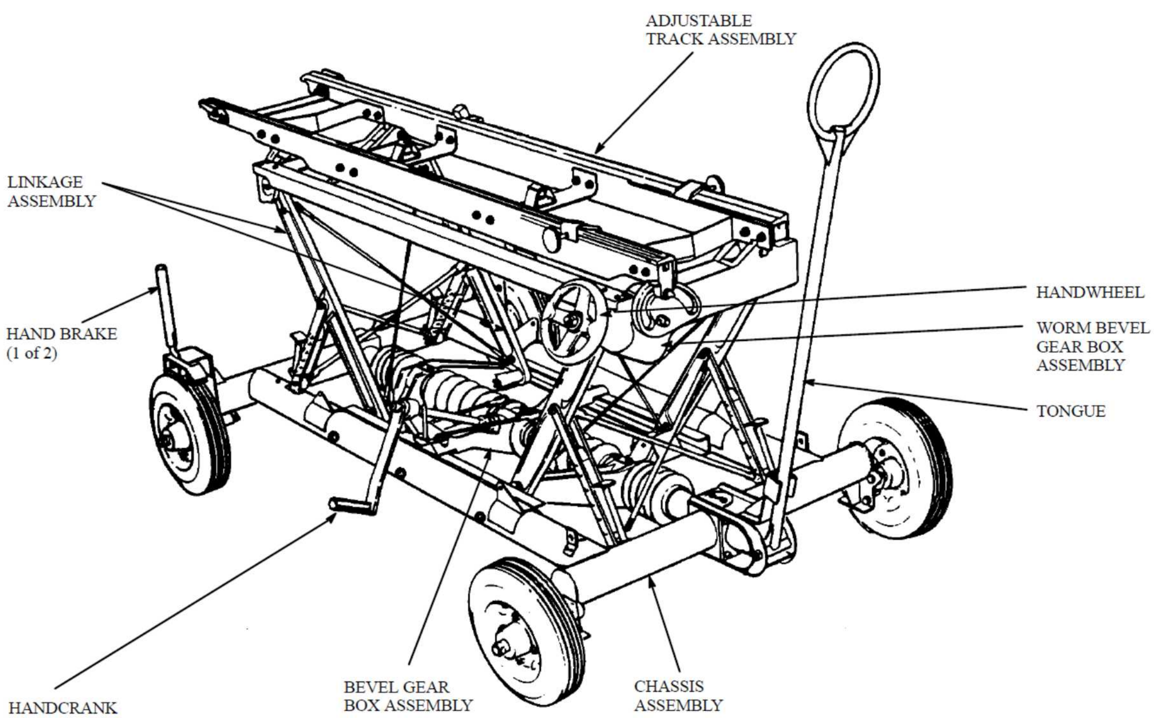
SYS645 Design for Reliability, Maintainability, and Supportability:

H12 Universal Cartridge Carrier (circa 1952)

Stevens Institute of Technology

Robert Morrison, January 2020



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National Nuclear Security Administration

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Executive Summary

The H12, Adjustable Hand Truck, formerly known as the Universal Cartridge Carrier, has lived well beyond original design intent, and continues to serve its purpose. Simplicity of use (no electromechanical parts) and ease of maintenance (accessible moving parts, protected from the elements) has allowed the H12 to truly provide a universal function for ordnance maintenance.

The H12 as a system includes hardware, software, the use of numerous policies/requirements, engineers/designers, and end users.

During the formation of this paper, it was difficult deciding whether to place a given case study or reference into the category of reliability, maintainability, or serviceability. The fact that there are differentiating opinions as to where the lines are to be drawn between these three characteristics is evidence that the lines are not concrete in concept or application. Therefore, the case studies included can fit into either (or multiple) a reliability, maintainability or serviceability category.

