the shaft while carrying a container. Figure 22 shows the space that would be lost if the ability to rotate a container inside the shaft was desired. Figure 23 shows what a rectangular layout would look like. In this case, the left and right container would have their fronts facing the shaft, but the top and bottom containers would have their sides facing the shaft meaning that they would have to be loaded from the side.

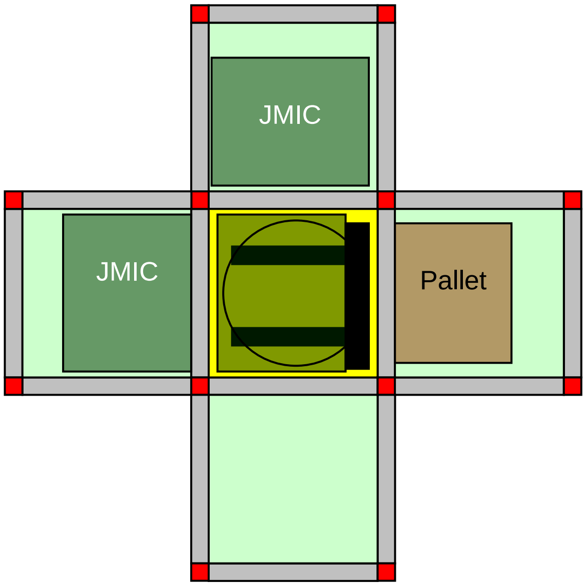


Figure 21: Square layout, with all containers facing the center.

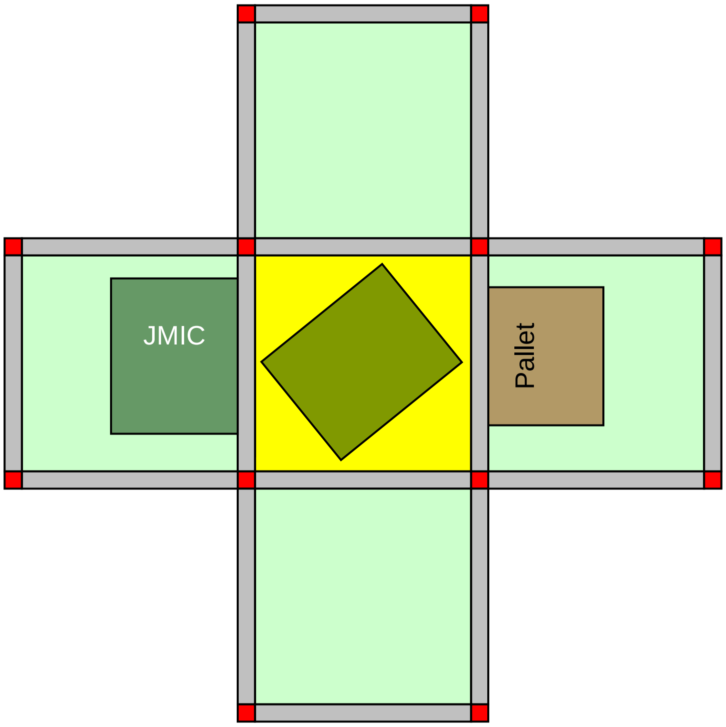


Figure 22: Square layout with ability to rotate container inside shaft.

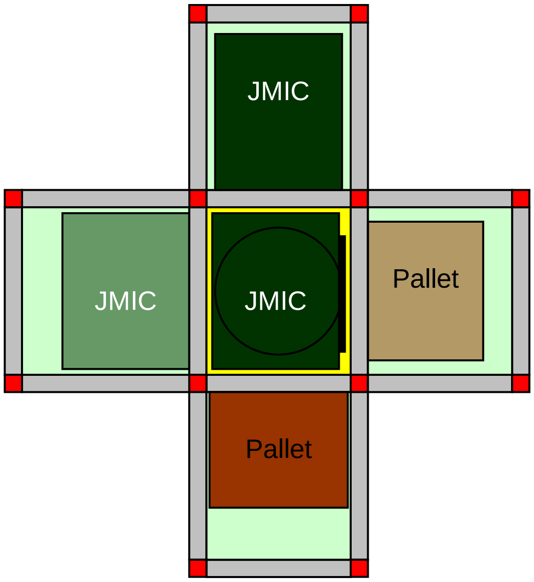


Figure 23: Rectangular layout with top and bottom container retrieved from the side.

Maintenance Systems

Since this design environment unlike other designs is extremely unfriendly to people, some other extra design considerations were made. In one of the other long-term storage designs, such as the branched or library shelf, if a malfunction occurred, personnel would be able to simply walk to the problem area. However in this setup it would be extremely hazardous for a person to attempt to make their way across and down the storage stacks. The use of several different automated as well as manned transfer system could make repair and maintenance tasks safer and easier. A maintenance unit could be made using a two-piece unit similar to that of the transfer unit. The maintenance unit would be able to automatically remove and replace turn tables on the top of the stack, clean all of the track, as well as a variety of other tasks. A single or two piece transfer unit could be converted into a manned transfer unit such that a repair crew could safely get to the problem area as shown below in Figure 24.

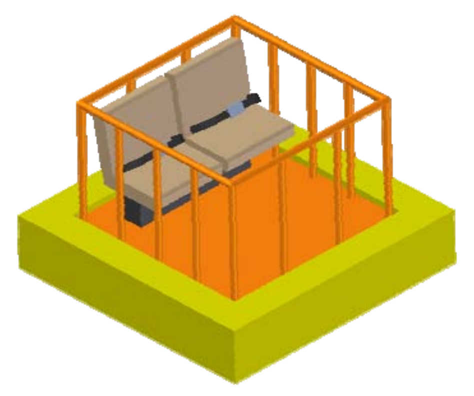


Figure 24: Manned transfer unit.

Also for regularly scheduled maintenance there could be a designated area on the ship, where the carts move themselves to the designated area and are then repaired if necessary. Using a separate area for preventative maintenance would reduce the hazard for workers. There could also be several different types of emergency vehicles that would have the capability of retrieving a lower transfer unit if it were experiencing problems. A system like this would me much larger on the top of the stacks and would be able to lift a lower transfer unit with a load back up to the top of the stacks to be taken to the repair area. One benefit of the construction of the frame design is the open construction. Since two cells from adjacent stacks have shared sides of their storage cells it makes it possible to access a cell that has a damaged locking cell from another shaft.

Sections on Different Planes

If for some reason the storage area for the plus sign has the top plane cut into by another area of the ship as shown in Figure 25, then it would be possible to have a separate x-y plane at a different level. The lower transfer unit would still be able to move up to the top to be picked up by an upper transfer unit, however there would need to be an intermediate upper transfer unit on the lower plane to allow the movement of the lower transfer unit from stack to stack. There would also need to be a small elevator system to allow for the upper transfer units on the lower plane to be retrieved and maintained.

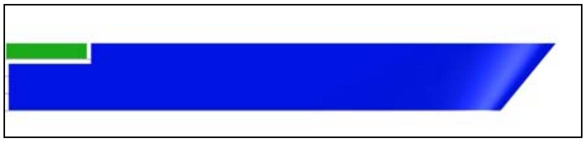


Figure 25: Dry stores area cut into by distribution center. Green represents distribution center, blue represents dry stores area.

Computer Control System

In order for the total system to be as automated as possible, a very complex computer control system would be necessary. A computer control system would be able to manage the storage and retrieval process, insuring the safe transit of all transfer units. This computer control system would also serve as the memory storage bank that would know the location of all of the items on the ship. By using an automated system the safety and efficiency of the system would be greatly improved. An example of the computer control system process is that when a container is brought on board, either an RFID is scanned or an electronic manifest of the contents is entered into the computer database to be stored along with the location data of that container. The computer would then control the movement of the transfer unit as well as the locking procedure. If a container was brought to the distribution center, the computer control system would then update the manifest for the container as items are removed, so that an accurate number of items on the ship can be known at all times. There would be a similar system to this for the vehicle storage area, but less complicated.

2.3.4. Analysis of Design

The stowage factor for the plus sign design was 78%. This was not the highest, however it was quite close to the best stowage factor of 82% for the library shelf design. For the stowage factor calculations, certain details were left out, such as the structure, locking mechanism placement, and other details, as well as in this design, there was some extra wasted space within the cell. The main factors that were used were the vertical shafts, unusable cells at the edge of the storage area, as well as the top x-y traverse are. The details from the calculations are shown in Appendix E.

The retrieval time for the plus sign was calculated to be 92.1 seconds. This was the fastest time for all of the designs. For this design the time was calculated from the x, y, and z movements of the upper and lower transfer units. This did not include the acceleration to full velocity, deceleration, locking systems, and turning. These factors can be added to the above average for a closer approximation if desired. The full details of this calculation can be found in APPENDIX F. The speeds that were chosen for the system were 10 ft/s horizontally across the top of the stacks, and 2 ft/s vertically up and down the stacks. These speeds were approximate, and the maximum speeds need to be verified by further study into the design as well as the use of LSMs at sea.

The energy requirements for this design were a maximum instantaneous power requirement of 19.7 kW; this occurred at the end of the acceleration to maximum velocity portion of the analysis. The overall energy required to move the transfer unit in the farthest distance at the worst possible angles was 602.6 W*hr

The stress analysis that was performed for this design was a basic stress analysis on the frame structure of the stack itself. For this analysis the frame was constructed out of 3”×3” square tubing with a wall thickness of ¼”. This was done using beam elements in ANSYS finite element analysis solver. The main purpose of these calculations was to verify the amount of material needed to find out how much space would be lost due to the structure of the frame. It was found that using the initial design would be sufficient for holding the load at the worst sea state conditions assumed for this system. The calculations and results of the stress analysis can be found in more detail in APPENDIX G.

Advantages

One of the main advantages of this design is the overall redundancy in the system. This was not designed into the system but is rather an added benefit from the design layout. In this design using the length of the dry stores area that would occupy the rest of a typical LMSR hull design there would be 720 vertical shafts. Where as in the branched there would be 120 side aisles, and in the library shelf design there would be only 34 side aisles. Also for the center aisle, there is only one two way aisle located in the center of the layout for the branched and library shelf designs. However in the plus sign design the tops of the stacks are completely open for movement. Since the upper transfer unit is slightly larger than that of one cell and thus overlaps into the adjacent cells each row on top could not be used. This only limits the number of main aisles to half the total number of cells wide. For an LMSR hull, there would be about 20 cells across, thus providing 10 main aisle ways. Having the larger number of side and main aisles not only adds to the time efficiency of the design but also adds a lot of redundancy to the system. If one upper transfer unit were to fail, it would not hinder the flow of traffic in the system. Also since there are a large number of shafts, if a lower transfer unit were to fail inside a stack, then only a small portion of the cargo would be inaccessible until the unit could be retrieved and repaired. Having more aisles makes the design more robust and allows for less strain to be put on the system when a malfunction occurs. This design also had one of the higher stowage densities. It was not the highest; however the structure of the design is much simpler than the library shelf design, which had the highest stowage factor. Also for this design it would be fairly easy to section off the ship into sections by bulkheads because of the small size of each stack, as well as the ability to have small armored sections for the storage of ammunition without wasting much space in the design.

Disadvantages

Some of the disadvantage of the plus sign design is the structure that is inside the ship’s hull. It is a rather simple structure, but overall has a large amount of material and possibly high construction costs. Also for this design, it is only efficient when used on a single deck ship; this is due to the fact that there needs to be a top or bottom plane for each set of stacks. If this design were to be placed on a four-deck ship, then there would be four x-y planes, which are not all, needed. This design becomes more efficient the deeper the stacks are. Also for this design the shear amount of LSM track needed is vast. If using a LSM track for the lower transfer unit to move up and down the shafts there would need to be 15 miles of total LSM rail including the top x-y plane if two rails were used in the shafts, and if four rails were used it would be close to 30 miles of LSM track. One possible solution to this is to use a one piece transfer unit that still has upper and lower sections, but the lower transfer unit is lowered from the upper transfer unit by a cable and pulley system. There is also the option of using an overhead crane system; however this takes away from some of the effectiveness of the design. One of the other disadvantages of this design is that the size of the cells in each stack must be the same. This could be a rectangular or square shape. However the transfer unit as well as the forklift blade mount must also fit into the vertical shaft, which must be the same dimensions as the storage cells. Currently for the design, a rectangular JMIC was used with square cells. This was determined to be the best compromise because if a rectangular layout was chosen then the JMIC would have to be loaded from the front and side into the storage cell, making the transfer unit as well as other parts of the design more complex. The two ways to minimize this space loss is to use a rectangular layout with a rectangular container such as the JMIC, or use a square layout with a square container. For both options some space will be lost in the storage cell since the shaft must be larger than the container, the main goal is to minimize the wasted space.

2.3.5. Future Considerations

For this design one of the main components that must be researched and developed further is the LSM power system. It is important that the LSM track is relatively cost effective since this design would heavily use the LSM track throughout the system. Currently the LSM tracks in production today have a low maintenance requirement, and a long life; both of these factors are very important in this design because of the difficulty in repairing or replacing parts. Thus it is important to ensure that these benefits of the LSM system still exist in this large scale design. Another area of further consideration is the emergency systems that would need to be put in place for this design. There would need to be emergency locking system for the upper transfer unit if the ship were to encounter rough seas suddenly; as well as a locking system for the lower transfer unit if its motors were to fail, similar to the emergency breaking system of an elevator. This design would also be heavily dependent on the computer’s situational awareness in order to be able to operate safely and efficiently. Thus a complex control and location sensing system would need to be integrated into the design. The LSM track has some built in ability to know and control the position of individual transfer units, however this may need to be expanded with further computer control.

2.4. Locking Systems

2.4.1. Storage Cell Locking Systems

The main requirement of the shelf locking system is that the locking device itself does not have its own motor. It is designed such that a device on the transfer unit would be able to actuate the locking mechanism in the storage cell. Also it is desired that if the locking system were to fail that it would fail in the locked position. Most of the designs would use a compressive spring to keep the mechanism pushed into the locked position, and the cart would then compress the spring, releasing the pressure to unlock the device. For some of the locking systems, the exact positioning of the cargo is more important, for these designs guide rails may need to be put into the storage cell such that as the container is set down, it is pre-positioned to be locked.

The first locking system is a pin-based system. It may simply be a pin that moves in and out of a hole or slot in the container, or if the container permitted, it would use a twist lock to secure the container to the storage cell, see Figure 26. Also a clamp system was considered as the locking mechanism, this would use rubber pads and apply sufficient pressure to the container, thus holding it in place. The clamp design can be seen in Figure 27. It is also possible to make use of the forklift slots, and have a side or rear entering system. If the locking device came from the side it would only need to be inserted, but if it came from the back of the storage cell it would need to expand inside the storage slot to lock the container down. There are some design limitations with the various locking mechanisms. For all of the designs but the clamp design, the use of wooden pallets is not possible. However with the clamp system it is possible to have the clamp apply pressure to a JMIC or a pallet.

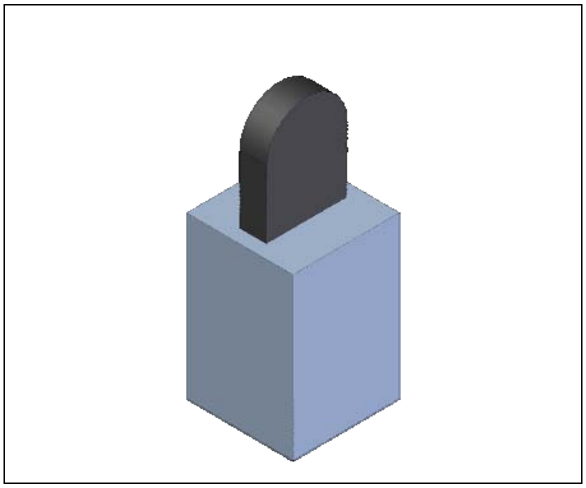


Figure 26: Various storage cell layouts.

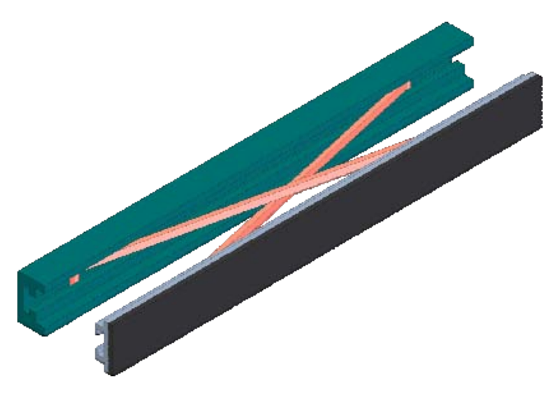


Figure 27: Various storage cell layouts.

2.4.2. Transfer Unit Locking System

For the transfer unit, the locking system would have to be slightly different from that of the storage cell locking mechanism. The two main driving design factors for this locking mechanism is the ability to completely constrain the cargo during movement, as well as be able to load the container into the cell and engage the locks on the cell before releasing the locks on the transfer unit. The locking system needs to keep the container from sliding off of the forklift blades, from sliding side to side on the forklift blades, as well as lifting off the forklift blades. The latter is of the least importance, since the container lifting off the blades is unlikely due to the weight of the container itself. If the container in constrained in the other two axes, then all the container could do is bounce up and come back down. The following designs were chosen as possible locking solutions for the transfer unit. A pin based system would enter a hole or slot in the JMIC in order to constrain movement. However unlike the shelf locking system, it is not possible to have the locking system engage on the bottom of the JMIC since then the locking mechanism would make it impossible to set the container in the storage cell and remove the locking pin, without having a much more complex transfer unit frame. Therefore the locking pin would have to come from the sides if this system was to be used on the transfer unit.

The next locking system is clamp based, and similar to that of the clamp on the storage shelf discussed above. However, the clamp would not need to use scissor jacks and springs, or other actuating devices to apply pressure. The clamps could slide along a rail on the transfer unit and be controlled by pneumatics, hydraulics, or a linear actuator. Two pads would be facing each other and would compress on the sides of the JMIC, applying enough force to hold the container firmly in place. The calculations for the force required to hold the JMIC in place can be seen in APPENDIX H. The third locking system is simply an added piece of material at the end of the forklift blade that supports no load down as the actual forklift blade does, but instead rotates up from horizontal to vertical once the load is onboard. This keeps the load from sliding off of the end of the forklift blades. In order to constrain movement from side to side, the forklift blades would simply extend outward to the edges of the forklift slots in the container before the blades lift the load. This rotating locking mechanism is shown below in Figure 28.

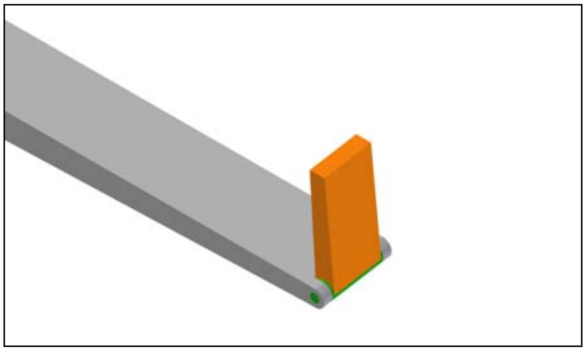


Figure 28: Detail of transfer unit together in x-y transfer configuration.

The last design is similar to that of the expandable locks in the storage cell. An expandable device would accompany each forklift blade, directly next to it such that when the forklift blades are inserted into the forklift slots, the expandable lock is inserted beside the blades, the lock is then expanded, applying pressure to the inside of the forklift slot, thus fully constraining the load. The benefit to this system of the other clamp based system, is that if one lock failed, the other could still keep the container locked in place.

3. Vehicle Storage Design Concepts

3.1. Introduction and Background

The U.S. Navy currently uses a dense packing arrangement to store vehicles on its cargo ships. Dense packing involves driving as many vehicles as possible into the storage hold of the ship. However, there are several disadvantages to this storage arrangement. First, in order to access any vehicle that is located in the rear of the storage area, every vehicle in the front must be moved. This situation is very inefficient. Moving all other vehicles out of the way and then restoring them to their original positions is a very time consuming and tedious process. As a result, the Selective Offload team was tasked with designing a storage system that provides 100% selectability while also maximizing volume efficiency. The following sections detail the evolution of the design and its components.

3.1.1. Evolution of Design

Initially, the team brainstormed several concepts for storing vehicles within the sea base. A list and brief description of these concepts can be found in APPENDIX B. These concepts were then analyzed using the evaluation criteria discussed previously and eventually two concepts were chosen for further development. The two concepts that were initially chosen included:

- Automated parking garage for light vehicles (<10 tons) on top of a single level for heavy vehicles
- Single level of storage rows that utilizes air pallets for movement of the vehicles around

the deck and stores all of the vehicles

However, this decision was made before a complete list of the vehicles and their specifications was made available. Once this list was made available, it was discovered that there was approximately a 2:1 ratio of heavy vehicles to light vehicles. This result made the separate automated parking garage for light vehicles a less viable option for storing vehicles within the sea base for several reasons. First, it would not be space efficient to have a large area for storing the heavy vehicles in long storage rows and then a smaller area to store on the lighter vehicles in a parking garage configuration. More importantly, using the separate automated garage for the light vehicles limits the flexibility of the design. For example, if for a specific mission the only vehicles that are needed are heavy vehicles, these additional heavy vehicles cannot be stored in the automated garage and that space is left unused. Flexibility of the storage area to store different amounts and configurations of vehicles is important because each type of mission requires a different set of vehicles. As a result, it was decided to pursue further development of the long storage rows using air pallets for transport. This decision was made based on the flexibility of the concept to store any MEB vehicle as well as other types of storage items such as TEU’s of water, POL, or dry stores. Also, it was determined that the concept’s use of automated storage and retrieval of the vehicles was an interesting topic and could lead to more efficient storage of vehicles within the sea base.

3.1.2. General Characteristics and Assumptions

The purpose of the vehicle storage system is to have an automated system to store and retrieve all of the vehicles, listed in TABLE 1, that are required to support 20% of an MEB for 20 days. However, the vehicle storage area will also store all of the water and POL (petroleum, oil, and lubricants) that is required by an MEB. All of the water and POL will be stored in the vehicle storage area based on the large quantity of the two supplies that is needed and also the containers within which they are transported. Currently, the Navy transports water and POL in containers known as SIXCONs. Due to the size of these containers, it would not be space efficient to store them with the JMICs in the dry stores section of the ship. As a result, not only would it be more space efficient to store these containers with the vehicles, which are similar in size to the TEUs, but it also increases the flexibility of the vehicle storage area. The storage area now has the capacity to store dry stores either in TEU containers or JMICs that are connected together to form standard TEUs. This added capability is important for humanitarian missions where storing more dry stores takes precedent over storing vehicles.

Another characteristic of the vehicle storage area is the near fully automated system that will be utilized to store and retrieve the vehicles. A system of air pallets and LSM tracks will be used to transport the vehicles throughout the ship and to store them in the storage spaces. The only portion of the vehicle storage that will not be automated is the task of chaining the vehicles down once they have entered the ship. Members of the crew will perform the task of chaining the vehicles down. This decision was made because automating the vehicle tie down process would require a large and complex group of machines. The most simple and space efficient solution would be to use manpower.

The vehicle storage area will also utilize standard storage plates for storing the vehicles in order to maximize the flexibility of storing different amounts of vehicles or containers. This flexibility is an important characteristic because not every mission requires the same vehicles and any vehicle storage area needs to account for this. Finally, there will be locking mechanisms within the storage area to ensure that the vehicles are not moving when they are not supposed to be. This unwanted movement can lead to damage of the ship or even the vehicles themselves. The following sections discuss the components listed in this section in further detail.

3.2. Process Description

The following section details the steps involved in storing a vehicle in the vehicle storage system as well as a relative time for the completion of each step. The times were calculated based on the speed of movement of the air pallets and elevators and the distance that is covered. However, these times are only estimates because some of the aspects of the system such as locking and unlocking the vehicles from storage cannot be accurately estimated. Also, this is just a general description of the steps in the storage process; the following sections provide more detail into the actual design of each component of the system.

3.2.1. Entering the Storage Area

The vehicle storage process begins by placing the vehicle that needs to be stored into the ship. There are two means by which this can be accomplished; the first of which involves the vehicle driving into the rear or side of the ship and entering the storage area. The vehicle will enter the ship through a rear or side door that allows access to one of the middle decks. Once the vehicle has entered through the door it will immediately drive onto an adjacent storage plate and air pallet. At this point, the vehicle’s engine will be turned off and will remain off for the entire time of storage. The vehicle will then be attached to the storage plate by chains that lock to the corners of the vehicle and the storage plate. A depiction of a vehicle, after it has driven onto the storage plate and air pallet, can be seen below in FIGURE 29.

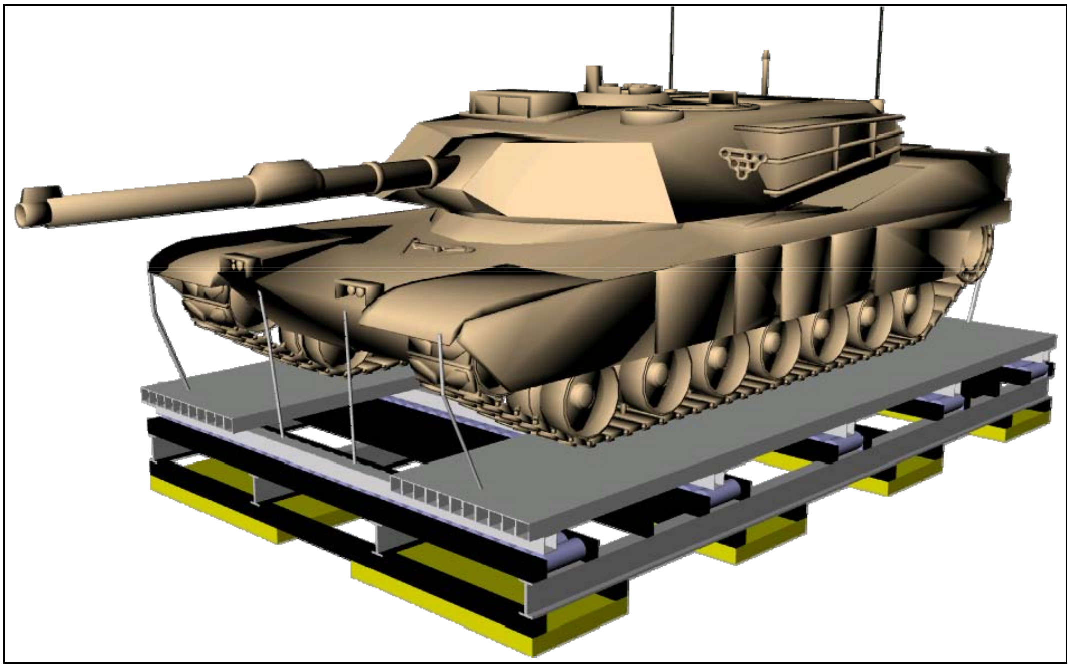


Figure 29: This image shows a vehicle that has been chained to a storage plate upon entrance to the ship. The storage plate is resting on top of an air pallet.

The system for locking the vehicle to the storage plate will require manpower to connect the chains. The time that is required to complete these steps is difficult to estimate because it depends on two factors: the speed of the vehicle driving onto the ship and the speed at which a person(s) can attach the chains to lock the vehicle to the metal pallet. The more personal available to attach the chains the faster the locking of the vehicle to the storage plate will be.

The second method for placing the vehicle in the ship involves transferring the vehicle from the top deck of one ship to the top deck of the storage ship while at sea. The vehicle will be placed directly on a storage plate and corresponding air pallet. The vehicle will then be transported to the storage area by an elevator. This method would involve the same chain system for securing the vehicle to the storage plate and would only differ in the manner of entry into the vehicle storage area.

3.2.2. Traveling to the Desired Storage Space

Once the vehicle is secured to the storage plate, it will be moved to an available storage space. This step is accomplished by an air pallet and linear synchronous motor (LSM) system. The storage plate is attached to an air pallet that is powered by an LSM. The purpose of the air pallet is to minimize the friction with the storage deck and to allow easier movement of the heavy vehicles. The LSM system will be used to move the air pallet around the storage deck. In the event that the level where the vehicle entered the ship is full, elevators at the end of the storage area are used to transfer the air pallet and corresponding vehicle to a level with available storage space. The time required to transfer the vehicle using the air pallets and LSM system within the ship will depend on the speed of the LSM system and the distance that needs to be traveled to reach an open storage space. A depiction of the vehicle entering the storage level can be seen below in FIGURE 30. FIGURE 31 below shows a vehicle entering an elevator for transfer to another storage level.

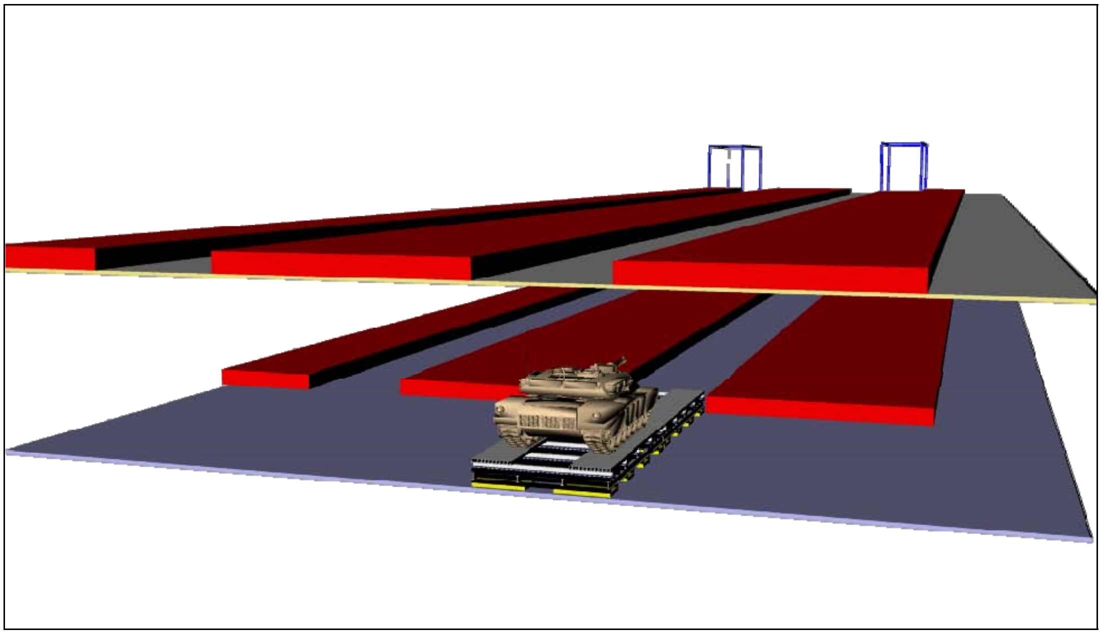


Figure 30: This figure shows the vehicle, which has been connected to a storage plate and air pallet, as it enters the storage area. The storage spaces are represented by the red rectangles. The elevators can be seen as the blue silhouettes at the rear of the storage area.

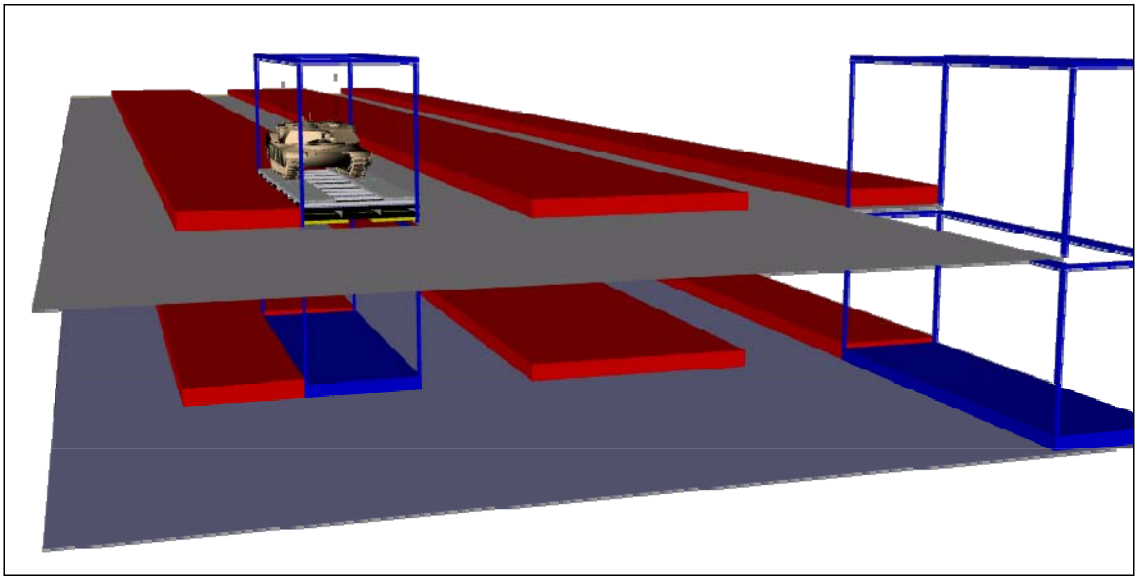
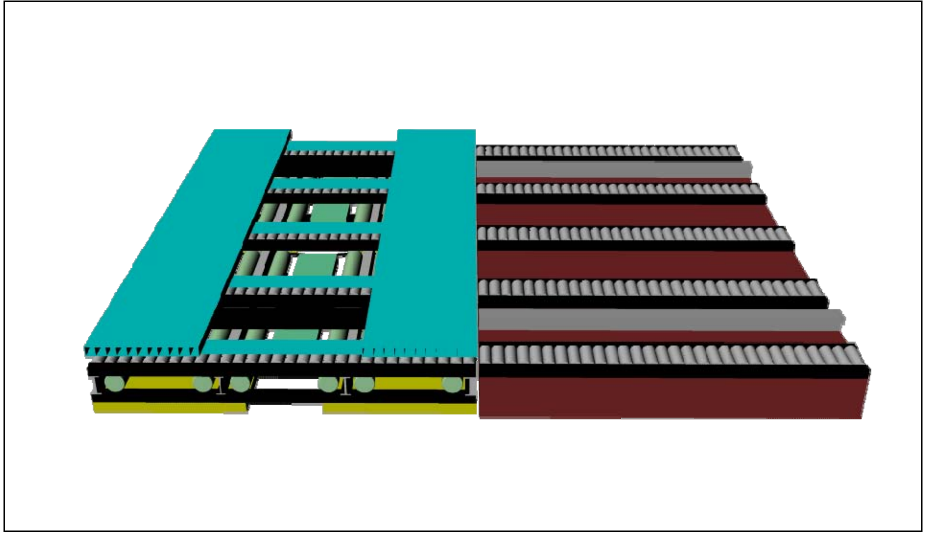
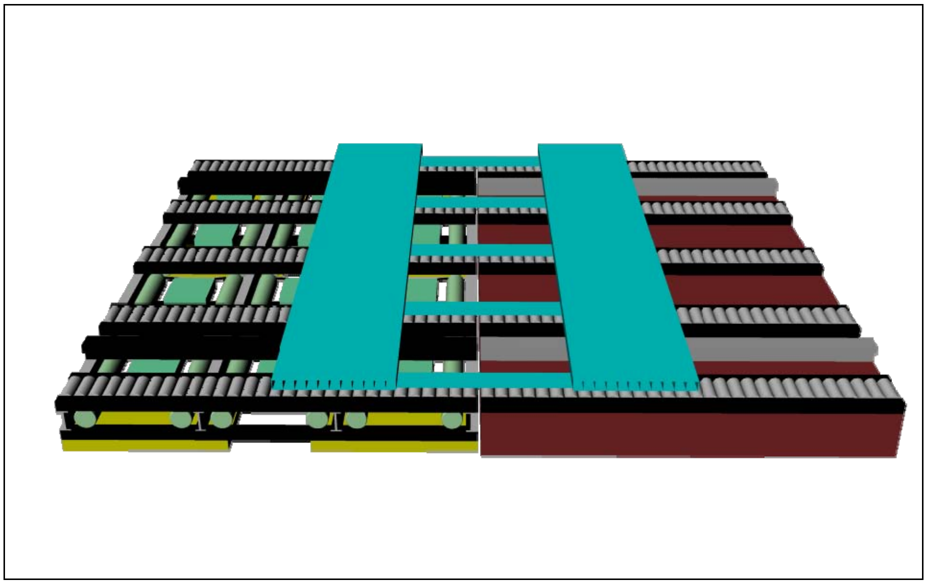


Figure 31: This figure shows the vehicle and air pallet entering an elevator in order to reach another level of the storage area.

3.2.3. Transfer of the Storage Plate to the Storage Space

Once the air pallet and corresponding vehicle have reached the storage space, the air pallet will stop and transfer the storage pallet along with the vehicle to the storage space. The storage plate will be transferred from the air pallet using a combination of rollers and LSM. Once the plate is transferred to the vehicle storage space, it will be locked down to allow for safe storage. The air pallet will then return to the entry of the vehicle storage area to repeat the process. The time required to complete these final steps depends on the speed of the LSM system on the air pallet. The faster the storage plate can be removed from the air pallet the faster the air pallet can return to the entry of the storage area to retrieve another vehicle. The following sections provide details of the components that make up the vehicle storage system. Also, FIGURE 32 below depicts a storage plate as it is transferred from an air pallet to a storage space.





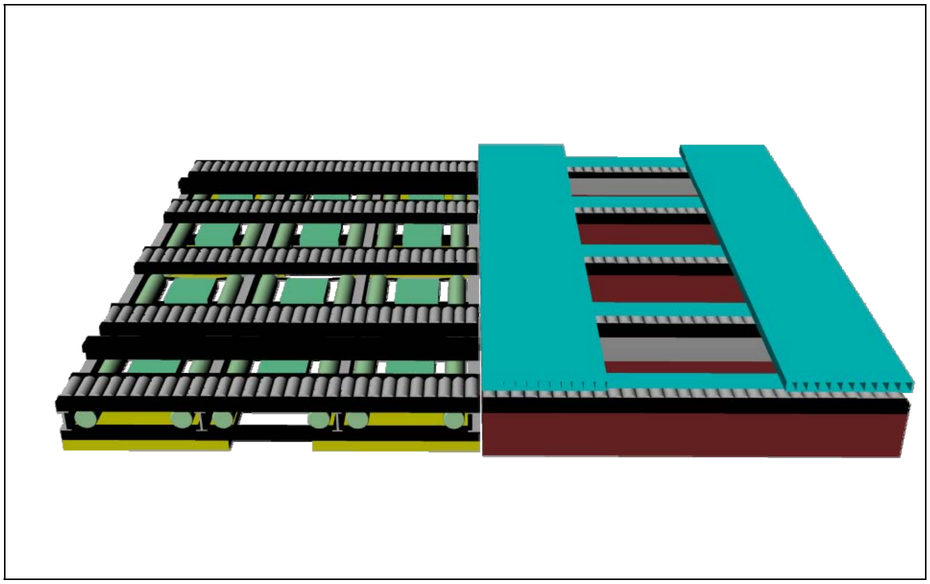


Figure 32: The following three images represent the transfer of a storage plate to an empty storage space. This process is accomplished using a system of LSM tracks and rollers.

3.3. Detailed Component Description

3.3.1. System Layout

Layout

The vehicle storage area will consist of rows of vehicles and aisle ways to access the vehicles. Ideally, the vehicle storage area would consist of one aisle for every two vehicle-storage rows. A diagram of a sample layout can be seen in FIGURE 33.

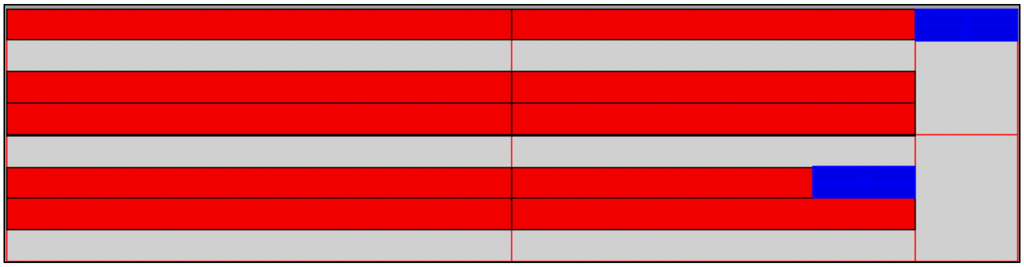


Figure 33: This figure shows the layout of the vehicle storage area. The red areas represent where the vehicles will be stored and the gray areas represent aisle ways. The blue rectangles represent elevators to the different levels of the storage area.

This configuration would allow for 100% selectability because every vehicle in storage can be accessed from an aisle at any time. At the end of the storage area there will be two elevators capable of moving from the top deck of the ship to the lowest level of storage. The position of the elevators will be as seen above in FIGURE 33. The elevator's location would ideally be near the middle of the ship. This situation is ideal because TEU containers will be stored in the vehicle storage area and the easiest place to transfer a TEU from one ship to another is near the middle of the ship. Having the elevators in the middle allows for the containers to be placed directly in the storage area when they are transferred from one ship to another rather than having to move the containers to the elevators once they are on the ship. The elevators position will be staggered to allow for movement between aisle ways by an air pallet coming from either elevator. If the elevators were next to each other and one of them was disabled, several of the vehicle storage rows would be unreachable until the elevator was fixed. This scenario is illustrated below in FIGURE 34.

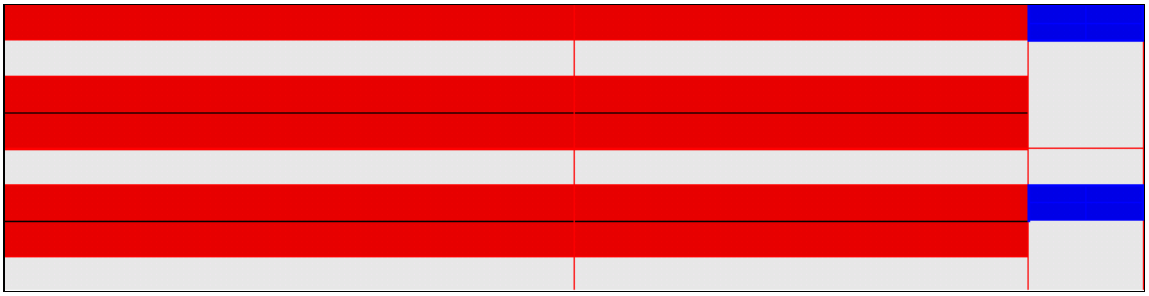


Figure 34: This image shows the vehicle layout if the elevators were to be placed parallel to each other.

A solution to the problem of placing the elevators next to each other requires leaving extra space at the end of the storage rows to allow for the air pallet to traverse the storage rows without elevator interference. An illustration of this configuration can be seen below in FIGURE 35. However, this configuration would not be as space efficient as if the elevators were staggered because of the extra space that is required at the end of the storage area.

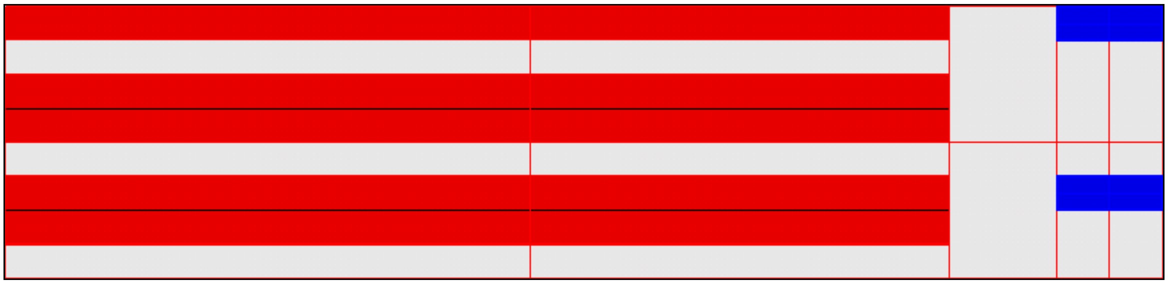


Figure 35: This image shows the vehicle layout if the elevators were parallel but allowing extra space for the vehicles to traverse to different aisles of the deck.

Another important characteristic of the elevator's position is that they are located at the end of the vehicle storage area, preferably in the middle of the ship. This position of the elevators is desirable to allow for vehicle to be transferred from the deck of one ship to the deck of the storage ship. Also, the water and POL containers that will be stored in the vehicle storage area are transferred to the ship via the top deck and require a means to reach the vehicle storage area. This position of the elevators takes this into consideration and provides a method to transfer the containers below deck to the storage area. Transferring the vehicles and containers from the deck of one ship to the deck of the storage ship is a difficult process, and placing the elevators in the middle of the ship allows for the most space to place the vehicle or container directly on the elevator. The disadvantage of placing the elevators in the middle of the ship is that when vehicles enter the ship through the rear door and are placed on an air pallet, it will take more time to reach the open storage space on another deck because the elevators are not directly at the entrance of the ship. However, placing the elevators at the middle of the ship also provides redundancy because the elevators can be accessed and used by the dry store area if needed, which would be located on the other half of the ship.

