MANTECH

Document # 40-01-771

TAYLOR MACHINE WORKS FORKLIFT,
MODEL TE-520N, SERIAL # S-W5-30862
FAILURE MODES AND EFFECTS ANALYSIS (FMEA)
AND CRITICAL ITEMS LIST (CIL)

Man-Tech Document No.

40-01-771

October 2007

PREPARED BY: 11/26/07
E. Hemminger, Project Engineer, Design & Analysis Function, ManTech — Date

APPROVED BY: 11/26/07
W. Thomas, Recertification Function, ManTech — Date

APPROVED BY; 11/26/07
S. Chan, RECERT Program Manager, Code 540, NASA/GSFC — Date

ManTech
International Corporation

Recertification Function
ManTech Aerospace Technology Applications Center
Goddard Space Flight Center
Greenbelt, Maryland 20771

TABLE OF CONTENTS

Page

LIST OF FIGURES ii
LIST OF ATTACHMENTS ii

1.0 SUMMARY OF FINDINGS 1
1.1 System Criticality 1
1.2 Mechanical Critical Items 1
1.3 Electrical Critical Items 1
1.4 Critical Flex Hoses 1
1.5 Critical Orifices 1
1.6 Critical Filters 1
1.7 Criticality Category 1R Items 1
1.8 Critical Control/Monitor Functions 1
1.9 Sneak Circuits Identified 2
1.10 Areas of Concern and Recommendations 2
1.11 Risk Assessment 2

2.0 SYSTEM SUMMARY 2
2.1 Specifications 2
2.2 Documentation List 3

3.0 DEFINITIONS AND GROUND RULES 5
3.1 Definitions 5
3.2 Ground Rules 7

4.0 CRITICALITY ASSESSMENT 9
4.1 Criticality Assessment Worksheets 9

5.0 FAILURE MODES AND EFFECTS ANALYSIS AND CIL 11
5.1 Mechanical FMEA Worksheets 11
5.2 Criticality Category 1R Worksheets 20

6.0 RATIONALE FOR ACCEPTABILITY 26
6.1 Design 26
6.2 Test and Inspection 26
6.3 Failure History 26
6.4 Operational Use 26

7.0 AREAS OF CONCERN AND RECOMMENDATIONS 27

8.0 RISK ASSESSMENT 28

LIST OF FIGURES

Figure	Title	Page
	MODEL TE-520N, TAYLOR MACHINE WORKS FORKLIFT	4

LIST OF ATTACHMENTS

A- NPR 8715.3 Section 1.6 "Risk Assessment and Risk Acceptance" 29

B- I.C. Inspection Report, September 27, 2007, "Periodic Inspection Report for TAYLOR MACHINE WORKS FORKLIFT Serial # S-W5-30862. 31

1.0 SUMMARY OF FINDINGS

1.1 System Criticality

The TAYLOR MACHINE WORKS Forklift, Model TE-520N, is assessed as critical. A catastrophic failure of this forklift could cause loss of life and/or critical flight hardware.

1.2 Mechanical Critical Items

There are no Critical items identified by the Failure Modes and Effects Analysis (FMEA).

1.3 Electrical Critical Items

There are no electrical functions associated with the mechanical forklift system.

1.4 Critical Flex Hoses

The FMEA identifies all flex hoses to be Critical Category 1R items.

1.5 Critical Orifices

There are no orifices identified to be a Critical Item.

1.6 Critical Filters

The sump tank filter has been identified to be a Category-3 Critical Item.

1.7 Criticality Category 1R Items

There are 15 Category 1R items identified during the analysis of the critical functions. The 1R items are summarized on the Criticality Category 1R Worksheets, Section 5.2. No single credible cause was identified to result in the loss of the redundant items.

1.8 Critical Control/Monitor Functions

There are no control/monitor functions associated with this system.

1.9 Sneak Circuits Identified

There is no Sneak Circuit Analysis performed for this forklift.

1.10 Areas of Concern and Recommendations

Several recommendations are presented to improve the level of protection and minimize or negate the uncertainties identified in the failure modes and effects analysis. In summary, the recommendations address:

- Inclusion of Category 1R Items in the inspection Procedure.
- Operator Certification per NASA-STD-8719.9 para 12.6.4 and refresher on annual basis for critical lift operators.