Based on nearly 70-years of use and a very limited number of anomalies reported over the past 27-years of available data, the H12 has shown to be a reliable system. This evidence also demonstrates that has a very high level of operational availability. The H12 has supported numerous systems over the years through the design of various adapters such that any near-cylindrical shape can be attached. Its adaptability to numerous ordnance configurations also demonstrates a strong reliability and sustainability basis.

The vast majority of maintenance can be performed in the field by the DoD pointing to an intermediate type of maintainability. However, the H12 system as a whole utilizes as a depot level maintainability where there is purposeful involvement inclusive of field maintainers, design organizations, SNL Liaison and other stakeholders.

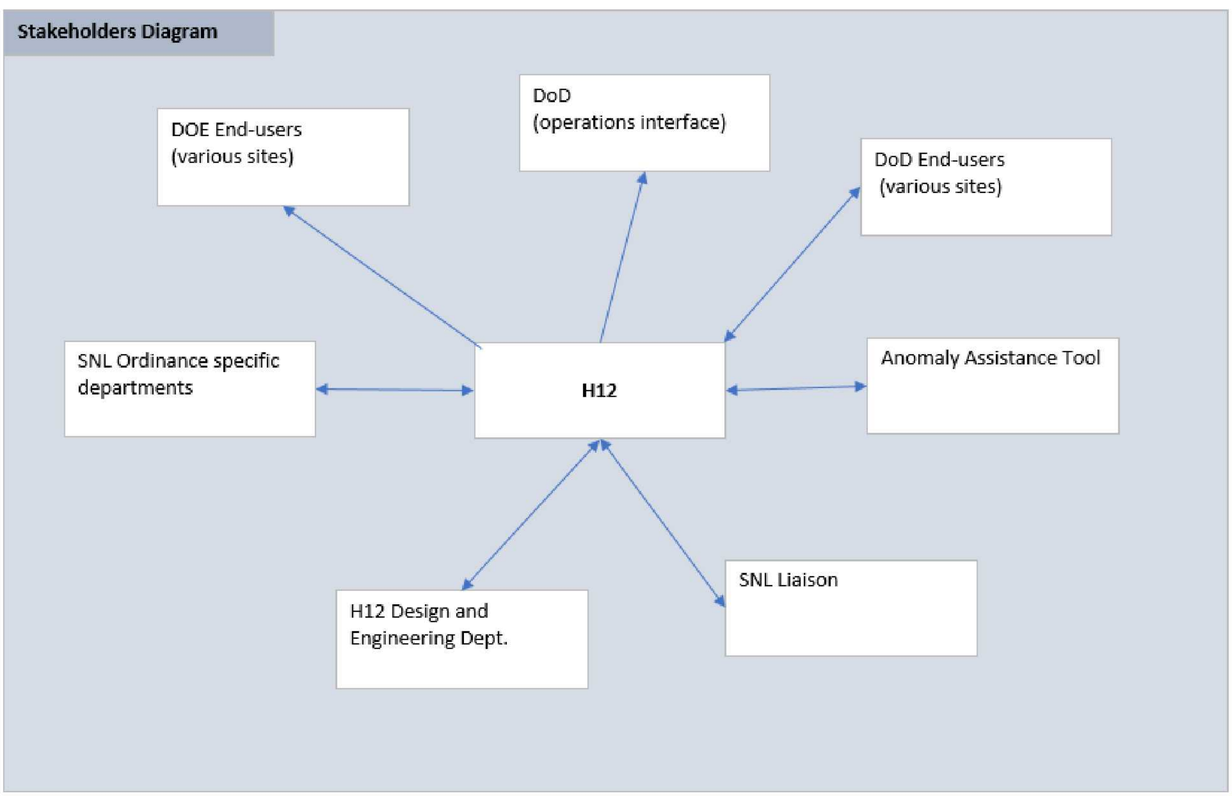
Keeping the H12 available for use by the DoD is critical. In fact, the system failure is defined as not having an H12 available for use at DoD location to support mission needs for ordnance maintenance activities. Therefore, the need for system sustainability calls for processes that strategically integrate end-users, software, parts stores, and engineering disciplines.