3.3.2. Air Pallets

The purpose of using air pallets within the vehicle storage system is to move large vehicles around the storage area relatively easily without having to drive them. The air pallet is the vehicle, which will move the vehicles and corresponding storage plates around the storage deck. When designing the air pallet several factors need to be considered including:

- Structure
- Air Bearings
- Motion
- Power

Structure

Each 20×12.5 ft air pallet will consist of sixteen 30×30 in. air bearings that are connected together by 4×4 in. structural tubing and 8 in. I-beams. The structure of the air pallet can be seen below in FIGURE 36. The yellow areas represent air bearings, the red cylinders represent rollers, and the green cylinders represent air tanks.

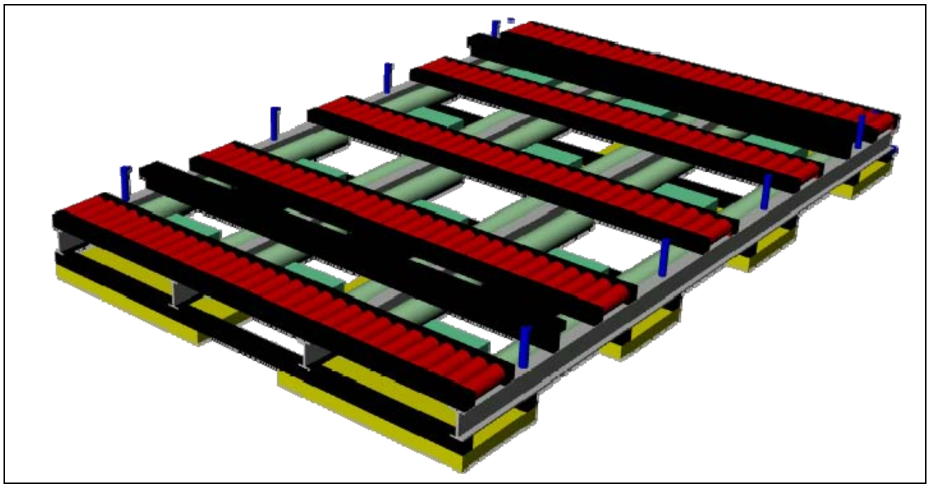


Figure 36: This figure shows the air pallet structure.

As can be seen from the above figure, in order to assist in the motion of the storage plate to the storage rack there will be rollers located on top of the air pallet. These rollers will line up with the rollers in the storage rack and will also line up with the 4×4 in. structural tubing on the bottom of the storage plate. There will be five rows of 3 in. diameter, 5 in. long rollers supported on both sides by 4×4 in. structural tubing.

There will also be two LSM tracks to power the movement of the storage plate to the storage rack. These LSM tracks will line up with the corresponding LSM tracks located on the storage racks to allow for easy transfer of the storage plate between the air pallet and storage rack. There will also be a space in the middle of the air pallet running the length of the 20ft axis to accommodate an LSM track. This LSM track will be used to move the air pallet around the deck of the storage area and will be discussed in a later section.

The LSM tracks and rollers will rest on top of four 8 in. tall I-beams that are each 20 ft long. The purpose of the four 8 in. tall I-beams is to distribute the large mass of the M1A1 tank. The 8 in. tall I-beams will rest upon eight 2×2 in. pieces of structural tubing that run along the 12.5 ft axis. These eight 2×2 in. pieces will be used as the connection point for the air bearings and the spacing of the eight 2×2 in. pieces is shown above in FIGURE 36. The reason two 2×2 in. pieces of structural tubing are connected to the end of each air bearing is to distribute the load more evenly on the bearing. For the air bearing to operate properly, it is important to distribute the load as much as possible about the center of the bearing. Therefore, it would be ideal to place one piece of structural tubing in the center of the air pallet. However, by placing a piece of structural tubing in this position, the ends of the I-beams are not supported and a cantilevered load is created at the end of the pallet. This cantilevered load will put a lot of stresses on the I-beam when the vehicle is driving on and off of the storage plate. By placing the two pieces of tubing on the air bearing, the load will be distributed while still supporting the end of the I-beams and not allowing a cantilevered load at the end of the air pallet.

Once the structure for the air pallet was established, it was analyzed to confirm that it would be able to support the load of a vehicle resting on a storage plate. In order to accomplish this analysis, ANSYS was used to run simulations on a 3-D model. The 3-D model used in the simulations can be seen below in FIGURE 37.

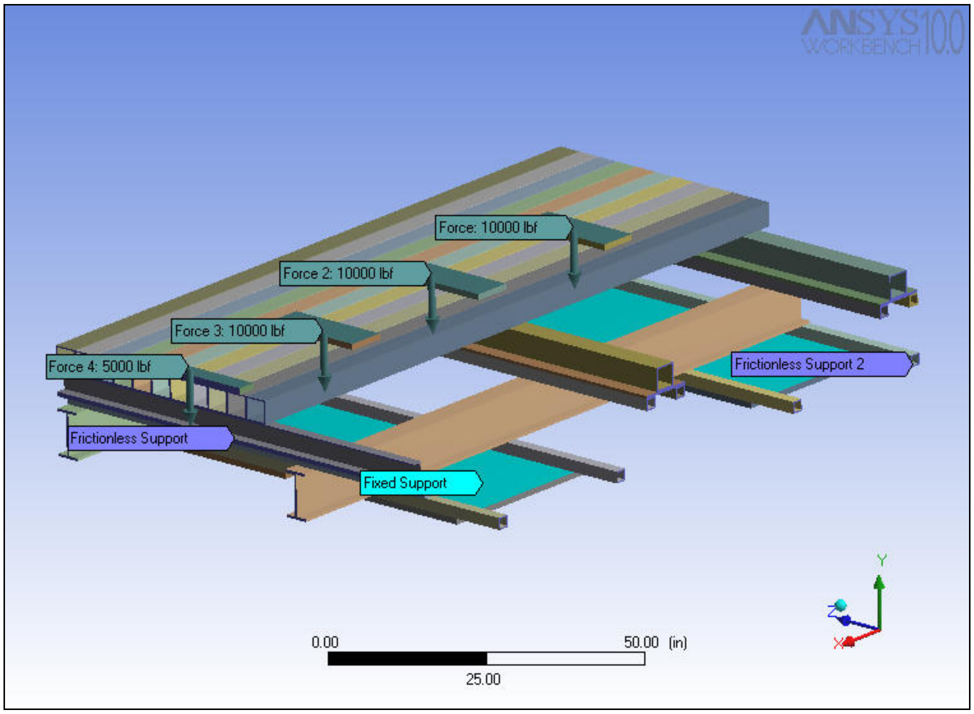


Figure 37: This figure shows the air pallet model used to test the loading effect of a vehicle, connected to a storage plate, resting on the air pallet

There were several assumptions made in the simulation of the air pallet supporting the load of a storage plate and M1A1 tank. In order to reduce the simulation time of such a large assembly with many nodes and elements, a quarter model was created that uses frictionless supports on both of the cut sides of the model in order to represent the other ¾ of the model. This assumption is possible because the model and the load are symmetric along the x and z-axis with respect to the coordinate axes shown in the figure. Also, the tops of the air bearings were fixed such that there would be no deformation across them. This does not represent the real case and is assumed because the material properties of the air bearings are unknown. As a result, the properties of the air bearings are not assumed and are omitted from this analysis. Another assumption that was made involves the rollers that act as a connection point between the air pallet and the storage plate. The rollers were modeled as rigid blocks with pins connected to the 4×4 in. structural tubing. By making this assumption, the deflections of the rollers are neglected, which may change the overall deflections and stresses on the air pallet. Using these assumptions and the dimensions discussed above, the deflections of the air pallet were analyzed and can be seen in FIGURE 38 below.

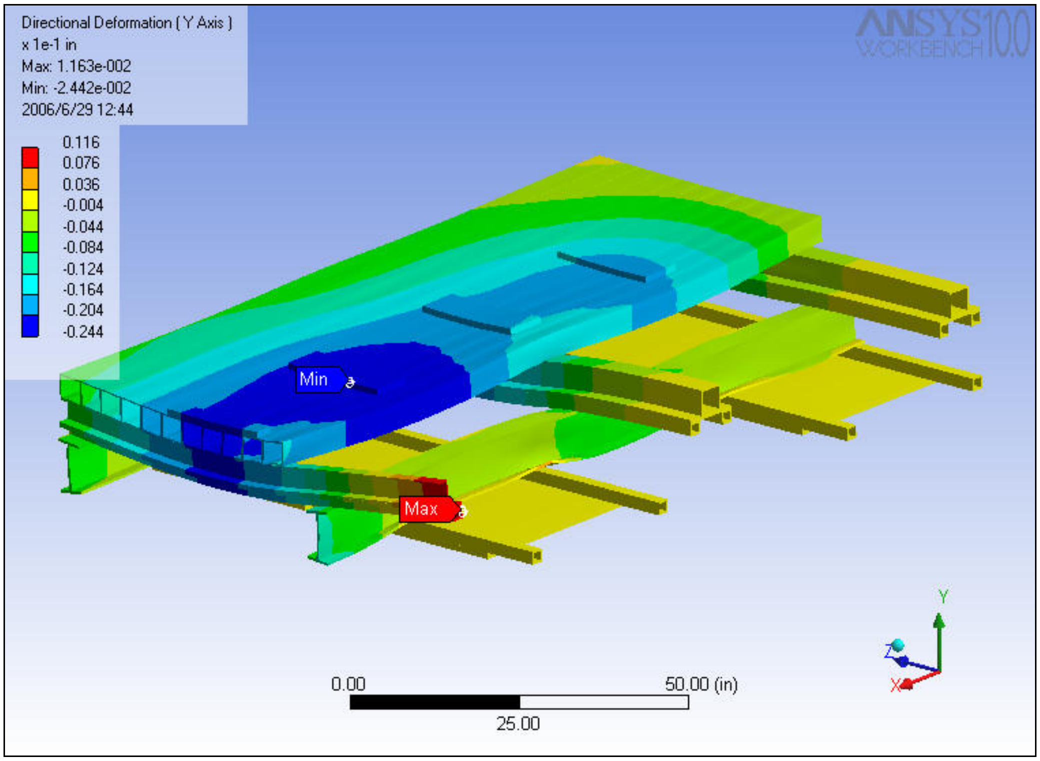


Figure 38: This figure shows the y-axis deflections experienced by the air pallet when subjected to the load of a storage plate and M1A1 tank.

As can be seen from FIGURE 38, the deflections of the air pallet are small and on the order of 10^{-2} in. However, these deflections do not take into account the deflections of the roller and also the deflections of the air bearings. However, these assumptions should not significantly alter the deflection seen by the air pallet.

Another significant feature of the air pallet is the ability to connect multiple air pallets together. This ability is required to accommodate some of the larger vehicles that are used by an MEB due to the fact that a standard size air pallet is used. The pallets will be connected together using a locking pin system, each pallet having locking pins on one end, and receiving sockets on the other end. The pins need to be strong enough to ensure a moment is not created between the air pallets. A moment at the center may limit the ability of the center air bearings to operate and therefore limit the movement of the air pallets. A close up image of the locking system between two air pallets can be seen below in FIGURE 39.

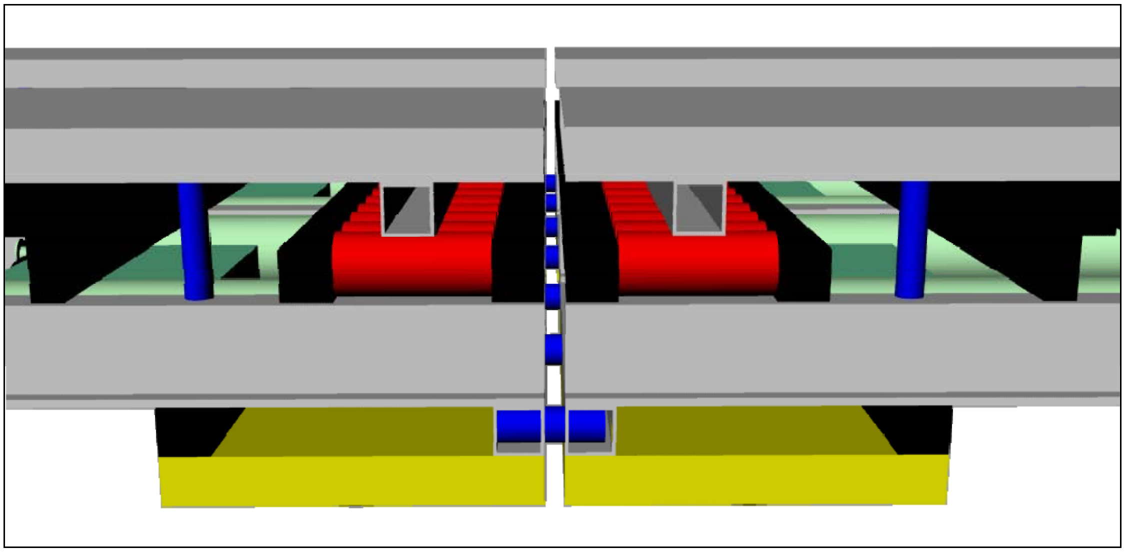


Figure 39: This image shows how two air pallets can be connected together through the use of pin locks. The horizontal blue cylinders represent the pin locks below.

Air Bearings

The air pallet will operate by forcing low-pressure air at a high flow rate through the air bearings providing a thin cushion of air under the pallet. Air bearings consist of a steel support plate that rests on a rubber bladder. In order to produce the thin film of air, air is pumped into the bladder at a constant rate and at a constant pressure. As a result, the thin cushion of air provides a relatively frictionless surface that allows for the easy movement of large, heavy objects.

The number of air bearings and amount of compressed air that is required depends on the weight of the object being moved and also the weight of the air pallet and storage plate structures. In this case, the air pallet was designed to support the heaviest vehicle in an MEB, a 70-ton M1A1 tank. The total weight that the air bearings will be required to support also includes approximately 2 tons for the air pallet structure and 3.2 tons for the storage plate structure bringing the total weight to approximately 75 tons (150,000 lbs). Different types of air bearings were researched to determine if it would be possible to support such a large load. Hovair Systems Incorporated from Kent, Washington does produce a series of air bearings that would be sufficient to support a 75-ton load. In order to support this total load, sixteen 30×30 in. bearings that each support 12,000 lbs will be more than sufficient. Each air bearing would require 18 CFM (cubic feet per minute) of air at 26 psi. As a result, an air tank and air compressor would need to be present on the air pallet to support each of the air bearings. The air tank and compressor can be seen below in FIGURE 40.

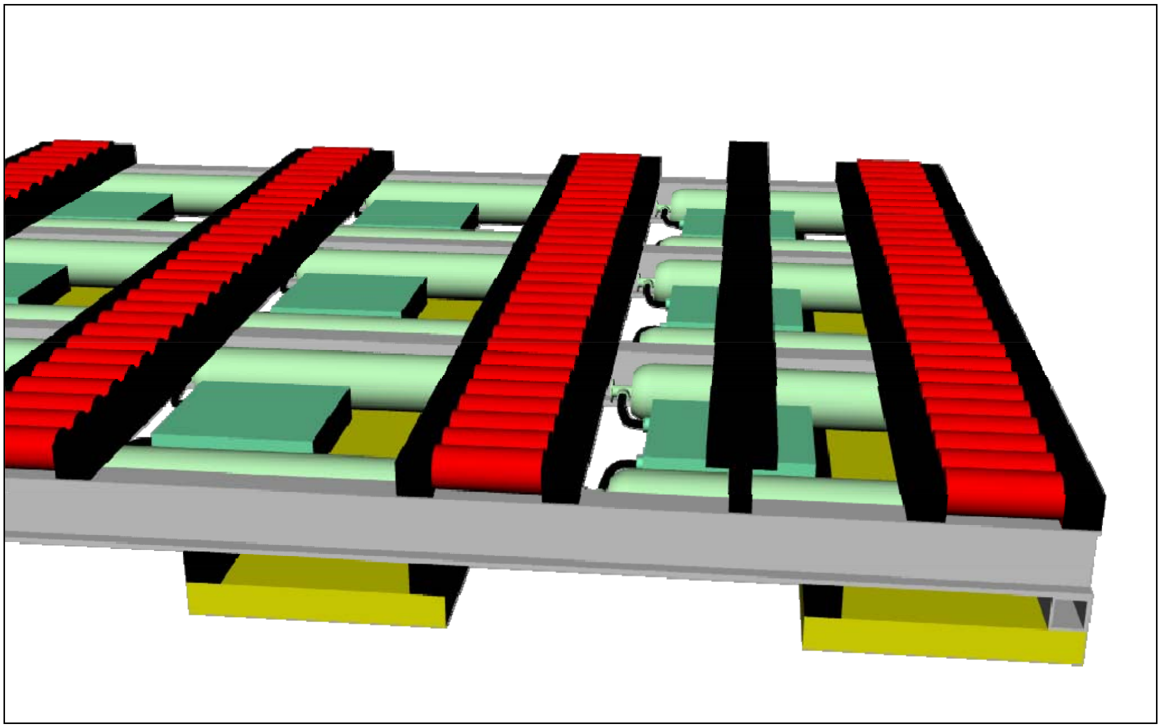


Figure 40: This figure shows the air tanks and compressors for each air bearing. The yellow boxes represent the air bearings. The green, cylindrical, storage tanks are connected to a green compressor by hoses.

One important requirement of the air bearings is that the bladder remains in contact and creates a seal with the floor at all times. The air bearing cannot travel across large cracks or deformations in the floor surface because the seal will be broken, the constant pressure within the bladder will be lost, and the air bearing will no longer be able to maintain the thin cushion of air required for movement of the heavy object. However, there have been experiments run with air bearings showing that small deformations or cracks in the floor can be traversed by the air bearing without causing significant impairment of the bearing's motion. The United States Marine Corps ran several tests using air bearings showing that the air bearing could move over vehicle tie downs and deck seams without significant disruption (Bickel et al. 2005). However, in order to achieve motion over these obstructions, increased airflow to the air bearing was required. As a result, the surface of the vehicle deck will have to be relatively smooth with little deformations.

If some deformations in the deck cannot be avoided, there are several methods to account for them and allow for uninterrupted movement of the air pallet. One solution is redundancy, which has already been incorporated in the air pallet for this design. By using sixteen air bearings that can each support 12,000 lbs the total load that can be supported is 192,000 lbs whereas the total load that it is required to support is only 150,000 lbs. Therefore, three air bearings can lose pressure from going over a deformation and the air pallet will not be interrupted when transporting the load. Also, if more than three air bearings lose pressure the air pallet will only be a little more difficult to move and will not stop completely. One solution to the losses of pressure in several air bearings is to design the compressors so they can detect a loss of pressure in an air bearing and increase the amount of air flowing to that air bearing. However, this would require a complex computer system to monitor the pressure in each air pallet and decide when increased pressure is necessary.

Movement and Power

The movement of the air pallet around the storage deck and also the movement of the storage plate to and from the air pallet will be driven by linear synchronous motors (LSM). A LSM is a type of linear electric motor that works similarly to a regular DC motor. The system is constructed by essentially taking the internal armature of an DC motor and laying it flat on a surface that the vehicle will be traveling across. This surface will act as a track for the vehicle as it travels down the vehicle aisles. The outer loop of the DC motor, consisting of a rare earth magnet, is then laid out flat on the bottom surface of the air pallet. This component of the LSM system will consist of a single connection point located in the center of the air pallet. The connection point will consist of the rare earth magnet, and rollers on both sides that will run along the LSM track in the deck. An image of the connection point can be seen below in FIGURE 41.

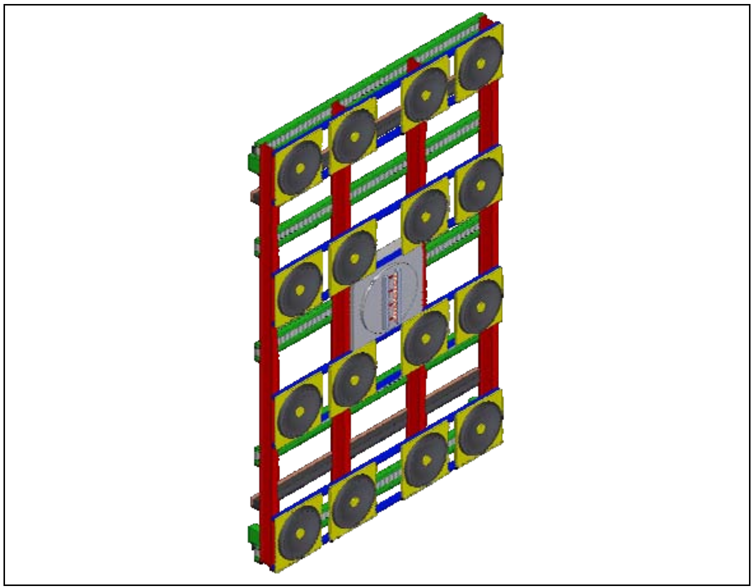


Figure 41: This figure shows how the air pallet is connected to the LSM track within the storage area. The gray box in the center of the image represents the connection point between the LSM track and the air pallet.

The track of the LSM has many small sections that can be turned on and off at specific times and the magnet on the air pallet has a constant polarity. The LSM system operates by turning the different sections of the track on and off to attract and repel the magnet in the air pallet allowing the air pallet to move up and down the track. This process can also be used to maintain the position of the air pallet when performing the transfer of the storage plate to and from the storage rack or to secure the air pallet during high sea state conditions. The air pallet lowers to rest on the deck before the transfer process occurs. However, it is important that the space between the rare earth magnet and track be very small in order for the system to operate effectively. If the space between the two components becomes too large, motion of the air pallet will cease. The same LSM system is used for the transfer of the storage plate to and from the storage rack, with the LSM track located on top of the air pallet and the rare earth magnet located on the bottom of the storage plate.

The power for the locking systems and also the secondary LSM on the air pallets will come from the primary LSM tracks on the deck of the ship through induction. This situation is desirable because direct power to the air pallets through a system of wires would be extremely complicated and there is a high degree of probability all of the wires would become entangled. If induction through the primary LSM tracks is not sufficient to power the air pallet, a secondary track can be added to the deck to provide direct power. This secondary track would be similar to the direct power systems used by some trains where wires are built into the track and the air pallet has a connection point that travels along the wires. An analysis of the energy requirements is located in section 4.3.7.

3.3.3. Storage Plates

An essential part of the vehicle storage system is the storage plates that each vehicle will rest on in storage. The vehicle will enter the ship and drive on to a storage plate, which is located on top of an air pallet. Once the vehicle is attached to the storage plate, the air pallet will take the vehicle to the specified storage space and transfer the storage plate with the vehicle attached to the storage rack. The air pallet will then return to the entrance of the storage area to transfer another storage plate with corresponding vehicle to the storage area. The following sections discuss the characteristics of the storage plates including:

- Structure and Material of the Plate
- Dimensions of the Plate
- Connection of Plate to Air Pallet
- Storage of the Plates

Structure and Material

The structure and material of the storage plate must be designed to support the largest vehicle in an MEB, a 70-ton M1A1 tank. The storage plate must also be lightweight, durable, and low cost. As a result, two different plate configurations were explored and analyzed to see if they could support the required load. The two configurations that were analyzed are listed as follows:

- A 20 ft long, 12.5 ft wide, and 1 in. thick steel plate supported by rollers
- A steel structure consisting of 4 in. structural tubing

20 ft long, 12.5 ft wide, and 1 in. thick Steel Plate Supported by Rollers

Originally, it was thought that a 20 ft long, 12.5 ft wide, and 1 in. thick metal plate would be sufficient to support a 70-ton load. The decision as to which material to use for the plate was based on the cost and strength of the plate. It was determined that steel and aluminum were the best two possible materials to use for the plate. The advantage of steel is that it has a high yield strength and is also relatively inexpensive. The disadvantage of using steel is the weight involved in using such a large piece of solid material; a 20 ft by 12.5 ft by 1 in. piece of steel would weight approximately five tons. Aluminum, rather, is much less dense than steel and an aluminum piece of the size required for the storage plate would only weight approximately one and a half tons. However, the disadvantage of using aluminum is the high cost and lower strength performance when compared to steel. One reason that aluminum is more expensive than steel is the fact that a single sheet of aluminum is not produced to fulfill the size requirements of the storage plate. As a result, several smaller sheets of aluminum must be welded together to form a larger sheet. Not only is this extra production more expensive, but it also limits the strength of the overall plate. There are certain aluminum alloys that have comparable yield strengths to steel, however, the welds that would be required to make such a large plate of aluminum are not as strong as steel and as a result the plate would not be able to perform its function without failing. As a result, it was decided that steel would be the more practical material to use for the plate.

Once the material for the storage plate was decided upon, the next step involved analyzing the plate to see if it could handle the 70-ton load. In order to accomplish this task, a model was created in ANSYS to simulate the actual load conditions on the plate. The model is composed of a 1ft section of the plate supported by rollers as seen below in FIGURE 42.

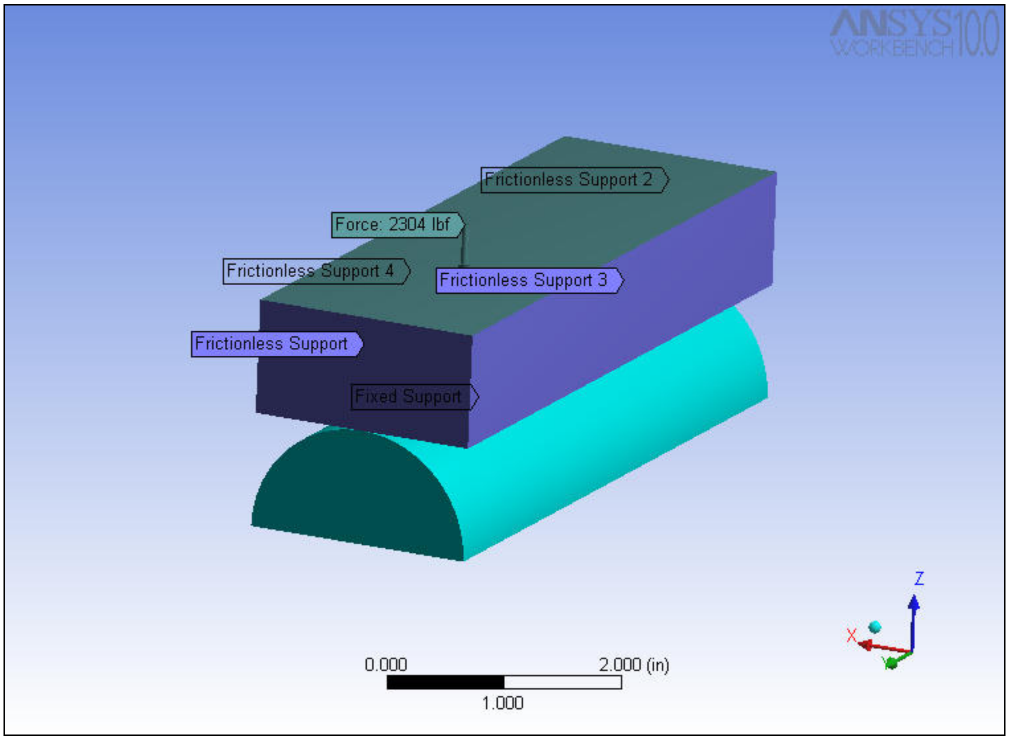


Figure 42: This model is a 1ft section of the steel storage plate used to assess the feasibility of the design.

There were several assumptions made during the simulation of the plate supported by rollers. For the simulations, the rollers were made up of cylinders, which have fixed sides. This arrangement means that the rollers do not deform and therefore there may be higher stress as well as larger deformations in the plate. Also, the model takes into account the footprint of the 70-ton M1A1 tracks. In order to accomplish this, it was assumed that only two individual tracks from the total tracks, measuring 17.6 inches in the y-direction by 6.5 inches in the x-direction, are present on the 1ft section (Note: the axis orientation is located in FIGURE 42). The two individual tracks are parallel to one another and spaced 66 inches apart. The load of 10,000 lbs that was placed on each of the footprints was determined by dividing the total weight of tank (140,000 lbs) by the number of tracks (14). Using these dimensions, the deflections of the plate were calculated and can be seen graphically in FIGURE 43 below.

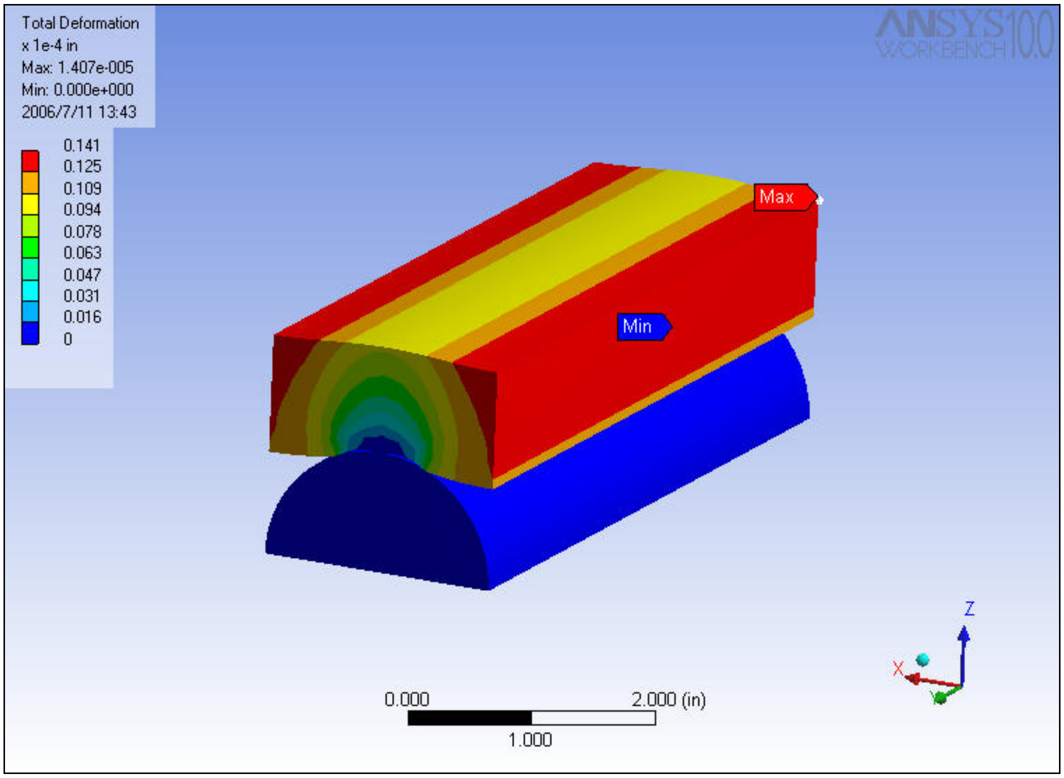


Figure 43: This figure shows the deformation on a 1ft cross section of the 20 ft long, 12.5 ft wide, and 1 in thick steel plate supported by rollers.

As can be seen from FIGURE 43, the deformations experienced by the steel plate are very small and are on the order of 10^{-5} in. As a result, it would seem that using a 1in thick steel plate would be sufficient to support the load of an M1A1 tank. However, the model that was tested does not take into account dynamic loading of the plate and also the full dimensions of the plate. For example, there may fatigue issues when continuously loading and unloading a 70-ton vehicle from a 20 ft long steel plate. Another consideration in this design of the storage plate is that there is a large number of rollers required to support the plate on the air pallet and in the storage rack itself. For example, if a 48 in long roller were used, in order to accommodate the 300 anticipated storage spaces as well as several air pallets a total of 75,000 rollers would be required. Without these rollers, the deflection of the plate when carrying a load becomes much larger. Although the 1in thick steel plate does not experience a significant amount of deflection, after considering the number of rollers as well as the maintenance required to keep the rollers in operation, it was decided that a different design for the storage plate must be found.

Steel Structure

The idea to use a steel structure for the storage plate was generated after speaking with several individuals with expertise in materials and structures. A structured plate rather than a large sheet of metal provides more strength and durability than using a sheet of metal. Also, a structured plate will distribute the 70-ton load more effectively than a large sheet of metal. The number of required rollers for the structured plate would be approximately the same for the structured plate, however, they would be smaller in width and would be able to distribute the load more efficiently. Steel was chosen as the material of the plate for the same reasons discussed in the previous section; although it is heavier than aluminum, steel is less expensive, has a higher yield strength, and also has higher strength in welding than aluminum. A representative image of the steel structured plate can be seen below in FIGURE 44.

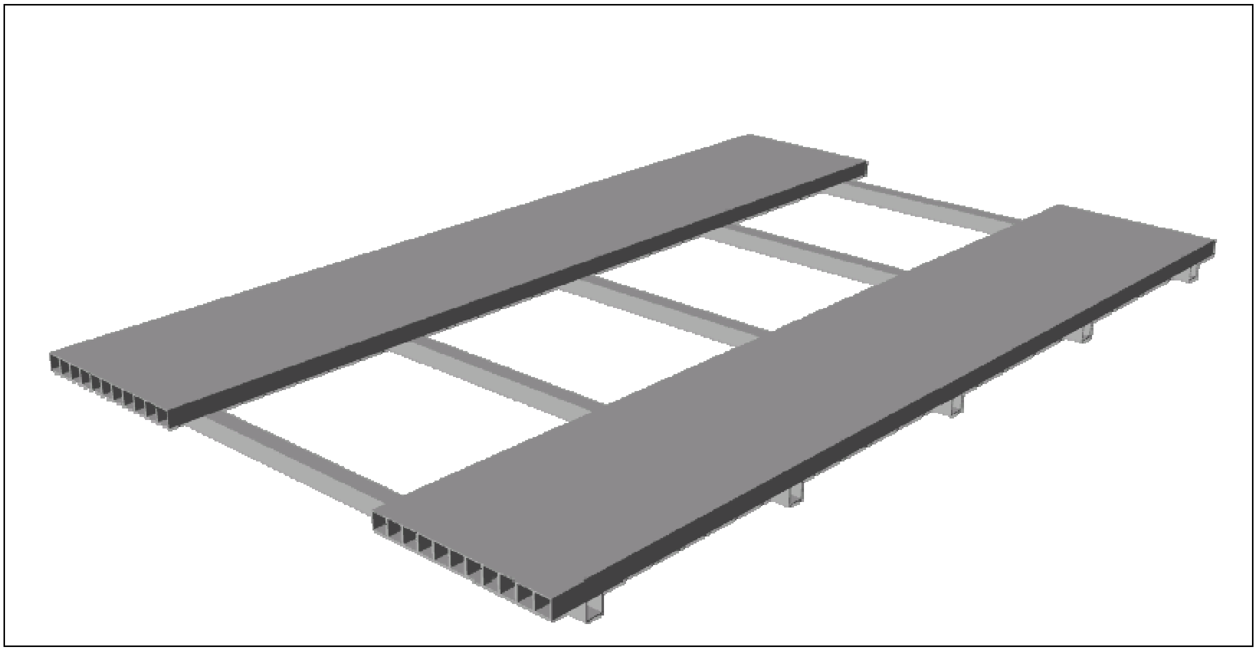


Figure 44: This figure shows the structured storage plate from several different perspectives.

As can be seen from the picture, the structure of the storage plate would consist of 4 in structural tubing. The dimensions of the structured pallet would be 20 ft long by 12.5 ft wide, similar to the flat sheet of steel design. There would be eleven 4 in pieces on each side of the 12.5 ft section to support the vehicle tracks and 62 in of open space in the center. The 20 ft structural tubing sections would be supported by five 4 in pieces that are 12.5 ft long and are evenly spaced across the 20ft section. These pieces will rest on the rollers on the air pallet to allow for the storage plate to be transferred from the air pallet to the storage rack.

This configuration of structural tubing was utilized for several reasons. Utilizing the eleven pieces of structural tubing on both sides provides enough surface area for each vehicle required for an MEB to drive on to the storage plate and have all of its weight distributed. The open space in the center of the plate can be left open because it is structure that would not be supporting a load for any of the vehicles that may be stored on the plate. The advantage of leaving this space open is that the overall weight of the plate is reduced. Utilizing this configuration of steel structural tubing would only weight approximately 3.2 tons whereas using a 1in thick sheet of steel would weight approximately 5 tons.

In order to calculate the feasibility of using a steel structure to support the weight of a 70-ton vehicle, a model of the structure was created and analyzed using ANSYS. This model was subjected to the same loading conditions as the model of the 1in thick sheet of steel. Two main models were used, one with fixed bases of the 4in structural tubing, and another with a set of rollers, with the faces of the rollers fixed so that the rollers did not deform. These two models can be seen below in FIGURE 45 and FIGURE 46. Again, with rollers that deform there should be a change in the stresses and deformation, however this is what is felt to be the best approximation without specific knowledge of the rollers. Also this assumption simplifies the model since the rollers do not deform, and are not hollow, or have pins/shafts, etc.

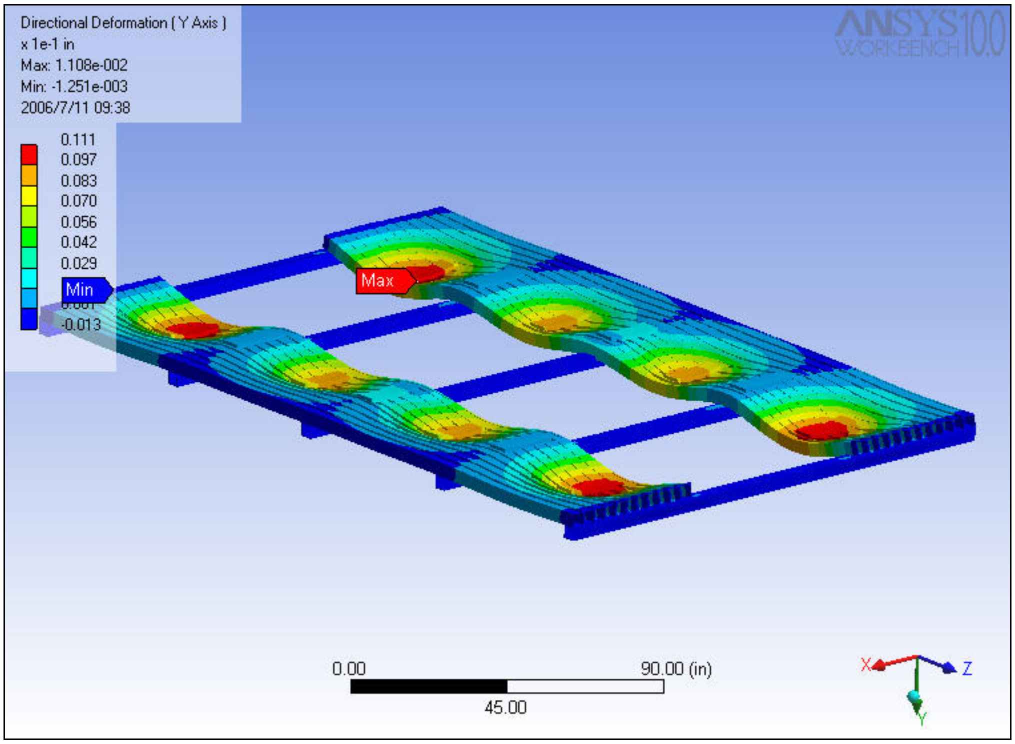


Figure 45: This figure shows the 4in structural tubing storage plate model using fixed bases.

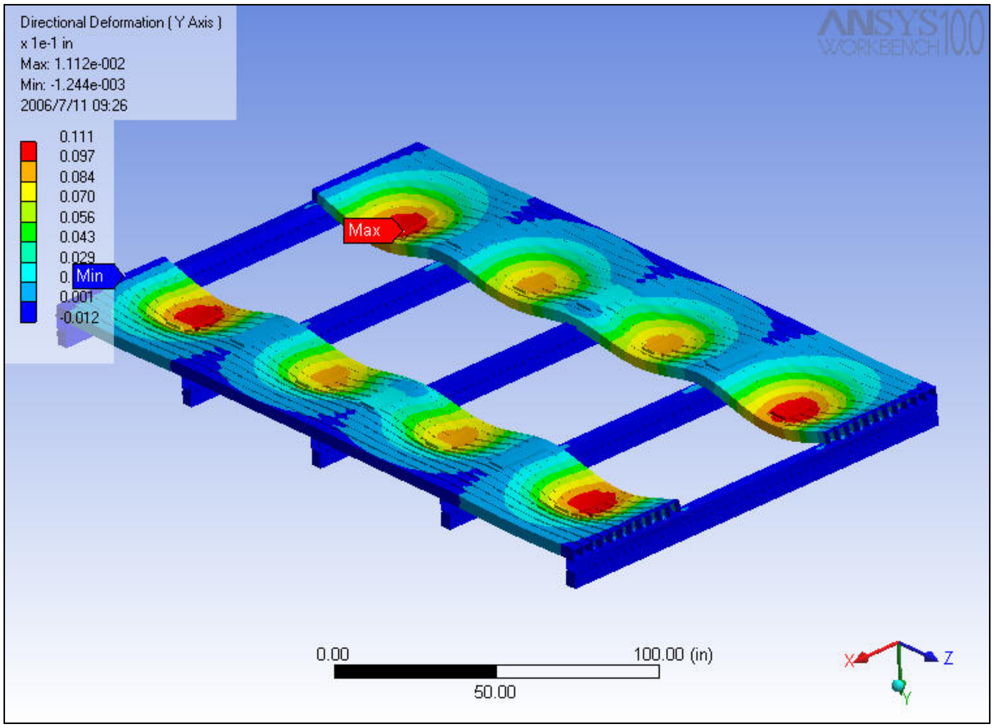


Figure 46: This figure shows the 4 in structural tubing storage plates using fixed rollers. The rollers are represented by the second layer of structural tubing that is not present in FIGURE 45.

As can be seen from the figures, the deformation of the plate when loaded with a 70-ton tank is on the order of 10^{-3} in. Although this deformation is greater than the deformation of the 1in thick steel sheet when subjected to the same load, it is still a very insignificant amount of deformation. As a result of this small deformation and the fact that the structured storage plate is lighter than the 1 in thick steel plate, it was decided that the structured storage plate would be the best design for the vehicle storage system.

Dimensions

Length

An important design parameter to take into consideration when designing the storage plates is the storage efficiency of the vehicle storage area. The storage plates should be designed to take into account the varying sizes of the vehicles that will be stored so that one plate is not much longer than the vehicle being stored on it. If this were the case the usable storage area of the vehicle storage system would be diminished and less vehicles could be stored. There are several methods that could be employed to account for the issue of a large difference between vehicle size and plate size. These methods include:

1. Using a specific plate size for each type of vehicle.
2. Using a single standard plate that is large enough to fit the largest vehicle.
3. Using a smaller sized standard plate that can be connected together to accommodate the

larger vehicles.

4. Grouping the vehicles together by weight and size and choosing a standard plate for each group. This method could be accomplished by either using a single large standard plate or using smaller standard plates that connect together for each group.

There are several advantages and disadvantages associated with the different plate sizes and configurations. Using a specific size plate for each type of vehicle would allow for maximum storage capacity because each plate will be just large enough to fit each type of vehicle; there would not be the case where a plate was longer than the vehicle that is attached to it. However, a disadvantage of employing this plate design is that there are only one or two vehicles for certain types of vehicles, so if the one or two plates that can be used to move these vehicles is damaged in some way, there is no way to move the vehicle. Also, the interchangeability of the plates is limited and they can only accommodate the vehicle that the plate for which the plate was designed.

Standardization of the storage plates alleviates the interchangeability issue involved with using a plate specific to each type of vehicle. A standard size air pallet could be used to store every type of vehicle and if one of the plates is damaged, another plate can be used in its place. The main disadvantage to using a standard size air pallet involves the excess space produced when a vehicle is smaller than the standard storage plate. For example, if a standard size storage plate of length 20 ft is used for a vehicle that is 16 ft in length, there is 4 ft of excess space that is not used. The excess space produced by all of the vehicles in the vehicle storage area could add up to a significant amount of storage space that is not used. There are several standard plate size configurations that could be used to minimize the amount of excess space on the plate. The first involves using a standard size plate that is large enough to accommodate the largest vehicle. In this case, placing multiple smaller vehicles on a single storage plate can reduce the excess space. The disadvantage of this plate design, however, is that selectability of the vehicles is reduced if there is more than one vehicle attached to a single plate.

Another method of utilizing standardized storage plates involves using smaller plates and connecting them together based on the size of the vehicle. For example, if a standard storage plate of length 4 ft is used and the vehicle is 14 ft in length, four plates can be connected together to accommodate the vehicle. The disadvantage of this design, however, is that if the wheelbase of the vehicle is placed on the connecting point between two plates, a large moment could be created that disrupts the system.

A combination of using a single standard plate and using a plate designed specifically for each vehicle could also be utilized. In this situation, vehicles of relatively the same length would be grouped together, and each of these groups would have a standard plate size. This type of plate design would be more efficient then using a single standard plate size at minimizing the amount of excess space on the plate. However, a disadvantage of this design is that the interchangeability is reduced because different groups could not use another group’s set up plates.