1.11 Risk Assessment

Risk assessment was performed in accordance with NASA-STD-8719.9. The TAYLOR MACHINE WORKS Forklift, Model TE-520N forklift is considered safe to operate. The overall risk assessment is arrived as follows:

Hazard Severity Level: Class II Critical
Likelihood: Improbable/Remote
Risk: RAC#5 Acceptable

Implementation of the recommendations would add control measures to improve equipment reliability and minimize failure risks.

2.0 SYSTEM SUMMARY

2.1 Specifications

TAYLOR MACHINE WORKS Forklift, Model TE-520N, Serial No. S-W5-30862, Capacity 52,000 lb @ 48", Fork Capacity 45,000 lb @ 48".

Refer to Parts and Maintenance Manual for additional Specifications.

2.2 Documentation List

The following documents were used in the performance of this analysis:

1. TAYLOR MACHINE WORKS Forklift, Model TE-520N, "SERVICE MANUAL."
2. ASME/ANSI B56.1-1988, "Safety Standard for Low Lift and High Lift Trucks";
3. NSTS 22206 Revision D, December 10, 1992, "Requirements for Preparation and Approval of Failure Modes and Effects Analysis (FMEA) and Critical Items List (CIL)."
4. NASA-STD-8719.9, latest Revision, "Standard for Lifting Devices and Equipment".
5. NPR 8715.3, latest Revision, "NASA General Safety Program Requirements".
6. GPR8719.1 "Certification and Re-certification of Lifting Devices and Equipment", latest revision.
7. Maintenance History File.

Figure 1

TAYLOR MACHINE WORKS MODEL TE-520N

3.0 DEFINITIONS AND GROUND RULES

3.1 Definitions

Definitions for the preparation and clarification of the Failure Modes and Effects Analysis are listed below.

Critical Item - A critical item is defined as any one of the following:

1. A Criticality Category 1, 1S or 2 Single Failure Point.

2. A redundant hardware item where the second failure results in loss of life or vehicle and the item are not capable of checkout during normal ground operations (i.e., a single fault tolerant item which fails Redundancy Screen A).

Critical (Reliability Impact) - If loss or improper performance of any one of the system's functions, without regard to redundancy, could result in loss of life or loss of critical flight hardware or damage to critical flight hardware, the total system is assessed as critical. If loss or improper performance of all of the system's functions could not result if any of the aforementioned effects, the system will be considered Non-critical.

Criticality Category

Criticality	Potential Effect or Failure
1	Single failure, which could result in loss of life or flight hardware.
1R	Two redundant hardware items, which if both failed, could result in loss of life or vehicle (or loss of a safety or hazard monitoring system).
1S	Single failure in a safety or hazard monitoring system that could cause the system to fail to detect, combat, or operate when needed during the existence

of a hazardous condition and could result in loss of life or flight hardware.

2 Single failure, which could result in loss (damage) of flight hardware.

3 All others.

Failure Modes and Effects Analysis (FMEA) - A bottoms up systematic, inductive, methodical analysis performed to identify and document all identifiable failure modes at a prescribed level and to specify the resultant effect of the modes of failure. It is usually performed to identify critical single failure point in hardware. The FMEA is subsidiary to a Hazard Analysis.

Hazard Analysis - A hazard analysis shall, as a minimum, determine potential sources of danger, identify most probable failure modes, and recommend resolutions for those conditions found in the hardware-facility-environment-human relationship that could cause loss of life, personal injury, or loss of lifting device, facility, or load.

Redundancy Screens - Redundancy screens must be addressed for all Criticality Category 1R items. Determination of "Pass," "Fail," or "N/A" (not applicable) must be documented in the summary list of 1R items. The GSE redundancy screens are defined as follows:

(a) Screen A - The redundant item is capable of being checked and verified during normal ground operations.

(b) Screen B - Loss of the redundant item is readily detectable by the operator. (This screen is not applicable to standby redundancy.)

(c) Screen C - Loss of all redundant items cannot result from a single credible cause, such as contamination. It is assumed here that loss of the redundant item(s) is not detectable by scheduled test, inspections, and neither

maintenance nor operator's daily check prior to first use daily.