1. Introduction

The initial product specification[1] for the H12 Universal Cartridge Carrier (UUC) was released in October 1952 and is the twelfth piece of H-Gear (sequentially numbered) ever developed. It is the oldest piece of H-Gear currently in use. To gain perspective on the number of H-Gear since designed, the most currently developed and deployed H-Gear is the H1768, Inspection Stand. The UUC, (commonly referred to as just the "H12") has since been renamed to the H12 Adjustable Hand Truck. It was developed to support various maintenance operations for ordnance assembly and disassembly.

This paper will provide evidence (where available) for the H12s current state of reliability, maintainability, and sustainability (RMA). Where documented evidence is not available, conclusions will be drawn based on its continued effective use over the past 67-years of service.

Below is a basic stakeholders diagram demonstrating that the H12 itself as a piece of hardware that includes many stakeholders with a vested interest. The H12 as a wholistic system, including its stakeholders, will be discussed in this paper, focusing on the elements of RMA.



2. Purpose

The H12[2] is used to support maintenance activities to allow the aft section to be separated horizontally from the forward section of multiple cylindrical, or near-cylindrically shaped ordnance. It consists of an adjustable track assembly supported by two linkage assemblies and a 4-wheeled steerable chassis assembly. The track assembly is adjusted for height and longitudinal tilt with the bevel gear box assembly operated with a hand crank and for lateral tilt (±5-degrees) with the worm gear box assembly operated with a handwheel. The H12 is maneuvered and towed with the tongue, which is secured to the front cross-member of the chassis. Each rear wheel is provided with a hand-operated brake. The published capacity rating is 600-lbs.

Throughout its nearly 70-years of use the H12 has been re-purposed for numerous weapon systems. As the design of weapons has changed over the decades, the functionality of the H12 preserves its purpose for weapon maintainers. In order to properly interface with different ordnance geometries, cradles have been developed for the track assembly, including the H1457 (the 1,457th piece of H-gear developed)[3]. Once the screws or tape joints are removed from the weapon forward/aft seam, the H12 can be rolled back on its wheels in order to access internal components. With certain configurations used in the past, a glide rail was affixed to the horizontal rails of the H12, allowing the H12 to remain locked/stable while separating the aft/forward sections.