It was decided that interchangeability was more important then the amount of storage space that is utilized within the vehicle storage area. Therefore, standardized storage plates would be used to attach the vehicles to for transportation in the storage area. In order to determine which of the standard plates provides the optimal performance, the designs were evaluated using the following evaluation criteria:

- Minimize excess plate space
- Minimize the number of connections between plates
- Minimize plate storage area
- Maximize Selectability

Maximizing the vehicle storage space efficiency is dependent on the amount of excess plate space; the more excess plate space there is the lower the storage space efficiency. In order to determine which storage plate design produced the smallest amount of excess space several calculations were performed in Excel for different size plates. The calculations add up the total plates necessary to store all of the required vehicles and subtract the total length of the vehicles stacked end to end. This procedure produces the amount of excess space on each plate. These calculations also take into account if multiple vehicles can be stored on one plate. For example, if a vehicle is 9 ft in length and is stored on a 20 ft plate, instead of calculating that only one vehicle can be stored on the plate with 11 ft of excess space, Excel calculates that two of the vehicles can be stored on one plate with 2 ft of excess space. The results of these calculations can be seen below in FIGURE 47.

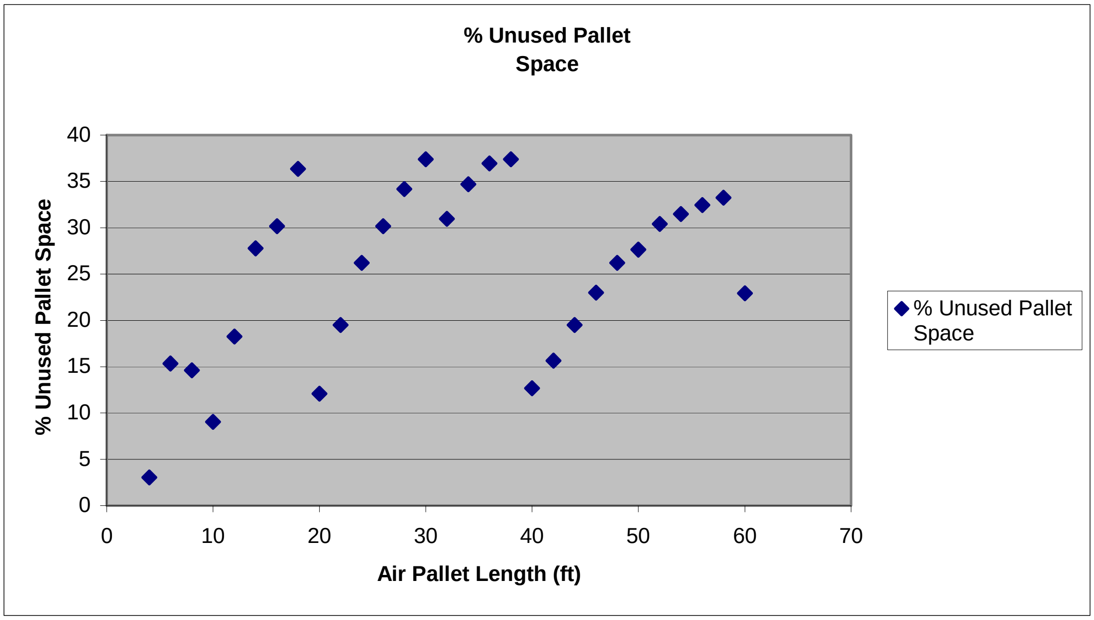


Figure 47: This figure shows the % of unused plate space vs. the air pallet length utilized.

As can be seen from the graph, there are four standard size air pallets that minimize the amount of excess and unused plate space; 4 ft, 10 ft, 20 ft, and 40 ft. There are several advantages and disadvantages associated with each of these plate lengths. For example, the 4 ft long plate provides the least amount of excess plate space. However, the 4 ft long plate also requires more connections between plates to make a large enough composite plate to support a vehicle. Therefore, the next step in determining the optimum plate size is to analyze the number of connections between plates.

Excel was used to calculate the number of connections between the plates. It is desirable to minimize the total number of connections between the plates for two reasons. The first reason involves the complications associated with connecting several storage plates to store one vehicle. For example, a vehicle that is 19 ft in length would require five 4 ft long plates to be connected together. Connecting this number of plates together would require an intricate locking system between the plates to ensure the larger composite plate is rigid. The second reason is related to the first and the rigidness of the connections between the plates. A composite plate that has many connections may encounter the situation when a vehicles wheels fall directly on the connection between the plates. This situation can generate a moment on the storage plate and may compromise the rigidity of the composite plate and could also damage the air pallet that the composite plate rests on. A graph showing the amount of connections compared to the amount of excess plate space can be seen in FIGURE 48 below.

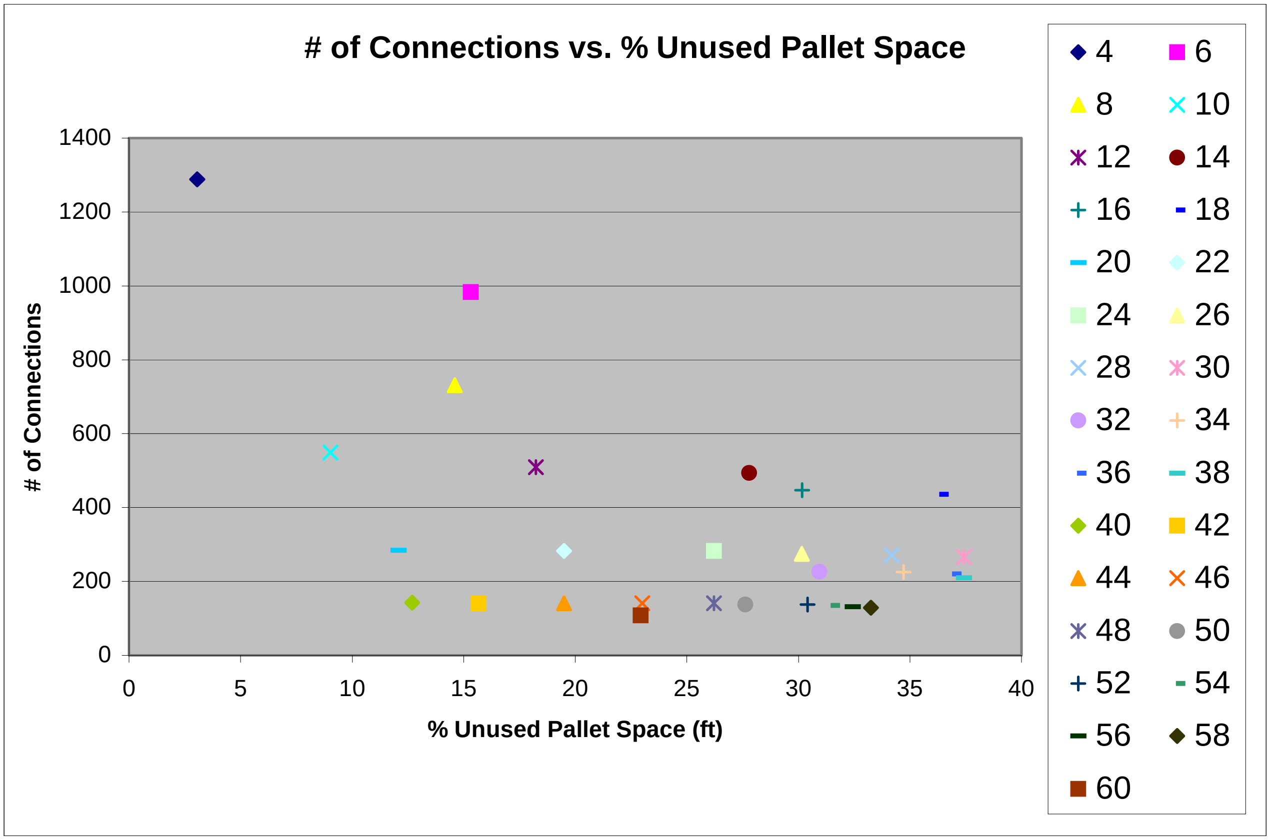


Figure 48: This figure compares the number of plate connections to the amount of unused plate space for different plate sizes.

As can be seen from the graph above, the smaller the individual plate size the more connections are needed to make composite plates large enough to store vehicles. As a result, the larger plates are desirable because they minimize the number of required connections to make composite plates. However, also evident from the graph in FIGURE 47 and also FIGURE 48 is that the larger the plate size, the more the percentage of unused plate space is. Therefore, a smaller plate with few connections is the optimal design for the vehicle storage area.

The final two evaluation criteria used in determining the optimum standard plate size were the storage area required for the plates and also the selectability of the plates. The storage area required by the plates effects the amount of storage space available for storing vehicles; the more area is required to store the plates the less area is available for storing vehicles. A graph of the total required storage area compared to the amount of unused plate space for each standard plate size is located below in FIGURE 49.

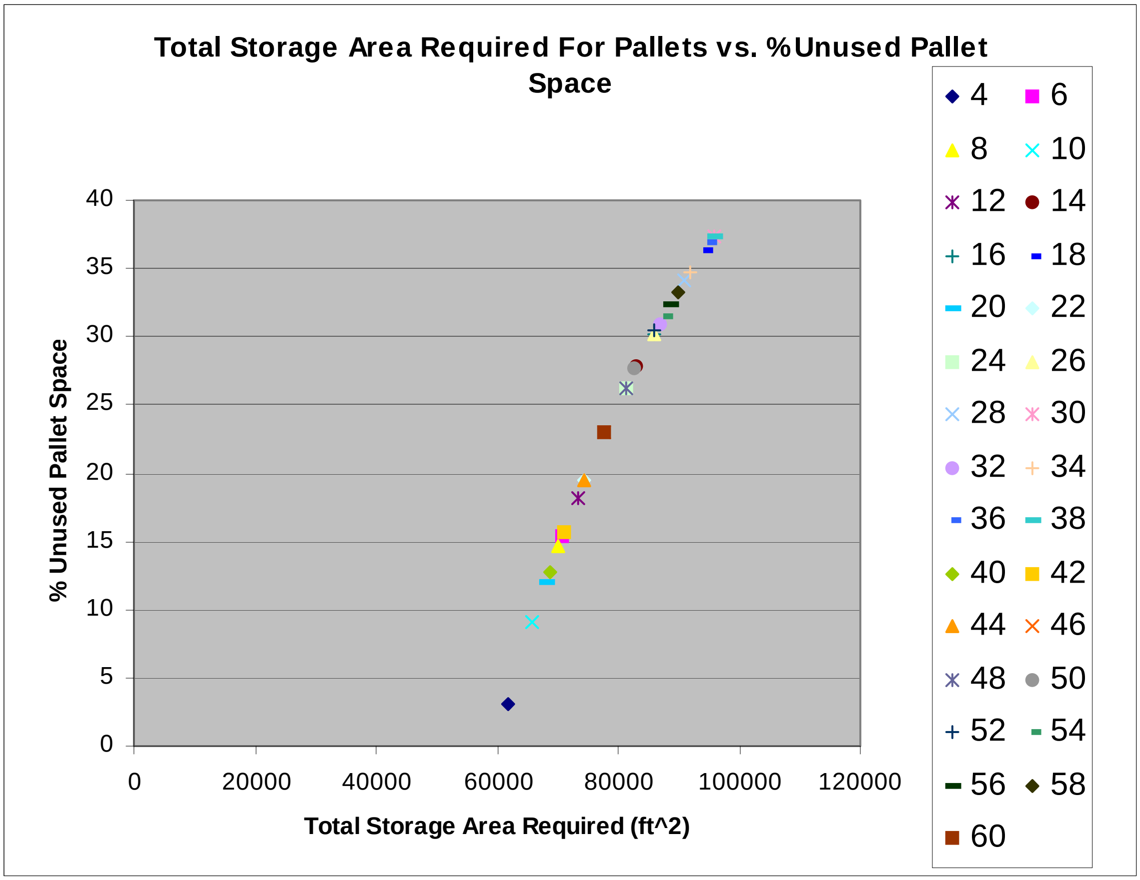


Figure 49: This figure shows a comparison between the amount of area required to store the standard plates and the amount of unused plate space.

As can be seen from the graph, as the standard plate size is increased the amount of storage area that is required to store the plates increases. Therefore, a smaller plate size is desirable because less plate storage space is necessary and more space can be devoted to storing vehicles.

Based on the evaluation criteria discussed above, standard plate sizes of 4 ft, 10 ft, 20 ft, or 40 ft were determined to be the best options for movement of vehicles within a vehicle storage system. There are several advantages and disadvantages of each of the plate size options. The 4 ft and 10 ft long plate options are the best options based on the criteria of minimizing the amount of excess plate space and the amount of storage area required for the plates. However, these two options require a lot of connections and therefore result in a more complicated system. Also, there is the potential for moments created on the storage plates causing damage to the air pallet system depending on if the wheels on the vehicles rest at a plate connection point. The 20 ft and 40 ft long plates offer a smaller number of connections when compared to the 4 ft and 10 ft plates. However, the 20 ft and 40 ft plates require more storage area for the storage plates themselves and also have a larger amount of excess plate space, although the amount of excess plate space is still relatively small. As a result of these findings, it was determined the 20 ft and 40 ft plates were the better options because they required few plate connections while also maintaining a low amount of excess plate space.

The decision of whether to use 20 ft or 40 ft plates was made on the basis of how many vehicles could be stored on each plate and selectability. A table showing the number of each vehicle that can be stored on either the 20 ft or 40 ft long vehicle is located below in TABLE 4.

Table 4: This table shows the number of each type of vehicle that can be stored on either the 20 ft or 40 ft long storage plate.

Vehicle	Pallet Size (ft)	
	20	40
M1A1	0	1
AAAV	0	1
M88A1	0	1
HMWVV	1	2
M198	0	1
LVS Mk48	0	1
M101A2	1	2
M390	1	2
LAV	0	1
FRKLFT	0	1
AVLB	0	1
MEWSS	0	1
MTVR	0	1
MRC	1	2
M9293/Q46	0	1
ABV	0	0
6Con Cont. (Water)	1	2
6Con Cont. (POL)	1	2

As can be seen from the table above, the 40 ft plate length has more than one vehicle stored on a single plate five times whereas the 20 ft plate does not have any instances where more than one vehicle is stored on a single plate. Any instance where more than one vehicle is stored on a single plate reduces selectability because in order to get one vehicle, two vehicles must be moved. As a result, because the 20 ft long plate does not have any instances where more than one vehicle is stored on a single plate, it was decided that this option for the storage plate length would best serve the selective vehicle storage system.

Width

The width of the storage plates was also designed to minimize the amount of excess space on the pallet. The width was also designed to be a standard size in order to limit the number of different plates that needed to be stored. As a result, the width of the plate was decided to be 12.5 ft, just larger than the widest vehicle. Using this width for the plate allows for the plate to be 100% adaptable to any vehicle that may be used by a Marine Expeditionary Brigade.

3.3.4. Storage Rack

The storage rack is designed to store the storage plates and corresponding vehicles. The design of the storage rack will be similar to the design of the air pallet except without the air bearings. A representation of a single space in the storage rack can be seen below in FIGURE 50.

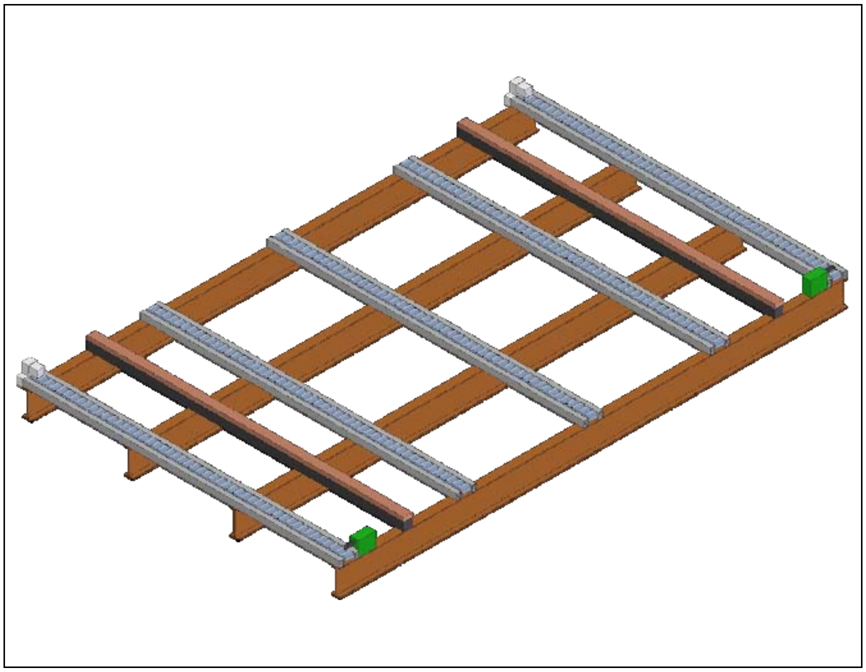


Figure 50: This figure depicts the storage rack that will hold the vehicle and corresponding storage plate in place. The storage rack is composed of a structure of steel, LSM tracks, and rollers.

The top of the rack will consist of rows of LSM tracks and rollers that line up exactly with the

LSM tracks and rollers on the air pallet. The purpose of the LSM tracks located on the storage rack is to aid in the movement of the storage plate from the air pallet to the rack and visa versa. If there were not LSM tracks on the storage rack and only on the air pallet, there would be difficulty moving the storage plate from the rack to the air pallet. This difficulty arises from the fact that there would not be an actuator on the rack to start the motion of the plate to the air pallet. By placing LSM on the storage rack itself, there now exists an actuator to allow for the transfer of the storage plate from the storage rack to the air pallet.

3.3.5. Vehicle Securing Systems

Due to the six degrees of motion experienced by a ship at sea, several securing systems needed to be designed to ensure the vehicles, storage plates, and air pallets do not move freely about the storage area. Motion of the vehicles when they are not supposed to can be dangerous and can lead to damage of the vehicle and more importantly damage of the ship. As a result, the following securing systems were designed for the vehicle storage area:

- Securing the vehicle to the storage plate
- Securing the storage plate to the air pallet and storage rack
- Securing the air pallet to the deck of the ship

Securing the vehicle to the storage plate

Once the vehicle or TEU container enters the ship, it will be immediately placed on a storage plate and transported by an air pallet to an empty storage space. It is important that the vehicle or container remain connected to the storage plate at all times. If the vehicle were to become disconnected from the storage plate it could be damaged or it could damage the ship. Also, the vehicle would need to be turned on in order to drive back on to the storage plate, and this situation should be avoided (the vehicle storage area and air conditioning system would be designed so that vehicles are not driving within the area). In order to secure the vehicle or container to the storage plate, it was decided that chains would be connected from the vehicle to the plate. This method of securing vehicles within ships is currently in use by the Navy and is reliable and relatively simple. The chains would be connected by personnel from the wheelbase of each vehicle or container to tie down holes at the corner of the storage plate. It was decided that using manpower would be the best option for connecting the chains due to the complexity and space requirements of an automated system for connecting them.

Securing the storage plate to the air pallet and storage rack

Once the vehicle or container is secured to the storage plate, the storage plate has to be secured to the air pallet. This is an important step because the air pallet will be used to transfer the storage plate to the storage rack and it would be undesirable for the storage plate to slide off of the air pallet while it is moving around the ship. It was decided that pin locks would be utilized in order to secure the storage plate to the air pallet. The pin lock would be composed of a steel cylinder with two notches on the end. These locks would originate from the air pallet, enter the side of the storage plate, and remain in place until the storage plate is removed. Side entering locks are ideal because they prevent motion in the x, y, and z directions. As a result, the motion of the storage plate on the air pallet would be fully constrained even if the ship is experiencing large pitch or roll characteristics. An example of the pin locks on the air pallet can be seen below in FIGURE 51.

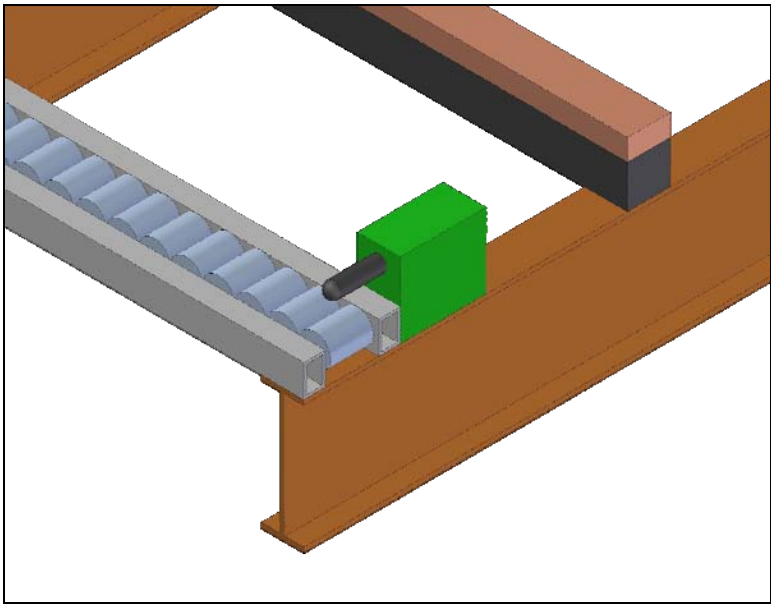


Figure 51: This figure shows the side entering pin locks that will be used on both the air pallet and storage racks.

A similar pin lock securing system will be used for the storage rack. However, the storage rack will only have the pin locks on the front side of the rack. At the rear of the rack, there will be stoppers that slide into the 4×4 in. structural tubing. These stoppers will act as additional securing mechanisms while the storage plate and vehicle are being stored. A representation of the stoppers can be seen below in FIGURE 52.

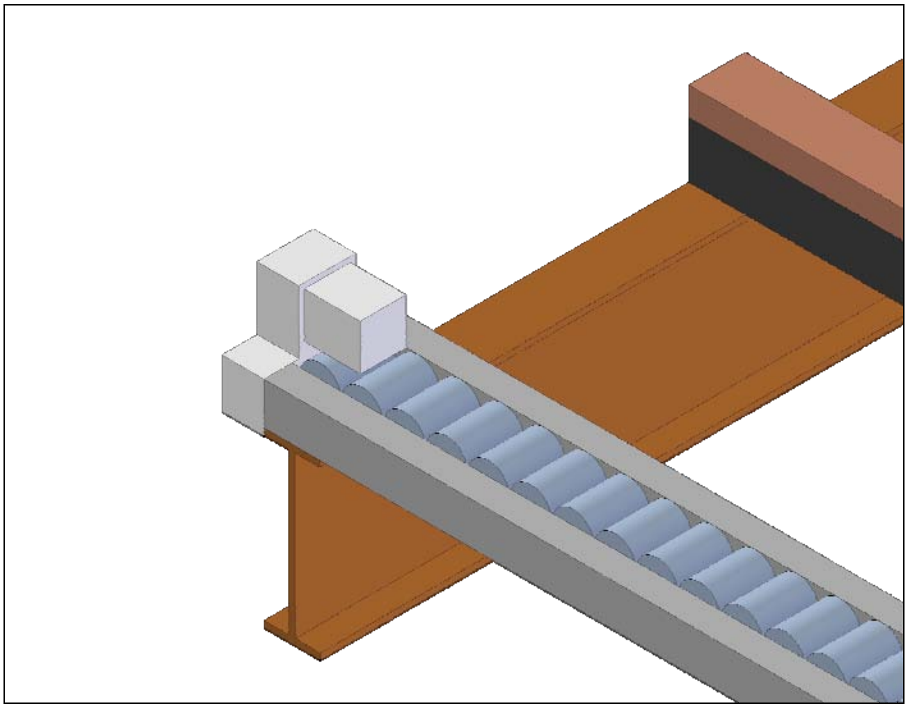


Figure 52: This figure shows the storage rack buffers that will act as additional securing mechanisms while the vehicle and storage plate are in storage.

In order to test the feasibility of using the pin locks to secure the storage plate to the air pallet, a model was created and analyzed using ANSYS. In order to conduct the simulations on the model several assumptions were made. The model consists of a 1.5 in. diameter, 6 in. long cylinder subjected to a load in the x-z plane. Also, it was assumed that there would be eight pins evenly distributed on a single air pallet that could support the weight of the 70-ton M1A1 and also the weight of the storage plate. The bottom of the lock was considered fixed to the air pallet whereas the top of the lock was free to move in any direction. An image of the model as well as the stress analysis can be seen below in FIGURE 53.

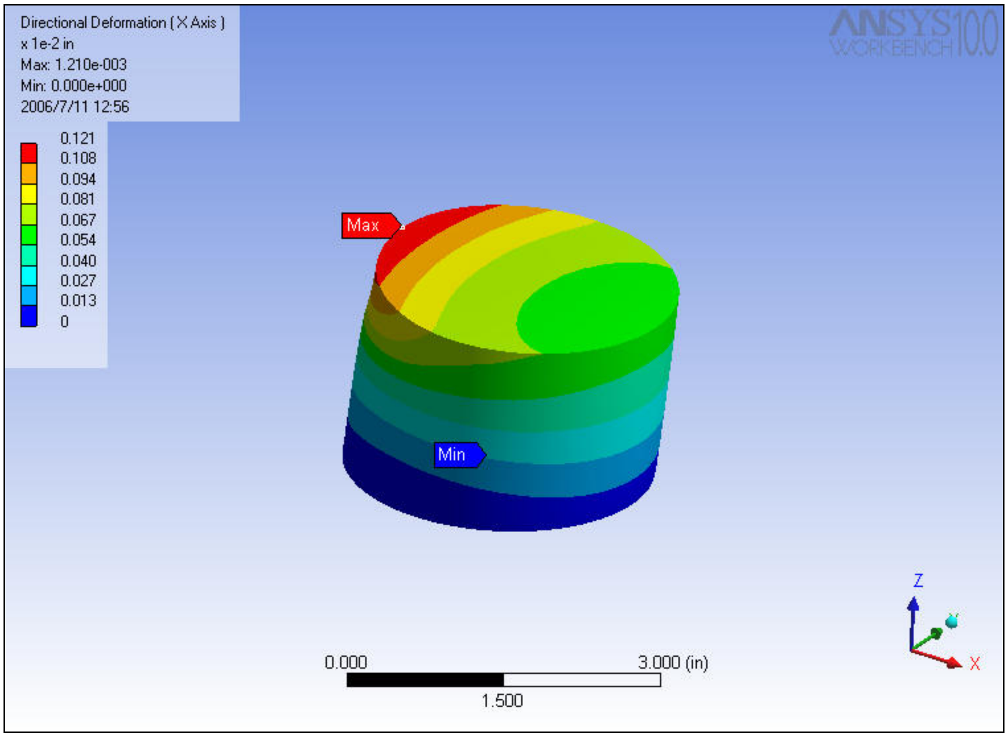


Figure 53: This figure shows the deflection experienced by the vehicle pin lock when under a load of 18,000 lbs.

As can be seen from the above image, the deflection of the locking pin in the x-direction is on the order of 10^{-3} in. This very small deflection is important because if any of these locks were to break in high sea states the storage plate could fall off the air pallet and do damage to the vehicle or the ship.

Securing the air pallet to the deck of the ship

Using air pallets provides a method of easily moving heavy objects around the vehicle storage area. However, this ease of movement can also become a problem when the ship is experiencing large pitch and roll characteristics. As a result, measures need to be taken to make sure the air pallet cannot move around as a result of the pitch and roll characteristics and damage either the air pallet itself, the vehicle on the air pallet, or the ship. It was determined that the LSM track the air pallet will be using to move around the deck should be sufficient to prevent unwanted movement of the air pallet. As explained in a previous section, LSM works by using induction to move the air pallet and the position of the air pallet with respect to the length of the aisle can be controlled by turning different sections of the track off and on. As a result, the position of the air pallet can be maintained constant even if the ship is experiencing large pitch characteristics. The LSM system can also be used to constrain the movement of the air pallet with respect to the width of the aisle while the ship is rolling. This constraint is accomplished by the track that is built into the deck of the ship that makes up half of the LSM system. As previously stated in the description of the motion of the air pallet, the air pallet has rollers on each side of the LSM track that are designed to keep the space between the track and motor small and also constrain the air pallet movement. These rollers will also act to limit the movement of the air pallet with respect to the width of the storage area.

3.3.6. Elevators

The elevators will be used to transport vehicles and their corresponding storage plates between the different levels of the storage area. As discussed in the layout section, there will be two elevators staggered at the end of the storage area and they will be ideally located near the middle of the ship. The elevators will have to be large enough to support the weight and dimensions of the largest vehicles. As a result, they will need to be at least 40×12.5 ft and be able to support a load greater than 70 tons. A representative image of the elevator can be seen below in FIGURE 54.

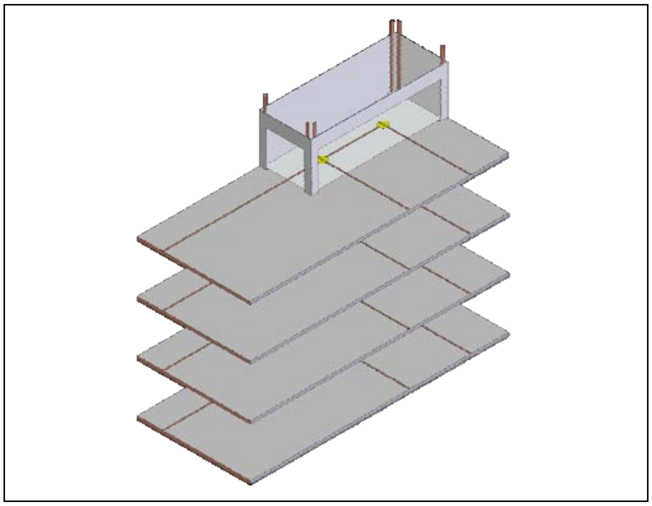


Figure 54: This figure is a representative image of one of the elevators that will be used to transfer air pallets between storage levels.

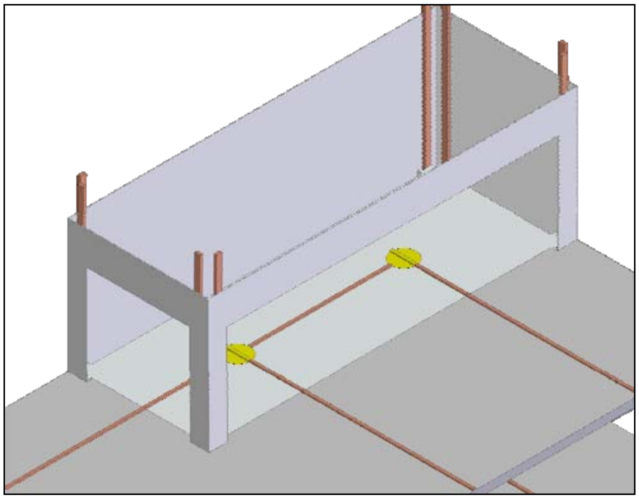


Figure 55: This figure shows a close-up of the elevator and the vertical LSM tracks that will be used to move the elevator from one level to another.

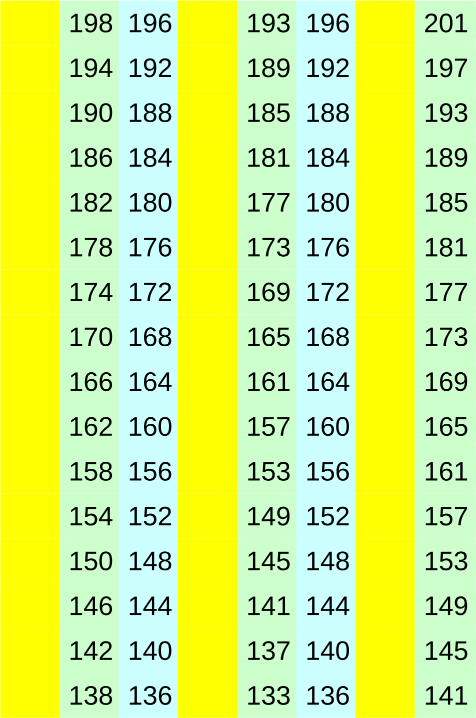
The elevators will utilize linear synchronous motors to move between the different levels of the storage area. Each corner of the elevator will run on a vertical LSM track that will run the total height of the ship. An LSM system will be used because of the large loads that they can support and also the relatively small footprint required for them in comparison with traditional hydraulic elevators. Each elevator will also have LSM tracks that line up with the LSM tracks on the vehicle level to allow for the air pallet to move on and off of the elevator. It is important that the floor of the elevator lines up exactly with the vehicle deck so the air pallet can make a smooth transition on and off the elevator. If the floors do not line up properly, the seal may be broken on the air bearings and the air pallet could be disabled.

3.3.7. Design Analysis

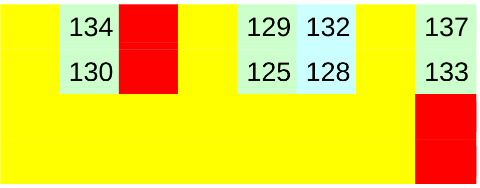
Retrieval Time

The time analysis involved using Microsoft Excel to calculate how long it would take to retrieve a vehicle from storage. The vehicle storage area was considered to be four decks, the top three of which are 400 ft long and 100 ft wide, while the bottom deck is 80 ft long and 100 ft wide. A grid representation of one of the upper decks as well as a side view of the deck layout can be seen below in FIGURE 56 and FIGURE 57 respectively. The yellow cells represent aisles within which the air pallets move, the green and blue cells represent storage slots and the red cell represents an elevator. Each cell is assumed to be 12ft wide and 20 ft long. The number in each cell represents the average time in seconds to retrieve a vehicle from that specific storage space when being loaded and unloaded from the rear door.

Figure 56: This figure shows the vehicle storage layout for one of the upper levels of the storage area.



	198	196		193	196		201
	194	192		189	192		197
	190	188		185	188		193
	186	184		181	184		189
	182	180		177	180		185
	178	176		173	176		181
	174	172		169	172		177
	170	168		165	168		173
	166	164		161	164		169
	162	160		157	160		165
	158	156		153	156		161
	154	152		149	152		157
	150	148		145	148		153
	146	144		141	144		149
	142	140		137	140		145
	138	136		133	136		141



🟨	134	🟥	🟨	129	132	🟨	137
🟨	130	🟥	🟨	125	128	🟨	133
🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟥
🟨	🟨	🟨	🟨	🟨	🟨	🟨	🟥

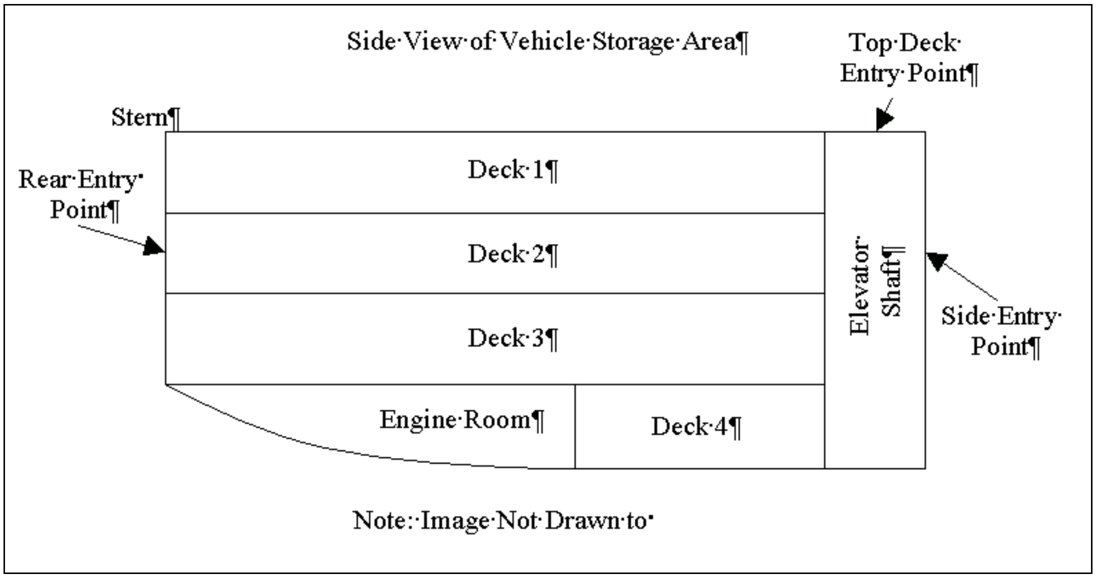


Figure 57: This figure shows a side view of the vehicle storage deck layout along with the entry points to the storage area.

Movement between decks is accomplished by means of two elevators located at the end of the vehicle storage area, towards the center of the ship. Three cases of how the vehicle entered and left the storage area were considered. These cases included entering and leaving through the rear, the side, and the top of the ship. The calculations for the retrieval time were based on the distances that the object would have to be moved, as well as the velocities specified for moving each different type of object. Each cell on each level of the ship was analyzed based on the X, Y, and Z travel times. Motion in the x-y plane is accomplished by using an air pallet while motion in the z direction between decks is accomplished by one of two elevators. In these calculations, the time to load and unload the vehicle from the storage slot was also included. The assumed travel speeds for these calculations were 5 ft/sec horizontally and 1 ft/sec vertically. Some space was lost on the rear-loading layout on the second deck to allow the air pallet to enter different aisles upon entering the ship. This extra area is not required on the other levels because the area where the elevators are located can be used to travel to different aisles. The retrieval times also vary greatly depending on which deck the vehicle is loaded on and which deck the vehicle needs to be stored. An example of this occurs if the vehicle enters the ship from the rear entrance on the second level and has to be stored in the rear of the third level. In order to accomplish this task the air pallet and vehicle must move down the length of the storage area to the elevators, travel down to the third level, and then travel back down the length of the storage area to the storage space. This situation would be a worst-case scenario in regards to storage time. In these calculations, the acceleration and deceleration periods were not considered, the air pallets were assumed to move at a constant velocity, and it was assumed the air pallets changed direction and speed instantaneously. Also the distances that could possibly be traversed by the air pallet and vehicle were rounded for each calculation. The times do not include locking or turning within the storage system, which can be summed and directly added to the averages if necessary. The results of the time analysis of the vehicle storage area for the different entry points is located in TABLE 5 below.

Table 5: This table lists the average retrieval time for a vehicle depending upon where the vehicle enters the storage area.

Layout	Average Retrieval Time (sec)
Rear Loading	273.8
Side Loading	172.6
Top Deck Loading	225.3
Average of the Three Loading Positions	223.9

As can be seen from the table above, the optimum loading position of the vehicles to the storage area is the side door because the average time that is required to store or retrieve a vehicle is the smallest. The average time it would be required to retrieve or store a vehicle regardless of the entry point to the storage area would be approximately 223.9 seconds (3.7 minutes). As a result, in order to fully unload or unload all of the vehicles and containers in the vehicle storage area it would take approximately thirteen hours. However, this time estimate only takes into account the amount of time required to move the vehicles within the ship. The time required to load the vehicle on the ship from land or from another ship is not included in the calculations and most likely will result in a longer required time to fully load and unload the storage area. Also, the amount of time required to secure the vehicle or container to the storage plate is not considered in these calculations and may increase the amount of time required to load or unload the storage area.

Stowage Capacity

The stowage capacity of the vehicle storage system was calculated by considering the amount of space that was not used to store an air pallet, which includes aisles as well as the areas at the end of the storage area used to transfer to different aisles. Another consideration in the stowage capacity calculations was the amount of wasted space on the standard size storage plates depending on the vehicle size. For example, on the standard 20×12.5 ft plate, a vehicle that is only 18 ft long will have two feet of wasted space. Considering the layout shown previously in FIGURE 54 and only taking into account the amount of aisle space, the stowage factor is approximately 66%. However, if the amount of unused space for a standard 20×12.5 ft plate is considered, calculated in APPENDIX I as being approximately 12 %, the stowage capacity decreases to 54%. As can be seen from the percentages, there is a tradeoff between standardization and stowage capacity. As discussed in SECTION 3.3.3, standardization of the storage plate is important so that there is the ability to adapt to different vehicle requirements depending on the type of campaign that is being embarked upon. If there were a specific size storage plate for each type of vehicle, the plates could not be interchanged between vehicle types in the situation where more plates than normal are needed for certain vehicle type. One option to standardize the plates while achieving a higher stowage capacity is to use a 4×12.5 ft pallet. Using this size plate would increase the stowage capacity to approximately 63%. However, there is a tradeoff with using a smaller standard plate because more connections would be required between the plates leading to a more complex system with a higher chance of failure. Ultimately, it was decided that the adaptability, automation and selectability of the design compensated for the low storage density.

Energy Requirements

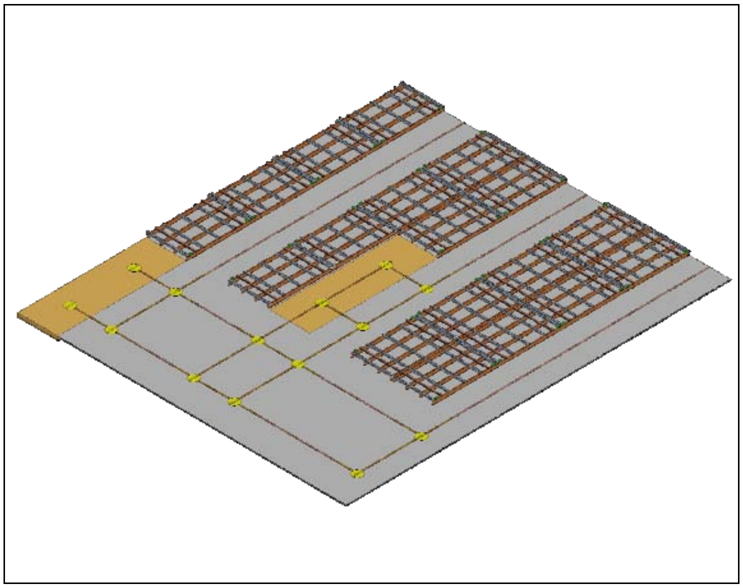
The energy requirements were evaluated for the LSM system in the vehicle storage area. In order to calculate the energy required to move a vehicle using an air pallet and LSM system several assumptions were made. The efficiency of the LSM system was assumed to be 70% for these calculations. For the operational movement of all the calculations, a maximum operating pitch of 5° and a maximum roll of 15° were assumed. Also, only the static forces from gravity and the applied forces to accelerate the air pallet to its final velocity were considered. The acceleration from the movement of the ship was not considered for this evaluation. The inputs for the calculations included the weight of the air pallet, storage plate, and M1A1 tank. Also included in the inputs were the angles of acceleration, initial velocity, and final velocity of the air pallet. A worst-case scenario for the distance traveled by the air pallet to reach the storage space was considered because it would require the most amount of power. This scenario involves starting from the rear entrance of the ship, traveling down the length of the storage area, using an elevator to travel up one level, and then traveling back down the entire length of the storage area. The amount of power to transfer the storage plate and vehicle from the air pallet to the storage rack was not included. The energy required for the vehicle system can be found in TABLE 6 below and the full set of calculations are shown in APPENDIX J.

Table 6: This table lists the energy requirement for the vehicle storage system.

Layout	Object Weight (lbs)	Maximum Instantaneous Power Required (kW)	Total Energy Required to Move Maximum Distance (W·hr)
Vehicle Storage	185,000	344.1	17474.0

3.4. Future Considerations

Due to the time constraints of this design project, there are several components of the vehicle storage system that require further development. One of the most significant areas that require further development is the LSM track that the air pallet will use to travel around the ship. When initially designing the track system, it was discovered that there would be a challenge in allowing the air pallet to transition between x and y-axis motion at the end of the storage rows. This challenge arises from the fact that the LSM track is raised from the deck of the storage level while the air bearings rest on the deck of the storage level. As a result, the raised track impedes the motion of the air bearings when the air pallet reaches a transition point between the x and y-axis. There were several solutions that were explored in order to alleviate this problem ranging from large turntables at the end of the storage rows to moving the LSM tracks to the side of the storage rows rather than placing them on the deck. Another possible solution that was explored involves having pieces of the LSM track recede into the deck to allow for the air bearings to pass by and having small rotating apparatuses to transition motion between the x and y-axis. Located below are several images that depict this LSM track design.



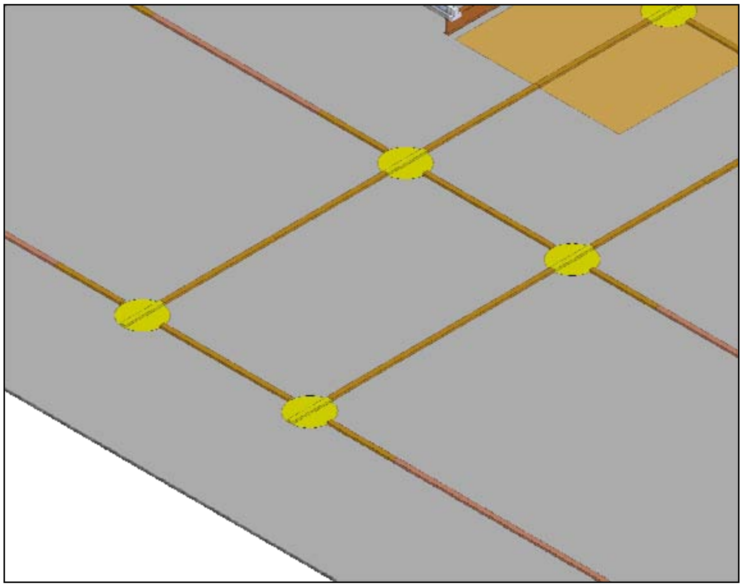


Figure 58: The two images above show the proposed LSM track system for the air pallet. The system would include pieces of LSM track that recede into the deck to allow for the air bearings to pass by and small rotating apparatuses. The rotating apparatuses allow for the transition between the x and y-axis and are represented by the yellow circles in the above figures.