Time to Effect - The time for the failure effect to occur in this analysis is specified as follows:

ST	Short Term - Months
LT	Long Term - Years

3.2 Ground Rules

This analysis is developed in accordance with NSTS 22206, Revision D, "Requirements for Preparation and Approval of Failure Modes and Effects Analysis (FMEA) and Critical Items List (CIL)."

The following ground rules and assumptions are established for this analysis:

a. For this analysis, it is assumed that lifting device operators are trained and certified to operate this lift system.

b. This analysis assumes worst-case scenario when analyzing Ground Support Equipment (GSE).

c. Passive components are not analyzed in this FMEA, but should be considered in a separate Hazard Analysis, which is not part of this effort.

d. Failures of redundant items which meet the criteria described in 3.1. (A), (b) and (c) above are classified as Criticality Category 1R. Requirements for periodic test, inspection or functional validation of these items are invoked through the appropriate operation and maintenance requirements documentation. Single failure within the system controls which could cause loss of a 1R item is not be identified as 1R but is listed as a cause of the failure of the 1R items which it controls. Such system controls are included in the periodic test, inspection or functional validation requirement invoked on the 1R item.

e. Redundancy screens are addressed for all Criticality Category 1R items. Determination of

"Pass," "Fail," or "N/A" (not applicable) are documented in the summary list of 1R items.

f. Failures due to human error in system setup (e.g., manual valves erroneously in the wrong position) are not considered in this FMEA.

g. This analysis assumes that all components, lubricants, and hydraulic fluids and fluid levels are as recommended by the original equipment manufacturer.

h. Fluids

1. Internal leakage is included in the assessment of the "fail open" failure mode.

2. External leakage is considered where leaks are detrimental to system operation or personnel safety.

3. All components located in the system downstream of the final filter are assessed for a possible source of contamination (e.g., transducers, temperature probes, component soft goods).

4. Filters, orifices and flex hoses are analyzed in the FMEA as part of the respective system.

i. The following classification of failure modes, as a minimum, is included in the CIL:

1. All Functional Criticality Category 1 and 2 items.

2. All Functional Criticality 1R items where (1) first failure could result in loss of life and/or flight hardware or (2) next failure of any redundant item could cause loss of operator/lifting device.

3. All Functional Criticality Category 1R items that fail one or more redundancy screens.

j. This FMEA only analyzes the failure modes and effects of the forklift system and components. Other safety issues involving operating personnel qualifications, inherent hazards of a specific critical lift, and provisions for facility protection and emergency recovery during lift operations, etc., will be addressed in the specific Critical Lift Procedure. The Procedure is usually initiated and funded by the Project, if warranted, and developed by integration support personnel.

4.0 CRITICALITY ASSESSMENT

4.1 Criticality Assessment Worksheets

This system input and output functions are assessed on the following Criticality Assessment Summary sheet.

The Criticality Assessment Worksheets are completed to determine whether the GSE is Critical or Non-critical in terms of reliability impact. If loss or improper performance of any one of the system's functions, without regard to redundancy, could result in loss of life or loss of critical flight hardware or damage to critical flight hardware, the total system is assessed as Critical. If loss or improper performance of all of the system's functions could not result in any of the aforementioned effects, the system is considered Non-critical.

SYSTEM CRITICALITY ASSESSMENT SUMMARY WORKSHEET				
System TAYLOR Forklift Model#TE-520N	Drawing See Figure 1, page 4	Location-Outside Building 7,10,15 and 29	Prepared by E. Hemminger 10/17/07	
INPUT/OUTPUT	FUNCTION	TIME PERIOD	EFFECT OF LOSS/FAILURE	CRIT. CAT.
Lift System	Provides ability to raise/lower loads up to 45K lbs.	Pick up, transport, and deposit of the load.	Failure of the overall lift system could cause the load to drop. Could cause loss of life and/or loss of critical flight hardware.	1
Tilt System	Provides ability to tilt the uprights/forks.	Pick up, transport, and deposit of the load.	Failure of the tilt system could cause delay for repairs.	3
Hydraulic	Provides hydraulic pressure to operate lift, tilt, side shift and steering functions.	Pick up, transport, and deposit of the load.	Failure of the hydraulic system could cause loss of critical flight hardware.	1
Diesel Motor	Vehicle power plant provides for hydraulic pressure to operate lift, tilt, side shift, steering, and vehicle movement functions.	Pick up, transport, and deposit of the load.	Failure of the Diesel system could result in the inoperable status of the forklift and result in delay for repairs.	3

5.0 FAILURE MODES AND EFFECTS ANALYSIS AND CIL

5.1 Mechanical FMEA Worksheets

The mechanical components of the Taylor Forklift, Model TE-520N are identified from documents referenced in the Documentation List and are analyzed on the following worksheets.