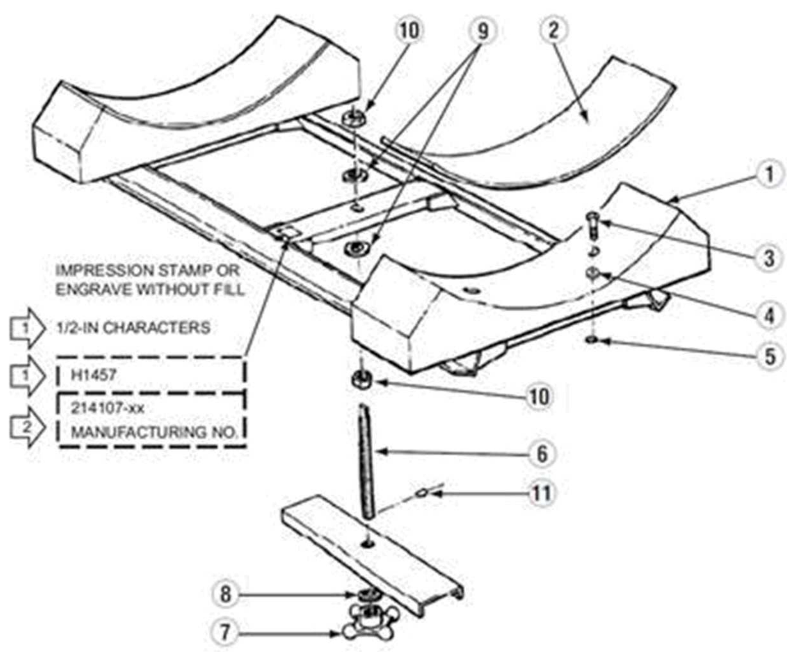


Figure 4-7 H1457, H12 Adapter

3. Findings: Sustainability

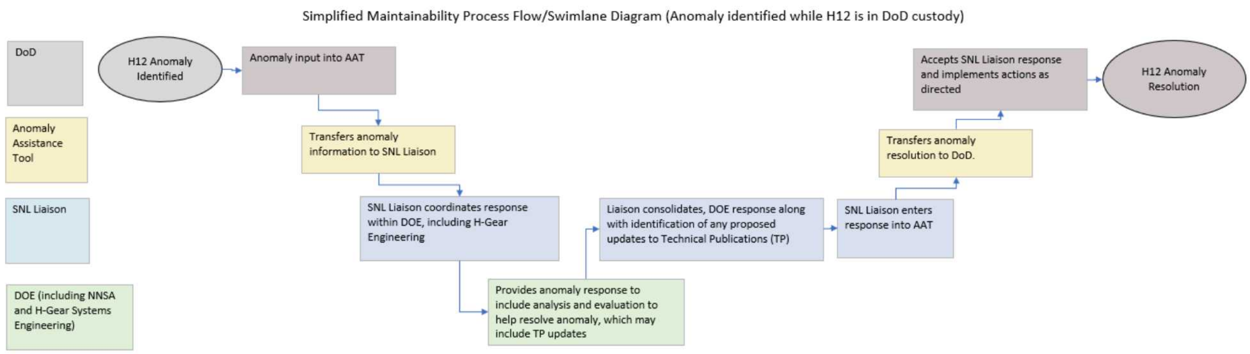
Most H-gear has a service life alongside a specific weapon for which it was originally intended. However, the H12 has lived well beyond its original design basis, mainly in part to the H12's flexibility attribute to support cylindrical, or near-cylindrical ordnance shapes.

Although the H12 consists of over 1000 individual components (screwjacks, bolts, washers, wheels, kingpins, split collars, etc.) only four components are field replaceable by the DoD. These include the wheel assemblies, collapsing boot, and left/right brake assemblies. If other parts fail within the system another/replacement H12 would normally be ordered. However, options exist per approved technical publications (TP) that would, pending H-Gear Systems Engineering Department and DOE approval, allow for special instructions be written for certain field maintenance activities to take place to replace parts not normally considered field replaceable. The procedures, once published, cannot be deviated from by the DoD. Nevertheless, these documents are living in a sense that they are continually being updated to ensure technical accuracy while also changing to best serve maintainability in the field, therefore leading to a greater sustainability.

The actual maintenance use of the H12 by the DoD is infrequent and can be up to a year between activities. A major part of the system's sustainability is that its use is practiced by the DoD and other users on a periodic basis to ensure user's proficiency. This is especially needed since the DoD weapons maintainers routinely change locations (Permanent Change of Station) approximately every three years. There is initial training as well as periodic training following the H12 technical publication manual. The manual itself is continually updated with lessons learned, best practices, and to help provide additional clarity for maintainers. When discrepancies are noted in the TP the DoD submits a technical publication specific request for change or point of clarification through AAT. This request is then evaluated by SNL Liaison in coordination with DOE, ultimately providing a response to DoD whether to make changes to the manual. Anomalies identified and reported through AAT in the field by the DoD may also necessitate a change as well.

Part of the sustainability is how the H12 is dispositioned, if while in the field, an anomaly or reject condition is identified, the DoD would be disallowed from using it. Below is a simplified maintainability process flow (swimlane) diagram identifying how an anomaly could be dispositioned. This diagram assumes a best-path resolution. In many cases there are elements that are iterative. One example of iteration includes the linkage between SNL Liaison and others in the DOE community to provide a technical basis for anomaly response. Another may be between SNL Liaison and the DoD, where there is negotiation for interim changes to technical publications and/or responses necessitating additional information. This could potentially necessitate a technical interchange meeting directly between the DoD and H-Gear Systems Engineering to resolve.