One of the main problems with these proposed solutions are the amount of moving parts that are involved. For example, if one of the pieces of LSM track fails to recede into the deck, then the entire system is disabled and an air pallet cannot pass by. As a result, there needs to be further research into efficient and simple methods for transferring motion of the air pallets between the x and y-axis directions.

Another part of the vehicle storage design that requires further development is the air bearings used on the air pallet. More specifically, the performance of the air bearings at sea on a ship requires further research and development. As they are designed now, air bearings require constant contact with a completely smooth and flat surface. It may be difficult to achieve these requirements on the deck of the ship. The hulls of ships are subject to large forces from the sea causing deformations and deflections in the surface of the decks. Although it has been shown that air bearings can travel over small tie downs and cracks surfaces, these deflections may be too large to allow for the seal of the air bearing to remain in tact (Bickel et al., 2006). As a result, the decks of the storage area may need to be isolated from the hull of the ship to limit the deformations and deflections that could limit the air pallet movement.

Another possible challenge involved with using air bearings on ships is the constant changing of the center of gravity of the load on the air pallet due to wave motion. For example, if the ship pitches forward, the center of gravity of the load on the air pallet will shift forward. If this situation occurs, more of the load will be on the air bearings at the front of the air pallet, possibly causing the air bearings to fail. One way to take into account the changing center of gravity of the load would be to increase the airflow through the air bearings that will be experiencing a larger load. However, this process would required a complex computer system that could detect the changing center of gravity of the load, identify which air bearings will be experiencing a greater applied load, and increasing the air pressure to the appropriate air bearings. As a result, further research needs to be performed into the effect of a changing center of gravity on the performance of the air bearings used for the air pallet.

4. Distribution Center Design Concepts

4.1. Introduction

The distribution center is the area for short-term storage items that will be needed as individual pieces, not a case at a time. For small arm ammunition and MRE rations, there is no need to send a JMIC worth of goods when all the troops need are a few of each. With this system, the operator can get the exact amount of goods that is required.

4.2. Vertical Distribution Center

4.2.1. Background

The idea for a vertical dispenser was based on a typical soda machine, where sodas are loaded into a gravity fed stack that dispenses a specific type of soda upon request. The vertical dispenser will work similarly in that it can dispense high demand items such as MREs, ammunition, and medical supplies to fill a specific request from the MEB. This concept was explored because it allows for dense packing and fast retrieval of high demand items. The system would accomplish these tasks using a relatively small amount of energy because the packages are fed through the system with the assistance of gravity. There will be a specific column for each type of high demand item. Each of these columns will use air bags to fit to the cases of dry stores as well as slow down the dry stores to an acceptable speed. Using a larger generic size for the dispenser will increase the adaptability of the system. This generic design allows for an adaptation of the system depending changes of the mission and environment.

4.2.2. Detailed Design Description

General Process Description

The system starts with a machine that will remove the contents of the JMIC onto the automated conveyor system. The conveyor system will then place the boxes into the proper distribution column, each column storing a specific type of high demand item. An image of the conveyor system and distribution columns can be seen below in FIGURE 59.

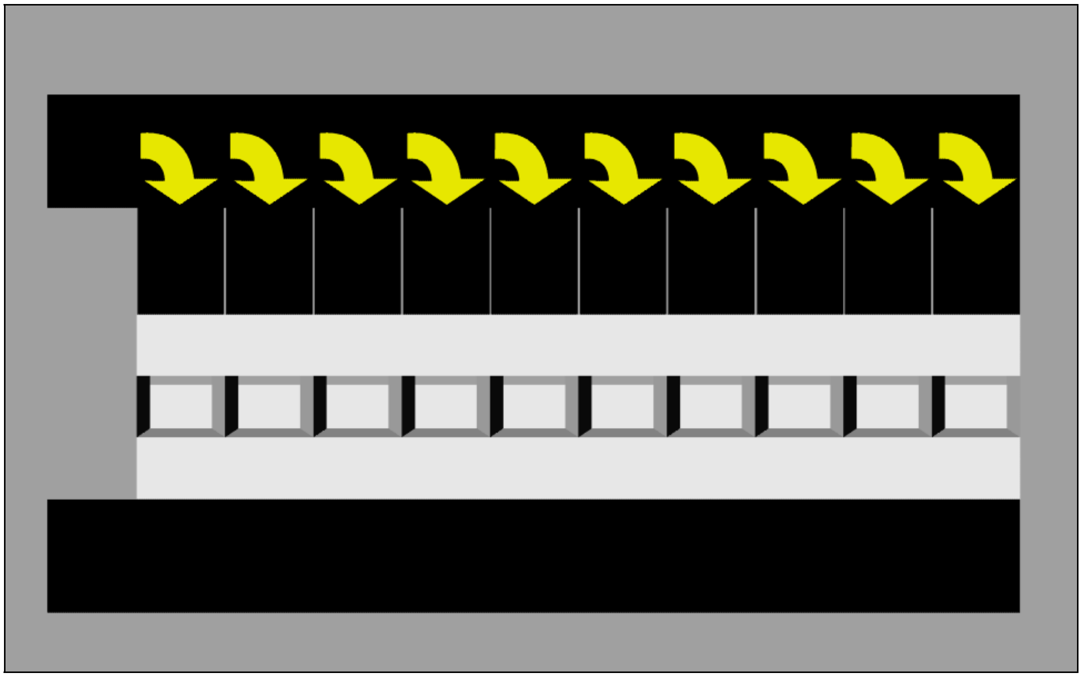


Figure 59: This image is a top view of the vertical dispenser system. The black area represents conveyor belts and the yellow arrows represent the directions the high demand items will travel. The gray boxes represent a top view of the vertical columns, each of which will store a specific high demand storage item.

In the distribution column, the contents of the case will be dropped safely using a system of air bags or springs that press into the cardboard boxes applying enough friction to slow down the boxes so they will not break or discharge the contents. The high demand items will remain in the columns until they are requested. Once a certain number of each type of high demand item is requested, an actuator will push the required number of items onto another conveyor belt. From this point, the items will travel to a packing area where they will be repackaged in another JMIC and shipped to the unit that requested the supplies. The columns will be continually refilled in order to make sure there are enough high demands in them to satisfy the demand of the MEB. Two images of the total system can be found below in FIGURE 60 and FIGURE 61.

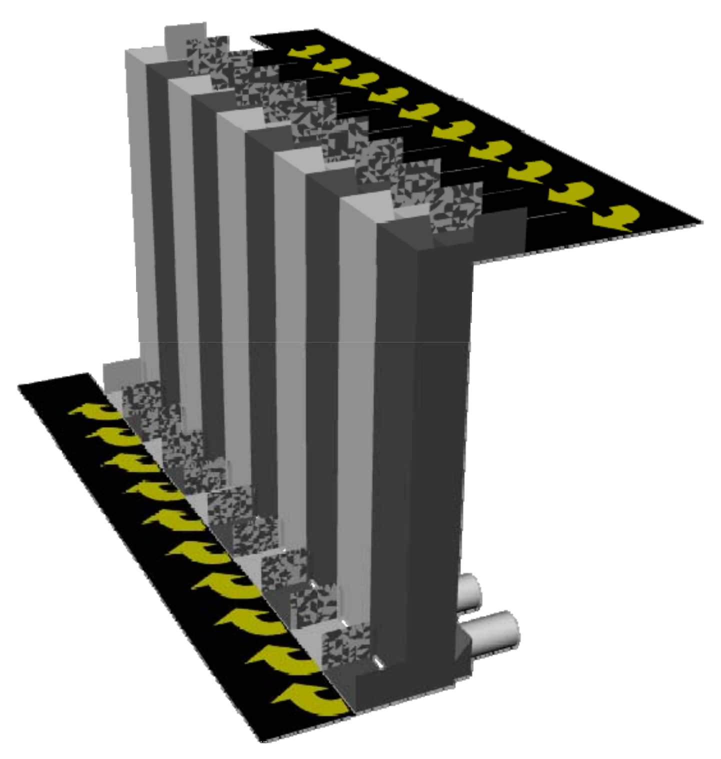


Figure 60: This image is a full-scale view of the vertical dispenser. The alternating gray colors represent distinct high demand storage columns. The yellow arrows represent the direction the high demand items will be traveling.

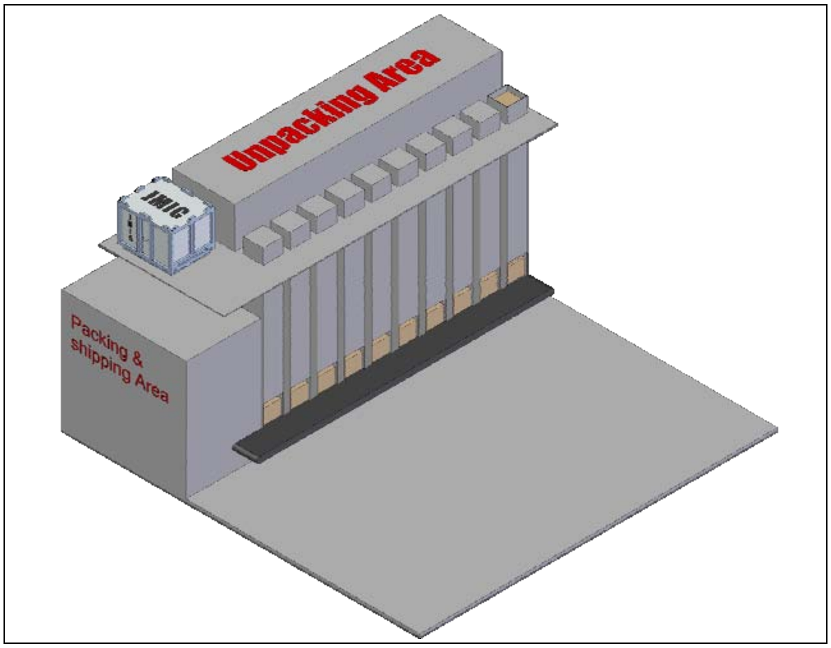


Figure 61: This figure shows another interpretation of the vertical distribution system. The brown images at the bottom of the columns represent high demand items. The black strip represents a conveyer belt to take the high demand items to the repacking area.

Loading/Unloading of Dispenser

The loading and unloading of the vertical dispenser could be accomplished by several methods. Unloading and loading the packages efficiently is important to maintaining the efficiency of the system and also the integrity of the high demand boxes. The loading of the distribution columns begins by unpacking the cargo items from the JMICs. This unpacking will most likely be accomplished by a robotic arm or gantry crane. The crane will have to remove the top of the JMIC, remove the specific box from the JMIC, and place it on the conveyer belt that travels to the vertical columns. The crane will have a suction device at the end of the telescoping arm in order to grip the top of the JMIC and cargo boxes for removal. PAR Systems has developed the PR 300 Gantry Robot, which can move in five axes and can accommodate payloads of up to 1200 pounds. However, the crane would not have to lift such a large load, the largest load that would be required for this system would be about 100 pounds. With the gantry system and the telescoping arm shipboard movement should not be a problem.

After the smaller boxes are removed from the JMIC, they travel down a conveyer belt to the distribution columns. There will be one central conveyer belt with smaller conveyer belts branched off on one side that lead to the individual columns. One of the challenges with this part of the system is that each column has a specific piece of cargo including but not limited to MREs, ammunition, medical supplies, etc. As a result, there has to be a system to identify the different types of packages and direct them to the correct dispensing column. FKI Logistex has conveyors that sort supplies using RFID tags. FKI Logistex also has the capability of turning boxes on a conveyor belt. This would allow for the cases to always align properly with the entrance to the distribution column. One challenge with using a system of conveyers is their operational capabilities at sea. The conveyers would have to have walls to constrain and secure the boxes during their transit to the distribution columns.

When a request for certain dry stores is made, the high demand items that are required need to be removed from the columns. One of the simplest methods of accomplishing this would be to use an automatic door and pushrod. The door is required to keep the bottom box fully constrained when the system is not in use. Once an item is requested, the door will open and a pushrod will push the box onto a conveyer belt. The box then travels to the repackaging center to be placed in a JMIC for shipment. One challenge with this setup is that when the bottom box is removed, the boxes above it will fall to the bottom of the column. In order to prevent this situation from occurring, the pushrod could be designed with an angled front. Using the angled front would allow for the boxes above the removed box to slide down a slope as the pushrod exits the system rather then directly falling. The pushrod is represented below in FIGURE 62.

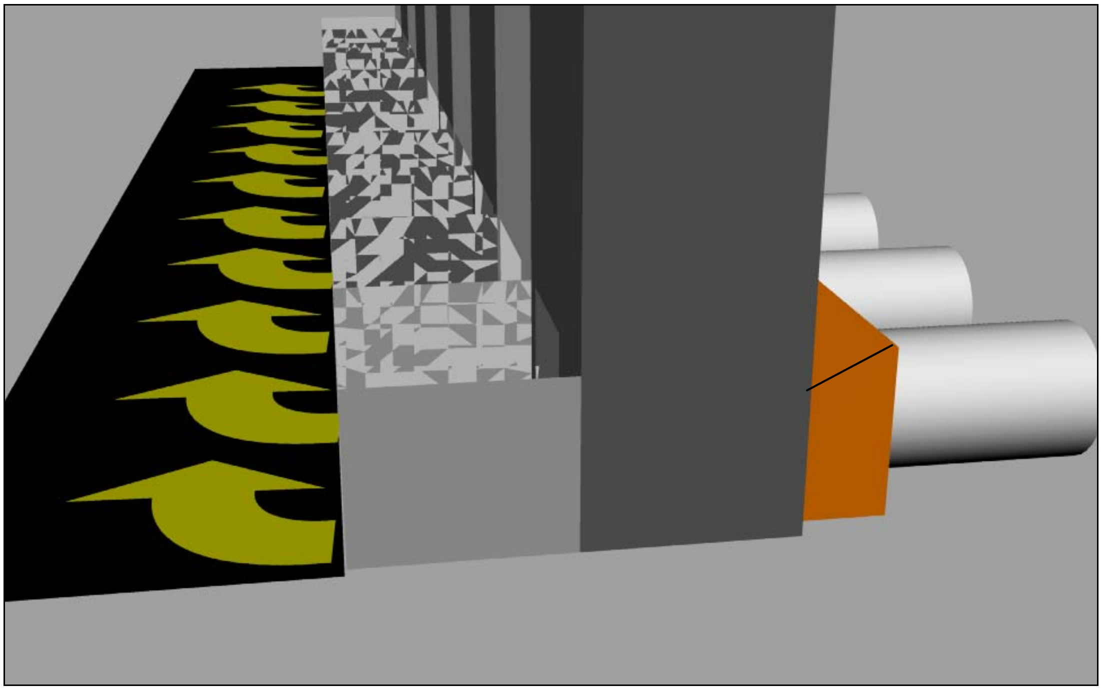


Figure 62: This figure shows the angled pushrod that would push the piece of cargo out of the vertical dispenser. The pushrod is shown in orange.

The expense of the gantry robot is not enormous. The initial investment for a robot is $200,000 to $500,000. The annual E-1 DOD composite rate for personnel would be $37,351 (Roth-3). The composite rate includes the average base pay with basic allowances plus retired pay accrual, Medicare retiree health care accrual, and permanent change of station expenses.

Freefall Prevention System

As stated above, the initial concept for the vertical dispenser involved placing the individual high demand items in vertical columns so they could be dispensed rapidly using gravity. However, one of the challenges with using vertical columns is the high demand items falling down the column when it is being refilled. This situation could damage the dry stores and also prove unsafe when considering some of the boxes will contain ammunition. As a result, a method of slowing the decent of the boxes within the vertical column was developed. There were two designs for freefall prevention systems that were explored.

The first design included using walls coated in a layer of rubber and had horizontal spring mounts to allow for some give in the wall. In order to determine if this design would be effective in slowing down the decent of a box in the dispenser, an analysis was performed on the speed of the falling box. A MRE is considerably heavier than a soda can at 22 pounds. After performing an analysis of an MRE free falling from 24 ft, it was found that the MRE would be traveling at 36 ft/s. This is not an acceptable speed for an MRE to drop. Next, a simple analysis was performed if the two walls restricted the MRE when dropping inside the vertical column. With a coefficient of friction set at 0.6, an average for rubber, and spring constant of 0.76 lb/ft the MRE slowed down to 2.58 ft/s. This is an allowable speed for the MRE to descend.

The other method that was explored to slow the decent of the boxes in the dispenser was using a system of air bags. The air bags would be located on the sides of the columns and provide a frictional force to slow the descent of the boxes. Not only would this design slow the descent of the boxes, it would also allow for different size containers to be used in the same box by changing the pressure in the bags.

4.2.3. Design Analysis

An important characteristic of the vertical dispenser unit is the volume that it would encompass. As a result, a volume analysis was performed on the system to see how it would fit into the storage area. To perform the analysis, the team decided that the system would hold about one percent of the dry stores. However, this number is only an estimate and may change based on the supply rate desired by an MEB. Specifically looking at MRE cases, the team determined the theoretical volume for one percent of the MRE’s which can be seen below in TABLE 7.

Table 7: This table shows the theoretical volume for 1% of total MRE's required for the sustainment of an MEB

Pallets	Cases	Volume (Case)	Volume (total)
#	#	ft^3	ft^3
12	576	1.03	593.28

After the theoretical volume was determined, the team could analyze the volume that the vertical columns would use. In the determination of the volume, the conveyor belt system was not considered, and this may contribute to the overall volume of the system. The base area is the area including the entrance and exit of the system. Twenty-four dispensers were used because one dispenser holds half of a pallet. The resulting volume of the system can be found below in TABLE 8.

Table 8: This table shows the theoretical volume of the vertical columns in the vertical dispenser system

Base Area	**Height**	**Dispenser**	**Volume (total)**
ft^2	**ft**	**#**	**ft^3**
5.78	23.1	24	3204.43

In order to see if this system was efficient in its storage capacity, the team calculated the volume required to house twelve pallets in the plus sign design with a handling area where a human would take MRE cases from one JMIC/Pallet to another JMIC/Pallet to get ready to be shipped out. First, the volume used for a plus sign design was calculated. The base area is the area of the footprint that the plus sign design would create. The plus sign consists of five spaces each 64×64 in. There is only the need for one column so only one dispenser was needed. The theoretical volume for the plus sign is listed below in TABLE 9.

Table 9: This table shows the theoretical volume of a single column plus sign of JMIC containers.

Base Area	Height	Dispenser	Volume (total)
ft^2	ft	#	ft^3
113.78	13.00	1	1479.11

The handling center where a human would package a JMIC to be shipped out would also have to be calculated. To calculate the area needed the base are of two JMIC containers along with the base area of their tops was used. Also through estimation, the team determined that a human would need two feet of extra space in order to open the doors of the JMIC and remove individual boxes. The theoretical area for the loading/unloading area is listed below in TABLE 10.

Table 10: This table lists the theoretical volume calculated for the loading/unloading area required for two JMIC's.

JMIC	JMIC Base	JMIC Lid Base	Human Base	Height	Volume (total)
#	ft^2	ft^2	ft^2	ft	ft^3
2	28.41	28.41	77.94	8	1532.64

To complete the analysis, the handling center and plus sign designs were added together. This showed that the two combined took up192.68 ft^3 less space than the vertical dispenser. However this analysis does not include the space for multiple high demand cargo. With that in mind one can improve the stowage factor of the vertical dispenser. This is because with multiple types of cargo, you need space to store that number of JMIC in the handling center. So if you needed to selectively send four different pieces of cargo in one package you would gain 1363.25 ft^3 of space in the handling center.

JMIC	JMIC Base	JMIC Lid Base	Human Base	Height	Volume (total)
#	ft^2	ft^2	ft^2	ft	ft^3
5*	28.41	28.41	77.94	8	2896.32

* Four JMIC used for the cargo, one to be packed and shipped.

However, with the “Vertical dispenser” no additional room would have to be added. Instead of having 24 dispensers only for MREs, six could be for the MREs and the other dispensers could be for the remaining three items. The key with the dispenser is that it has to be adaptable with multiple containers.

4.2.4. Future Considerations

The entire width of the system would be about 40 feet in length including the Gantry Robot. Further analysis has to be taken to optimize the number of dispensers needed. The optimum orientation of this system would be in the longitudinal direction. This would prevent the problem of the ships rolling motions at sea to enable movement of the system’s cargo on a conveyor belt.

The vertical dispenser offers a quick method for selectability. However, it does not allow for a specific case to be sent to the Marines. If selectability of specific cases is needed, further development of the Vertical Lift Modula (VLM) and carousel is needed. However, for certain supplies such as MREs, small arms ammunition, and certain personal demand items there is no need to have them placed in a specific case. Any M16A1 can fire any M16A1 cartridge.

There are also other proven methods that can be used as a dispenser system. MegaStar systems and other companies have created a Vertical Lift Modula (VLM) and Vertical Carousel systems that can handle the load of the supplies. Some re-engineering would have to be considered to optimize these systems. The systems need a loading door and unloading door. The system would have to be retrofitted for military supplies.

Using either a VLM or carousel would have benefits compared to the vertical dispenser. The VLM and carousel both have the capability of lifting the dry stores being used. Because of the lifting mechanisms and their method of operation, both the VLM and carousel offer a better selectability of items. However, the team was not extremely concerned with being able to receive a certain box. The team felt that there was no difference between a box of MREs to another box of MREs.

4.3. Horizontal Distribution Center

4.3.1. Background

The horizontal distribution is very similar to the vertical dispenser system, however it is placed on its side with a little different design. Having the option to have either a vertical or horizontal distribution center allows for adaptation of designs for different ships and storing capacity. Sometimes it might not be desirable to use vertical packaging system, but rather than a horizontal layout, so there is not a need for an elevator to raise cargo to its original height.

4.3.2. Detailed Design Description

The major difference is in the physical design of the horizontal dispenser when compared to the vertical dispenser. The horizontal dispenser has different issues involved with the design. The design does not have to deal with the dropping of packages like the “vertical dispenser”, however it does have to deal with filling the dispenser. If only one conveyor belt is used inside one of the dispensers the system would not be able to fill the dispenser. This would create a problem with the back up of stores in the system. If you look at a grocery store check out line, the conveyor system never removes the space in between two consumer’s groceries. Some how the dispenser will have to pack the conveyor system so there is not extra wasted space in the dispenser. A probable way this would work is to have multiple conveyor belts in a single dispenser. An individual conveyor can shut down when it senses a stationary box, while the remaining conveyors keep working until all the boxes are in the dispenser. There are several different ways of using the conveyor belts in order to completely stack the boxes with no wasted space, these designs as shown in Figures 63-64. Other than using horizontal conveyors for the dispenser system, the overall design will be the same as the vertical distribution system. It will still have two robotic arms, one depalletizing and one palletizing, and use a conveyor system to sort the dry stores into their proper dispensers.

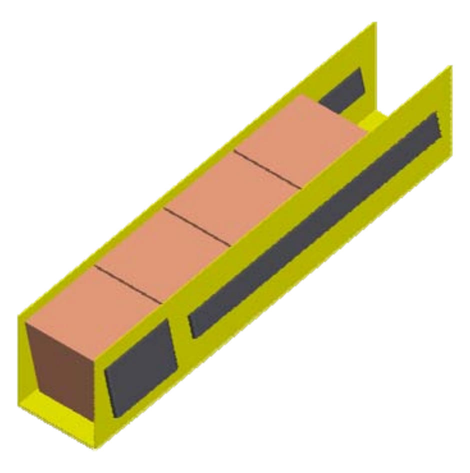


Figure 63: Horizontal conveyor belt design 1.

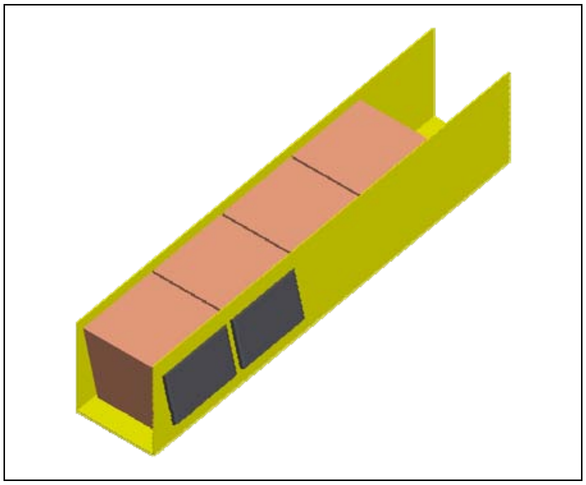


Figure 64: Horizontal conveyor belt design 2.

4.3.3. Design Analysis

The horizontal dispenser will encompass the same volume of area as the vertical dispenser. However the footprint of the system will be much larger. Looking at the same system using 24 dispensers the area would be 261 ft^2. If the system were to allow the dispensers to be stacked you could cut down on the footprint by increasing the height of the system as shown in Figure 65. Different facility layouts should be considered for choosing between a horizontal and vertical distribution, as well as the difference between a stacked and single level horizontal distribution system.

The cost of the horizontal system would be about the same price as the vertical distribution. Being there are still two gantry robots, the system’s overall cost will be above a million dollars. The economical difference between the two systems is the cost differences between a conveyor belt and air bags.

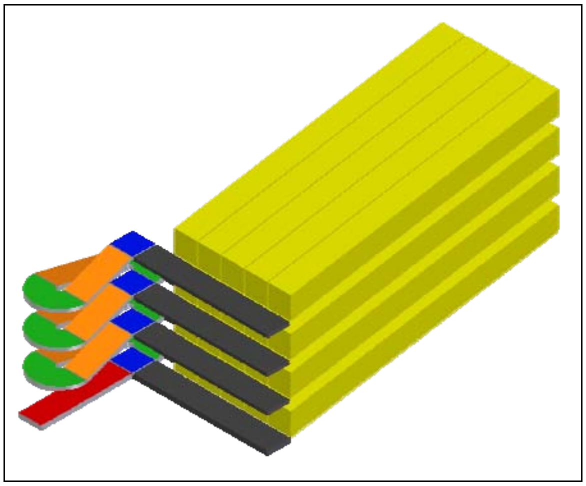


Figure 65: Stacked horizontal conveyor belt distribution system.

4.3.4. Future Considerations

Sea keeping analysis is the most important aspect when considering this system. Using different conveyors would have the need to constrain cargo from moving while at sea. A dependable way of locking the cargo to the conveyor, while still having the freedom of dropping of cargo where needed, is very important.

4.4. On-Demand Distribution Center

4.4.1. Background

The on-demand system was developed because the team wanted a simple solution to the distribution concept. Dispensers seem like there are some inherent problems that would occur like jamming of the machine and possibly breaking of the system. The finished design has to take a lot into consideration. The team wanted a system that would not need further development of technology.

4.4.2. Detailed Design Description

The on-demand system also works the same as the vertical and horizontal system. However the overall system is very different. First, there is no dispenser. JMICs are brought from the dry store area to the distribution system. The new JMICs replace the empty units. Here the cover has to be removed. It is likely that the gantry robot would take off the cover. Further developments should be considered to remove the lid. Next, the gantry robot will pack the case ready to be shipped out. The gantry robot has the capability to pick up the cases inside the JMIC with a vacuum gripper. PAR systems have a variety of grippers that could be used for the system. After the system packs the JMIC it will be sent out.

The movements of the JMICs offer the greatest problem with this system. For the storage side of the system, the easiest way to have a working system with minimum parts is to always have an empty JMIC hold. This will allow for a new JMIC to be brought to the system by a transfer unit. The dry stores transfer unit will then bring the old JMIC to the break down area. The break down area is just a storage facility for used JMIC. On the packaging side of the process the JMIC should move in unison with the robotic arm. This will allow the arm to only have to travel across the aisle as shown in Figure 66. This will save packaging time. Another option is to use a gantry crane along with a conveyor belt and dedicated packing area. Thus the gantry crane would take items out of the JMICs, place them on a conveyor belt, and then be taken to the packing area when another gantry crane would pack the outbound JMIC, this can be seen in Figure 67.

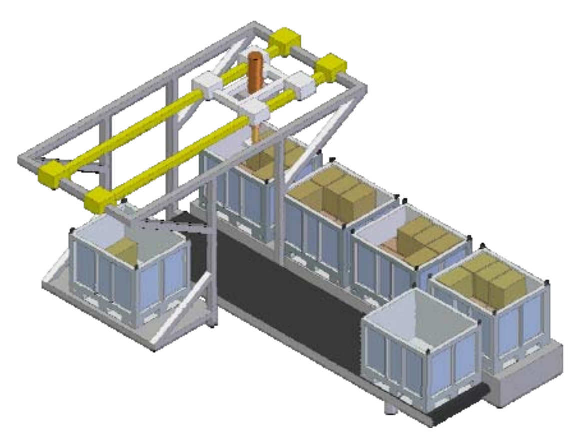


Figure 66: On demand distribution center with direct packing.

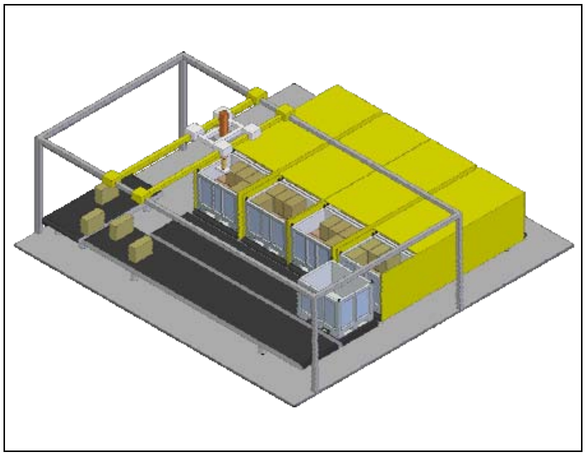


Figure 67: On demand distribution center with packing center.

The securing of the JMIC would operate the same as the dry storage locking system. This would allow for redundancy of the overall system. The on-demand system would function the best with the plus-grid design. The ability of multiple carts running at one time means the system will not get backed up. This is important because it will allow for the marines to get what they need in time.

4.4.3. Design Analysis

The on-demand system is completely different from the other systems. It does not use a dispenser for the high demand dry stores. The on-demand packaging system uses a single gantry robot to fill a JMIC that will be shipped. The system could use multiple gantry robots, depending on the retrieval speed needed. Using a conveyor system for the JMIC needed to be stored can bring the JMIC from one crane to the next. This could allow for shorter retrieval time. Further analysis should be performed using a material handling computer program.

There are many advantages to the on-demand system. An advantage to the system is that the technology has been developed. Only further research has to be performed in the removal of the JMIC lid and software programs. The system has economical advantages as well. If using just one gantry robot the system saves a minimum of the cost for a second robot. Also the system will save the cost for developing and production of the dispenser system.

Simplicity of the design is also an advantage to the distribution systems. The only complicated part of the design is the use of a gantry robot. The rest of the system would be the same as the manned on-demand system. However this system would allow for 24 hours service. Also concerns for ammunition and medical supplies would not be of a concern. There would be no dropping or considerable movement of the dry stores. The dry stores would either be secured in the JMIC or secured by the gantry robot.

There are disadvantages when compared with the dispenser systems. The on-demand system requires more space and time. The on-demand system would use the same footprint as a manned system. This is because the gantry robot only takes the place of the man. With more JMICs the system becomes less efficient when compared to the dispensers. The adaptability of the on-demand system does not mean a loss of space. The vertical and horizontal system loses space inside the dispenser to allow for adaptability. The on-demand system stays in the JMIC allowing for a more dense packaging system.

Not only is this system is very adaptable; it can also work with a human running the system. If the gantry robot were to break down the system could still work by having humans packaging. It would be a slower process, but there is no extra room needed to package during a breakdown.

Time is not a disadvantage. The dispenser system is about on average one second faster per case than the on-demand system. This means to transfer one JMIC worth of MREs to another JMIC the system would lose 48 seconds. If the JMIC were to travel with the system the packaging time would decrease. Having a JMIC travel with the system allows it to be one second faster. However, this time does not seem like it would be a huge deal. There is not a large enough difference in magnitude to say one is better from the other. However more analysis on the system needs to be done. Not having accurate information on the logistics of consumption does not allow for an accurate time analysis for a day.

Humans vs. Robots

The question of whether a gantry robot is a better than a human is a challenging question. Economically, a gantry robot would be paid off in around six years when comparing the cost of a human versus a gantry robot. However maintenance cost for the gantry robot are hidden, as well as the cost for the operator. The positive of a gantry robot being used is in case of a casualty at sea a new one can be built. The gantry robot also has the ability to work 24-hour days with out a break unlike a human. The gantry robot also won't get tired the longer it works. If a human were to pack for an entire day, its productivity would decrease through out the day. A case of MREs weighs twenty-two pounds, which will become heavy at the end of the day.

On the other hand a human has the ability to solve problems unlike the gantry robot. A sailor could pack a JMIC more efficiently than a gantry robot. The team believes with further software developments the gantry robot could successfully to pack a JMIC with multiple case sizes efficiently.

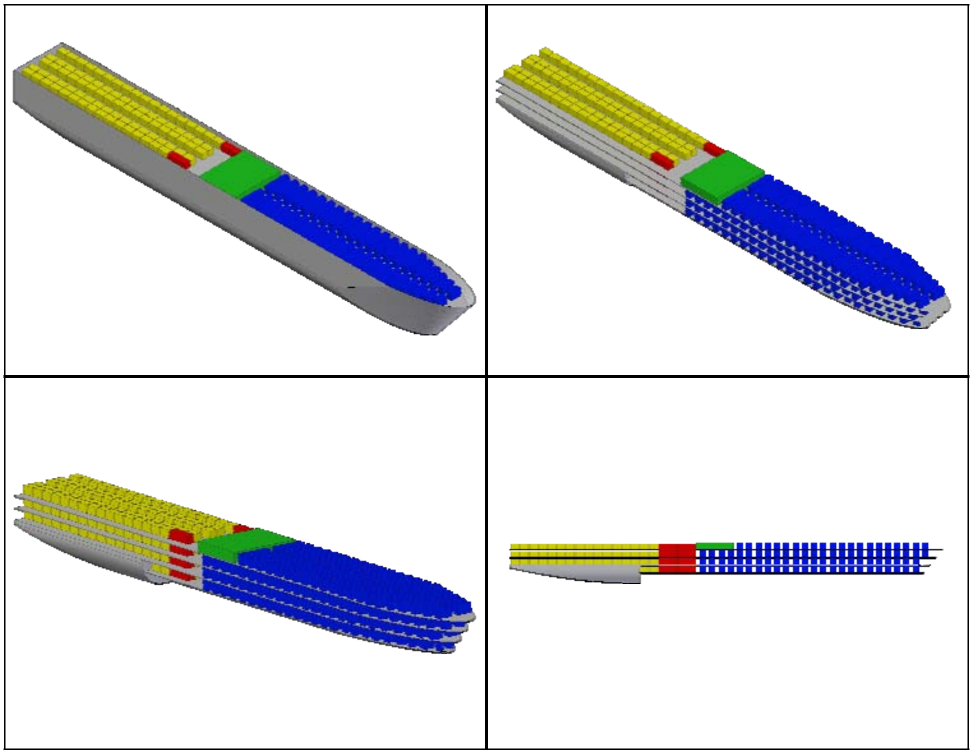
4.4.4. Future Considerations

Further analysis should be performed in order to optimize packing time along with minimizing the system's footprint. The system needs to create a method of knowing where each JMIC is located and also the number of packing spaces available for the JMIC. With the team not receiving consumption rates and packaging sizes for smaller dry stores, no high demand list was created. If that list could have been produced, the team would have minimized the footprint.

Being that the gantry crane is rigid with in its frame, the crane should be able to operate at sea conditions. This system should be tested while using JMIC both on land and at sea.

5. Total Ship Model

From the three main systems that were designed, several representative models were assembled to show what a whole ship model would look like. For this, an LMSR hull was assumed, and the three main sections were installed into the hull. For both of the ship models shown below, the vehicle storage area as well as the distribution center are the same size. For this representative ship hull size, the vehicle section would hold the required roughly 300 vehicles and six-cons. Each twenty foot vehicle storage cell is shown in yellow, and the vehicle elevators are shown in red. For the dry stores section, the branched layout would hold 21,024 JMICs, and library shelf layout would hold 28,800 JMICs, and the plus sign would hold about 28,032 JMICs. The actual number of containers required by the design criteria was only 4,564 containers. Thus the ship could be smaller, or hold more supplies for a longer period. The dry stores section is shown in blue, and the distribution center is shown in green. The placement of the distribution center may be altered however the amount of room occupied by it would remain around the same. The two layouts shown are for the branched layout, shown in Figure 1, and the plus sign layout, shown in Figure 2. The plus sign dry stores area is simply shown as a large block for simplicity. Also for the library shelf layout, it would be similar to that of the branched layout, just with fewer aisles.



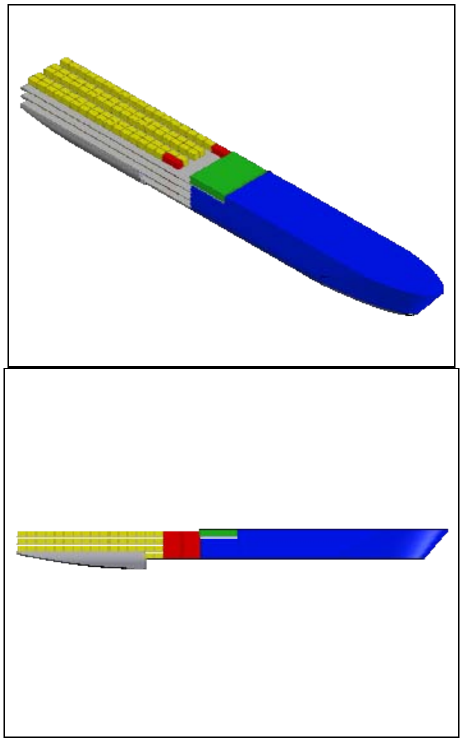


Figure 68: The series of photos above show representative ship models.

One possible use of the top deck space is to extend the long-term storage area upwards in an enclosed structure. This would allow for a large amount of extra storage to be added to the design. For the branched and library shelves, there would have to be added decks every 17 feet above the top deck. But for the plus sign the enclosure would simply be placed on top of an additional set of stacks. These stacks would be separate from the stacks in the main storage area of the ship. The two storage areas would be constructed such that the shafts of the stacks would line up and the upper transfer unit would be able to raise up slightly instead of lowering to allow the lower transfer unit to move up into the added stacks. This added area to the ship can be seen in Figure 68 below.

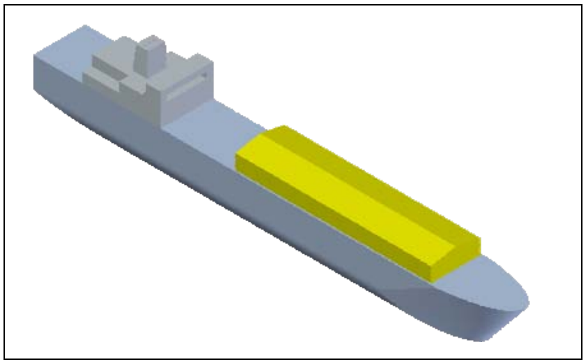


Figure 69: Use of area on top deck for additional storage.

6. Conclusion

The goal of this project was to identify systems that could achieve 100% selective offload of materials from a sea base.

The team was successful in developing several concepts that offer 100% selective offload of containers while maintaining high storage efficiencies compared to traditional warehouses. Through these concepts it is clearly possible to reach a storage efficiency of 80% with 100% selectability of dry stores. The high storage efficiency is an equally important quality of the designs. To achieve selective offload with low storage efficiency is not operationally useful.

Individual units in the field require certain amounts of specific supplies and it is not efficient to send a container full of one supply when they only require half a container. As a result, the requirement of 100% selectability of containers was taken a step further to allow for selectability of the goods within the containers using a distribution center. This additional selectability will allow individual fighting units to request specific individual supplies from the sea base.

For the vehicle storage system, an emphasis was placed on the adaptability of the design. The vehicle storage system still maintains relatively dense packing with 100% selectability. The system also has the ability to store different configurations of vehicles as well as extra dry stores if necessary. The flexibility to store extra dry stores is important if the sea base is used for humanitarian missions.

Ultimately, there is a trade off between storage efficiency and selectability; as the storage efficiency increases, the selectability decreases. One recommendation for future work would be to explore the necessity of achieving 100% selectability of a single container. It is often the case that there are several containers of the same type of dry store and it does not matter which container the dry store is retrieved from. For example, one container of MREs is exactly the same as another with MREs, so it does not matter which container the MREs are chosen from. Therefore, in order to increase the storage efficiency of the dry store areas, it may be beneficial to have 100% selectability of a specific type of dry store rather than a specific container of dry stores.

If 100% selectability is decided to be the best method of storing supplies within the sea base, the designs presented in this report can achieve this requirement while maintaining high storage efficiencies.

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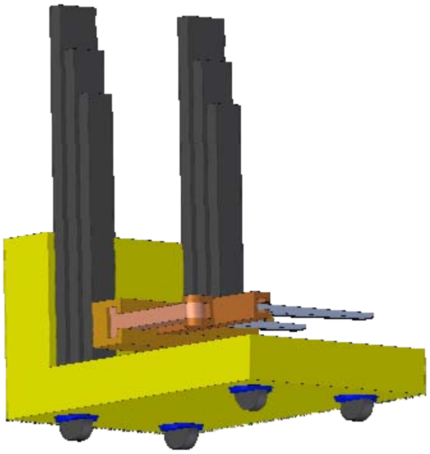
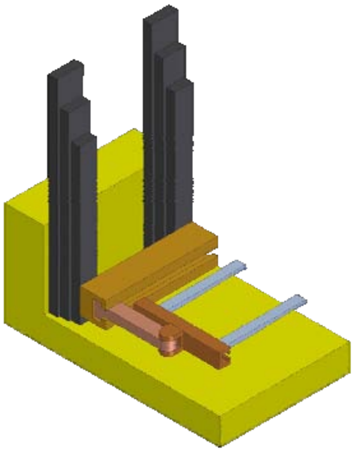
Vaughn, Deborah, Air Sled. Telephone interview. 29 June 2006.

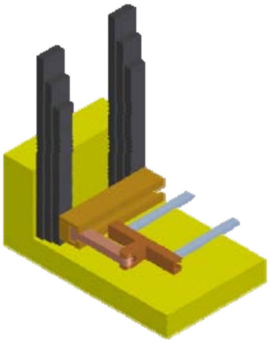
Welsh, Bob, Sea Box Inc. Telephone interview. 26 May 2006.