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET

SYSTEM: TAYLOR Forklift Model No. TE-520N DATE: October 17, 2007
SUBSYSTEM: Lift PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Forklift Model No. TE-520N, "SERVICE MANUAL."

NO.	PART NAME	FAILURE CAUSE	FAILURE EFFECT ON SYSTEM PERFORMANCE	FAILURE EFFECT ON CRITICAL HARDWARE AND/OR PERSONNEL SAFETY	TIME TO EFFECT	CRIT CAT
1	Hoist Cylinder	Impeded movement of hoist cylinder due to debris, scratches on the cylinder rod surface causing leaks	Intermittent fork hang-up and resultant upright unloading.	Uncontrolled fork movement/dropping the load. Requires multiple failures.	LT	1R
2	Hoist cylinder rod	Surface debris or scratches	Intermittent fork hang-up and resultant upright unloading.	Uncontrolled fork movement/dropping the load. Requires multiple failures.	LT	1R
3	Cylinder rod seals	Surface debris	Hydraulic oil leakage. Fork hang-up and resultant upright unloading.	Uncontrolled fork movement/dropping the load. Requires multiple failures.	LT	1R
4	Roller, uprights	Clearance changed as a result of stress released in the welded areas.	Fork hang-up and resultant upright unloading.	Uncontrolled fork movement/dropping the load. Requires multiple failures.	LT	1R

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET

SYSTEM: TAYLOR Forklift Model No. TE-520N DATE: October 17, 2007
SUBSYSTEM: Lift PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Forklift Model No. TE-520N, "SERVICE MANUAL."

NO.	PART NAME	FAILURE CAUSE	FAILURE EFFECT ON SYSTEM PERFORMANCE	FAILURE EFFECT ON CRITICAL HARDWARE AND/OR PERSONNEL SAFETY	TIME TO EFFECT	CRIT CAT
5	Roller, uprights	Not adjusted to the rails	Intermittent fork hang-up and resultant upright unloading.	Uncontrolled fork movement/dropping the load.	ST	1R
6	Upper/lower carriage rollers, outer thrust rollers	Broken or misadjusted	Intermittent fork hang-up and resultant upright unloading.	Uncontrolled fork movement/dropping the load.	ST	1R
7	Roller shaft	Misalignment	Premature wear.	Shortened life. Delay for repairs.	LT	3
8	Piston head	Surface debris, paint, or scratches	Hydraulic oil leakage. Fork hang-up and resultant unloading.	Uncontrolled fork movement/dropping the load. Requires multiple failures.	LT	1R
9	Inner rails	Distance between inner rails narrow	Intermittent fork hang-up and resultant upright unloading.	Uncontrolled fork movement/dropping the load.	LT	1R

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET

SYSTEM: TAYLOR Forklift Model No. TE-520N DATE: October 17, 2007
SUBSYSTEM: Lift PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Forklift Model No. TE-520N, "SERVICE MANUAL."

NO.	PART NAME	FAILURE CAUSE	FAILURE EFFECT ON SYSTEM PERFORMANCE	FAILURE EFFECT ON CRITICAL HARDWARE AND/OR PERSONNEL SAFETY	TIME TO EFFECT	CRIT CAT
10	Upright and tilt cylinder	Uneven test load distribution during test	Intermittent fork hang-up and resultant upright unloading.	Requires multiple failures.	ST	1R
11	Uprights	Twisted	Intermittent fork hang-up and resultant upright unloading.	Requires multiple failures.	LT	1R
12	Stop blocks	Misalignment	Unequal stop block loading.	Uncontrolled fork movement. Requires multiple failures.	LT	1R
13	Flex hoses	Leakage/rupture	Upright unloading.	Uncontrolled fork movement/dropping the load. Requires multiple failures.	LT	1R
14	Flex hose retainer	Overloading	Unrestrained hose. Hydraulic oil leakage. Upright unloading.	Uncontrolled fork movement/dropping the load. Requires multiple failures.	ST	3

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET

SYSTEM: TAYLOR Forklift Model No. TE-520N DATE: October 17, 2007
SUBSYSTEM: Lift PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Forklift Model No. TE-520N, "SERVICE MANUAL."