Although this figure depicts a maintainability process it is a key component in the sustainability of the H12.



4. Findings: Reliability

The reliability functions or systems developed to support the H12 is the key aspect to insure its operational availability, or A_o. The A_o is defined as the probability that the system, when used, will operate satisfactorily as required. The A_o accounts for mean time between maintenance and mean downtimes as demonstrated in the following equation.

$$A_o = \frac{MTBM}{MTBM + MDT}$$

All DoD locations that utilize the H12 have at minimum two in service. In addition, there are currently five in spares, five in custody of Sandia National Laboratories (SNL) Liaison (not all are in a known state of repair); and at least four between two sister organizations at SNL. This should not be taken as a system redundancy since all H12s have common single points of failure in its design. It would be extremely rare that both H12s at any DoD location would ever be used at the same time, since mission needs, crews, and oversight resources are limited.

Evidence in the AAT System identify eleven instances going back to 2001 where the DoD identified a reportable anomaly with the H12. Of these, seven are attributed to needing clarification in the technical publications while the other four involved hardware components. This paper contains two case studies on obsolete hardware components that were initially identified through the AAT System.

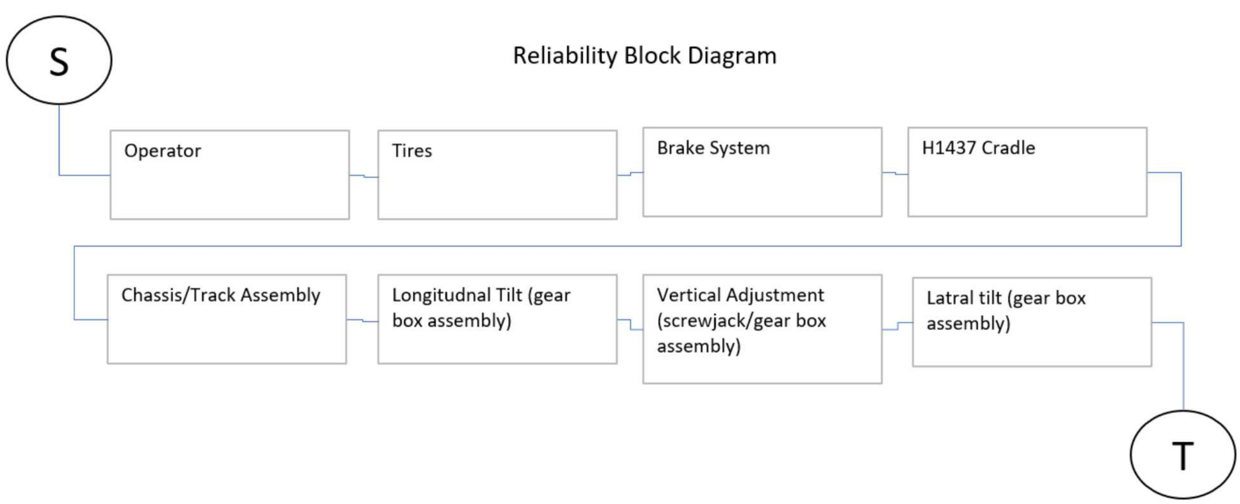
4.1. H12 System Failure Definition

Failure of the system is when an anomaly is identified (by DoD) that is considered a reject condition of the H12 and its backup, inhibiting ordnance maintenance operations.

4.2. Reliability Block Diagram/Failure Identification

Below is a high-level Reliability Block Diagram (RBD) identifying various key components necessary for successful operation of the H12. This diagram purposefully is not intended to show functionality and should not be confused with Functionality Block Diagram (not included).