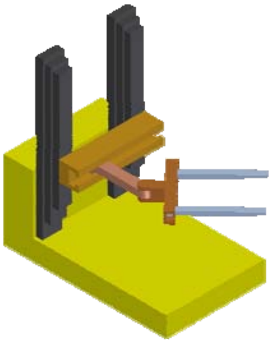
Appendix A: Additional Images

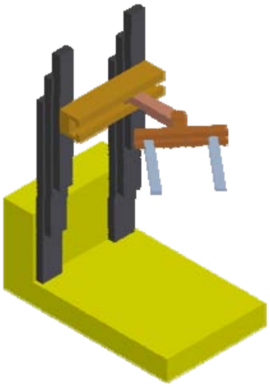
8. Transfer Unit:

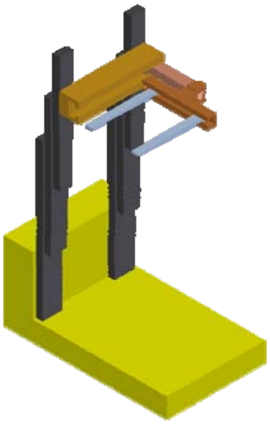












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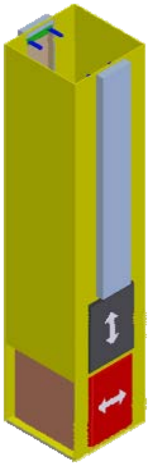

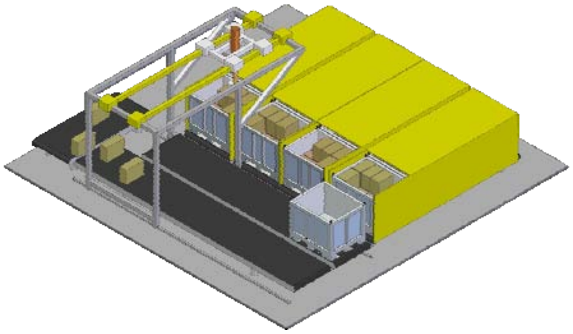

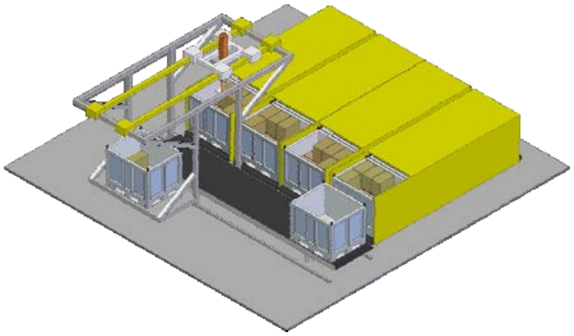

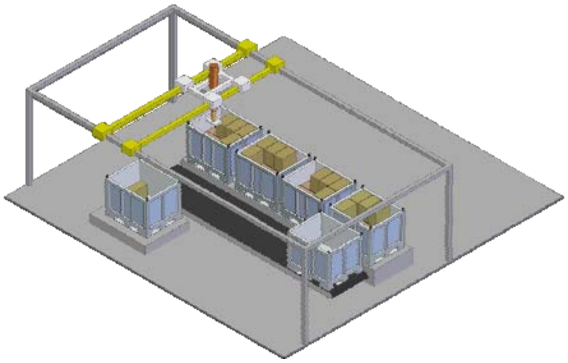

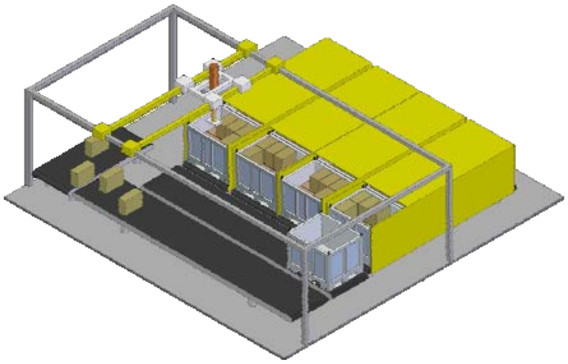

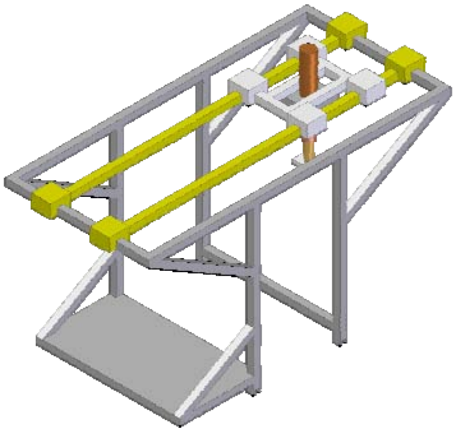

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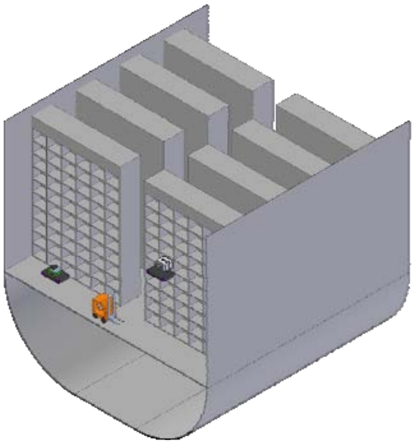

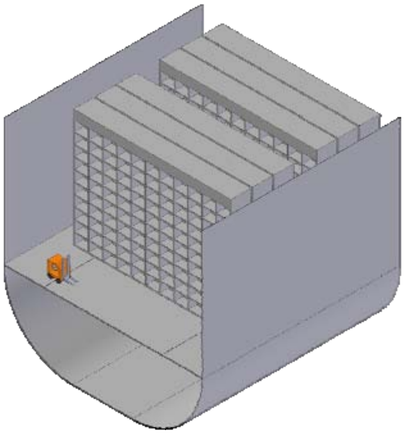

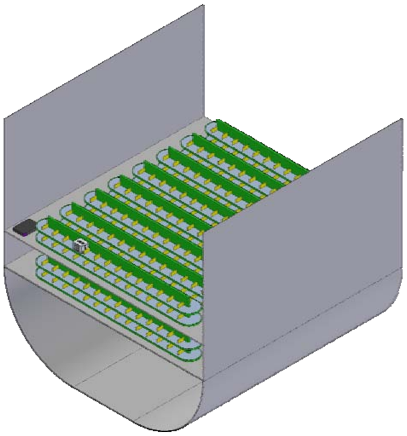

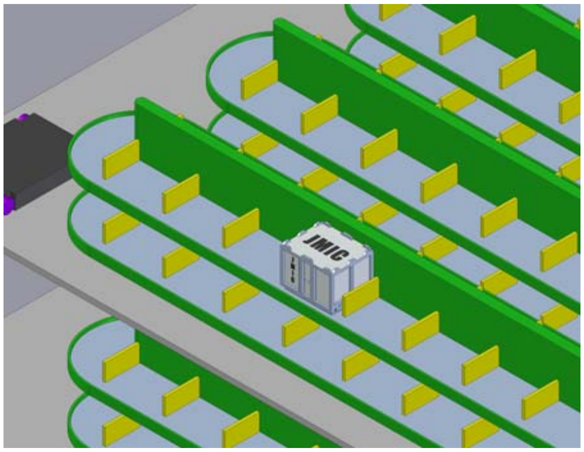

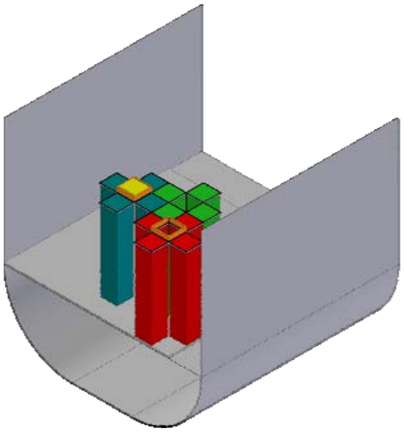

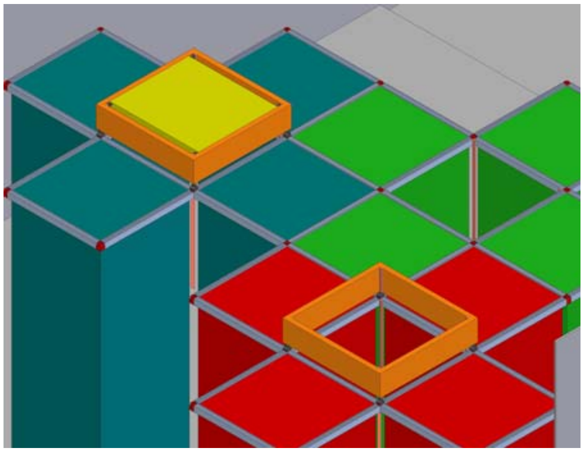

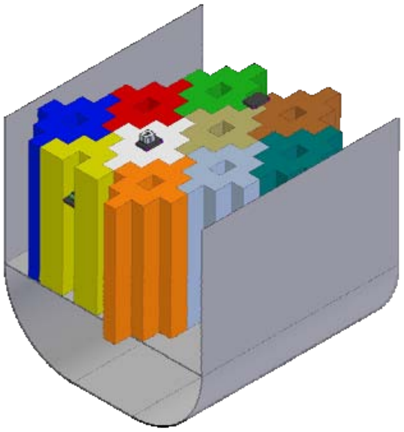

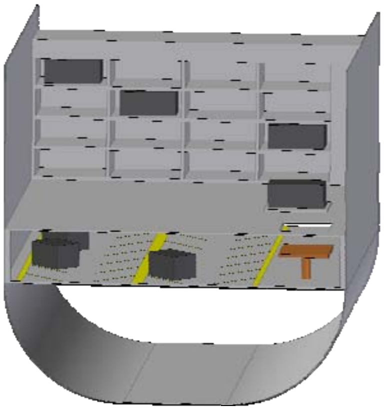

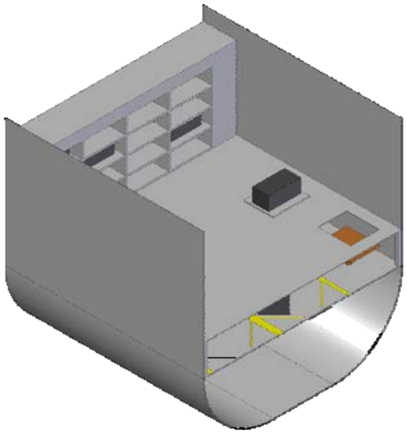

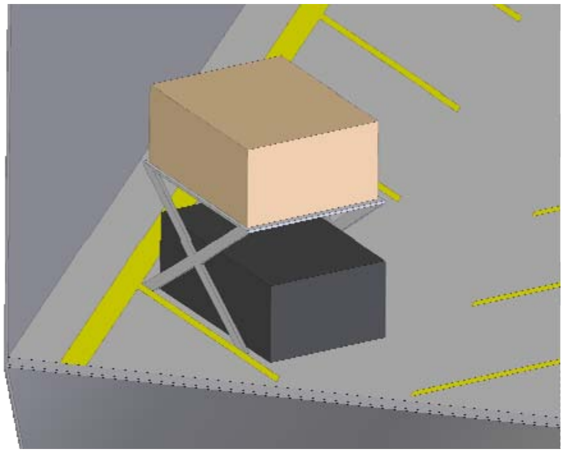

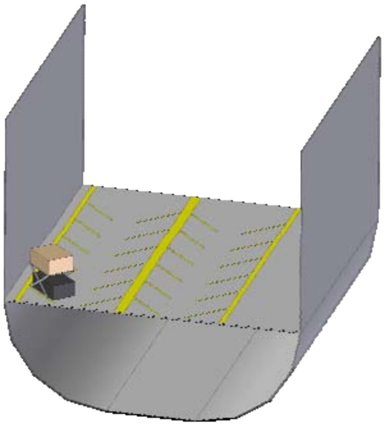

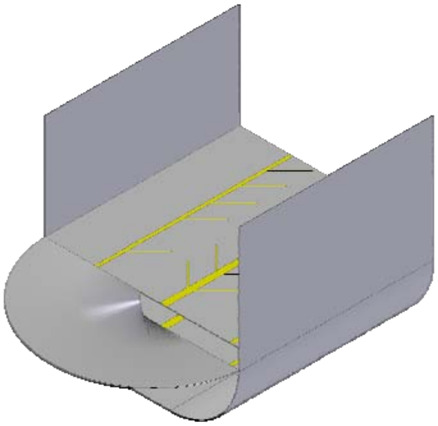

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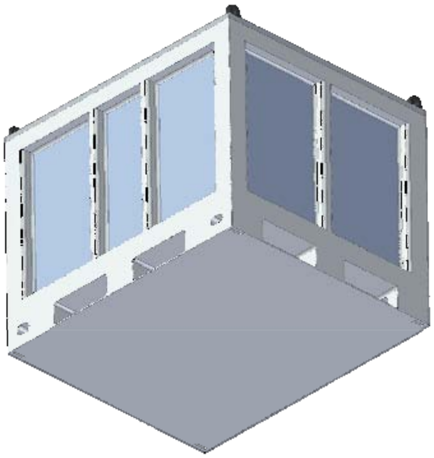

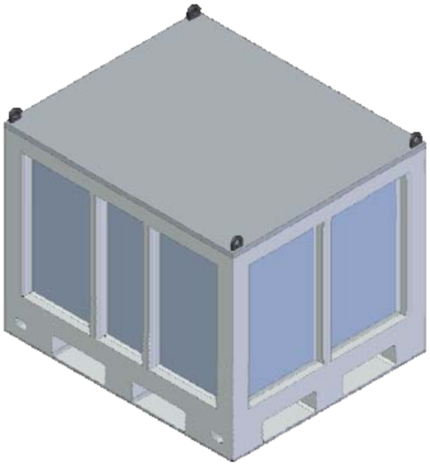

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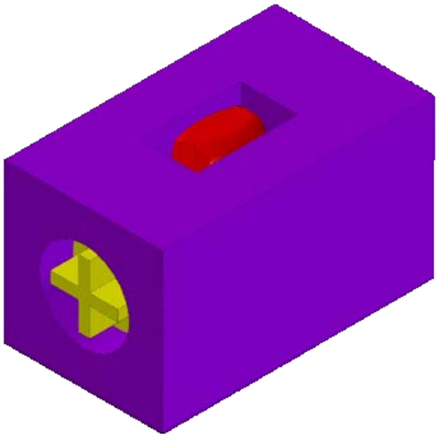

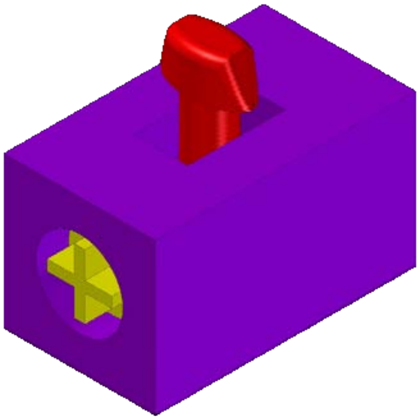

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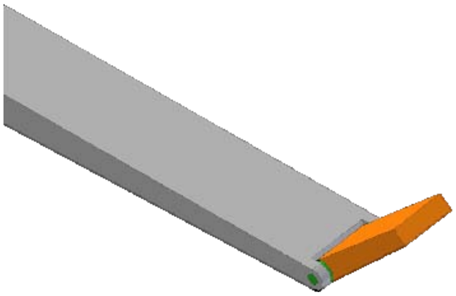

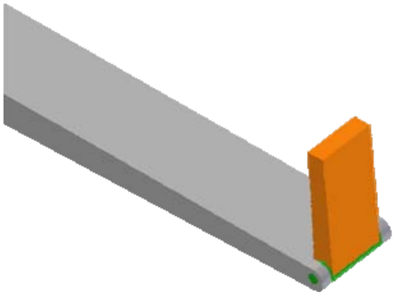

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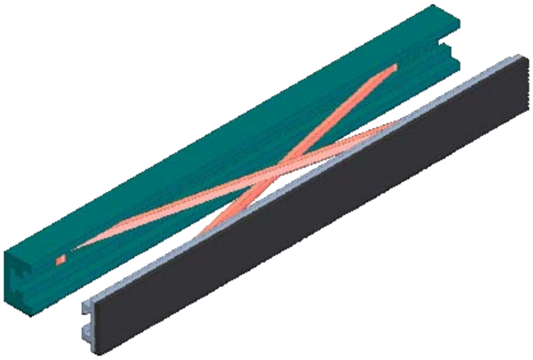

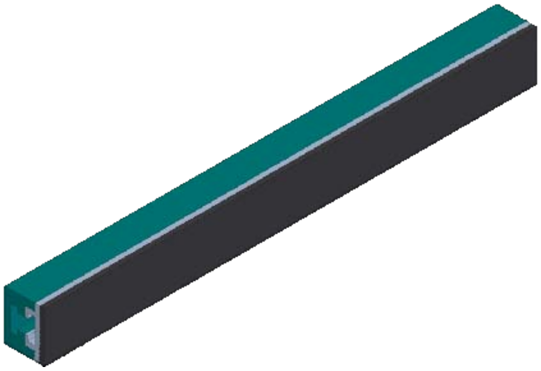

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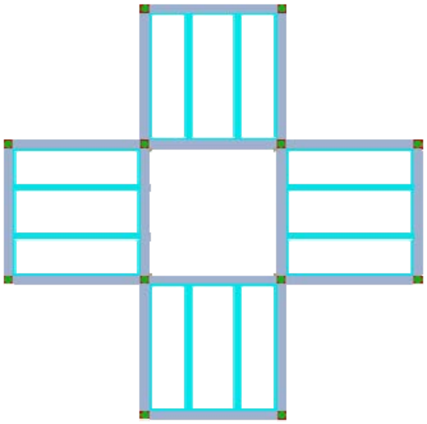

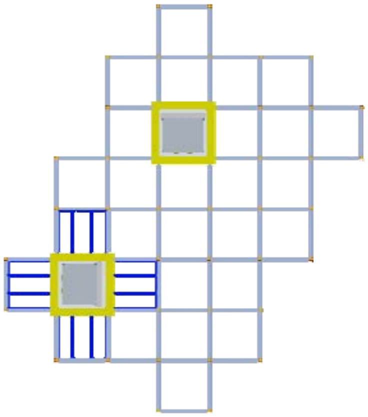

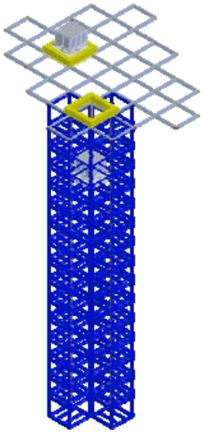

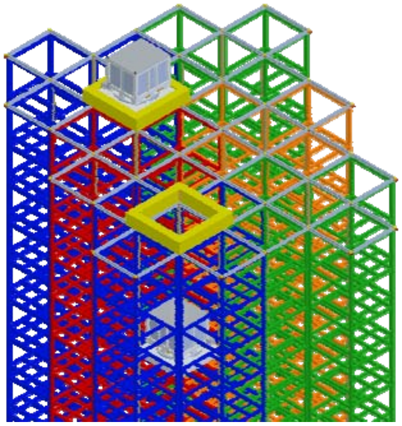

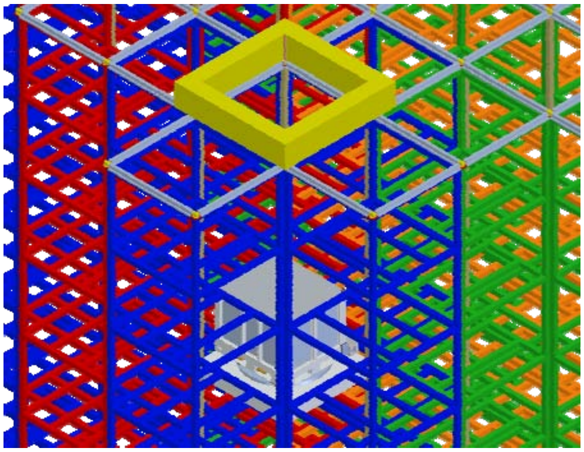

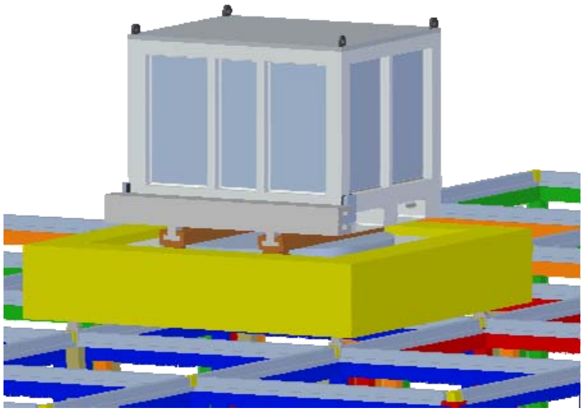

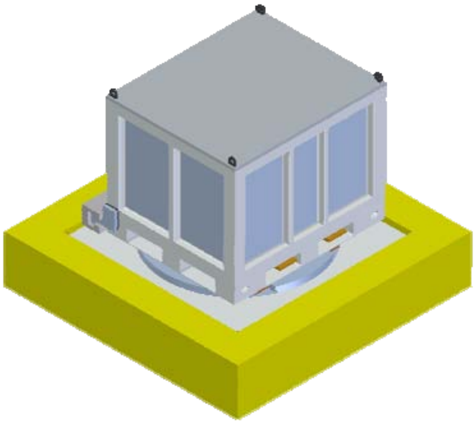

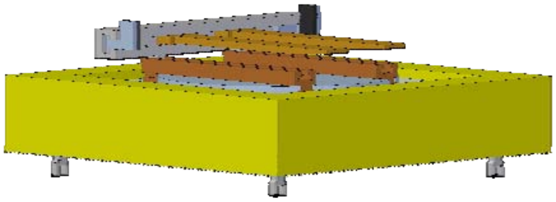

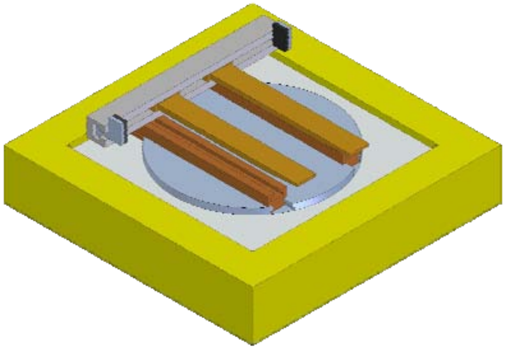

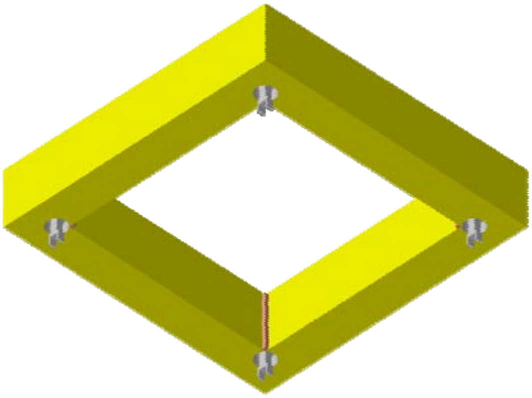

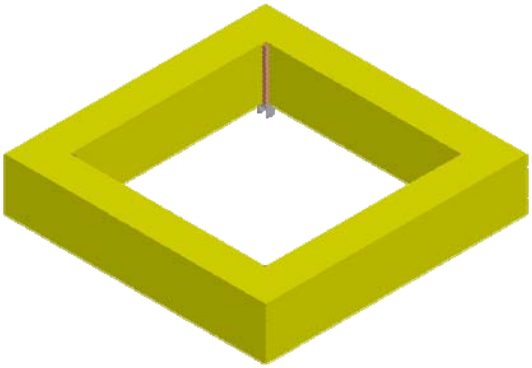

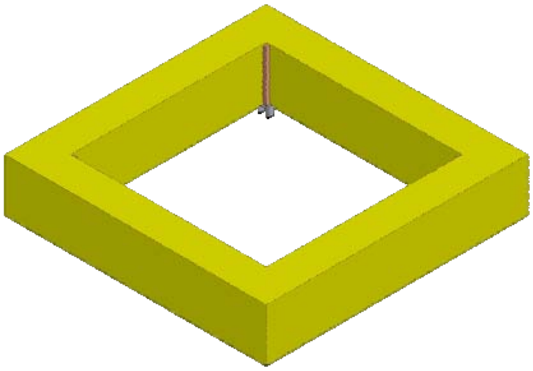

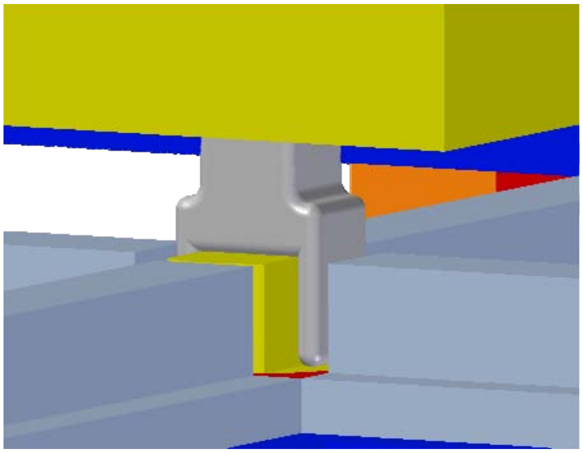

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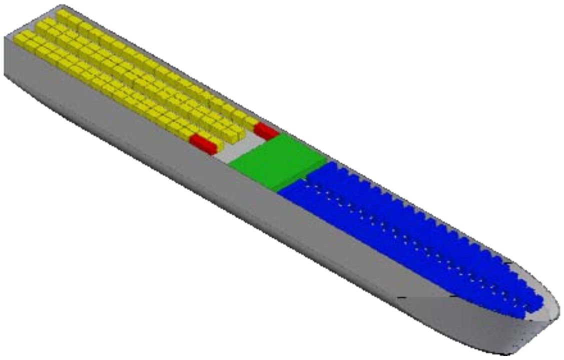
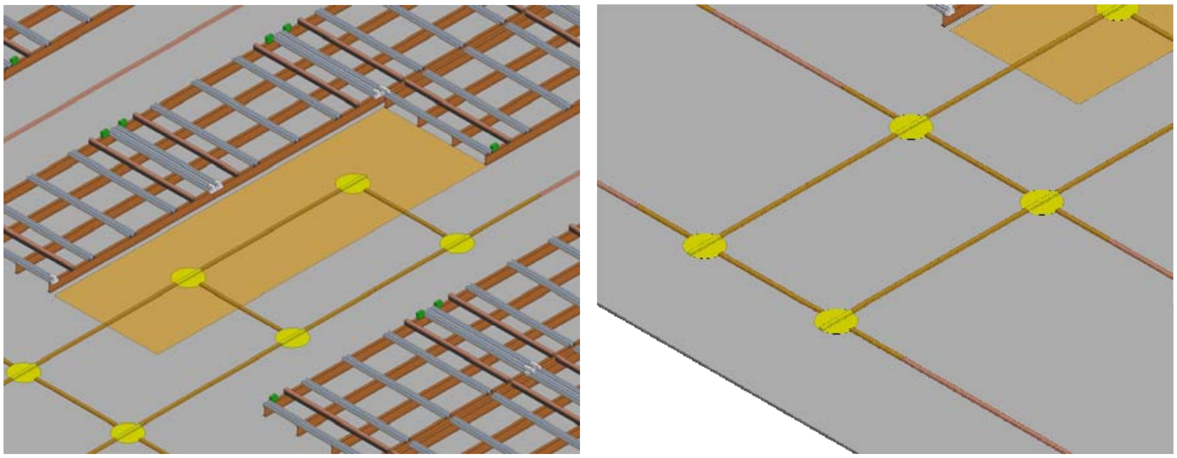
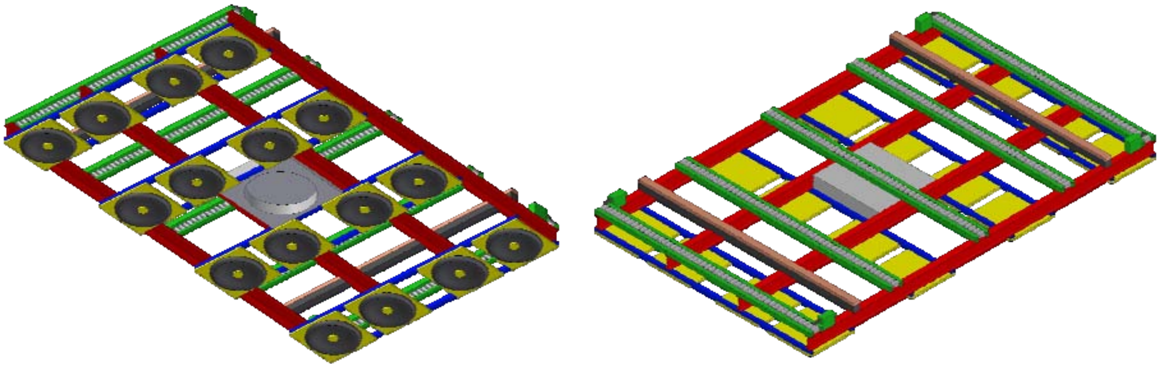
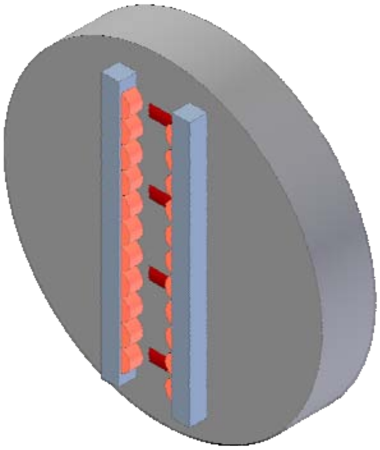


17. Vehicle Storage:

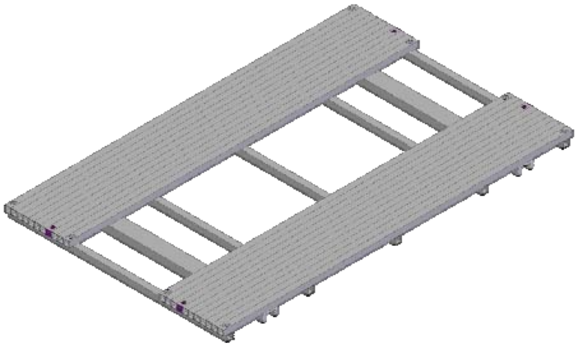


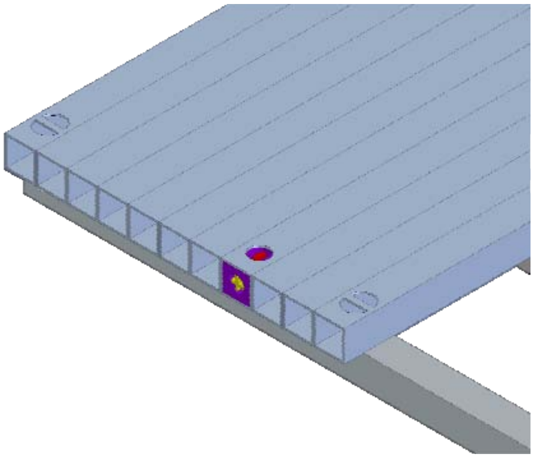
18. Air Pallet:

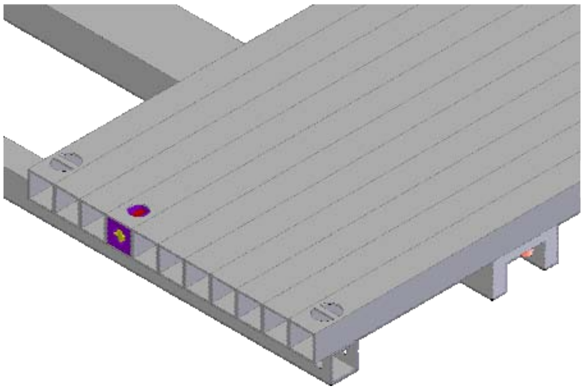


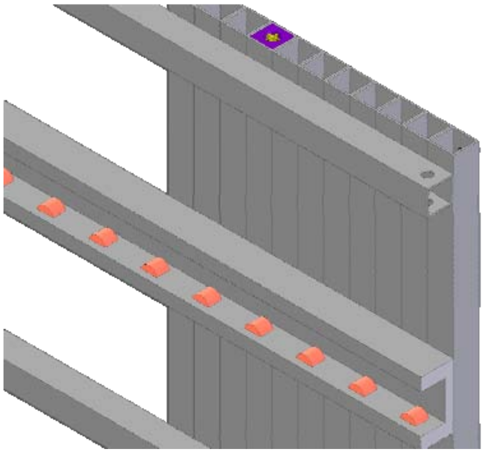


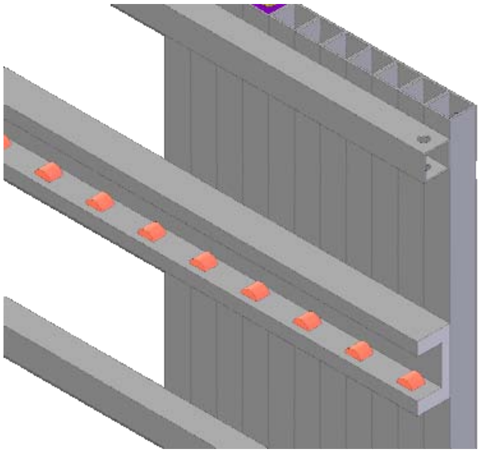
19. Vehicle Storage Plate:



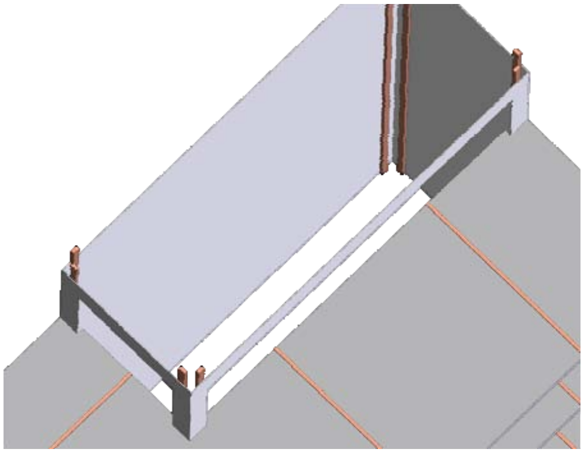


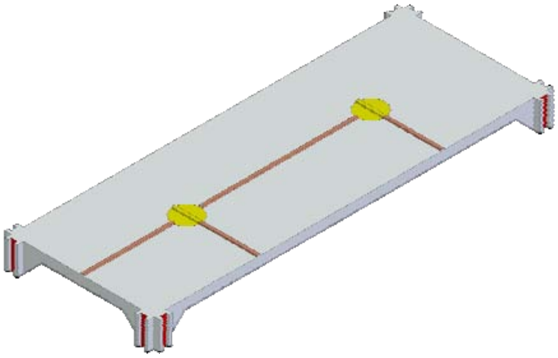


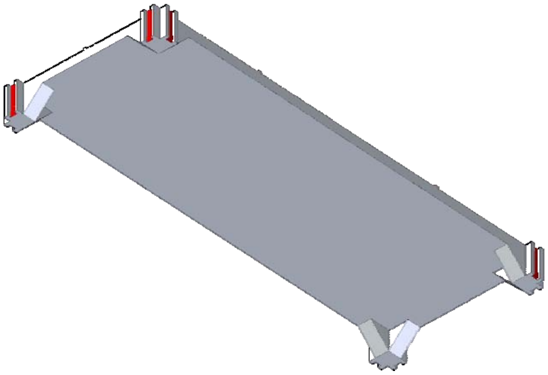




20. Vehicle Elevator:







Appendix B: Brainstorming Ideas

21. Dry Stores

Idea	Description
Library Shelves	Similar to many library shelves stacked perpendicular to the keel, however each shelve moves in the x direction allowing for increased stowage by only needing one row to retrieve the item.
Christmas Tree	A Storage system that has one central aisle with branches off the aisle. Similar layout to a home depot.
Single Grid Column	Four storage racks that are accessible through central elevator. Essentially in a plus sign with multiple components.
Pez Dispenser	Like the candy dispenser. The whole grid moves up and down to get into the storage space.
Pez Dispenser, Fixed	Dry Stores are stored vertically while lift retrieves the store.
Conveyor Belt	Much like airline luggage, stores are arranged on multiple conveyors with carts to access any given store.
Hat Rack	Storage Area is set up similar to a hat rack.
Gravity Fed	Storage grid is angled to use gravity as for assistance of moving stores.

22. Vehicle Storage

Idea	Description
Automated Parking Garage, Elevator	A parking garage where air pallets place car instead of drivers. Lower level is for heavy lift vehicle parking so no lifting is evolved with them.
Pez Dispenser	Similar to dry stores, where entire storage area lifts the system.
Long storage rows using air pallets	Similar to the bottom heavy lift level in the first concept, except would store all of the vehicles and use air pallets to transfer the vehicles around the deck.
Single Deck with scissor lift	A single parking lot with a hydraulic scissor lift to have one like vehicle over the other.
Extended Ramp	Curved Ramps from one level to the other.

23. Dispenser

Idea	Description
Vertical Soda Machine	Similar to the Soda Machine, however it is packed with MREs and M16A1 ammunition
Horizontal Dispenser	Similar to the Vertical Soda Machine however just turned on its side.
Conveyor Belt	Components are broken down from the beginning in the storage space. Then they are placed individually on the conveyor belt to be packaged.
Actuator	A system that arranged horizontally. It uses a push rod that is actuated to move the individual supplies into a packing line.
Carousel	A system that has the individual supplies on a rotating system. When a MRE is needed it then places it on a conveyor belt to be packaged.
On Demand System	JMIC are brought to the packing area when needed. There are a number of robotic arms that can then unpack multiple JMIC

Appendix C: Pairwise Comparison & Weighted Decision Matrix

24. Pairwise Comparison:

Pairwise Comparison	Maximize Storage Capacity	Minimize Retrieval Time	Minimize Complexity/# of Parts	Rugged Design	Easy Accessability/Serviceability	Minimal Maintenance Required	Minimal Reliance on Machines	Fail Safe/ Redundancy	Operation in Sea State 4	Safe Storage in Sea State 8	Minimize Man Power	Easily Adaptable to Different Size Containers/Pallets	Easily Identifiable Containers/Pallets	Maximize Selectibility	Total	Percent
Maximize Storage Capacity		0	1	1	1	1	1	0	0	0	0	0	0	0	5	0.074
Minimize Retrieval Time	1		0	1	0	0	1	0	0	0	1	0	0	0	4	0.059
Minimize Complexity/# of Parts	-1	1		1	0	0	1	1	0	0	0	0	0	0	3	0.044
Rugged Design	-1	-1	-1		0	0	0	0	0	0	0	0	0	0	-3	-0.044
Easy Accessability/Serviceability	-1	1	1	1		0	1	0	0	0	0	0	0	0	3	0.044
Minimal Maintenance Required	-1	1	1	1	1		1	0	0	0	0	0	0	0	4	0.059
Minimal Reliance on Machines	-1	-1	-1	1	-1	-1		0	0	0	0	0	0	0	-4	-0.059
Fail Safe/ Redundancy	1	1	-1	1	1	1	1		0	0	0	0	0	0	5	0.074
Operation in Sea State 4	1	1	1	1	1	1	1	1		1	1	1	1	1	13	0.191
Safe Storage in Sea State 8	1	1	1	1	1	1	1	1	-1		1	1	1	1	11	0.162
Minimize Man Power	1	-1	1	1	1	1	1	1	-1	-1		0	0	0	4	0.059
Easily Adaptable to Different Size Containers/Pallets	1	1	1	1	1	1	1	1	-1	-1	1		0	0	7	0.103
Easily Identifiable Containers/Pallets	1	1	1	1	1	1	1	1	-1	-1	1	1		1	9	0.132
Maximize Selectibility	1	1	1	1	1	1	1	1	-1	-1	1	1	-1		7	0.103
														Total	68	1

25. Weighted Decision Matrix:

Weighted Decision Matrix	**Maximize Storage Capacity**	**Minimize Retrieval Time**	**Minimize Complexity/# of Parts**	**Rugged Design**	**Easy Maintenance/Serviceabilit y**	**Minimal Maintenance/Serviceabilit y**	**Minimal Relia on Machines**	**Ability to Operate Manually/Man Power**	**Operation in Sea State 4**	**Operational in Sea State 6**	**Minimize Man Power**	**Easily Adaptable to Different Size Containers/Pallets**	**Easily Identifiable Containers/Pallets**	**Maximize Selectibility**	**Total**
Weighted Values	0.022	0.044	0.055	0.000	0.055	0.066	0.011	0.066	0.143	0.132	0.077	0.099	0.121	0.110	
Christmas Tree															
Fork Lift (x, y, z)	2.0	5.0	4.0	0.0	4.0	4.0	5.0	5.0	3.0	3.0	5.0	3.0	5.0	5.0	4.011
Fork Lift (z) Shelve Carts (x, y)	2.0	4.0	2.0	0.0	3.0	3.0	2.0	2.0	4.0	4.0	5.0	3.0	5.0	5.0	3.780
Grid Connected Rail Cart (Automated Cart, Fork, or Air Pallet)	2.5	5.0	3.5	0.0	2.0	3.0	1.0	1.0	4.0	4.0	5.0	3.0	5.0	5.0	3.786
Pully System (Automated Cart, Fork, or Air Pallet)	1.5	4.0	2.0	0.0	2.0	4.0	4.0	5.0	3.0	3.0	5.0	3.0	5.0	5.0	3.725
Human Operated Forklift	2.0	4.0	5.0	5.0	5.0	5.0	4.0	5.0	3.0	1.0	0.0	3.0	5.0	5.0	3.484

Library Shelves															
Fork Lift (x, y, z)	5.0	3.0	1.0	5.0	2.0	2.0	2.5	3.5	2.5	2.5	5.0	3.0	5.0	5.0	3.319
Fork Lift (z) Shelve Carts (x, y)	4.0	2.5	1.0	5.0	1.5	1.5	1.0	2.0	2.5	2.5	5.0	3.0	5.0	5.0	3.099
Grid Connected Rail Cart (Automated	4.5	2.5	1.0	5.0	1.5	1.5	1.0	2.0	2.5	2.5	5.0	3.0	5.0	5.0	3.110

Cart)															

Vertical Storage															
Grid Connected Rail Cart	5.0	4.0	3.0	5.0	1.5	3.0	1.0	2.0	3.0	3.0	5.0	3.0	5.0	4.5	3.478

Pez Dispenser															
Air Pallets	5.0	3.5	2.0	5.0	2.0	2.0	1.0	1.0	4.0	4.0	5.0	3.0	5.0	4.0	3.516

Vehicle Storage															
First Level-Heavy Vehicles (Air Pallets) Second Level-Light Vehicles (Automated Parking Garage), Elevator to Second Level	4.5	4.0	3.0	5.0	4.0	4.0	3.0	2.5	4.0	4.0	5.0	3.0	5.0	5.0	4.055
First Level-Heavy Vehicles (Driven) Second Level-Light Vehicles (Automated Parking Garage), Elevator to Upper Levels	4.0	3.0	3.0	5.0	4.5	4.5	4.0	4.5	4.0	4.0	1.5	3.5	5.0	5.0	3.984
Pez Dispenser with Rollers/Air Pallets	5.0	3.5	1.5	5.0	2.0	2.0	1.0	2.0	3.0	2.0	5.0	3.5	5.0	4.0	3.198
Grid with Lift and Rollers/Air Pallets	3.5	4.0	3.5	5.0	3.5	2.5	2.0	2.5	3.5	3.5	5.0	3.5	5.0	5.0	3.835

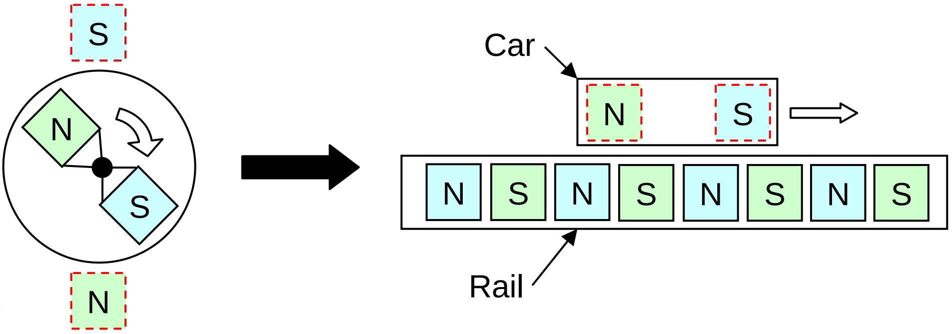
First Level- Heavy Vehicles (Air Pallets) Second Level- Light Vehicles (Automated Parking Garage), Ramp to Upper Levels	3.5	3.5	4.0	5.0	4.5	4.0	4.5	5.0	3.5	3.5	5.0	3.0	5.0	5.0	4.137
Extended Ramp Levels	3.0	3.0	5.0	5.0	5.0	5.0	4.0	5.0	4.0	4.0	5.0	3.0	5.0	5.0	4.385
Single level, Hydraulic Lifts to Store Lighter Vehicles on Top of One Another	3.5	3.0	4.0	5.0	4.5	4.0	4.0	5.0	4.0	4.0	5.0	4.0	5.0	4.0	4.236

Distribution System															
High Demand (Soda Machine, Gravity Fed, Specific Container for Each Supply Type, Conveyer Belt to Take Items From Columns) Low Demand (Robotic Arm From Shelves), Long Term Store Bulk Materials then Breakdown	4.0	5.0	2.5	5.0	3.0	3.0	4.0	4.0	4.0	3.0	5.0	3.0	5.0	4.0	3.808
Horizontal Conveyer Belt w/ Adjustable Sides to Handle Different Sized Supplies	3.5	5.0	3.0	5.0	3.0	4.0	3.5	4.5	2.5	2.0	5.0	5.0	5.0	5.0	3.879

Breakdown Materials Initially, Bulk Storage, Robotic Arm Lift System Retrieves Supplies and Places On Central Conveyer Belt	5.0	3.0	3.0	5.0	3.0	4.0	3.0	3.0	2.5	1.0	5.0	5.0	5.0	5.0	3.588
Carousel	3.0	4.0	1.0	5.0	2.0	2.0	3.0	3.5	4.0	3.0	5.0	5.0	5.0	5.0	3.802

Appendix D: LSM OVERVIEW

In order to decrease the complexity, and number of moving parts in the design, Linear Electric Motors (LEMs) were considered. There are several different types of LEMs, including Linear Induction Motors (LIMs) and Linear Synchronous Motors (LSMs). The newer LSMs have some benefits over the older LIMs, and were thus chosen to be used in the design in a variety of ways. A LSM works similarly to a regular AC motor. The external loop of a regular motor is laid flat on a surface, and the inner moving armature of a regular motor is flattened out as well. The inner loop becomes the moving piece that is attached the device being moved. This consists of a permanent rare earth magnet. The lower stationary portion of the LSM has many small electromagnets that can be turned on an off at specified times. The magnet on the device has a constant polarity, which in turn is used by turning sections of the track on and off to attract and repel the permanent magnet in such a way that the device move left or right down the track. This setup is depicted in Figure 124; where the rotating DC motor is shown as it is transitioned into a linear DC motor. The light dashed red lines represent a permanent magnet, where as all other magnets alternate polarity to induce movement in the system. It can be see for the cart that the north and south poles will This is a fairly efficient method of moving objects, with about a 70-85% efficiency. The LSMs were used in the track system for the transportation of the air pallets, the transfer unit in the plus sign layout, various elevators, as well as other actuators.