NO.	PART NAME	FAILURE CAUSE	FAILURE EFFECT ON SYSTEM PERFORMANCE	FAILURE EFFECT ON CRITICAL HARDWARE AND/OR PERSONNEL SAFETY	TIME TO EFFECT	CRIT CAT
15	Load back rest	Damage due to load	Premature replacement.	Shortened life. Delay for repairs.	LT	3
16	Cylinder base/bolts	Misalignment	Chain wear.	Delay for repair.	LT	3
17	Lift chains	Adjusting with upright forward of vertical	Intermittent fork hang-up and resultant unloading.	Uncontrolled fork movement/dropping the load. Requires multiple failures.	ST	1R
18	Lift chain	Uneven wear/tension	Intermittent fork hang-up and resultant unloading.	Uncontrolled fork movement/dropping the load. Requires multiple failures.	LT	1R
19	Chain anchor	Wear, damage, misalignment	Chain twisting or poor alignment.	Unbalanced load. Delay for repairs.	LT	3
20	Chain sheaves	Worn flanges	Chain side wear.	Delay for repairs.	LT	3

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET

SYSTEM: TAYLOR Forklift Model No. TE-520N DATE: October 17, 2007
SUBSYSTEM: Lift PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Forklift Model No. TE-520N, "SERVICE MANUAL."

NO.	PART NAME	FAILURE CAUSE	FAILURE EFFECT ON SYSTEM PERFORMANCE	FAILURE EFFECT ON CRITICAL HARDWARE AND/OR PERSONNEL SAFETY	TIME TO EFFECT	CRIT CAT
21	Chain retainers	Overloading	Chain unloading.	Uncontrolled fork movement/dropping the load. Requires multiple failures.	LT	1R
22	Flow control valve	Restricted flow due to debris	System inoperative.	Delay for repairs.	ST	3

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET

SYSTEM: TAYLOR Fork Lift Model No. TE-520N DATE: October 18, 2007
SUBSYSTEM: Tilt PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Fork Lift Model No. TE-520N, "SERVICE MANUAL"

NO.	PART NAME	FAILURE CAUSE	FAILURE EFFECT ON SYSTEM PERFORMANCE	FAILURE EFFECT ON CRITICAL HARDWARE AND/OR PERSONNEL SAFETY	TIME TO EFFECT	CRIT CAT
1	Tilt cylinder	Inadequate maintenance of cylinder and hydraulic valves	Stability determined by load weight/ distribution subsequent to failure.	Delay for repairs. Requires multiple failures.	LT	3
2	Tilt cylinder rod	Unequal adjustment	Stability determined by load weight/ distribution subsequent to failure.	Delay for repairs. Requires multiple failures.	ST	3
3	Flex hose	Leakage, rupture	Upright unloading.	Uncontrolled fork movement/dropping the load.	ST	1R

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET

SYSTEM: TAYLOR Fork Lift Model No. TE-520N DATE: October 18, 2007
SUBSYSTEM: Diesel Engine PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Fork Lift Model No. TE-520N, "SERVICE MANUAL"

NO.	PART NAME	FAILURE CAUSE	FAILURE EFFECT ON SYSTEM PERFORMANCE	FAILURE EFFECT ON CRITICAL HARDWARE AND/OR PERSONNEL SAFETY	TIME TO EFFECT	CRIT CAT
1	Engine & Lube Systems	Inadequate maintenance	Loss of pressure source to drive Hydraulic system.	Delay for repairs. Requires multiple failures.	LT	3
2	Fuel System	Inadequate maintenance, leakage or damage to lines/tank.	Loss of pressure source to drive Hydraulic system.	Delay for repairs. Requires multiple failures.	ST	3
3	Battery Electrical	Inadequate maintenance.	Loss of pressure source to drive Hydraulic system.	Delay for repairs. Requires multiple failures.	ST	3