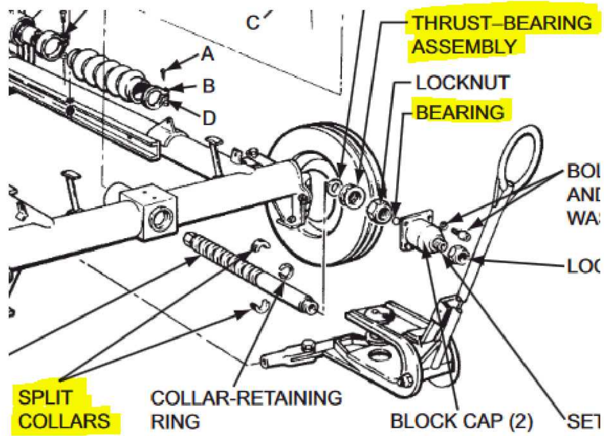
Therefore, arrows are not used to connect items. It begins with the source S, then ends with termination T. It is a useful tool to identify potential single point failures at the top level. It can be broken down into further detail showing various subcomponents. It is also helpful to identify critical expectations, key assumptions and components critical to its lifecycle.



4.3. Case Study: RBD Single Point Failure (split-collar)

One of the components that provides for vertical adjustment of the track assembly are the screwjacks (2 ea.). One is forward and the other aft, allowing for vertical adjustment as well as longitudinal tilt since the screwjacks can be operated in parallel or independently (see figure below). Each of the screwjacks have a split-collar at each end.

The purpose of the split-collar is to prevent running out the screwjacks too far out when raising the track, such that it could disengage with the inner gear hub, causing it to fall out. During prescribed operational use of the H12, the maximum height of the track would never be exceeded that would engage the split-collar. However, during inspection operations prior to actual use, the TP calls for the jackscrews be run to their highest extent. In the scenario that both split-collars (function in parallel) are missing or failed to operate properly the jackscrews could run out of the inner gear hub, potentially damaging the jackscrew or hub.



In one instance during replacement of a dried-out rubber boot, the DoD noticed that the split-collar was missing altogether from one of the screwjacks. The manufacturer of this item is no longer in business. Since the part is integral to the certified system, it cannot be readily replaced with another with similar form and function. Due to the cost for engineering, design, and testing of a replacement part, the H12 was placed out of service and considered unrepairable.

5. Findings: Maintainability

The level of maintenance structure that supports the H12 is referred to as supplier/manufacturer/depot maintenance. This is the highest level of maintenance for a system, yet also includes elements of both organizational and intermediate maintenance. The repair policy currently governing the H12 is that it be partially repairable, and even that is very limited in scope as to what is repairable with replacement components in the field.

Since the H12 was initially put into service in the early 1950's I am not able to ascertain whether it was purposefully designed with a high rigor maintainability profile. However, evidence nearly 70-years later shows that the H12 system (hardware, plus software) has at least evolved into a high-rigor/mature design. The core elements of mature maintainability of a system consist of planned levels of maintenance, well defined functionality, organizational responsibilities, support documents that include change/quality controls, design criteria and requirements that anticipate future maintenance needs. Many of these elements are realized in following required technical manuals and design guides.

There are numerous technical publications applicable to the maintainability of the H12. Each of these are described in brief below.

- TP 1-1 Technical Publications Control Document. Provides overall requirements for implementation of all technical publications to include quality, change control and configuration management.

- TP 4-1 Glossary of Ordnance Related Terms. Provides for a consistent basis for definitions, terminology, acronyms, and abbreviations used across various ordnance types.

- TP 5-1 Anomaly Assistance Tool (AAT). Provides direction to DoD, Sandia Liaison, and DOE for proper reporting and resolution of system anomalies.

- H12-2 Adjustable Hand Truck. Provides DoD and DOE requirements for general operation, inspection, maintenance, identification of anomaly conditions and information to order/install authorized replacement parts.

- TP-XYZ for Ordnance Specific System. Provides specific operational direction for the use of the H12 with specific ordnance. Where discrepancies in direction occur, this TP takes precedence.