Error!

Figure 70: Representative layout of LSM track.

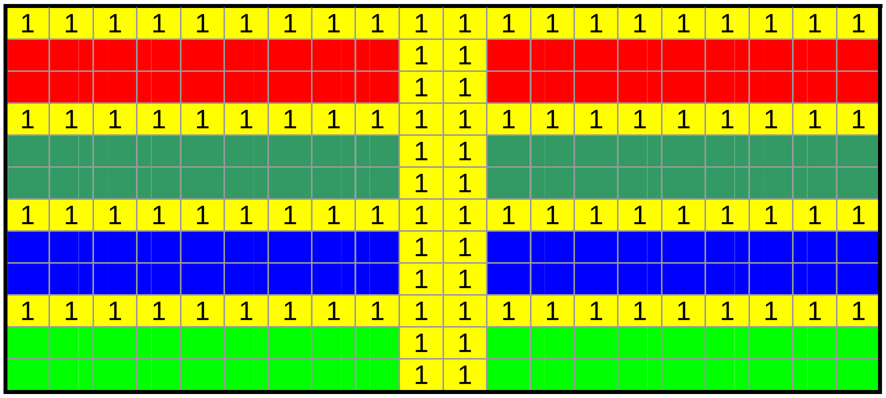
Appendix E: Stowage Factor

From the weighted decision matrix, the main four designs were chosen. The following designs were Library Shelves, Single Grid Column, Plus Sign, and Branches. Using Microsoft Excel, the aforementioned layouts were scaled in excel using a single cell equal to five feet. The layouts were set up with multiple colors for readability. Various colors represent storage spaces, where yellow which represent aisle ways or elevator shafts, and white represents wasted space that could not be used for storage. By assigning a value of one for aisles/elevators as well as wasted space, a ratio could be obtained. By dividing the sum of the cells for scaled ship by the total number of cells (20 x 180) a wasted space to possible storage ratio was obtained. The smaller the value the less wasted space the layout contains. From this analysis the results were as follows from best to worst: Single Grid Column, Plus Sign, Library Shelves, and Branches with the numeric values equal to 9.33%, 22.2%, 27.6, and 40.5% respectively. Even Though Single grid Column layout scored the best, its design feasibility and complexity may lessen the significance of such a high score. In this analysis, supporting structures as well as other design items were not considered. This was used as a rough estimation to better evaluate the storage capacity of each design.

Table 11: Percent storage space for various storage layouts.

Layout	Percent Storage Space	Lost Space to Storage Ratio
Single Grid Column	90.667	0.093
Library Shelves	81.500	0.185
Plus Sign	77.778	0.222
Christmas Tree	59.500	0.405

Representative Section of Branched Layout:

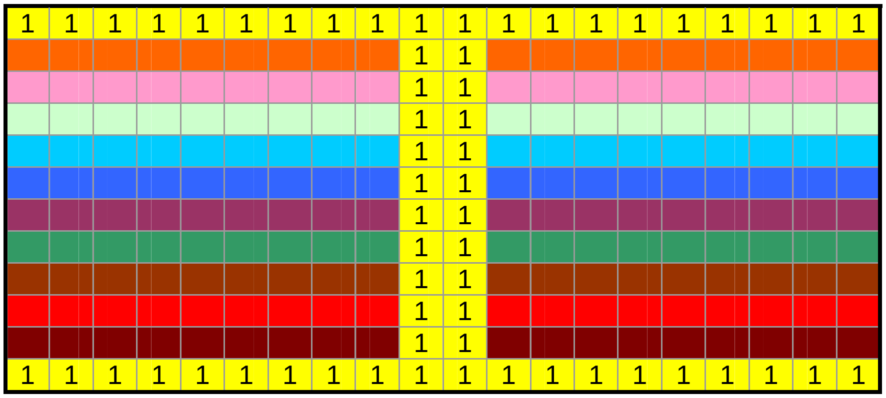


1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
									1	1									
									1	1									
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
									1	1									
									1	1									
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
									1	1									
									1	1									
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
									1	1									
									1	1									

Representative Section of Plus Sign Layout:

	1		1			1		1			1		1			1		1	
1				1					1					1					1
		1					1					1					1		
1					1					1					1				1
			1					1					1					1	
	1					1					1					1			
1				1					1					1					1
		1					1					1					1		
1					1					1					1				1
			1					1					1					1	
	1					1					1					1			
1				1					1					1					1

Representative Section of Library Shelf Layout:



1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
									1	1									
									1	1									
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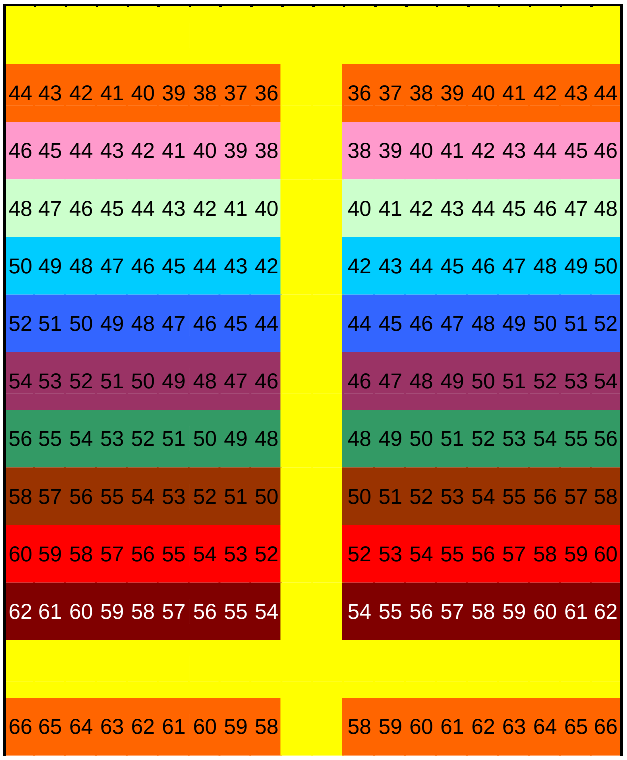
									1	1									
									1	1									
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Appendix F: Retrieval Time

The retrieval time or time to get and retrieve an object, whether vehicle, or dry-stores was calculated using Microsoft Excel. The following design concepts were analyzed: library shelf, plus sign, vehicle storage – rear ramp loading, vehicle storage – side ramp loading, and vehicle storage – top deck amidships loading. The calculations for the retrieval time were based on the distances that the object would have to be moved, as well as the velocities specified for moving each different type of object. In these calculations, the acceleration and deceleration periods were not considered, and the objects were assumed to move at a constant velocity, and change direction and speed instantaneously. Also the distances are rounded for each of calculation. The times do not include locking, turning, etc. These can be summed and directly added to the averages. In the following dry-store layouts, the tapering of the bow is not considered. The number listed in each cell is the total time to retrieve the object from start to finish. The following figures are top views of their respective storage systems.

26. Library Shelves

Below is an example of the library shelf layout of the ship in Excel:

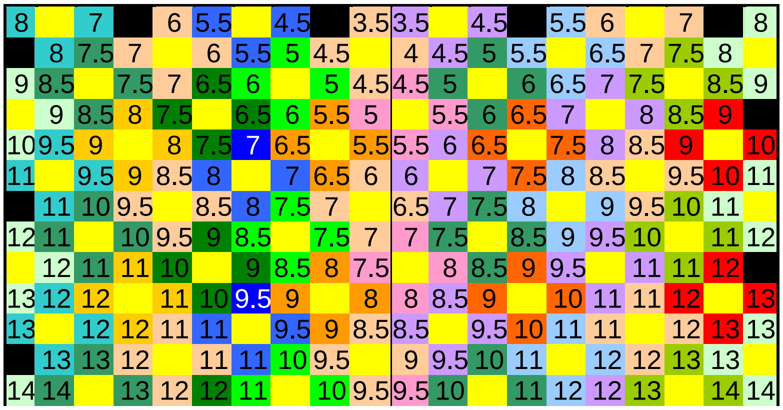


44	43	42	41	40	39	38	37	36		36	37	38	39	40	41	42	43	44
46	45	44	43	42	41	40	39	38		38	39	40	41	42	43	44	45	46
48	47	46	45	44	43	42	41	40		40	41	42	43	44	45	46	47	48
50	49	48	47	46	45	44	43	42		42	43	44	45	46	47	48	49	50
52	51	50	49	48	47	46	45	44		44	45	46	47	48	49	50	51	52
54	53	52	51	50	49	48	47	46		46	47	48	49	50	51	52	53	54
56	55	54	53	52	51	50	49	48		48	49	50	51	52	53	54	55	56
58	57	56	55	54	53	52	51	50		50	51	52	53	54	55	56	57	58
60	59	58	57	56	55	54	53	52		52	53	54	55	56	57	58	59	60
62	61	60	59	58	57	56	55	54		54	55	56	57	58	59	60	61	62
66	65	64	63	62	61	60	59	58		58	59	60	61	62	63	64	65	66

In this layout yellow represents an aisle, and the colored bars represent one moveable shelf. Each shelf can move independently, and collected in groups of ten with one aisle space in between each group. This means that the worst case is the five shelves would have to be moved to get the opening to where the JMIC needs to be placed. This layout was used for a multi deck design with four total decks. Each shelf has four JMIC slots high, two deep, and nine wide. For this approximation, the depth of two was assumed to be only one since the time for both crates is approximately the same. The width of the layout is the one hundred feet, and the length of the layout is five hundred and thirty feet. The length was obtained by using a representative LMSR hull length, and subtracting out the length needed for the vehicle storage area. Each shelf on each deck was broken down into its four individual levels and analyzed based on the X, Y, and Z travel times. Moving the JMIC is a forklift on a rail system but powered by rubber wheels. The movement between each deck of the ship was an elevator that transports the forklift. The forklift speed was 5 ft/sec horizontally, 2 ft/sec vertically, and the elevator speed was 1 ft/sec. The start point for this layout was the top deck of the ship at the upper end of the dry stores area. The final results for retrieval time as listed in table 11.

27. Plus Sign

Below is an example of the plus sign layout of the ship in Excel:

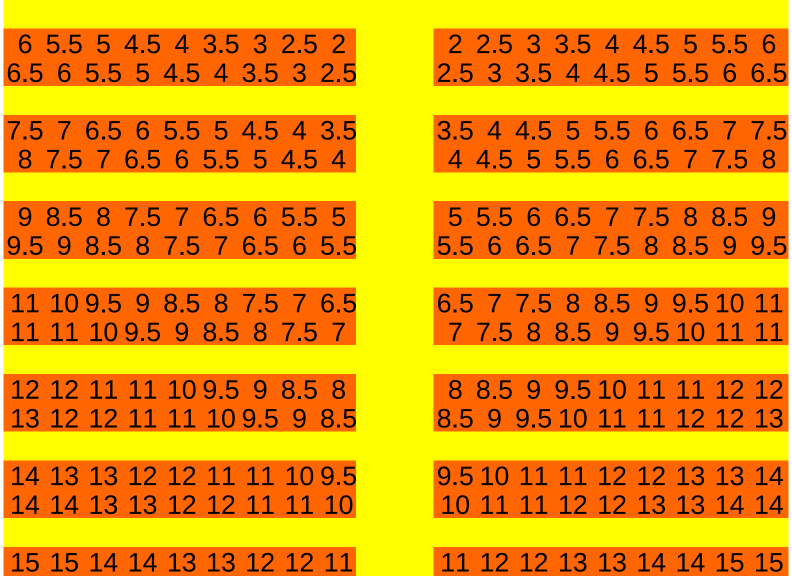


8		7		6	5.5		4.5		3.5	3.5		4.5		5.5	6		7		8
	8	7.5	7		6	5.5	5	4.5		4	4.5	5	5.5		6.5	7	7.5	8	
9	8.5		7.5	7	6.5	6		5	4.5	4.5	5		6	6.5	7	7.5		8.5	9
	9	8.5	8	7.5		6.5	6	5.5	5		5.5	6	6.5	7		8	8.5	9	
10	9.5	9		8	7.5	7	6.5		5.5	5.5	6	6.5		7.5	8	8.5	9		10
11		9.5	9	8.5	8		7	6.5	6	6		7	7.5	8	8.5		9.5	10	11
	11	10	9.5		8.5	8	7.5	7		6.5	7	7.5	8		9	9.5	10	11	
12	11		10	9.5	9	8.5		7.5	7	7	7.5		8.5	9	9.5	10		11	12
	12	11	11	10		9	8.5	8	7.5		8	8.5	9	9.5		11	11	12	
13	12	12		11	10	9.5	9		8	8	8.5	9		10	11	11	12		13
13		12	12	11	11		9.5	9	8.5	8.5		9.5	10	11	11		12	13	13
	13	13	12		11	11	10	9.5		9	9.5	10	11		12	12	13	13	
14	14		13	12	12	11		10	9.5	9.5	10		11	12	12	13		14	14

In this layout yellow represents a vertical elevator shaft, and the colored cells represent the four horizontal cells that are linked to one central elevator shaft. The Upper Transfer Unit (UTU) is free to move about the x-y plane above the stacks of JMICs. The Lower Transfer Unit (LTU) only moves up and down the elevator shaft and retrieves that JMIC from its respective cell. This layout was used for a single deck hull design. Each “Plus Sign” stack holds four containers on each level, and each stack is twelve levels high, holding a total of forty eight containers each. The stacks are interconnected, however at the sides and ends of the ship, some spaces cannot be accessed, which are shown in black. The overall dimensions for the dry-stores area is the same for that of the library shelf design. Each cell on each level of the stacks were broken down and analyzed based on the X, Y, and Z travel times. The travel speed was 10 ft/sec horizontally, 2 ft/sec vertically. The start point for this layout was the top deck of the ship at the upper end of the dry stores area. The final results for retrieval time as listed in Table 11.

28. Branched

Below is an example of the branched layout of the ship in Excel:

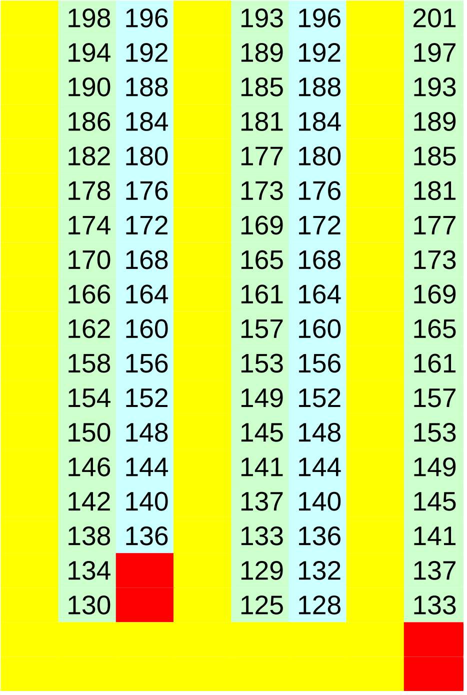


6	5.5	5	4.5	4	3.5	3	2.5	2		2	2.5	3	3.5	4	4.5	5	5.5	6
6.5	6	5.5	5	4.5	4	3.5	3	2.5		2.5	3	3.5	4	4.5	5	5.5	6	6.5
7.5	7	6.5	6	5.5	5	4.5	4	3.5		3.5	4	4.5	5	5.5	6	6.5	7	7.5
8	7.5	7	6.5	6	5.5	5	4.5	4		4	4.5	5	5.5	6	6.5	7	7.5	8
9	8.5	8	7.5	7	6.5	6	5.5	5		5	5.5	6	6.5	7	7.5	8	8.5	9
9.5	9	8.5	8	7.5	7	6.5	6	5.5		5.5	6	6.5	7	7.5	8	8.5	9	9.5
11	10	9.5	9	8.5	8	7.5	7	6.5		6.5	7	7.5	8	8.5	9	9.5	10	11
11	11	10	9.5	9	8.5	8	7.5	7		7	7.5	8	8.5	9	9.5	10	11	11
12	12	11	11	10	9.5	9	8.5	8		8	8.5	9	9.5	10	11	11	12	12
13	12	12	11	11	10	9.5	9	8.5		8.5	9	9.5	10	11	11	12	12	13
14	13	13	12	12	11	11	10	9.5		9.5	10	11	11	12	12	13	13	14
14	14	13	13	12	12	11	11	10		10	11	11	12	12	13	13	14	14
15	15	14	14	13	13	12	12	11		11	12	12	13	13	14	14	15	15

29. Vehicle Storage:

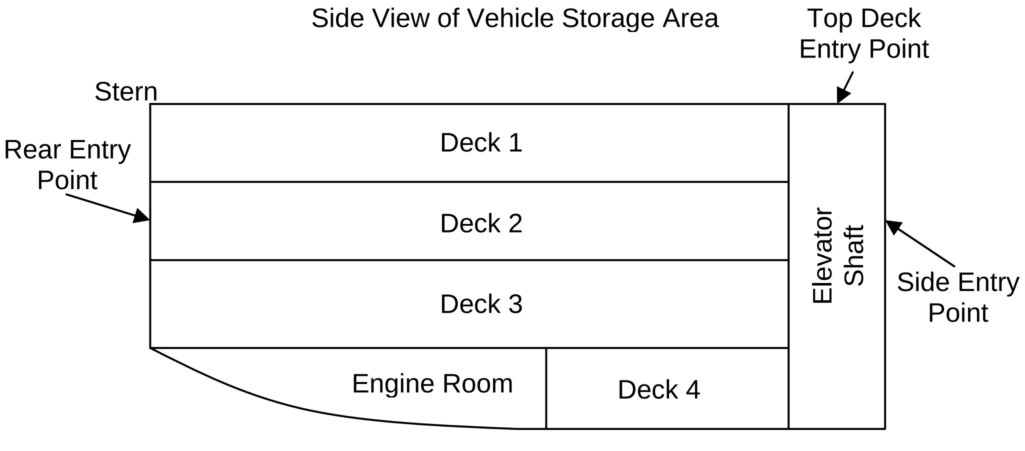
The vehicle storage area consists of four decks. Movement between the decks is accomplished by means of two elevators located at the end of the vehicle storage area, towards the center of the ship. There are several different possible loading points, rear ramp, side ramp, and top deck. Each of these loading points was analyzed separately. Each cell represents a 12 feet wide, and 20 feet long area. The yellow cells represent aisles within which the air pallets move, the colored cells are storage slots, and the red cells represent elevator shafts. The overall dimensions for the vehicle storage area are 100 feet wide, and 400 feet long. Each cell on each level of the was analyzed based on the X, Y, and Z travel times. An air pallet moves the vehicles in the X-Y plane, and an elevator moves the air pallets between decks. In these calculations, the time to load and unload the vehicle from the storage slot was also included. The travel speed was 5 ft/sec horizontally, 1 ft/sec vertically. The start point for this layout varied based on where the vehicles were being loaded from. Some space was lost on the rear loading layout on the second deck such that there would be room to load and unload the vehicles. In the other layouts, this area is already accounted for near the elevators. Also the retrieval times vary greatly between the loading point and which deck it is on, since in a rear loading case, the air pallet has to move the vehicle down deck two up the elevator and the back down the final deck. The various start points are shown in

Figure 70. The final results for retrieval time as listed in Table 11.



	198	196		193	196		201
	194	192		189	192		197
	190	188		185	188		193
	186	184		181	184		189
	182	180		177	180		185
	178	176		173	176		181
	174	172		169	172		177
	170	168		165	168		173
	166	164		161	164		169
	162	160		157	160		165
	158	156		153	156		161
	154	152		149	152		157
	150	148		145	148		153
	146	144		141	144		149
	142	140		137	140		145
	138	136		133	136		141
	134	🟥		129	132		137
	130	🟥		125	128		133
							🟥
							🟥

Figure 71**: Layout for rear loading of vehicles**



Note: Image Not Drawn to

Figure 72: Layout of vehicle storage area

Layout	Average Retrieval Time (sec)
Library Shelf	134.9
Plus Sign	92.1
Branched	99.7
Vehicle – Rear Loading	273.8
Vehicle – Side Loading	172.6
Vehicle – Top Deck Loading	225.3

Table 12: Average retrieval times for various storage layouts.

Appendix G: Forces Required

Shown below are the calculations used in determining the force that would be required to apply to hold a JMIC in place while at a specified roll angle. The forces for both the storage cell locking mechanism as well as the transfer unit locking mechanism are shown. For the transfer unit calculations the maximum possible roll is safer than assuming the maximum operating roll of 15 degrees because the system could enter high seas unpredictably, and a transfer unit may be stuck while transferring a container.

Shown below are the calculations for the clamps

Side Clamp Locking Mechanism Calculations for Storage Cell

$\text{Weight} := 3000 \cdot \text{lb}$

$\text{mass} := \text{Weight}$

$\text{mass} = 93.243\,\text{slug}$

$g := 47.18 \frac{\text{ft}}{\text{s}^2}$

$\theta := 50 \cdot \text{deg}$

$\mu := 3$

$F_{parallel} := \text{mass} \cdot g \cdot \sin(\theta)$ $\quad F_{parallel} = 3369.981\,\text{lbf}$

$F_{normal} := \text{mass} \cdot g \cdot \cos(\theta)$ $\quad F_{normal} = 2827.75\,\text{lbf}$

$F_{frictionrequired} := F_{parallel}$ $\quad F_{required} := \frac{F_{frictionrequired}}{\mu}$ $\quad F_{required} = 1123.327\,\text{lbf}$

$F_{half} := \frac{F_{required}}{2}$ $\quad F_{half} = 561.663\,\text{lbf}$

There are two sides to the clamp, thus the result is halved, delivering half of the force from either side

$l := 18 \cdot \text{in}$ $\quad h := 4 \cdot \text{in}$

$\text{Area} := l \cdot h$ $\quad \text{Area} = 72\,\text{in}^2$

Using a rectangular pad on either side of dimensions L and h, the area and pressure is obtained

$\text{Pressure} := \frac{F_{half}}{\text{Area}}$ $\quad \text{Pressure} = 7.801\,\text{psi}$

Side Clamp Locking Mechanism Calculations for Transfer Unit

$\text{Weight} := 3000 \cdot \text{lb}$

$\text{mass} := \text{Weight}$

$\text{mass} = 93.243 \text{slug}$

$g := 47.18 \frac{\text{ft}}{\text{s}^2}$

$\theta := 50 \cdot \text{deg}$

$F_{\text{parallel}} := \text{mass} \cdot g \cdot \sin(\theta)$

$F_{\text{parallel}} = 3369.981 \text{lbf}$

$F_{\text{normal}} := \text{mass} \cdot g \cdot \cos(\theta)$

$F_{\text{normal}} = 2827.75 \text{lbf}$

$\mu := 3$

$F_{\text{frictionrequired}} := F_{\text{parallel}}$

$F_{\text{required}} := \frac{F_{\text{frictionrequired}}}{\mu}$

$F_{\text{required}} = 1123.327 \text{lbf}$

$F_{\text{required}} = 1123.327 \text{lbf}$

$F_{\text{half}} := \frac{F_{\text{required}}}{2}$

There are two sides to the clamp, thus the result is halved, delivering half of the force from either side

$F_{\text{half}} = 561.663 \text{lbf}$

$l_{TU} := 6 \cdot \text{in}$ $h_{TU} := 6 \cdot \text{in}$

$\text{Area} := l_{TU} \cdot h_{TU}$ $\text{Area} = 36 \text{in}^2$

Using a rectangular pad on either side of dimensions L and h, the area and pressure is obtained

$\text{Pressure} := \frac{F_{\text{half}}}{\text{Area}}$

$\text{Pressure} = 15.602 \text{psi}$

Appendix H: Stress Calculations

30. Stress Analysis of Dry Stores Locking Pin:

This analysis was conducted on a type of locking pin that could be used as the primary means of restraining a JMIC while in the storage cell. The pin would be of a small diameter and would protrude from the locking mechanism into the JMIC. For this analysis, the base of the pin was considered to be fixed and attached to the rest of the locking mechanism. The applied load is raised up from the fixed end only a short distance, and the load is applied over the area that would come in contact with the JMIC. The load used was a bearing load over the circumference of the cylinder. The material further past the applied force is there simply for safety of the locking mechanism, but does not carry any load. The applied load was 570lbf and was perpendicular to the long axis of the pin. This load was obtained through analysis of the forces from a 3,000lb JMIC on the deck of a ship. This load came from the use of a computer model of an LMSR and it’s respective accelerations that it would see in SS8. From the analysis, the maximum stress was found to be at the base of the pin (most likely from the bending moment) The max stress was found to be 4518 psi which, when using A36 steel with a yield strength of 36,000 psi is well within the desired limit of 12,000 psi for a factor of safety of at least 3 to yield.

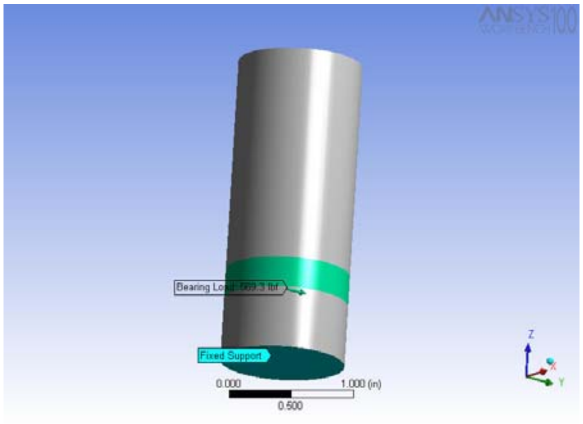


Figure 73: Environmental conditions of locking pin.

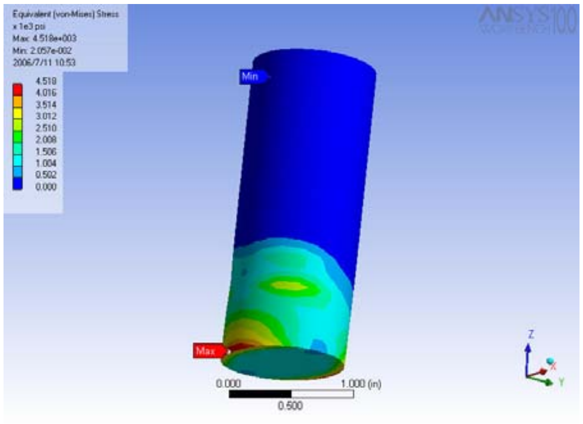


Figure 74: Equivalent stress of locking pin.

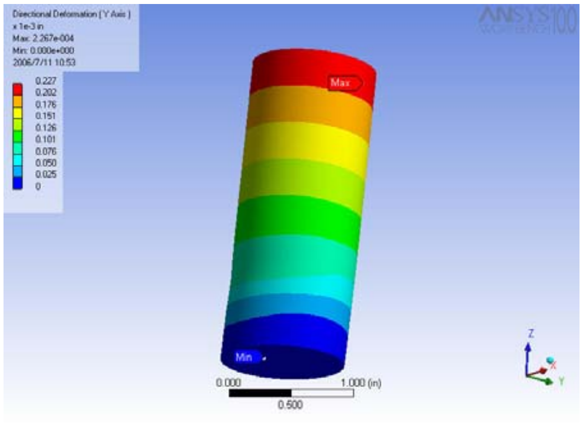


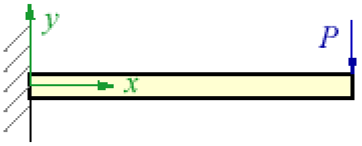
Figure 75: Directional deformation of locking pin.

31. Hand Calculations for Locking Pin:

Stress for Locking Pin (Turn lock or straight pin)

Diameter	$D := 1 \cdot in$		
Cross Sectiontal Area	$A := \pi \cdot \left(\frac{D}{2}\right)^2$	$A = 0.785\,in^2$	
Cargo Load Weight	$W := 3000 \cdot lb$		
Half of Load	$w := \frac{W}{2}$	$w = 1500\,lb$	Assuming there are 4 total pins, and in worst case, only two pins are supporting the load at a time
Mass of Half of Load	$m := w$	$m = 46.621\,slug$	
Gravity	$g := 47.18 \frac{ft}{s^2}$		
Angle of Ship List	$\theta := 15 \cdot deg$		
Force on Pin	$F := m \cdot g \cdot \sin(\theta)$	$F = 569.298\,lbf$	
Angle of Shear	$\phi := 0 \cdot deg$		Angle phi assumes that the force is perpendicular to the surface for 0 degrees, and paraller to the surface for 90 degrees
Shear Stress	$\tau := \frac{F \cdot \cos(\phi)}{A}$	$\tau = 724.853\,psi$	

Bending Stress



Circular Cross Section Moment of Inertia $I := \frac{\pi \cdot D^4}{64}$ $I = 0.049\,\text{in}^4$

Distance from Fixed Surface $x := .5 \cdot \text{in}$

Moment $M := F \cdot x$ $M = 284.649\,\text{in} \cdot \text{lbf}$

Distance to extreme fibers $y := \frac{D}{2}$ $y = 0.5\,\text{in}$

Stress Due to Bending $\sigma_{bend} := \frac{M \cdot y}{I}$ $\sigma_{bend} = 2899.411\,\text{psi}$

Distance from Neutral Axis to Centriod of Area $y_c := \left(\frac{D}{2}\right) - \frac{(3 \cdot \pi - 4) \cdot D}{6 \cdot \pi}$ $y_c = 0.212\,\text{in}$

$Q := A \cdot y_c$ $Q = 0.167\,\text{in}^3$

Chord length at yc $d := 2 \cdot \sqrt{\left(\frac{D}{2}\right)^2 - {y_c}^2}$ $d = 0.905\,\text{in}$

Shear Stress Due to Bending $\tau_{bend} := \frac{F \cdot Q}{I \cdot d}$ $\tau_{bend} = 2134.741\,\text{psi}$

32. Stress Analysis of Dry Stores Locking Bar With No Hole:

Setup:

This is an alternative to a locking pin based on how one of the prominent JMIC designs couples together. Instead of being a round shaft, it is a vertical plate/bar. Since the part of interest is not completely symmetric there are two loading conditions. One is for if the load is on the narrow side, and one is for if the load is on the broad side. The load used is the same as what was used for the locking pin of 570 lbf. This part it modeled exactly as the called for in the JMIC specs, allowing this bar to slide into the bottom of the JMIC. As with the locking pin, the base of the piece was assumed to be fixed to the rest of the locking mechanism which extends and retracts the piece. The load is applied at a distance away from the area where the piece would contact with the floor. In the side loaded condition there is more surface area, but because of the orientation of the force the moment of inertia is less, thus causing the stresses to be higher, which is seen in the results. In both cases, the locking bar does not exceed the accepted value of 12,000 psi

The maximum Stress was found to be 4,802 psi for front loaded setup, and 9,986 psi for the side loaded condition.

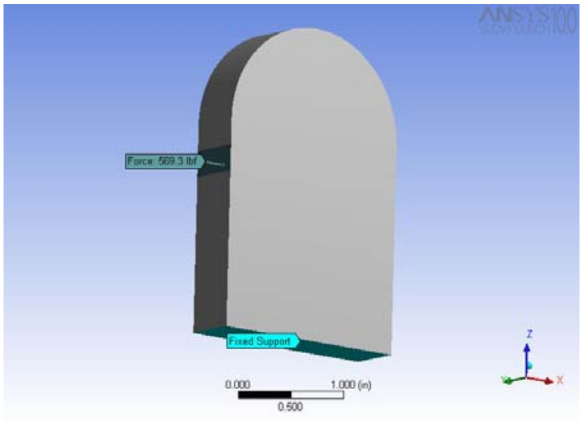


Figure 76: Environmental conditions for front loaded locking bar.

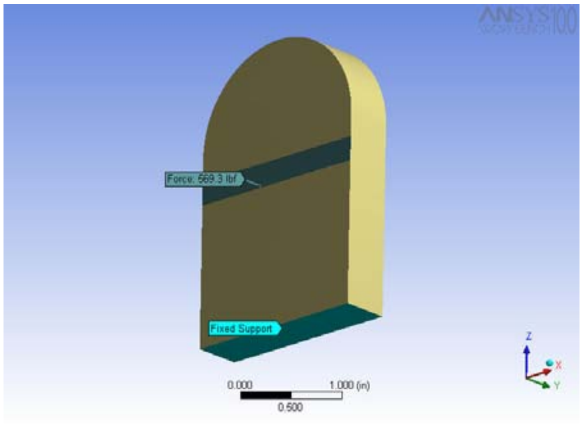


Figure 77: Environmental conditions for side loaded locking bar.

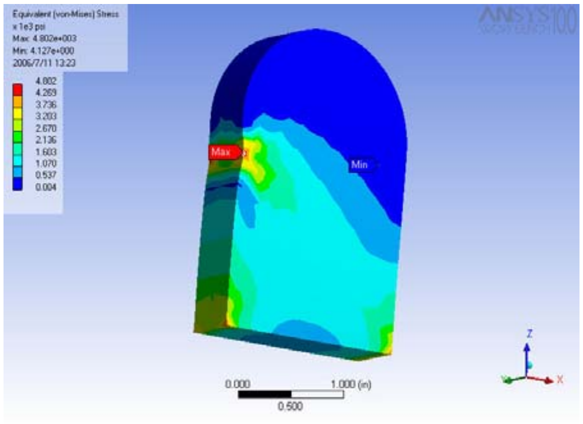


Figure 78: Equivalent stress for front loaded locking bar.

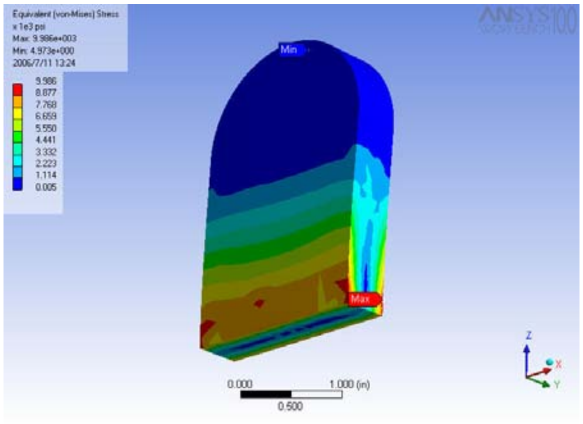


Figure 79: Equivalent stress for side loaded locking bar.

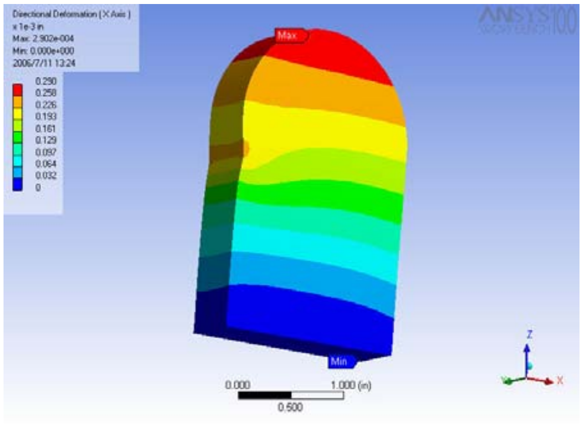


Figure 80: Directional deformation for front loaded locking bar.

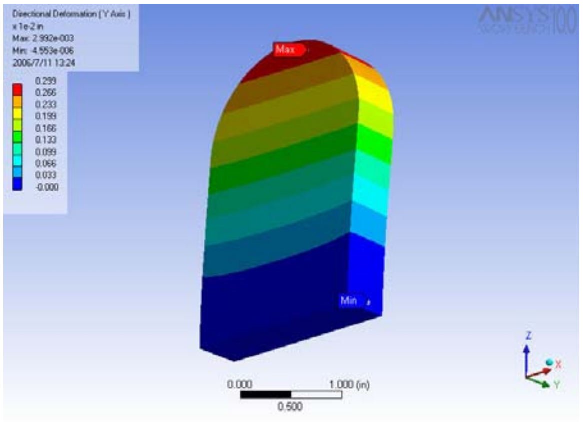


Figure 81: Directional deformation for side loaded locking bar.

33. Stress Analysis of Dry Stores Locking Bar With Hole:

This model is simply the same part as the flat pin with a hole in it, fitting the exact size of the actual slot in this JMIC variation. This may be used with a smaller size hole if there were to be a second pin that slid through the JMIC and into this bar to prevent movement in the vertical direction off of the storage rack. The assumptions are the same, but there is a change in the surface are for the side loaded case, and with the material removed from the center, it is expected that the stresses will be higher. In both cases, the locking bar does not exceed the accepted value of 12,000 psi. The maximum Stress was found to be 3,741 psi for front loaded setup, and 6,905 psi for the side loaded condition. Which were both somewhat higher that the model with no hole.

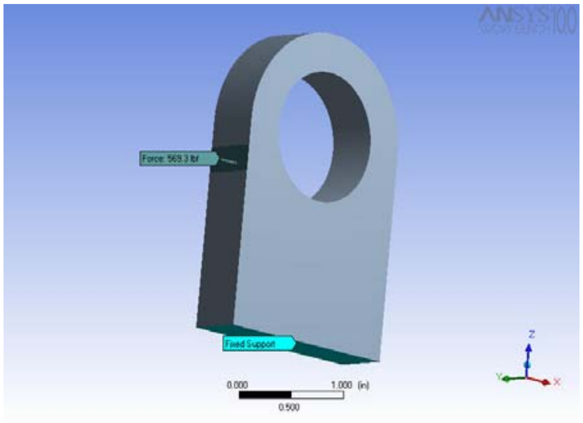


Figure 82: Environmental conditions for front loaded locking bar with hole.

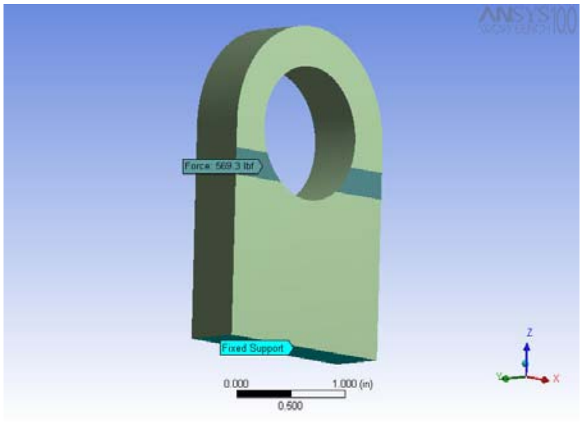


Figure 83: Environmental conditions for side loaded locking bar with hole.

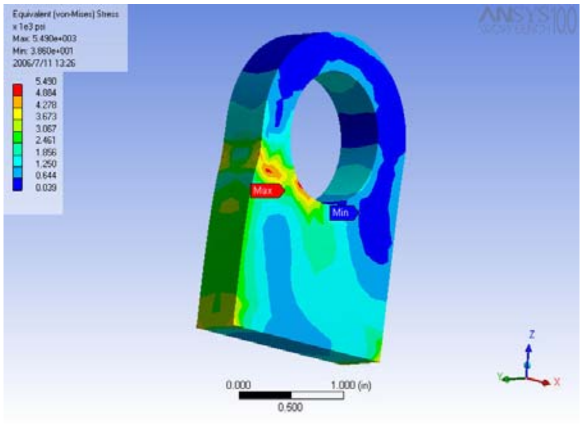


Figure 84: Equivalent stress for front loaded locking bar with hole.

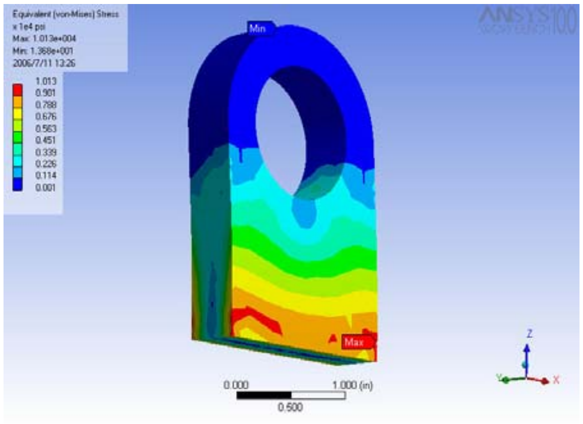


Figure 85: Equivalent stress for side loaded locking bar with hole.

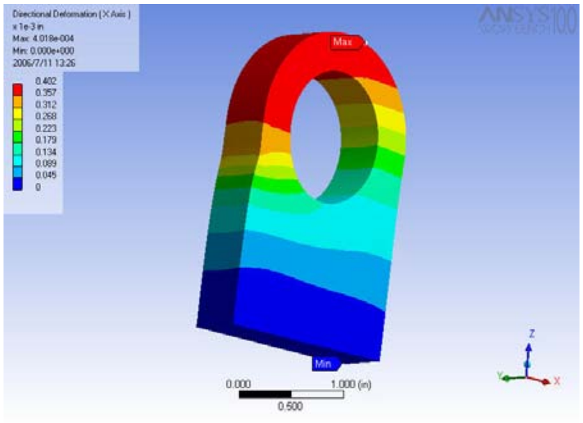


Figure 86: Directional deformation for front loaded locking bar with hole**.**

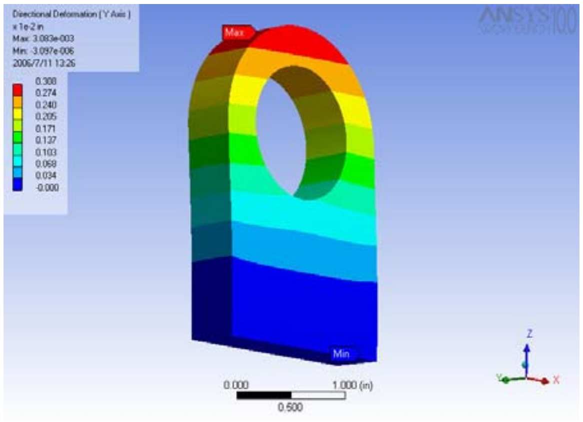


Figure 87: Directional deformation for side loaded locking bar with hole.

34. Stress Analysis of Forklift Blade End:

This is the model is of a locking device for the end of the forklift blade mounted on the transfer unit. There are two loading conditions, if the load is parallel to the forklift blade, as well as if it is at a 30 deg angle since the load may contact higher up on the rotating arm. For both cases, a bearing load was applied to the pins such that the load is only distributed on the 180 deg face perpendicular to the load. It is assumed that using a normal forklift blade, that the load can be supported by the blade itself. This is assuming that the part in question is mounted to the end of the forklift blade. The max stresses were 6,708 psi for the Parallel setup, and 7,622 psi for the 30 Deg Angle setup.

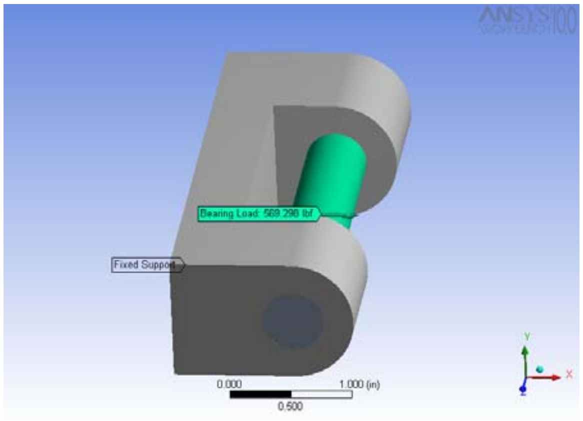


Figure 88: Environmental conditions for forklift blade end with parallel loading.

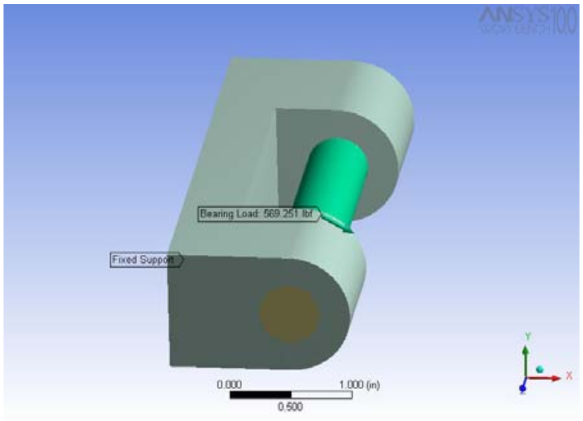


Figure 89: Environmental conditions for forklift blade end with thirty degree loading.