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET

SYSTEM: TAYLOR Fork Lift Model No. TE-520N DATE: October 18, 2007
SUBSYSTEM: Hydraulic PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Fork Lift Model No. TE-520N "SERVICE MANUAL"

NO.	PART NAME	FAILURE CAUSE	FAILURE EFFECT ON SYSTEM PERFORMANCE	FAILURE EFFECT ON CRITICAL HARDWARE AND/OR PERSONNEL SAFETY	TIME TO EFFECT	CRIT CAT
1	Hydraulic relief valve	External leakage	Capacity limited.	Delay in operation.	ST	3
		Fail to relieve	System pressure exceeded.	System leaks. Delay in operation.	ST	3
		Fail to close	System inoperative.	Delay in operation.	ST	3
2	Sump tank filter, 10 micron, return line	Clogged sump tank filter element	Bypasses fluid flow. Unable to lower forks. Load transfer required.	Delay for repairs.	LT	3
3	Hydraulic pump	External leakage	Capacity limited.	Delay in operation.	ST	3
		Fail to operate	System inoperative.	Delay in operation.	ST	3

5.2 Criticality Category 1R Worksheets

There are sixteen (16) Category 1R items identified during the analysis of the critical output functions. The 1R items are summarized on the following Criticality Category 1R Worksheets.

CRITICALITY CATEGORY 1R WORKSHEETS

SYSTEM: TAYLOR Fork Lift Model No. TE-520N DATE: October 18, 2007
SUBSYSTEM: Lift PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Fork Lift Model No. TE-520N "Service Manual" & NSTS 22206, Revision D

NO.	PART NAME	FAILURE CAUSE(S)	FAILURE EFFECT	REDUNDANCY SCREENS		TEST AND INSPECTION REQUIREMENT(S)
				PASS	FAIL	
1	Lift cylinder	Impeded movement due to surface debris	Up-mode: Unable to operate. Down-mode: Uncontrolled lowering.	A B C		• Operator inspection prior to first use daily. • Periodic inspection annually.
2	Lift cylinder rod	Surface debris, scratches	Hydraulic leakage. Intermittent fork hang-up/upright unloading. Uncontrolled fork movement/dropping the load.	A B C		• Operator inspection prior to first use daily. • Periodic inspection annually.
3	Cylinder rod seals	Surface debris	Hydraulic leakage. Intermittent fork hang-up/ unloading. Uncontrolled fork movement/could result in dropping the load.	A B C		• Operator inspection prior to first use. • Periodic inspection annually.
4	Roller uprights	Clearance change	Intermittent fork hang-up and resultant unloading.	A B C		• Operator inspection prior to first use. • Annual inspection

CRITICALITY CATEGORY 1R WORKSHEETS

SYSTEM: TAYLOR Fork Lift Model No. TE-520N DATE: October 18, 2007
SUBSYSTEM: Lift PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Fork Lift Model No. TE-520N "Service Manual" & NSTS 22206, Revision D

NO.	PART NAME	FAILURE CAUSE(S)	FAILURE EFFECT	REDUNDANCY SCREENS		TEST AND INSPECTION REQUIREMENT(S)
				PASS	FAIL	
5	Roller uprights	Not adjusted	Intermittent fork hang-up and resultant unloading.	A B C		• Operator inspection prior to first use. •Periodic inspection annually.
6	Upper or lower carriage rollers, outer thrust rollers	Broken or misadjusted	Intermittent fork hang-up and resultant unloading.	A B C		• Operator inspection prior to first use daily. • Periodic inspection annually.
8	Piston head	Surface debris, scratches	Hydraulic oil leakage. Intermittent fork hang-up/upright unloading. Uncontrolled fork movement/could result in dropping the load.	A B C		• Operator inspection prior to first use daily. • Periodic inspection annually.
9	Inner rails	Distance between inner rails narrow	Intermittent fork hang-up and resultant unloading.	A B C		• Operator inspection prior to first use daily.