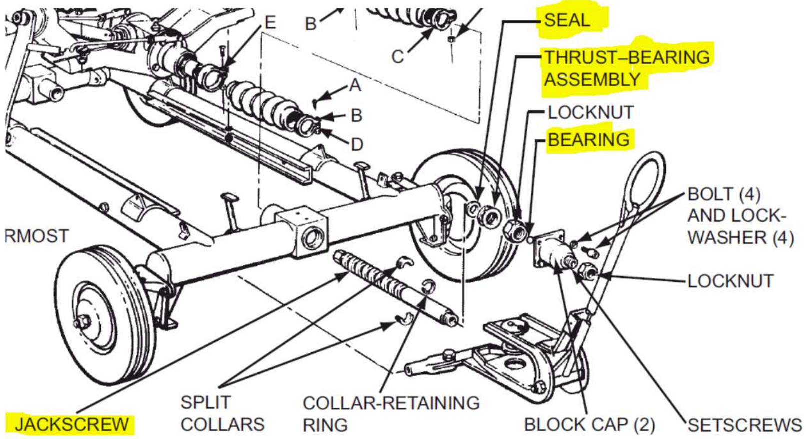
- TP 35-51 General Instructions Applicable to Ordnance. Provides users with general inspection criteria (e.g.: mechanical and electrical components), cleaning procedures, packaging instructions and minor repair of systems.

- Process Requirement 303 Ancillary Equipment. Provides requirements and testing parameters as it pertains to H-Gear design, procurement, assembly and inspection.

- Design Guide 10220, Designing H-Gear. Providing specifications for hardware design, serviceability and maintainability, focusing on national consensus standards such as those published by ASME, IEEE and ASTM, as well as various military specifications.

5.1. Case Study: Seal, Plain Encased

This seal is purposed to keep lubrication from the screwjacks (liberally applied) from the inside of the thrust-bearing assembly and bearing (thin coat). The same grease is specified for use in each location.



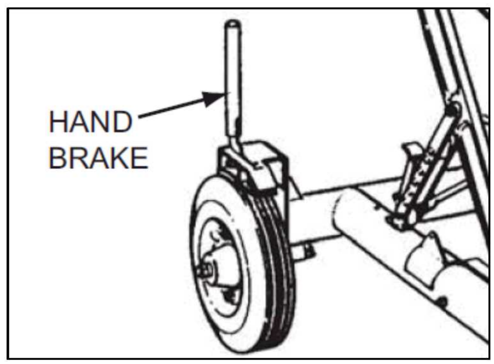
The Seal, Plain, Encased is a raw-hide (leather) seal the keeps grease in for the jackscrews, dirt out, while allowing a moderate amount of the same grease to the thrust assembly and bearings.

Through AAT an anomaly was reported by the DoD that the technical publication for the H12 required that the seal be removed for each maintenance activity when replacing the jackscrew. This is because removal of the jackscrew can damage the raw-hide sealing surface. However, there was no instruction to replace it, nor was that part called out in the spares listing. The fact that this anomaly was not reported or identified earlier goes to show how infrequent this operations takes place. When investigating the part called out by the spares list, it was determined that the manufacturer has since been twice sold. The specific part, based on a phone call with the new owner/manufacturer, and verifying the National Stock Number, that part has not been manufactured since the early 1990's. We then identified that the DoD had a replacement part that utilized a rubber sealing surface. Although it met the same dimensional needs it was not certified or tested to allow use on the H12. As with the split-collar, the cost for engineering, design, and testing of a replacement part, the H12 was placed out of service and considered unrepairable.