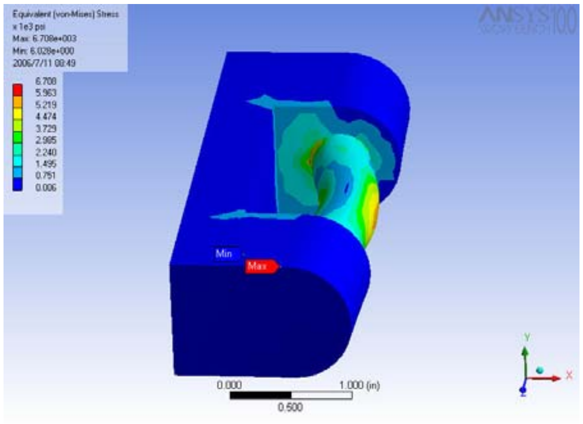


Figure 90: Equivalent stress for forklift blade end with parallel loading.

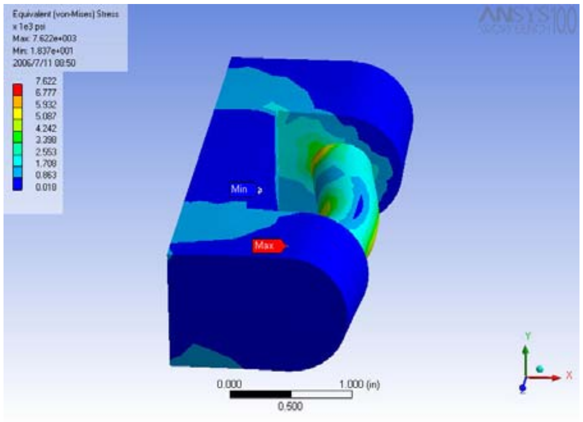


Figure 91: Equivalent stress for forklift blade end with thirty degree loading.

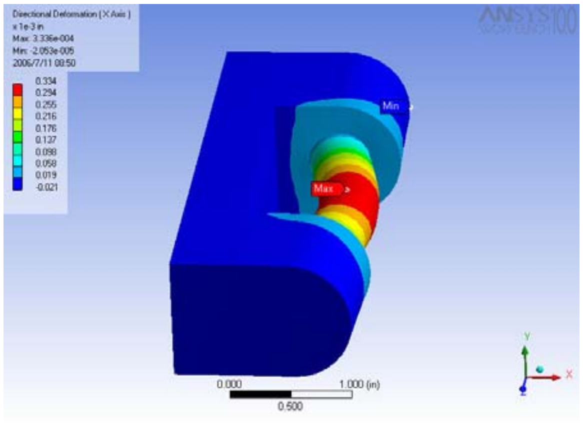


Figure 92: Directional deformation for forklift blade end with parallel loading.

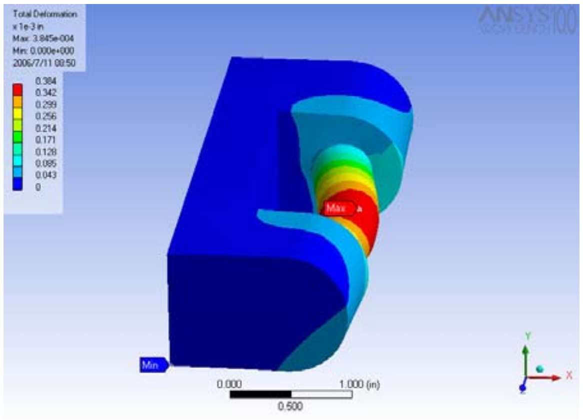


Figure 93: Directional deformation for forklift blade end with thirty degree loading.

35. Stress Analysis of Hex Slot:

This model is representative of the way in which rollers would fit into the structural tubing for the vehicle storage are support structure. This is using the hex shaped shaft that is on most rollers. There could be other ways of attaching the rollers to the frame, possibly with a sacrificial bearing so that the cuts could be made more easily. This hex shape would cause more stress than if the cutout was circular. The loads are assuming that the weight of the tank is not distributed throughout the frame, and the load is applied directly from the width of the treads. The max stresses were 11,940 psi for the Parallel setup, and 12,070 psi for the fixed base.

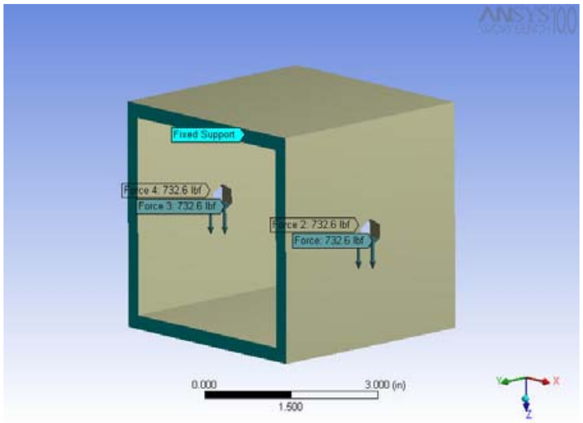


Figure 94: Environmental conditions for hex slot with fixed ends.

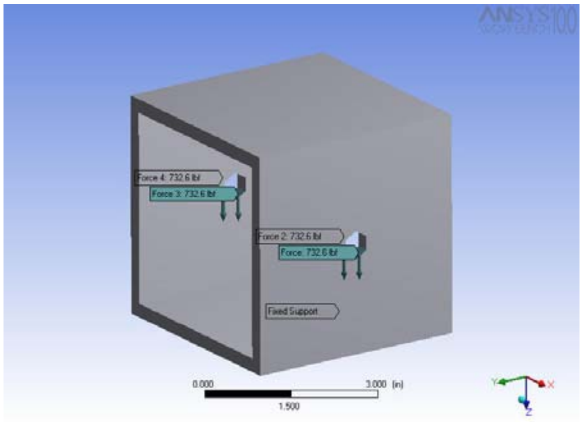


Figure 95: Environmental conditions for hex slot with fixed base.

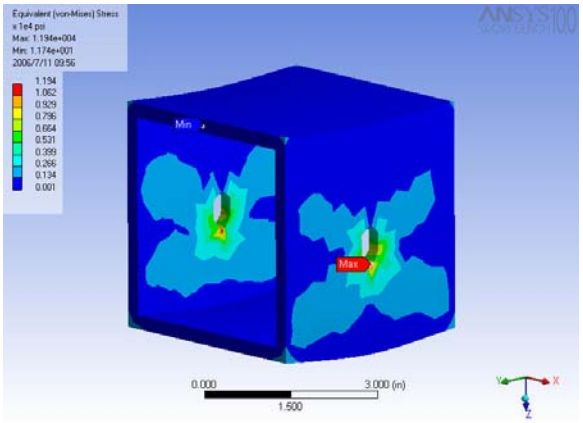


Figure 96: Equivalent stress for hex slot with fixed ends.

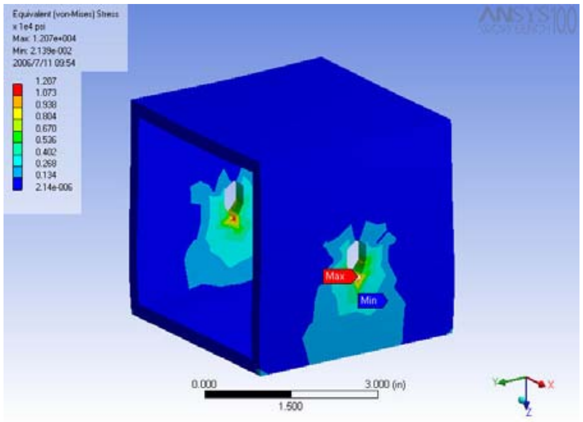


Figure 97: Equivalent stress for hex slot with fixed base.

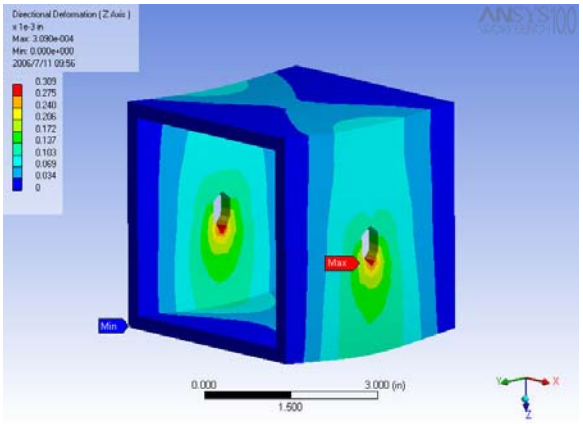


Figure 98: Directional deformation for hex slot with fixed ends.

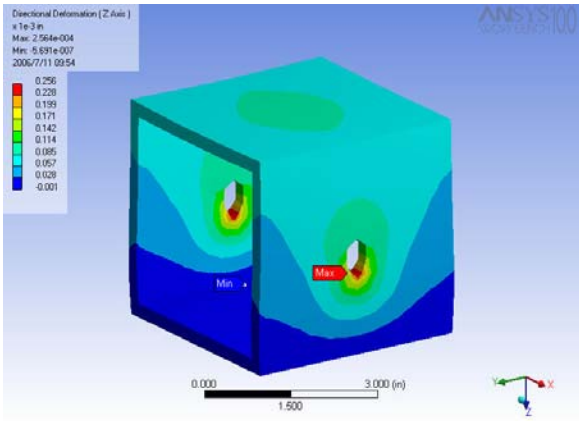


Figure 99: Directional deformation for hex slot with fixed base.

36. Stress Analysis of Plus sign Frame:

To analyze the structure of the plus sign, a single cell out of the five cells was considered. This one cell was the entire height of the actual stack, just one fifth of the structure. This means that the analysis is not having different pieces of the structure share the loads in one 5 cell stack. The model was created with ANSYS Design Modeler using beam elements. The loads came from the weight of a JMIC while under SS8, including the accelerations from gravity as well as the ship. The loads were put such that the forces of one JMIC was distributed evenly on each level. The max stresses were 11,940 psi for the Parallel setup, and 12,070 psi for the fixed base.

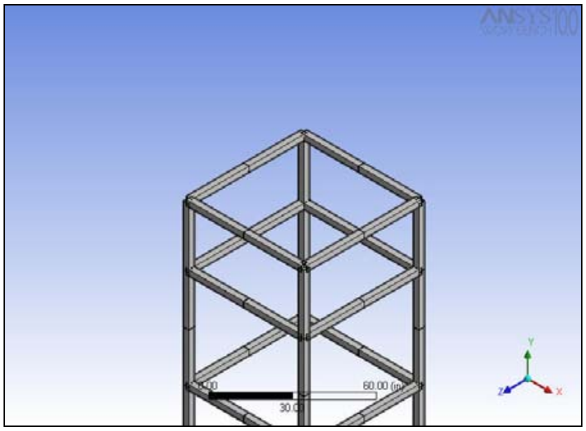


Figure 100: Model and mesh for plus sign frame.

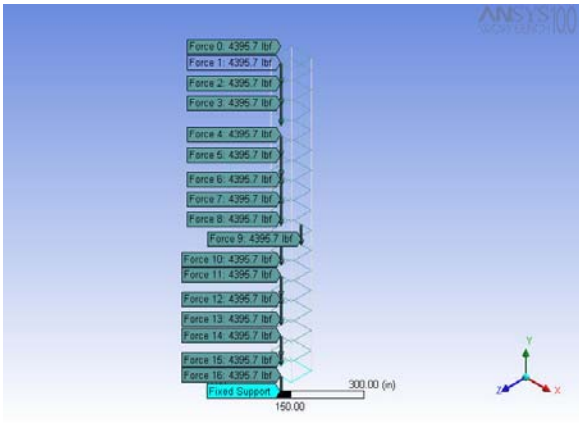


Figure 101: Environmental conditions for plus sign frame.

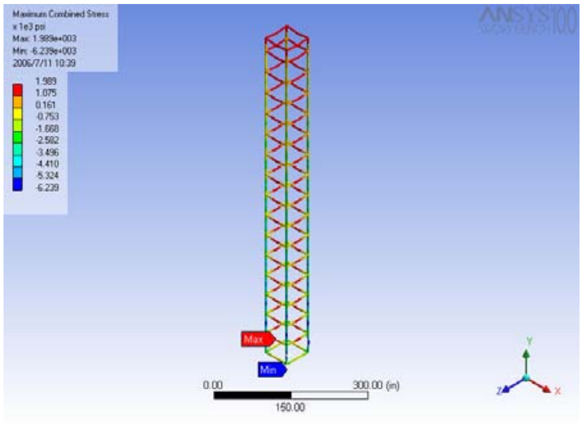


Figure 102: Equivalent stress for plus sign frame.

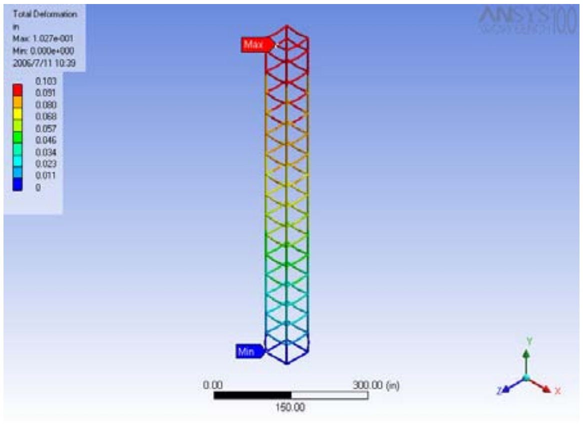


Figure 103: Directional deformation for plus sign frame.

37. Weight used for vehicle storage of M1A1 Tank:

Tank Load on Plate

Tank Weight $w := 140000\,\mathrm{lb}$

$$w_{Actual} := w \cdot \frac{47.18 \frac{ft}{s^2}}{32.3 \cdot \frac{ft}{s^2}}$$

Note: This is due to the acceleration of the ship as well as the acceleration of Gravity

Number of Wheels in Tread $N := 14$

$w_{Actual} = 204495.356\,\mathrm{lb}$

Rubber Plates per Wheel Under Track $R := 2$

Rubber Plate Length $L := 8.8 \cdot in$

Rubber Plate Width $W := 6.5 \cdot in$

Area per Wheel $A := R \cdot (L \cdot W)$ $A = 114.4\,in^2$

Total Area $A_{Total} := A \cdot N$ $A_{Total} = 1601.6\,in^2$

Pressure $P := \frac{w_{Actual}}{A_{Total}}$ $P = 127.682 \frac{lb}{in^2}$

Weight per Wheel Area $W_{Wheel} := \frac{w_{Actual}}{N}$ $W_{Wheel} = 14606.811\,\mathrm{lb}$

38. Stress Analysis of Vehicle Plate 1in thick with 3in rollers:

To analyze the feasibility of a large plate only supported by rollers, a one foot section of the model was taken and used to run the simulation. Several other setups were used as well, fixing the base of the section of air pallet, and fixing the base but making the air pallet and rollers extremely stiff. However both of these seemed to misrepresent what would really be happening. It was decided that fixing the rollers themselves may not provide the best answer, but it would be the most realistic of the setups tested. For this model, the rollers are made up of cylinders which have fixed sides. This means that the rollers do not deform. This would change the results, if the rollers do deform, there may be higher stress as well as larger deformations in the plate. This does incorporate the smaller footprint where the weight of the pads from an M1A1 is distributed. The max stress was 122 psi for the vehicle plate.

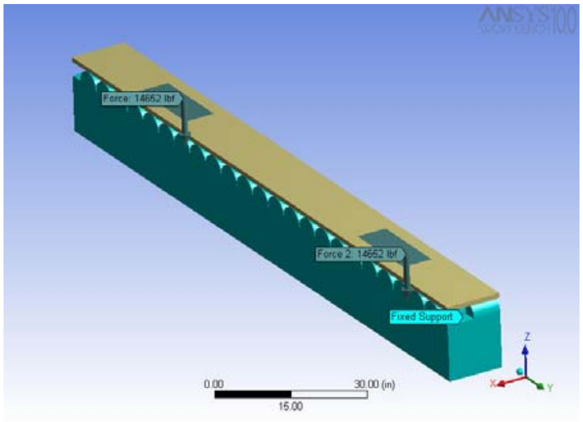


Figure 104: Environmental conditions for vehicle plate with fixed rollers.

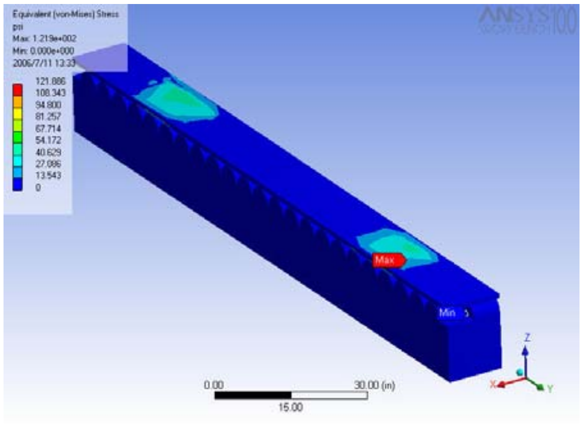


Figure 105: Equivalent stress for vehicle plate with fixed rollers.

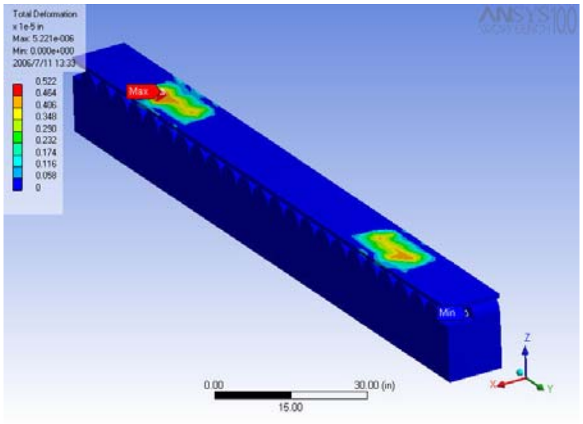


Figure 106: Directional deformation for vehicle plate with fixed rollers.

39. Stress Analysis of Test Section of Vehicle Plate:

This model is representative of a flat one inch thick metal plate to be used in the vehicle storage section. The load was that of the same force that would be applied directly under the tank onto one roller. The sides of the plate were assumed to have frictionless supports in order to represent the other material surrounding it. The max stress was 415 psi for the test section.

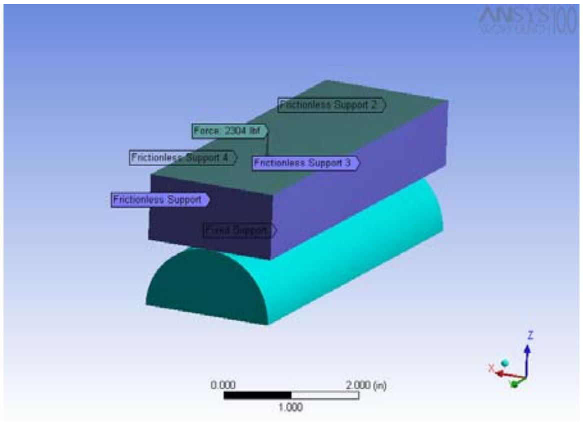


Figure 107: Environmental conditions for test section of vehicle plate.

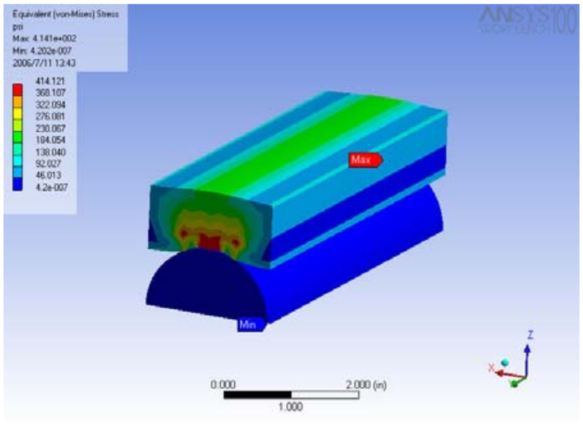


Figure 108: Equivalent stress for test section of vehicle plate.

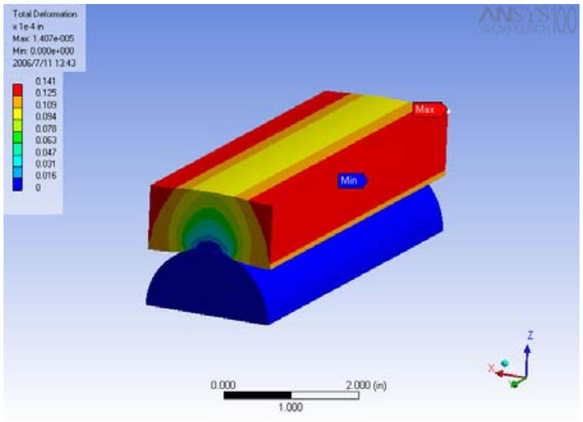


Figure 109: Directional deformation for test section of vehicle plate.

40. Stress Analysis of Vehicle Locking Pin:

This model is very similar to the other locking pin, just using different sizes and loads. The max stress was 19,040 psi for the Parallel setup. From this high stress, either the material would need to be a high strength alloy, the pin needs to be redesigned, or more that four pins would need to be used.

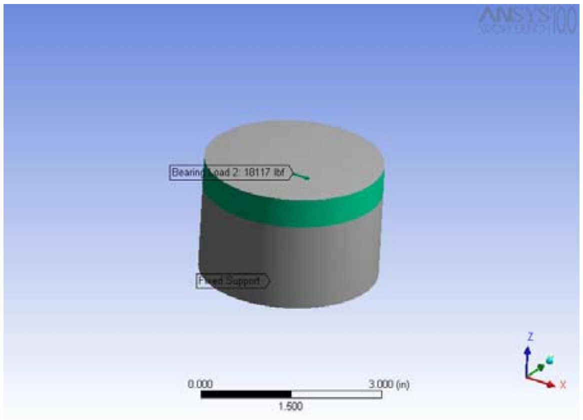


Figure 110: Environmental conditions for vehicle locking pin.

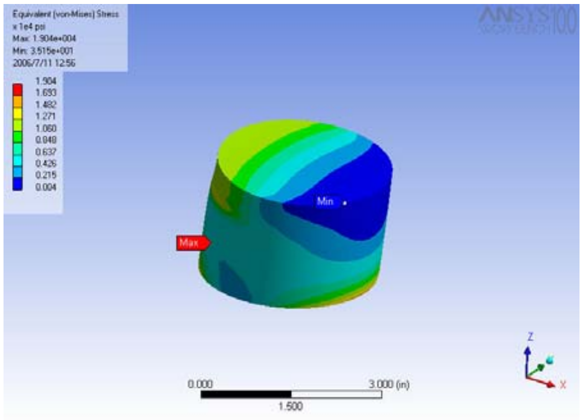


Figure 111: Equivalent stress for vehicle locking pin.

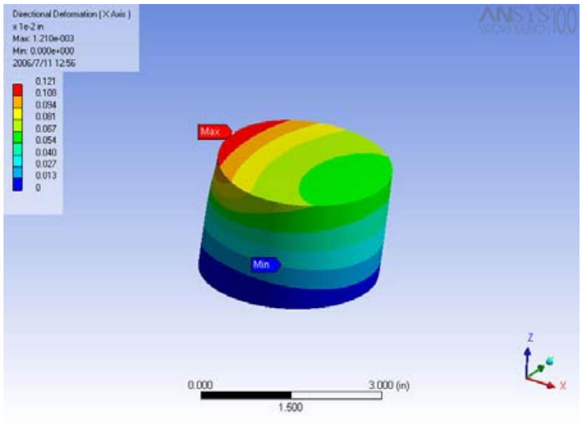


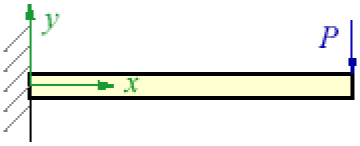
Figure 112: Directional deformation for vehicle locking pin.

41. Hand calculations for vehicle locking pin:

Stress for Locking Pin (Turn lock or straight pin)

Diameter	$D := 3 \cdot \text{in}$		
Cross Sectional Area	$A := \pi \cdot \left(\frac{D}{2}\right)^2$	$A = 7.069\,\text{in}^2$	
Cargo Load Weight	$W := 140000\,\text{lb}$		
Half of Load	$w := \frac{W}{2}$	$w = 70000\,\text{lb}$	Assuming there are 4 total pins, and in worst case, only two pins are supporting the load at a time
Mass of Half of Load	$m := w$	$m = 2175.667\,\text{slug}$	
Gravity	$g := 47.18\,\frac{\text{ft}}{\text{s}^2}$		Also assuming no friction for worse case
Angle of Ship List	$\theta := 15 \cdot \text{deg}$		
Force on Pin	$F := m \cdot g \cdot \sin(\theta)$	$F = 26567.243\,\text{lbf}$	
Angle of Shear	$\phi := 0 \cdot \text{deg}$		Angle phi assumes that the force is perpendicular to the surface for 0 degrees, and paraller to the surface for 90 degrees
Shear Stress	$\tau := \frac{F \cdot \cos(\phi)}{A}$	$\tau = 3758.496\,\text{psi}$	

Bending Stress



Circular Cross Section Moment of Inertia $I := \frac{\pi \cdot D^4}{64}$ $I = 3.976\,\text{in}^4$

Distance from Fixed Surface $x := 1.0 \cdot \text{in}$

Moment $M := F \cdot x$ $M = 26567.243\,\text{in} \cdot \text{lbf}$

Distance to extreme fibers $y := \frac{D}{2}$ $y = 1.5\,\text{in}$

Stress Due to Bending $\sigma_{bend} := \frac{M \cdot y}{I}$ $\sigma_{bend} = 10022.656\,\text{psi}$

Distance from Neutral Axis to Centriod of Area $y_c := \left(\frac{D}{2}\right) - \frac{(3 \cdot \pi - 4) \cdot D}{6 \cdot \pi}$ $y_c = 0.637\,\text{in}$

$Q := A \cdot y_c$ $Q = 4.5\,\text{in}^3$

Chord length at yc $d := 2 \cdot \sqrt{\left(\frac{D}{2}\right)^2 - y_c^{\,2}}$ $d = 2.716\,\text{in}$

Shear Stress Due to Bending $\tau_{bend} := \frac{F \cdot Q}{I \cdot d}$ $\tau_{bend} = 11069.026\,\text{psi}$

42. Stress Analysis of Complex Vehicle Plate:

This is an alternative to the large sheet of metal. For this case a frame was designed to roughly estimate what would be needed to support the vehicle. This is only a rough attempt at designing the structure, and was mainly used to validate the concept as well as determine the material needed so that the overall weight could be obtained. Two main models were used, one with fixed bases of the 4x4 structural tubing, and another with a set of rollers, with the faces of the rollers fixed so that the rollers did not deform. Again, with rollers that deform there should be a change in the stresses and deformation; however this is what is felt to be the best approximation without specific knowledge of the rollers. Also this simplifies the model since the rollers do not deform, are not hollow, or have pins/shafts, etc. This is assuming that the structure beneath it can hold the load, and will not deform much. To see if this is true a second model was created with the air pallet included in the simulation. The max stresses were 7,230 psi for the vehicle plate with fixed base, and 7,208 psi for vehicle plate with fixed rollers.

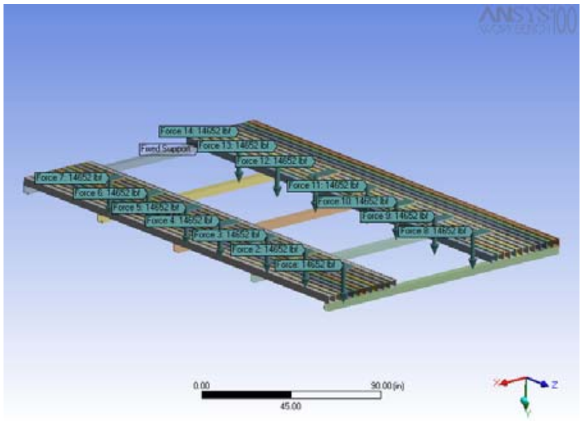


Figure 113: Environmental conditions for vehicle plate with fixed base.

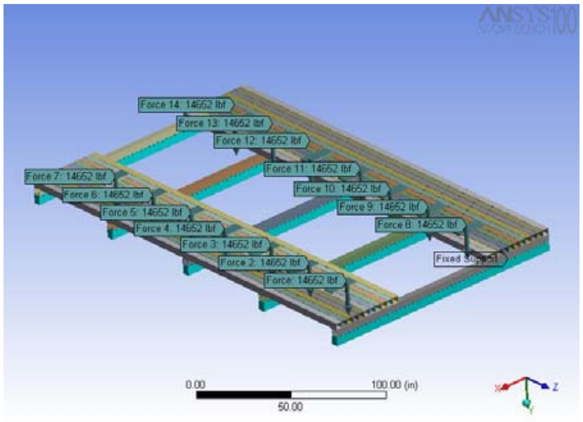


Figure 114: Environmental conditions for vehicle plate with fixed rollers.

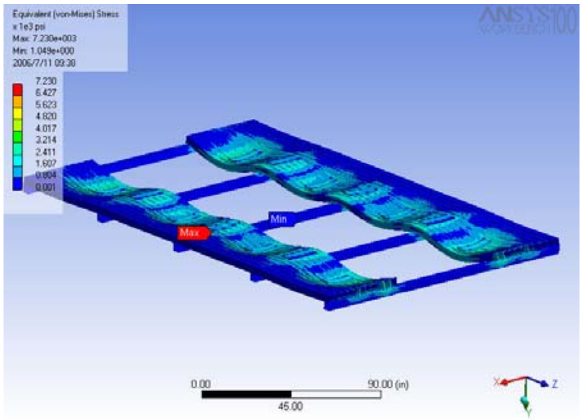


Figure 115: Equivalent stress for vehicle plate with fixed base.

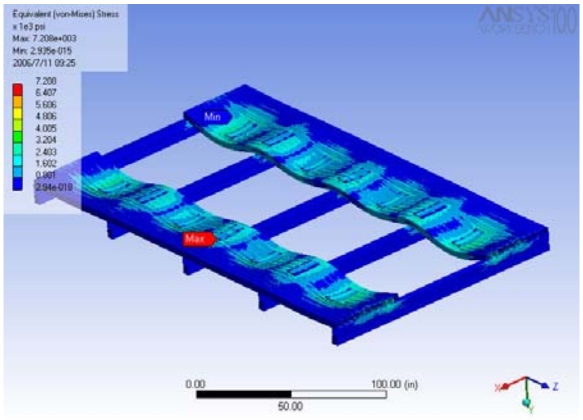


Figure 116: Equivalent stress for vehicle plate with fixed rollers.

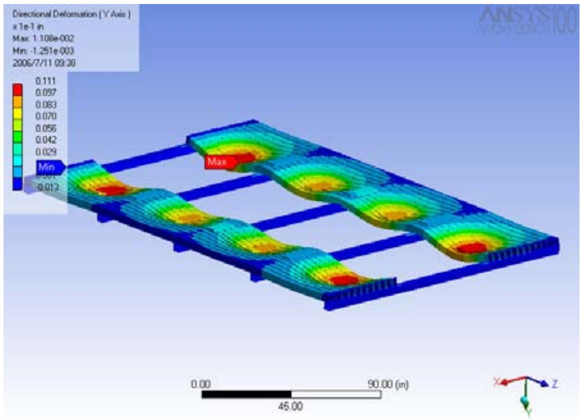


Figure 117: Directional deformation for vehicle plate with fixed base.

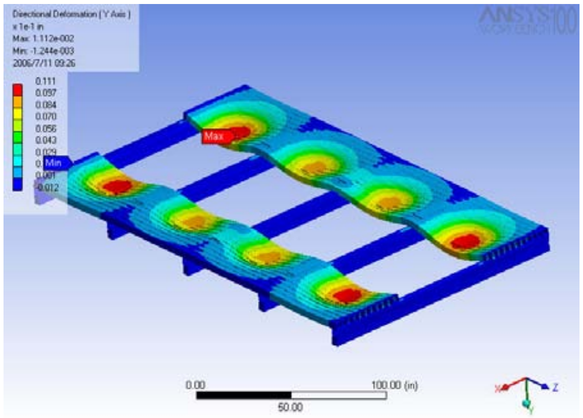


Figure 118: Directional deformation for hex vehicle plate with fixed rollers.

43. Stress Analysis of Dry Stores Locking Pin:

Setup:

This model uses the same Complex vehicle plate, just set on top of the Air Pallet frame. Several different types of setups were used to try and analyze the connection between the vehicle plate and the air pallet, which is made through the rollers. Again it is hard to accurately depict what will happen to the rollers. Several different setups connecting the pieces with a long flexible plate, small rigid plates which can be rigid because there was no contact between the individual metal plates, and finally using rigid blocks with pins to represent the rollers. In order to reduce the simulation time of such a large assembly, with many nodes and elements, a quarter model was created, which uses frictionless supports on both of the cut sides of the model in order to represent the other ¾ of the model still being there. This is possible because the model is symmetric down the middle of both the short and long axis. The top of the air bearings were fixed such that there would be no deformation across them. This is not the real case, but we do not know the material properties of the air bearing, thus they are not being assumed, but omitted from this analysis. The max stresses were 51,570 psi for the air pallet with flat rollers, and 14,300 psi for the air pallet with flat plate. Both appear to be much higher that they actually are, which is most likely due to stress risers due to the mesh. The scale of the flat rollers equivalent stress image has been altered such that the contours are more representative of the actual stresses throughout the material.

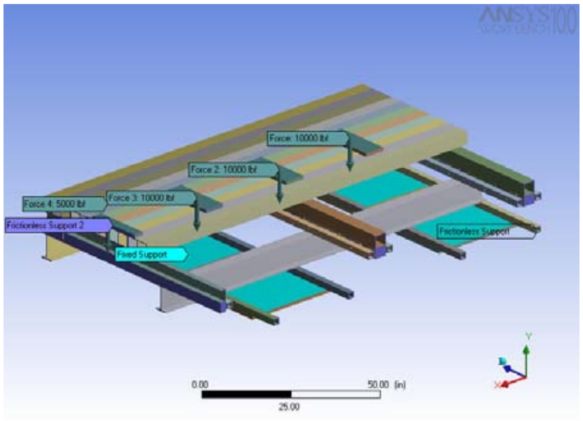


Figure 119: Environmental conditions for air pallet with flat rollers.

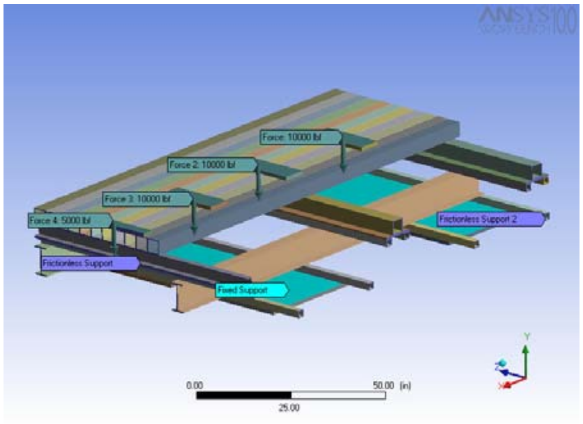


Figure 120: Environmental conditions for air pallet with flat plate.

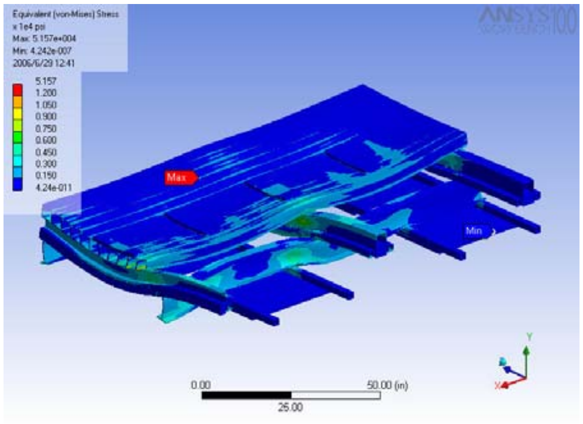


Figure 121: Equivalent stress for air pallet with flat rollers.

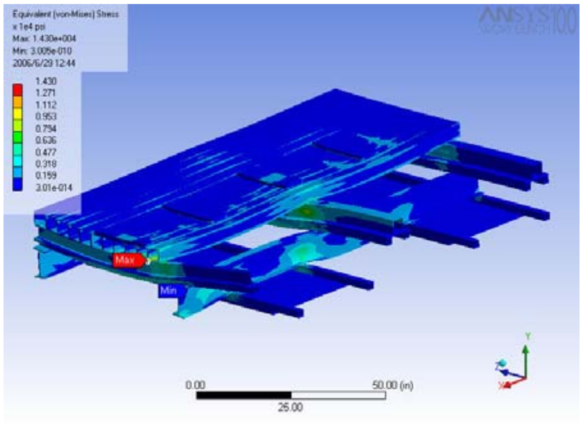


Figure 122: Equivalent stress for air pallet with flat plate.

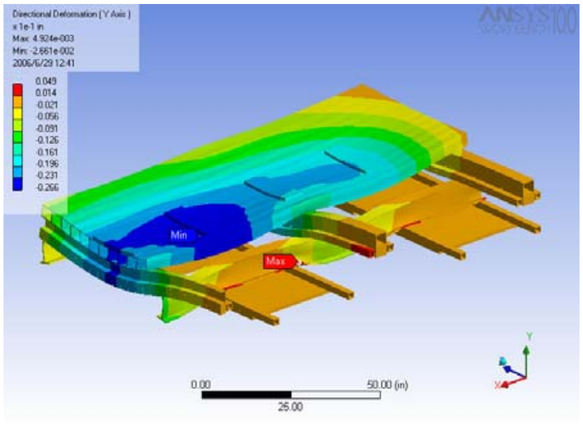


Figure 123: Directional deformation for air pallet with flat rollers.

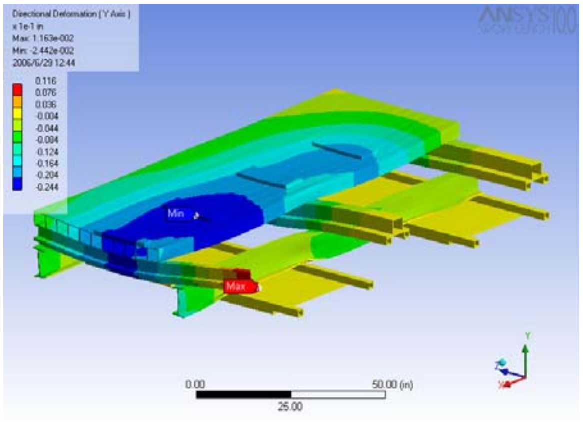


Figure 124: Directional deformation for air pallet with flat plate.

Appendix I: Vehicle Calculations

ITEM	20%	Length	Number of Vehicles/Pallet Rounded Down (Pallet Size in ft)																												
	#	(ft)	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
M1A1	3	28.01	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
AAAV	10	31.85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M88A1	1	28.93	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
HMWVV	20	18.43	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3
M198	4	26.67	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2
LVS Mk48	2	39.98	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
M101A2	4	14.23	0	0	0	0	0	0	1	1	1	1	1	1	1	2	2	2	2	2	2	2	3	3	3	3	3	3	3	4	4
M390	4	17.48	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3	3
LAV	5	24.93	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2
FRKLFT	2	31.06	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
AVLB	1	33.72	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MEWSS	2	24.93	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2
MTVR	25	30.54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MRC	6	17.91	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	3	3	3	3
M9293/Q46	2	28.17	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	2	2
ABV	2	41.49	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
6Con Cont. (Water)	76	20.00	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3
6Con Cont. (POL)	54	20.00	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	2	2	2	2	2	2	2	2	2	2	3

Table 13 Number of Vehicles/Pallet Rounded Down

ITEM	20%	Length	# of Pallets/Vehicle Rounded Up																											
	#	(ft)	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
M1A1	3	28.01	8	5	4	3	3	3	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
AAAV	10	31.85	8	6	4	4	3	3	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M88A1	1	28.93	8	5	4	3	3	3	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
HMWVV	20	18.43	5	4	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M198	4	26.67	7	5	4	3	3	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
LVS Mk48	2	39.98	10	7	5	4	4	3	3	3	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1
M101A2	4	14.23	4	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M390	4	17.48	5	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
LAV	5	24.93	7	5	4	3	3	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FRKLFT	2	31.06	8	6	4	4	3	3	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
AVLB	1	33.72	9	6	5	4	3	3	3	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MEWSS	2	24.93	7	5	4	3	3	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MTVR	25	30.54	8	6	4	4	3	3	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MRC	6	17.91	5	3	3	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
M9293/Q46	2	28.17	8	5	4	3	3	3	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ABV	2	41.49	11	7	6	5	4	3	3	3	3	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1
6Con Cont. (Water)	76	20.00	5	4	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6Con Cont. (POL)	54	20.00	5	4	3	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 14 Number of Pallets/Vehicle Rounded Up

ITEM	20%	Length	# of Pallets/Vehicle for Total Vehicles in MEB Rounded Up																												
	#	(ft)	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
M1A1	3	28.01	24	15	12	9	9	9	6	6	6	6	6	6	6	3	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2
AAAV	10	31.85	80	60	40	40	30	30	20	20	20	20	20	20	20	20	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
M88A1	1	28.93	8	5	4	3	3	3	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
HMWVV	20	18.43	100	80	60	40	40	40	40	40	20	20	20	20	20	20	20	20	20	10	10	10	10	10	10	10	10	10	7	7	7
M198	4	26.67	28	20	16	12	12	8	8	8	8	8	8	8	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2
LVS Mk48	2	39.98	20	14	10	8	8	6	6	6	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2
M101A2	4	14.23	16	12	8	8	8	8	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
M390	4	17.48	20	12	12	8	8	8	8	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2
LAV	5	24.93	35	25	20	15	15	10	10	10	10	10	10	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3
FRKLFT	2	31.06	16	12	8	8	6	6	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
AVLB	1	33.72	9	6	5	4	3	3	3	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MEWSS	2	24.93	14	10	8	6	6	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1
MTVR	25	30.54	200	150	100	100	75	75	50	50	50	50	50	50	50	50	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
MRC	6	17.91	30	18	18	12	12	12	12	6	6	6	6	6	6	6	6	6	3	3	3	3	3	3	3	3	3	2	2	2	2
M9293/Q46	2	28.17	16	10	8	6	6	6	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
ABV	2	41.49	22	14	12	10	8	6	6	6	6	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2
6Con Cont. (Water)	76	20.00	380	304	228	152	152	152	152	152	76	76	76	76	76	76	76	76	76	76	38	38	38	38	38	38	38	38	38	38	26
6Con Cont. (POL)	54	20.00	270	216	162	108	108	108	108	108	54	54	54	54	54	54	54	54	54	54	27	27	27	27	27	27	27	27	27	27	18

Table 15 Number of Pallets/Vehicle for Total Vehicles in MEB Rounded Up

ITEM	20%	Length	# of Pallets/Vehicle for Total Vehicles in MEB (taking into account instances of zero pallet occurrence above)																												
	#	(ft)	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
M1A1	3	28.01	24	15	12	9	9	9	6	6	6	6	6	6	6	6	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2
AAAV	10	31.85	80	60	40	40	30	30	20	20	20	20	20	20	20	20	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10
M88A1	1	28.93	8	5	4	3	3	3	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
HMWVV	20	18.43	100	80	60	40	40	40	40	40	20	20	20	20	20	20	20	20	20	10	10	10	10	10	10	10	10	10	7	7	7
M198	4	26.67	28	20	16	12	12	8	8	8	8	8	8	8	4	4	4	4	4	4	4	4	4	4	4	4	4	2	2	2	2
LVS Mk48	2	39.98	20	14	10	8	8	6	6	6	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2
M101A2	4	14.23	16	12	8	8	8	8	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
M390	4	17.48	20	12	12	8	8	8	8	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2
LAV	5	24.93	35	25	20	15	15	10	10	10	10	10	10	5	5	5	5	5	5	5	5	5	5	5	5	3	3	3	3	3	3
FRKLFT	2	31.06	16	12	8	8	6	6	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
AVLB	1	33.72	9	6	5	4	3	3	3	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1
MEWSS	2	24.93	14	10	8	6	6	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1
MTVR	25	30.54	200	150	100	100	75	75	50	50	50	50	50	50	50	50	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25
MRC	6	17.91	30	18	18	12	12	12	12	6	6	6	6	6	6	6	6	6	3	3	3	3	3	3	3	3	3	2	2	2	2
M9293/Q46	2	28.17	16	10	8	6	6	6	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1
ABV	2	41.49	22	14	12	10	8	6	6	6	6	4	4	4	4	4	4	4	4	4	4	2	2	2	2	2	2	2	2	2	2
6Con Cont. (Water)	76	20.00	380	304	228	152	152	152	152	152	76	76	76	76	76	76	76	76	76	76	38	38	38	38	38	38	38	38	38	38	26
6Con Cont. (POL)	54	20.00	270	216	162	108	108	108	108	108	54	54	54	54	54	54	54	54	54	54	27	27	27	27	27	27	27	27	27	27	18
		Total	1288	983	731	549	509	494	447	436	284	282	282	275	271	266	226	225	220	210	143	141	141	141	141	138	138	135	132	129	108

Table 16 Number of Pallets/Vehicle for Total Vehicles in MEB

	Total Amount of Required Space if Pallets Stacked in Long Row (ft)																												
	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
Total	5152	5898	5848	5490	6108	6916	7152	7848	5680	6204	6768	7150	7588	7980	7232	7650	7920	7980	5720	5922	6204	6486	6768	6900	7176	7290	7392	7482	6480

Table 17 **Total Amount of Required Space if Pallets Stacked in Long Row**

Total Amount of Required Space if Vehicles Lined up in Long Row (ft)			
ITEM	**20%** #	**Length (ft)**	Total Length (ft)
M1A1	3	28.01	84
AAAV	10	31.85	318
M88A1	1	28.93	28.9
HMWVV	20	18.43	369
M198	4	26.67	107
LVS Mk48	2	39.98	80
M101A2	4	14.23	56.9
M390	4	17.48	69.9
LAV	5	24.93	125
FRKLFT	2	31.06	62.1
AVLB	1	33.72	33.7
MEWSS	2	24.93	49.9
MTVR	25	30.54	763
MRC	6	17.91	107
M9293/Q46	2	28.17	56.3
ABV	2	41.49	83
6Con Cont. (Water)	76	20.00	1520
6Con Cont. (POL)	54	20.00	1080
		Total	4994

Table 18 Total Amount of Required Space if Vehicles Lined up in Long Row

	Amount of Unused Space (ft)																												
	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60
Total	158	904	854	496	1114	1922	2158	2854	686	1210	1774	2156	2594	2986	2238	2656	2926	2986	726	928	1210	1492	1774	1906	2182	2296	2398	2488	1486
% Unused Plate Space	3.06	15.3	14.6	9.03	18.2	27.8	30.2	36.4	12.1	19.5	26.2	30.2	34.2	37.4	30.9	34.7	36.9	37.4	12.7	15.7	19.5	23	26.2	27.6	30.4	31.5	32.4	33.3	22.9

Table 19 Amount of Unused Space

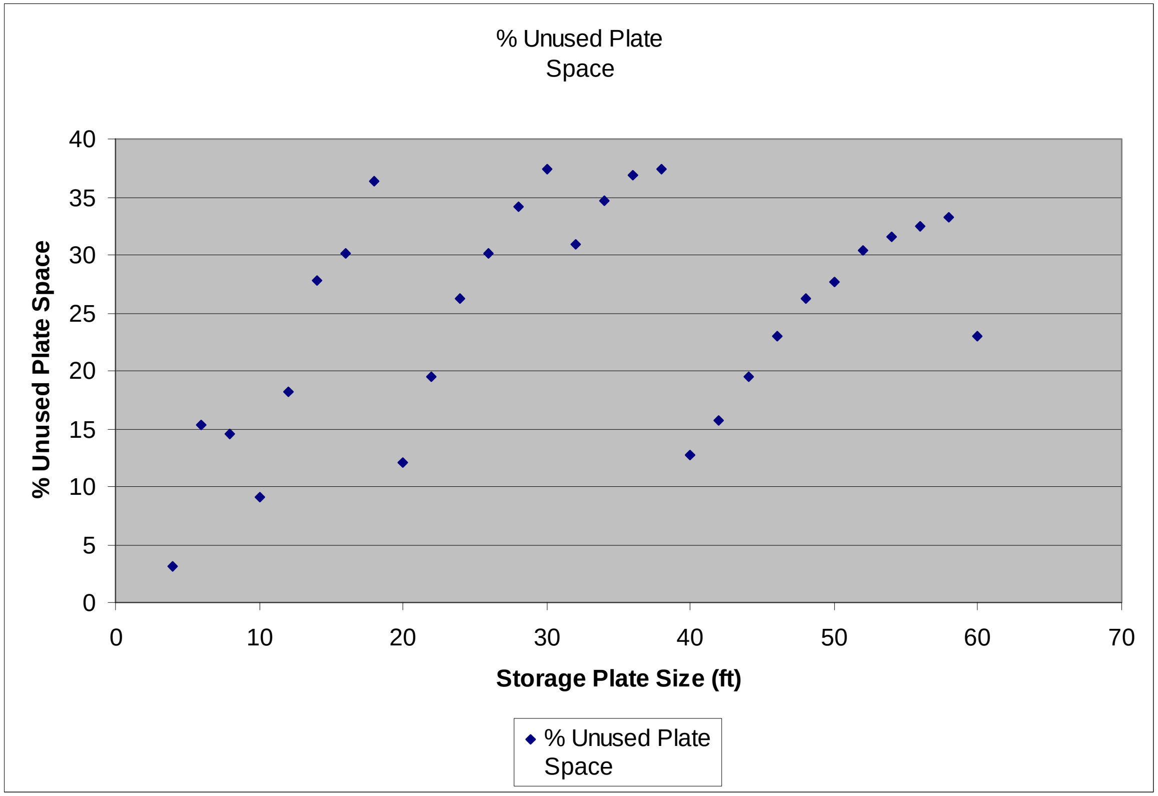


Figure 125 Unused Space to Storage Plate Size

Appendix J: Energy Requirements

Energy requirements were evaluated for the vehicle storage area, the plus sign dry-stores area, and the library shelf-dry stores area. For these calculations, the drive motor is a Linear Synchronous Motor (LSM). LSMs are explained in further detain in APPENDIX J.
The efficiency of the LSM is assumed to be 70% for the calculations. For the operational movement of all the calculations, a maximum operating pitch of 5 degrees, and a maximum operating roll of 15 degrees was assumed. In the calculations, only the static forces from gravity, and the applied forces to accelerate the objects to their final velocity were considered. The acceleration from the movement of the ship was not considered for this evaluation. The inputs for the calculations were the objects weight, angles, acceleration, initial velocity, and final velocity. For the library shelf calculations, this was the energy to move a single shelf, in a worse case a total of five shelves would have to be moved together to get to the JMIC that was desired. Multiplying the total time the number of shelves moved will yield the overall total energy needed. Also the library shelf calculations do not include the energy for the forklift, which is not powered by a LSM track. The weights of the objects being moved, as well as the total energy to move the object the farthest possible distance, and the maximum instantaneous power needed are shown in table 13. Further calculations to find the total energy to load and unload the ship would be of value.