CRITICALITY CATEGORY 1R WORKSHEETS

SYSTEM: TAYLOR Fork Lift Model No. TE-520N DATE: October 18, 2007
SUBSYSTEM: Lift PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Fork Lift Model No. TE-520N "Service Manual" & NSTS 22206, Revision D

NO.	PART NAME	FAILURE CAUSE(S)	FAILURE EFFECT	REDUNDANCY SCREENS		TEST AND INSPECTION REQUIREMENT(S)
				PASS	FAIL	
						• Periodic inspection annually.
10	Upright and tilt cylinder	Uneven test load distribution during setup or maintenance/ repair lead to improper adjustment	Unbalanced lift could drop load.	A B C		• Operator inspection prior to first use daily. • Periodic inspection annually.
11	Uprights	Twisted	Intermittent fork hang-up and resultant unloading.	A B C		• Operator inspection prior to first use daily. • Periodic inspection annually.
12	Stop blocks	Misalignment	Unequal stop block loading.	A B C		• Operator inspection prior to first use daily. • Periodic inspection annually.

CRITICALITY CATEGORY 1R WORKSHEETS

SYSTEM: TAYLOR Fork Lift Model No. TE-520N DATE: October 18, 2007
SUBSYSTEM: Lift PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Fork Lift Model No. TE-520N "Service Manual" & NSTS 22206, Revision D

NO.	PART NAME	FAILURE CAUSE(S)	FAILURE EFFECT	REDUNDANCY SCREENS		TEST AND INSPECTION REQUIREMENT(S)
				PASS	FAIL	
13	Flex hoses	Leakage, rupture	Hydraulic oil leakage. Intermittent fork hang-up/upright unloading. Uncontrolled fork movement/could result in dropping the load.	A B C		• Operator inspection prior to first use daily. • Periodic inspection annually.
14	Flex hose retainer	Overloading	Unrestrained hose. Hydraulic oil leak. Upright unloading.	A B C		• Operator inspection prior to first use daily. • Periodic inspection annually.
15	Lift chains	Adjusted with upright forward of vertical	Intermittent fork hang-up/upright unloading. Uncontrolled fork movement/could result in dropping the load.	A B C		• Operator inspection prior to first use daily. • Periodic inspection annually.
16	Lift chains wear	Uneven wear, tension	Intermittent fork hang-up/upright unloading. Uncontrolled fork	A B C		• Operator inspection prior to first use daily.

CRITICALITY CATEGORY 1R WORKSHEETS

SYSTEM: TAYLOR Fork Lift Model No. TE-520N DATE: October 18, 2007
SUBSYSTEM: Lift PREPARED BY: E. Hemminger
REFERENCE: TAYLOR Fork Lift Model No. TE-520N "Service Manual" & NSTS 22206, Revision D

NO.	PART NAME	FAILURE CAUSE(S)	FAILURE EFFECT	REDUNDANCY SCREENS		TEST AND INSPECTION REQUIREMENT(S)
				PASS	FAIL	
			movement/could result in dropping the load. Requires multiple failures.			• Periodic inspection annually.
17	Chain retainers	Overloading	Intermittent fork hang-up/upright unloading. Uncontrolled fork movement/could result in dropping the load.	A B C		• Operator inspection prior to first use daily. • Periodic inspection annually.
18	Flex hose - tilt	Leakage, rupture	Hydraulic oil leakage. Intermittent fork hang-up/upright unloading. Uncontrolled fork movement/could result in dropping the load.	A B C		• Operator inspection prior to first use daily. • Periodic inspection annually.

6.0 RATIONALE FOR ACCEPTABILITY

No mechanical critical items were identified by the FMEA. Justification for retaining any of the items analyzed is, therefore, not required in accordance with the instructions provided in NSTS 22206, Revision D. Note that the Criticality 1R items are acceptable in that each item is capable of checkout during normal ground operations. Documentation of the following data elements: Design, Test and Inspection, Failure History and Operational Use are provided to categorize the analysis for risk assessment.

6.1 Design

Forklift design is in accordance with ASME/ANSI B56.1-1988, "Safety Standard for Low Lift and High Lift Trucks," to minimize the probability of occurrence of the critical failure modes and causes.