5.2. Lifecycle

The H12 has most likely lived well beyond its original intended use. Most of the components that make up the H12 contain or are painted with a cadmium-based paint which is anti-fungal and prevents corrosion, much like lead based paints. Design and intent of using cadmium was common 70+ years ago, yet since then it has become known that Cd is cancer causing. Its is a metal controlled by the Resource Conservation and Recovery Act (RCRA), and its disposition is very expensive as a hazardous waste. The parts listing for the H12 contains 111 individual components, all of which either contain cadmium as part of the base metal (e.g.: bolts or cast parts) or are painted with a cadmium-based paint. The use of cadmium would currently be prohibited based on requirements from the Consumer Product Safety Commission (if adopted as a requirement standard by DOE) and the Restriction of Hazardous Substances Directive (RoHS) for the European Union[5, 6].

In addition to cadmium, the two hand brake assemblies contain asbestos which is governed by the Toxic Substances Control Act of 1976 (TSCA) for disposition. To the best of my knowledge not all the brake pads have not been replaced and are still in use today. Since the brakes are only applied when the H12 is in a stationary position, not causing an airborne release of asbestos, the use of the handbrake does not constitute a hazard to the operator.



The additional cost for disposition of the H12 was certainly not anticipated during its development which was well before these substances were recognized as hazardous. Where applicable, when components need replacing a suitable non-hazardous material would be used. This may create the need for a new component to be designed by the SNL H-Gear department applying current design guide standards using non-hazardous substances. However, the possibility exists that as the stock numbers of H12s becomes small, there may be a need to cannibalize some H12s to repair others.

6. Results/Conclusions

The H12 system comprising hardware, support software (AAT), policies, and design guides are evidence that this is a mature system as it pertains to reliability, maintainability and sustainability. There is also clear evidence that at least over the past 27-years (according to readily available data in AAT) that the system has a high level of operational availability. There have not been any “urgent” AAT submissions in this timeframe where the system was unavailable for use, meeting our definition for system failure. In addition, although the organizational structure, and personnel (subject matter experts) of who and how the H12 is maintained has changed, again, it provides an excellent track record of operational availability, again demonstrating its maturity as a system.

An unintended mortgage was also purchased during initial design base on the use of cadmium and asbestos containing parts. This has led to increased cost for disposition of any H12 that is put out of service. Fortunately, how the H12 is used, does not constitute an occupational hazard to those that use it.

7. Recommendations

The H12 will be around for some time to come and based on its age will need additional resources to continue its RMA characteristics for continued success. More specifically, the current technical publication for the H12 provides steps for replacing the asbestos padding on the brake subsystem, however the parts for doing such are not listed as a spared part individually, only as a whole. As the service life of the H12 continues, it would be beneficial for an in-depth Fagan Inspection of the H12 technical publication (versus software Fagan Inspection).

There is no evidence that a Failure Modes and Effects Analysis (hardware or process focused) was ever performed on the H12 system, yet if it were developed today, due to the complexity of its operations and many moving/working parts that one would be essential.

Finally, based on the number of spares of H1s2 available, the number of expected uses of the hardware over the next 10-years plus, that minimal engineering effort be expended for designing replacement parts that are no longer COTS available. There is a strong sense around DOE that the current numbers of available H12 will meet current mission needs. However, if a significant number of H12s start failing (see case-studies for examples), due to the unavailability of parts, additional engineering and administrative resources will be required to continue the H12 RMA profile.

References

[1]Sandia Corporation, Product Specification, H12 Universal Cartridge Carrier, Issue A, 23 August, 1952.

[2]Sandia National Laboratory Technical Publication (TP), H12-2 Adjustable Hand Truck, 2016.

[3]Sandia National Laboratory, TP H-61 Operation and Maintenance Instructions with Illustrated Parts Breakdown, Systems Special Handling Equipment.

[4]Sandia Corporation, various parts listings and drawings for the H12

[5]Sandia National Laboratories, Spare Parts List for the H12 Hand Adjustable Truck, Issue K, 16 August 2001.

[6]https://en.wikipedia.org/wiki/Restriction_of_Hazardous_Substances_Directive

Multiple interviews with Liaison Engineers and Technologists who have used the H12 in the past, November 2019 through January 2020.