Table 20 Power and Energy Required

Layout	Object Weight (lb)	Maximum Instantaneous Power Required (kW)	Total Energy Required to Move Maximum Distance (W*hr)
Library Shelf	251,683	10.7	117.9
Plus Sign	5,000	19.7	602.6
Vehicle Storage	185,000	344.1	17474.0

44. Library Shelf:

Shown below are the energy calculations for the library shelf design:

Weight of Structure

Length	$L_{Str} := W_{Shelf}$	$L_{Str} = 45\,ft$
Width	$W_{Str} := 2 \cdot W_{Con}$	$W_{Str} = 9\,ft$
Height	$H_{Str} := H_{Deck}$	$H_{Str} = 17\,ft$
Number of Rows Across	$N_{RA} := 15$	
Number of Columns High	$N_{CH} := 18$	
Number or Rows Deep	$N_{RD} := 30$	
Total Linear Feet of Structure	$L_{TotalLinear} := L_{Str} \cdot N_{RA} + W_{Str} \cdot N_{RD} + H_{Str} \cdot N_{CH}$ $L_{TotalLinear} = 1251\,ft$	
Cross Sectional Area of Supporting Structure Material	$Area_{CS} := (3 \cdot 3 - 2.5 \cdot 2.5) \cdot in^2$	Note: Area based on using 3" square tubing with 1/4" wall thickness
Volume of Supporting Structure Material	$V := L_{TotalLinear} \cdot Area_{CS}$	$V = 41283\,in^3$
Density of Material	$D := 0.283 \dfrac{lb}{in^3}$	Note: This is the density of A36 Steel
Weight of Structure	$Weight_{Str} := V \cdot D$	$Weight_{Str} = 11683.089\,lb$
Total Weight of Containers and Structure	$Weight_{Total} := Weight_{Shelf} + Weight_{Str}$ $Weight_{Total} = 251683.089\,lb$	

Library Shelf Design

Total Ship Height $H := 68 \cdot ft$

Number of Desks $N_D := 4$

Height Per Desk $H_{Deck} := \frac{H}{N_D}$ $H_{Deck} = 17\,ft$

Width of Ship $W_{Ship} := 100 \cdot ft$

Width of Aisle $W_{Aisle} := 60 \cdot in$

Number of Aisles $N_{Aisle} := 2$

Number of Shelves Across $N_{Shelf} := 2$

Note: The two Aisles will be in the center of the ship running the long axis of the ship, between two separate shelves.

Width of Shelf $W_{Shelf} := \frac{W_{Ship} - N_{Aisle} \cdot W_{Aisle}}{N_{Shelf}}$ $W_{Shelf} = 45\,ft$

Note: Each shelf will be double sided such that it holds the length of containers multiplied by the width of the containers times two

Shelf Clearance and Drive Motor Height $H_{Clear} := 2 \cdot ft$

Height of Shelf $H_{Shelf} := H_{Deck} - H_{Clear}$ $H_{Shelf} = 15\,ft$

Container Height $H_{Con} := 42 \cdot in$

Contaienr Width $W_{Con} := 54 \cdot in$

Note: These calculations do not consider the space required for the structure and locking mechanisms.

Number of Containers High $N_{ConHigh} := \text{round}\left(\frac{H_{Shelf}}{H_{Con}}, 0\right)$ $N_{ConHigh} = 4$

Number of Containers Across $N_{ConAcross} := \text{round}\left(\frac{W_{Shelf}}{W_{Con}}, 0\right)$ $N_{ConAcross} = 10$

Number of Containers per Shelf $N_{Con} := N_{ConHigh} \cdot N_{ConAcross} \cdot 2$ $N_{Con} = 80$

Weight of Container $Weight_{Con} := 3000 \cdot lb$

Weight per Shelf $Weight_{Shelf} := Weight_{Con} \cdot N_{Con}$ $Weight_{Shelf} = 240000\,lb$

Note this weight does not include the weight of the structure itself

Force Calculations

Static Loads:

Total Weight $\mathrm{Weight}_{\mathrm{Total}} = 251683.089\,\mathrm{lb}$ $\mathrm{mass} := \mathrm{Weight}_{\mathrm{Total}}$

Max Pitch $\theta := 15 \cdot \mathrm{deg}$ $\mathrm{mass} = 7822.55\,\mathrm{slug}$

Max Roll $\phi := 50 \cdot \mathrm{deg}$

Operational Pitch $\gamma := 5 \cdot \mathrm{deg}$

Gravity $g = 32.174 \frac{\mathrm{ft}}{\mathrm{sec}^2}$

Force Required $F_{\mathrm{Parallel}\theta} := \mathrm{mass} \cdot g \sin(\theta)$ $F_{\mathrm{Parallel}\theta} = 65140.377\,\mathrm{lbf}$

$F_{\mathrm{Parallel}\phi} := \mathrm{mass} \cdot g \sin(\phi)$ $F_{\mathrm{Parallel}\phi} = 192800.432\,\mathrm{lbf}$

Operating Pitch

$F_{\mathrm{Parallel}\gamma} := \mathrm{mass} \cdot g \sin(\gamma)$ $F_{\mathrm{Parallel}\gamma} = 21935.627\,\mathrm{lbf}$

Energy Required to Move While at Max Pitch

During Acceleration & Deceleration:

Mass $\text{mass} = 7822.55\,\text{slug}$

Note: This is not considering that the device will have to overcome acceleration from the ship

Acceleration $a_Y := .25\cdot\frac{\text{ft}}{\text{s}^2}$

Initial Velocity $V_{Yi} := 0$

Final Velocity $V_{Yf} := \frac{20}{60}\,\frac{\text{ft}}{\text{s}}$

Force Required For Desired Acceleration $F_Y := \text{mass}\cdot a_Y$ $F_Y = 1955.637\,\text{lbf}$

Total Force Expended $F_{YA} := F_Y + F_{\text{Parallel}_y}$

$F_{YB} := F_{\text{Parallel}_y}$

$F_{YC} := F_{\text{Parallel}_y} - F_Y$

Note: Where A is during the Acceleration, B is during the constant velocity, and C is during the deceleration

Distance Moved $D_{YA} := \frac{V_{Yf}^2 - V_{Yi}^2}{2\cdot a_Y}$ $D_{YA} = 0.222\,\text{ft}$

Time to move $t_{YA} := \frac{V_{Yf} - V_{Yi}}{a_Y}$ $t_{YA} = 1.333\,\text{s}$

During Constant Velocity:

Velocity $V_{Yf} = 0.333\,\frac{\text{ft}}{\text{s}}$

Total Distance $D_{YT} := 10\cdot\text{ft}$

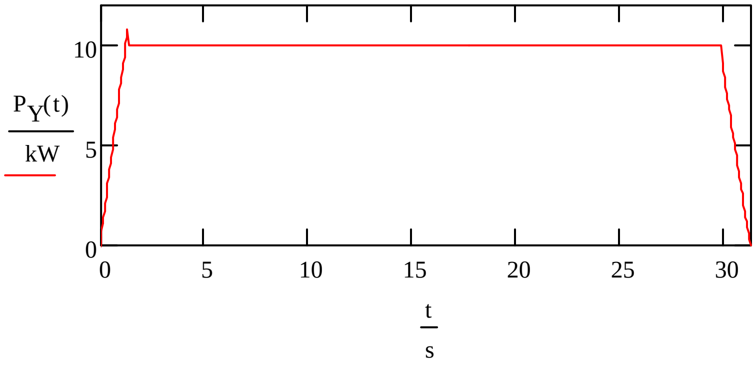
Distance Moved $D_{YV} := D_{YT} - 2\cdot\left(\frac{V_{Yf}^2 - V_{Yi}^2}{2\cdot a_Y}\right)$

$D_{YV} = 9.556\,\text{ft}$

Time to move $t_{YV} := \frac{D_{YV}}{V_{Yf}}$ $t_{YV} = 28.667\,\text{s}$

Total Energy and Instantaneous Power During Travel on the X-Axis

$$P_Y(t) := \begin{cases} F_{YA}\cdot\left(a_Y\cdot t\right) & \text{if } t \le t_{YA} \\ F_{YB}\cdot V_{Yf} & \text{if } t_{YA} < t < t_{YA} + t_{YV} \\ F_{YC}\cdot\left[V_{Yf} - a_Y\cdot\left[t - \left(t_{YA} + t_{YV}\right)\right]\right] & \text{if } t \ge t_{YA} + t_{YV} \end{cases}$$



Max Power Required $P_{YMax} := P_Y\left(t_{YA}\right)$ $P_{YMax} = 10.797kW$

Total Energy Required in the Y Direction:

$$W_Y := \int_{0\cdot s}^{2\cdot t_{YA}+t_{YV}} P_Y(t)\,dt \qquad W_Y = 82.582W\cdot hr$$

Efficiency $Eff_Y := 0.7$

Total Energy Due to Efficiency Losses $E_Y := \frac{W_Y}{Eff_Y}$ $E_Y = 117.974W\cdot hr$

Energy Required to Move 5 Shelves to Create and Aisle:

Total Energy Required $E_T := E_Y\cdot 5$ $E_T = 589.872W\cdot hr$

Maximum Instantaneous Power Required $P_{Max} := P_{YMax}\cdot 5$ $P_{Max} = 53.987kW$

45. Plus Sign:

Shown below are the calculations for the Plus Sign Energy Requirements:

Force Calculations

Static Loads:

Total Weight	$\text{Weight}_{\text{Total}} := 5000 \cdot \text{lb}$	$\text{mass} := \text{Weight}_{\text{Total}}$
Max Operating Pitch	$\theta := 5 \cdot \text{deg}$	$\text{mass} = 155.405\,\text{slug}$
Max Operating Roll	$\phi := 15 \cdot \text{deg}$	
Gravity	$g = 32.174 \dfrac{\text{ft}}{\text{sec}^2}$	

Opposing Forces

From Pitch (Longitudinal)	$F_{\text{Parallel}\theta} := \text{mass} \cdot g \cdot \sin(\theta)$	$F_{\text{Parallel}\theta} = 435.779\,\text{lbf}$
From Roll (Transverse)	$F_{\text{Parallel}\phi} := \text{mass} \cdot g \cdot \sin(\phi)$	$F_{\text{Parallel}\phi} = 1294.095\,\text{lbf}$
From Gravity (Vertical)	$F_{\text{Gravity}} := \text{mass} \cdot g$	$F_{\text{Gravity}} = 5000\,\text{lbf}$

Energy Required to Move In the X Direction (Transverse) Going Up

During Acceleration & Deceleration:

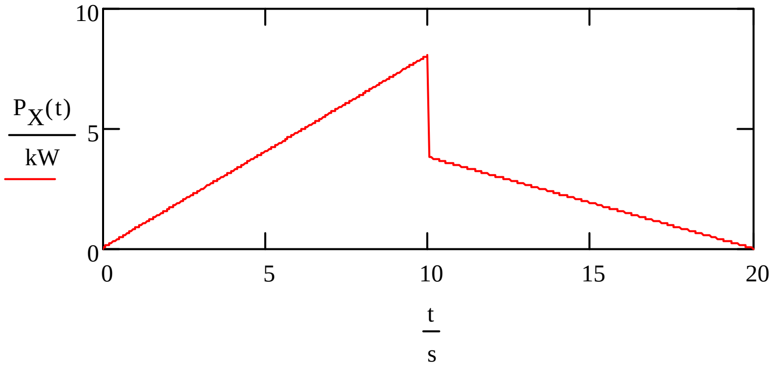
Mass	$\text{mass} = 155.405\,\text{slug}$	Note: This is not considering that the device will have to overcome acceleration from the ship
Acceleration	$a_X := 1\cdot\frac{\text{ft}}{\text{s}^2}$	
Initial Velocity	$V_{Xi} := 0$	
Final Velocity	$V_{Xf} := 10\,\frac{\text{ft}}{\text{s}}$	
Force Required For Desired Acceleration	$F_X := \text{mass}\cdot a_X$	$F_X = 155.405\,\text{lbf}$
Total Force Expended	$F_{XA} := \left(F_X + F_{\text{Parallel}\theta}\right)$ $F_{XB} := F_{\text{Parallel}\theta}$ $F_{XC} := F_{\text{Parallel}\theta} - F_X$	Note: Where A is during the Acceleration, B is during the constant velocity, and C is during the deceleration
Distance Moved	$D_{XA} := \frac{V_{Xf}^2 - V_{Xi}^2}{2\cdot a_X}$	$D_{XA} = 50\,\text{ft}$
Time to move	$t_{XA} := \frac{V_{Xf} - V_{Xi}}{a_X}$	$t_{XA} = 10\,\text{s}$

During Constant Velocity:

Velocity	$V_{Xf} = 10\,\frac{\text{ft}}{\text{s}}$	
Force	$F_{XV} := F_{\text{Parallel}\phi}$	$F_{XV} = 1294.095\,\text{lbf}$
Total Distance	$D_{XT} := 100\cdot\text{ft}$	
Distance Moved	$D_{XV} := D_{XT} - 2\cdot\left(\frac{V_{Xf}^2 - V_{Xi}^2}{2\cdot a_X}\right)$	$D_{XV} = 0\,\text{ft}$
Time to move	$t_{XV} := \frac{D_{XV}}{V_{Xf}}$	$t_{XV} = 0\,\text{s}$

Total Energy and Instantaneous Power During Travel on the X-Axis

$$P_X(t) := \left| \begin{array}{l} F_{XA}\cdot(a_X\cdot t) \quad \text{if } t \le t_{XA} \\ F_{XC}\cdot\left[V_{Xf} - a_X\cdot\left[t - \left(t_{XA} + t_{XV}\right)\right]\right] \quad \text{if } t > t_{XA} + t_{XV} \end{array} \right.$$



Max Power Required $P_{XMax} := P_X(t_{XA})$ $P_{XMax} = 8.015kW$

Total Energy Required in the X Direction:

$$W_X := \int_{0\cdot s}^{2\cdot t_{XA}+t_{XV}} P_X(t)\, dt \qquad W_X = 16.412W\cdot hr$$

Efficiency $Eff_X := 0.7$

Total Energy Due to Efficiency Losses $E_X := \frac{W_X}{Eff_X}$ $E_X = 23.446W\cdot hr$ $P_X = f(Time) => Power$

Energy Required to Move In the Y Direction (Longitudinal) Going Up

During Acceleration & Deceleration:

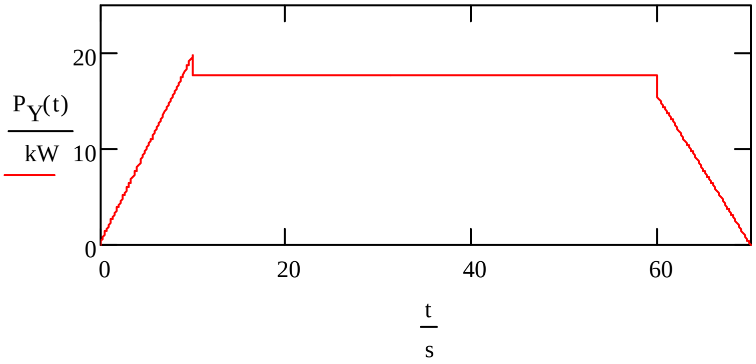
Mass	$\text{mass} = 155.405\,\text{slug}$	Note: This is not considering that the device will have to overcome acceleration from the ship
Acceleration	$a_Y := 1 \cdot \frac{\text{ft}}{\text{s}^2}$	
Initial Velocity	$V_{Yi} := 0$	
Final Velocity	$V_{Yf} := 10 \frac{\text{ft}}{\text{s}}$	
Force Required For Desired Acceleration	$F_Y := \text{mass} \cdot a_Y$	$F_Y = 155.405\,\text{lbf}$
Total Force Expended	$F_{YA} := \left(F_Y + F_{\text{Parallel}\phi}\right)$ $F_{YB} := F_{\text{Parallel}\phi}$ $F_{YC} := F_{\text{Parallel}\phi} - F_Y$	Note: Where A is during the Acceleration, B is during the constant velocity, and C is during the deceleration
Distance Moved	$D_{YA} := \frac{V_{Yf}^2 - V_{Yi}^2}{2 \cdot a_Y}$	$D_{YA} = 50\,\text{ft}$
Time to move	$t_{YA} := \frac{V_{Yf} - V_{Yi}}{a_Y}$	$t_{YA} = 10\,\text{s}$

During Constant Velocity:

Velocity	$V_{Yf} = 10 \frac{\text{ft}}{\text{s}}$	
Total Distance	$D_{YT} := 600 \cdot \text{ft}$	
Distance Moved	$D_{YV} := D_{YT} - 2 \cdot \left(\frac{V_{Yf}^2 - V_{Yi}^2}{2 \cdot a_Y}\right)$	$D_{YV} = 500\,\text{ft}$
Time to move	$t_{YV} := \frac{D_{YV}}{V_{Yf}}$	$t_{YV} = 50\,\text{s}$

Total Energy and Instantaneous Power During Travel on the X-Axis

$$P_Y(t) := \begin{cases} F_{YA}\cdot(a_Y\cdot t) & \text{if } t \le t_{YA} \\ F_{YB}\cdot V_{Yf} & \text{if } t_{YA} < t < t_{YA} + t_{YV} \\ F_{YC}\cdot\left[V_{Yf} - a_Y\cdot\left[t - \left(t_{YA} + t_{YV}\right)\right]\right] & \text{if } t \ge t_{YA} + t_{YV} \end{cases}$$



Max Power Required $P_{YMax} := P_Y(t_{YA})$ $P_{YMax} = 19.653kW$

Total Energy Required in the Y Direction:

$$W_Y := \int_{0\cdot s}^{2\cdot t_{YA}+t_{YV}} P_Y(t)\,dt \qquad W_Y = 292.41W\cdot hr$$

Efficiency $Eff_Y := 0.7$

Total Energy Due to Efficiency Losses $E_Y := \frac{W_Y}{Eff_Y}$ $E_Y = 417.729W\cdot hr$ $P_Y = f(Time) => Power$

Energy Required to Move In the Z Direction (Vertical) Going Up

During Acceleration & Deceleration:

Mass $mass = 155.405\,\mathrm{slug}$

Acceleration $a_Z := 1 \cdot \frac{\mathrm{ft}}{\mathrm{s}^2}$

Note: This is not considering that the device will have to overcome acceleration from the ship

Initial Velocity $V_{Zi} := 0$

Final Velocity $V_{Zf} := 2\frac{\mathrm{ft}}{\mathrm{s}}$

Force Required For Desired Acceleration $F_Z := mass \cdot a_Z$ $F_Z = 155.405\,\mathrm{lbf}$

Total Force Expended

$F_{ZA} := \left(F_Z + F_{Gravity}\right)$

$F_{ZB} := F_{Gravity}$

$F_{ZC} := F_{Gravity} - F_Z$

Note: Where A is during the Acceleration, B is during the constant velocity, and C is during the deceleration

Distance Moved $D_{ZA} := \frac{{V_{Zf}}^2 - {V_{Zi}}^2}{2 \cdot a_Z}$ $D_{ZA} = 2\ \mathrm{ft}$

Time to move $t_{ZA} := \frac{V_{Zf} - V_{Zi}}{a_Z}$ $t_{ZA} = 2\,\mathrm{s}$

During Constant Velocity:

Velocity $V_{Zf} = 2\,\frac{ft}{s}$

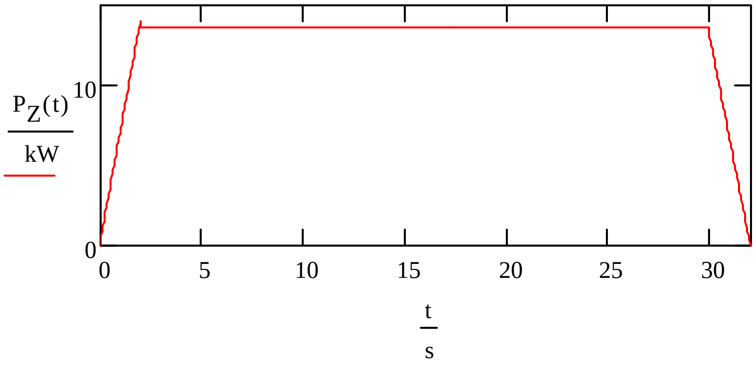
Total Distance $D_{ZT} := 60 \cdot ft$

Distance Moved $D_{ZV} := D_{ZT} - 2 \cdot \left(\frac{V_{Zf}^{2} - V_{Zi}^{2}}{2 \cdot a_Z} \right)$ $D_{ZV} = 56\ ft$

Time to move $t_{ZV} := \frac{D_{ZV}}{V_{Zf}}$ $t_{ZV} = 28s$

Total Energy and Instantaneous Power During Travel on the X-Axis

$$P_Z(t) := \left| \begin{array}{l} F_{ZA} \cdot (a_Z \cdot t) \ \text{ if } \ t \le t_{ZA} \\ F_{ZB} \cdot V_{Zf} \ \text{ if } \ t_{ZA} < t < t_{ZA} + t_{ZV} \\ F_{ZC} \cdot \left[V_{Zf} - a_Z \cdot \left[t - (t_{ZA} + t_{ZV}) \right] \right] \ \text{ if } \ t \ge t_{ZA} + t_{ZV} \end{array} \right.$$



Max Power Required $P_{ZMax} := P_Z(t_{ZA})$ $P_{ZMax} = 13.98kW$

Total Energy Required in the Z Direction:

$W_Z := \int_{0 \cdot s}^{2 \cdot t_{ZA} + t_{ZV}} P_Z(t)\,dt$ $W_Z = 112.985W \cdot hr$

Efficiency $Eff_Z := 0.7$

Total Energy Due to Efficiency Losses $E_Z := \frac{W_Z}{Eff_Z}$ $E_Z = 161.407W \cdot hr$

Total Energy Required to Move the Object

Energy Total $E_T := E_X + E_Y + E_Z$ $E_T = 602.582\,W\cdot hr$

46. Vehicle Storage:

Shown below are the calculations for the Vehicle Storage Energy Requirements:

Force Calculations

Static Loads:

Total Weight $Weight_{Total} := 185000\,lb$ $mass := Weight_{Total}$

Max Operating Pitch $\theta := 5\cdot deg$ $mass = 5749.976\,slug$

Max Operating Roll $\phi := 15\cdot deg$

Gravity $g = 32.174\,\frac{ft}{sec^2}$

Opposing Forces

From Pitch (Longitudinal) $F_{Parallel\theta} := mass\cdot g\,\sin(\theta)$ $F_{Parallel\theta} = 16123.812\,lbf$

From Roll (Transverse) $F_{Parallel\phi} := mass\cdot g\,\sin(\phi)$ $F_{Parallel\phi} = 47881.523\,lbf$

From Gravity (Vertical) $F_{Gravity} := mass\cdot g$ $F_{Gravity} = 185000\,lbf$

Energy Required to Move In the X Direction (Transverse) Going Up

During Acceleration & Deceleration:

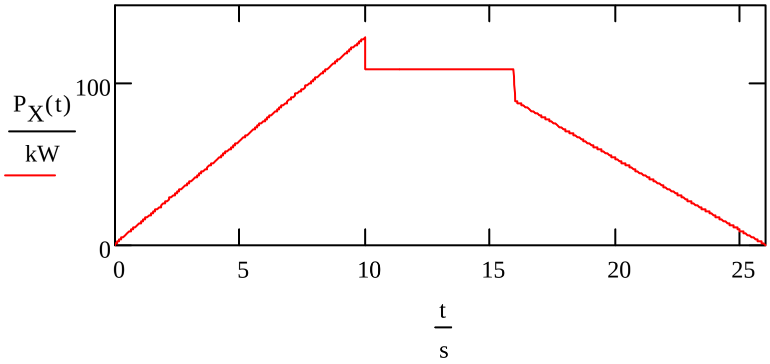
Mass	$\text{mass} = 5749.976\,\text{slug}$	Note: This is not considering that the device will have to overcome acceleration from the ship
Acceleration	$a_X := .5 \cdot \frac{\text{ft}}{\text{s}^2}$	
Initial Velocity	$V_{Xi} := 0$	
Final Velocity	$V_{Xf} := 5\,\frac{\text{ft}}{\text{s}}$	
Force Required For Desired Acceleration	$F_X := \text{mass} \cdot a_X$	$F_X = 2874.988\,\text{lbf}$
Total Force Expended	$F_{XA} := \left(F_X + F_{\text{Parallel}\theta}\right)$ $F_{XB} := F_{\text{Parallel}\theta}$ $F_{XC} := F_{\text{Parallel}\theta} - F_X$	Note: Where A is during the Acceleration, B is during the constant velocity, and C is during the deceleration
Distance Moved	$D_{XA} := \frac{V_{Xf}^2 - V_{Xi}^2}{2 \cdot a_X}$	$D_{XA} = 25\,\text{ft}$
Time to move	$t_{XA} := \frac{V_{Xf} - V_{Xi}}{a_X}$	$t_{XA} = 10\,\text{s}$

During Constant Velocity:

Velocity	$V_{Xf} = 5\,\frac{\text{ft}}{\text{s}}$	
Force	$F_{XV} := F_{\text{Parallel}\phi}$	$F_{XV} = 47881.523\,\text{lbf}$
Total Distance	$D_{XT} := 80 \cdot \text{ft}$	
Distance Moved	$D_{XV} := D_{XT} - 2 \cdot \left(\frac{V_{Xf}^2 - V_{Xi}^2}{2 \cdot a_X}\right)$	$D_{XV} = 30\,\text{ft}$
Time to move	$t_{XV} := \frac{D_{XV}}{V_{Xf}}$	$t_{XV} = 6\,\text{s}$

Total Energy and Instantaneous Power During Travel on the X-Axis

$$P_X(t) := \begin{cases} F_{XA}\cdot(a_X\cdot t) & \text{if } t \le t_{XA} \\ F_{XB}\cdot V_{Xf} & \text{if } t_{XA} < t < t_{XA} + t_{XV} \\ F_{XC}\cdot\left[V_{Xf} - a_X\cdot\left[t - (t_{XA} + t_{XV})\right]\right] & \text{if } t \ge t_{XA} + t_{XV} \end{cases}$$



Max Power Required $P_{XMax} := P_X(t_{XA})$ $P_{XMax} = 128.795\,kW$

Total Energy Required in the X Direction:

$$W_X := \int_{0\cdot s}^{2\cdot t_{XA}+t_{XV}} P_X(t)\,dt \qquad W_X = 485.774\,W\cdot hr$$

Efficiency $Eff_X := 0.7$

Total Energy Due to Efficiency Losses $E_X := \frac{W_X}{Eff_X}$ $E_X = 693.963\,W\cdot hr$ $P_X = f(Time) => Power$

Energy Required to Move In the Y Direction (Longitudinal) Going Up First Part

During Acceleration & Deceleration:

Mass $mass = 5749.976\,slug$

Note: This is not considering that the device will have to overcome acceleration from the ship

Acceleration $a_{Y1} := .5 \cdot \frac{ft}{s^2}$

Initial Velocity $V_{Y1i} := 0$

Final Velocity $V_{Y1f} := 5\,\frac{ft}{s}$

Force Required For Desired Acceleration $F_{Y1} := mass \cdot a_{Y1}$ $F_{Y1} = 2874.988\,lbf$

Total Force Expended $F_{Y1A} := \left(F_{Y1} + F_{Parallel\phi}\right)$

Note: Where A is during the Acceleration, B is during the constant velocity, and C is during the deceleration

$F_{Y1B} := F_{Parallel\phi}$

$F_{Y1C} := F_{Parallel\phi} - F_{Y1}$

Distance Moved $D_{Y1A} := \frac{V_{Y1f}^2 - V_{Y1i}^2}{2 \cdot a_{Y1}}$ $D_{Y1A} = 25\,ft$

Time to move $t_{Y1A} := \frac{V_{Y1f} - V_{Y1i}}{a_{Y1}}$ $t_{Y1A} = 10\,s$

During Constant Velocity:

Velocity $V_{Y1f} = 5\,\frac{ft}{s}$

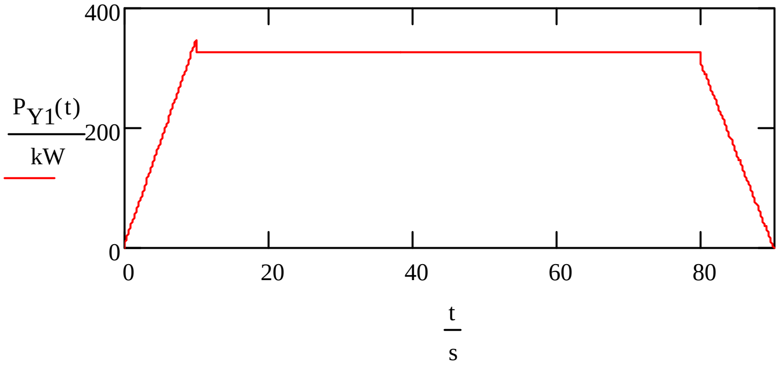
Total Distance $D_{Y1T} := 400 \cdot ft$

Distance Moved $D_{Y1V} := D_{Y1T} - 2 \cdot \left(\frac{V_{Y1f}^2 - V_{Y1i}^2}{2 \cdot a_{Y1}}\right)$ $D_{Y1V} = 350\,ft$

Time to move $t_{Y1V} := \frac{D_{Y1V}}{V_{Y1f}}$ $t_{Y1V} = 70\,s$

Total Energy and Instantaneous Power During Travel on the X-Axis

$$P_{Y1}(t) := \left| \begin{array}{l} F_{Y1A}\cdot\left(a_{Y1}\cdot t\right) \ \text{ if } \ t \le t_{Y1A} \\ F_{Y1B}\cdot V_{Y1f} \ \text{ if } \ t_{Y1A} < t < t_{Y1A} + t_{Y1V} \\ F_{Y1C}\cdot\left[V_{Y1f} - a_{Y1}\cdot\left[t - \left(t_{Y1A} + t_{Y1V}\right)\right]\right] \ \text{ if } \ t \ge t_{Y1A} + t_{Y1V} \end{array} \right.$$



Max Power Required $P_{Y1Max} := P_{Y1}\left(t_{Y1A}\right)$ $P_{Y1Max} = 344.083\,kW$

Total Energy Required in the Y Direction:

$$W_{Y1} := \int_{0\cdot s}^{2\cdot t_{Y1A}+t_{Y1V}} P_{Y1}(t)\,dt \qquad W_{Y1} = 7213.186\,W\cdot hr$$

Efficiency $Eff_{Y1} := 0.7$

Total Energy Due to Efficiency Losses $E_{Y1} := \frac{W_{Y1}}{Eff_{Y1}}$ $E_{Y1} = 10304.552\,W\cdot hr$

Energy Required to Move In the Y Direction (Longitudinal) Going Up Second Part

During Acceleration & Deceleration:

Note: This is not considering that the device will have to overcome acceleration from the ship

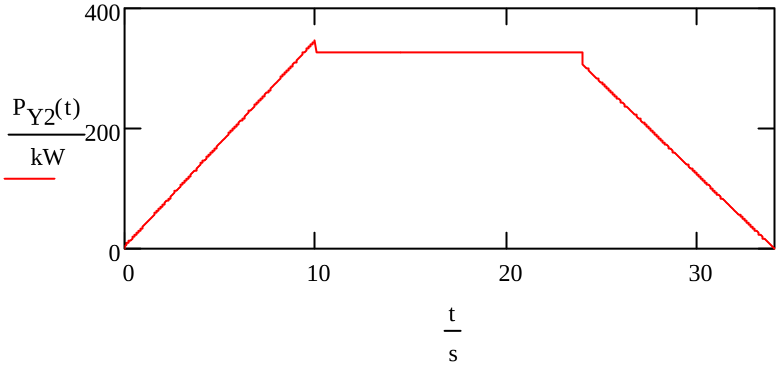
Mass	$\text{mass} = 5749.976\,\text{slug}$	
Acceleration	$a_{Y2} := .5 \cdot \frac{\text{ft}}{\text{s}^2}$	
Initial Velocity	$V_{Y2i} := 0$	
Final Velocity	$V_{Y2f} := 5\,\frac{\text{ft}}{\text{s}}$	
Force Required For Desired Acceleration	$F_{Y2} := \text{mass} \cdot a_{Y2}$	$F_{Y2} = 2874.988\,\text{lbf}$
Total Force Expended	$F_{Y2A} := \left(F_{Y2} + F_{Parallel\phi}\right)$ $F_{Y2B} := F_{Parallel\phi}$ $F_{Y2C} := F_{Parallel\phi} - F_{Y2}$	Note: Where A is during the Acceleration, B is during the constant velocity, and C is during the deceleration
Distance Moved	$D_{Y2A} := \frac{V_{Y2f}^2 - V_{Y2i}^2}{2 \cdot a_{Y2}}$	$D_{Y2A} = 25\,\text{ft}$
Time to move	$t_{Y2A} := \frac{V_{Y2f} - V_{Y2i}}{a_{Y2}}$	$t_{Y2A} = 10\,\text{s}$

During Constant Velocity:

Velocity	$V_{Y2f} = 5\,\frac{\text{ft}}{\text{s}}$	
Total Distance	$D_{Y2T} := 120 \cdot \text{ft}$	
Distance Moved	$D_{Y2V} := D_{Y2T} - 2 \cdot \left(\frac{V_{Y2f}^2 - V_{Y2i}^2}{2 \cdot a_{Y2}}\right)$	$D_{Y2V} = 70\,\text{ft}$
Time to move	$t_{Y2V} := \frac{D_{Y2V}}{V_{Y2f}}$	$t_{Y2V} = 14\,\text{s}$

Total Energy and Instantaneous Power During Travel on the X-Axis

$$P_{Y2}(t) := \begin{cases} F_{Y2A}\cdot\left(a_{Y2}\cdot t\right) & \text{if } t \le t_{Y2A} \\ F_{Y2B}\cdot V_{Y2f} & \text{if } t_{Y2A} < t < t_{Y2A} + t_{Y2V} \\ F_{Y2C}\cdot\left[V_{Y2f} - a_{Y2}\cdot\left[t - \left(t_{Y2A} + t_{Y2V}\right)\right]\right] & \text{if } t \ge t_{Y2A} + t_{Y2V} \end{cases}$$



Max Power Required $P_{Y2Max} := P_{Y2}\left(t_{Y2A}\right)$ $P_{Y2Max} = 344.083\,kW$

Total Energy Required in the Y Direction:

$$W_{Y2} := \int_{0\cdot s}^{2\cdot t_{Y2A}+t_{Y2V}} P_{Y2}(t)\,dt \qquad W_{Y2} = 2163.997\,W\cdot hr$$

Efficiency $Eff_{Y2} := 0.7$

Total Energy Due to Efficiency Losses $E_{Y2} := \frac{W_{Y2}}{Eff_{Y2}}$ $E_{Y2} = 3091.424\,W\cdot hr$

Energy Required to Move In the Z Direction (Vertical) Going Up

During Acceleration & Deceleration:

Mass $\text{mass} = 5749.976\,\text{slug}$

Note: This is not considering that the device will have to overcome acceleration from the ship

Acceleration $a_Z := .5\cdot\frac{\text{ft}}{\text{s}^2}$

Initial Velocity $V_{Zi} := 0$

Final Velocity $V_{Zf} := 1\,\frac{\text{ft}}{\text{s}}$

Force Required For Desired Acceleration $F_Z := \text{mass}\cdot a_Z$ $F_Z = 2874.988\,\text{lbf}$

Total Force Expended $F_{ZA} := \left(F_Z + F_{Gravity}\right)$

$F_{ZB} := F_{Gravity}$

$F_{ZC} := F_{Gravity} - F_Z$

Note: Where A is during the Acceleration, B is during the constant velocity, and C is during the deceleration

Distance Moved $D_{ZA} := \frac{{V_{Zf}}^2 - {V_{Zi}}^2}{2\cdot a_Z}$ $D_{ZA} = 1\ \text{ft}$

Time to move $t_{ZA} := \frac{V_{Zf} - V_{Zi}}{a_Z}$ $t_{ZA} = 2\,\text{s}$

Total Energy Required to Move the Object

Energy Total $E_T := E_X + E_{Y1} + E_{Y2} + E_Z$ $E_T = 17474.084\,W \cdot hr$

Appendix K: Accelerations

In order to find more accurate forces that would be applied to the designed components, a typically sized LMSR was used to find operating accelerations. Data was obtained for sea states as high as SS8 using SMP95. This work was done outside of our group with the help of Tim Smith at NSWC – Carderock. The analysis from SMP95 included analysis at several different locations. The pilothouse was chosen since it would be the farthest from the ships center of gravity, thus yielding the highest possible roll accelerations. Pitch accelerations may be higher at other points; however those values should still be less than that of the highest roll accelerations. Several different roll periods were looked at while at wave heights of 45.90 ft (representative of SS8). The lateral, longitudinal, and vertical accelerations were considered in this analysis. The three accelerations were added together to get an overall magnitude at SS8, various roll periods, and various ship headings. From this the highest magnitude was found at the shortest roll period, and was then used in component form to adjust the various loading analysis done in order to yield more accurate results.

Below are the calculations done in order to get a magnitude of the overall acceleration:

$$\begin{pmatrix} \text{Lat} \\ \text{Long} \\ \text{Vert} \end{pmatrix} = \begin{pmatrix} X \\ Y \\ Z \end{pmatrix} \qquad \text{Original} := \begin{pmatrix} 17.79 \\ 3.82 \\ 45.38 \end{pmatrix}$$

$$\text{CorrectUnits} := \frac{\text{Original}}{100} \cdot 32.2 \cdot \frac{\text{ft}}{\text{s}^2} \qquad \text{CorrectUnits} = \begin{pmatrix} 5.73 \\ 1.23 \\ 14.61 \end{pmatrix} \frac{\text{ft}}{\text{s}^2} \qquad \text{Gravity} := \begin{pmatrix} 0 \\ 0 \\ 32.2 \end{pmatrix} \cdot \frac{\text{ft}}{\text{s}^2}$$

$$\text{WithGravity} := \text{CorrectUnits} + \text{Gravity} \qquad \text{WithGravity} = \begin{pmatrix} 5.73 \\ 1.23 \\ 46.81 \end{pmatrix} \frac{\text{ft}}{\text{s}^2}$$

$$\text{Magnitude} := \sqrt{\sum \text{WithGravity}^2} \qquad \text{Magnitude} = 47.18 \frac{\text{ft}}{\text{s}^2}$$

Weight of Container $\text{Weight}_{\text{Con}} := 3000 \cdot \text{lb}$ $\text{Weight}_{\text{Con}} = 93.24\,\text{slug}$

$$\text{ActualForces}_{\text{Con}} := \text{Weight}_{\text{Con}} \cdot \text{WithGravity} \qquad \text{ActualForces}_{\text{Con}} = \begin{pmatrix} 534.13 \\ 114.69 \\ 4364.92 \end{pmatrix} \text{lbf}$$

Weight of Tank $\text{Weight}_{\text{Tank}} := 140000\,\text{lb}$ $\text{Weight}_{\text{Tank}} = 4351.33\,\text{slug}$

$$\text{ActualForces}_{\text{Tank}} := \text{Weight}_{\text{Tank}} \cdot \text{WithGravity} \qquad \text{ActualForces}_{\text{Tank}} = \begin{pmatrix} 24926.09 \\ 5352.31 \\ 203696.17 \end{pmatrix} \text{lbf}$$