6.2 Test and Inspection

- Operator inspection prior to use.
- Periodic inspection annually per the attached Inspection Report dated 9/27/07.

6.3 Failure History

No Failures have been experienced.

6.4 Operational Use

6.4.1 Failures due to human error are not considered in the performance of a failure modes and effects analysis.
The inclusion here of the following paragraph reproduced from ASME/ANSI B56.1-1988 is considered most appropriate:

> The use of powered industrial trucks is subject to certain hazards that cannot be completely eliminated by mechanical means, but the risks can be minimized by the exercise of intelligence, care, and common sense. It is therefore

essential to have competent and careful operators, physically and mentally fit, thoroughly trained in the safe operation of the equipment and the handling of the loads. Serious hazards are overloading, instability of the load, obstruction to the free passage of the load, poor maintenance, and using equipment for a purpose for which it was not intended or designed.

7.0 AREAS OF CONCERN AND RECOMMENDATIONS

The following recommendations are provided to further improve operational safety and reliability of this equipment for flight project support.

7.1 It is recommended that:

7.1.1 Critical forklift inspections are performed by qualified, designated personnel;

7.1.2 All Criticality Category 1R items identified in this analysis should be included in the Periodic inspection.

7.1.3 Periodic inspections should be performed according to approved RECERT technical operating procedures.

7.2 No critical items were identified as a result of this analysis. Numerous redundant hardware items were identified and all are capable of checkout during normal operations. The time for failure to occur for 13 of the 31 components analyzed herein was determined to be "Short Term," i.e., months. Implementation of the aforementioned scheduled test and inspections are recommended to mitigate these respective failure modes. Certain hazards cannot be eliminated by mechanical means.

Operators thoroughly trained in the safe operation of the equipment can minimize the risk of human error. The present forklift operator refresher course interval is three years. The Goddard Space Flight Center RECERT

Program requires that crane operators attend annual refresher training per OSHA guidelines.

8.0 RISK ASSESSMENT

Risk assessment was performed in accordance with NPR 8715.3.

Hazard Severity Level: Class II Critical
Likelihood: Improbable/Remote
Risk: RAC#5 Acceptable (Uncertainties Controlled/Managed)

ATTACHMENT- A

The following information was excerpted from the former NPR8715.3, "NASA Safety Manual:"

NPR 8715.3 Section 3.6 "Hazard Assessment"

The hazard assessment process is a principal factor in the understanding and management of technical risk. Hazards are identified and resultant risks are assessed by considering probability of occurrence and severity of consequence. Risk may be assessed qualitatively or quantitatively. System safety is an integral part of the overall program risk management decision process. A sample format to document the risk process is provided in Appendix E.

3.6.1 Risk Assessment Code (RAC). The RAC is a numerical expression of comparative risk determined by an evaluation of both the potential severity of a condition and the probability of its occurrence. RAC`s are assigned a number from 1 to 7 in a risk matrix (see figure 3.2.). The RAC number will serve as a means to prioritize corrective actions, e.g., RAC 1 is unacceptable and mitigation actions must be taken immediately or operations terminated, RAC 2`s must be addressed before RAC 3`s, etc. (Requirement 25246). Differences between higher number RAC`s (beyond 4) probably cannot be discerned due to low risk levels. The cognizant safety and program officials may approve variations to the matrix.

3.6.1.1 Severity is an assessment of the worst potential consequence, defined by degree of injury or property damage, which could occur. The severity classifications are defined as follows:

Class I - Catastrophic - A condition that may cause death or permanently disabling injury, facility destruction on the ground, or loss of crew, major systems, or vehicle during the mission.

Class II - Critical - A condition that may cause severe injury or occupational illness, or major property damage to facilities, systems, equipment, or flight hardware.

Class III - Moderate - A condition that may cause minor injury or occupational illness, or minor property damage to facilities, systems, equipment, or flight hardware.

Class IV - Negligible - A condition that could cause the need for minor first aid treatment though would not adversely affect personal safety or health. A condition that subjects facilities, equipment, or flight hardware to more than normal wear and tear.

3.6.1.2 Probability is the likelihood that an identified hazard will result in a mishap, based on an assessment of such factors as location, exposure in terms of cycles or hours of operation, and affected population. The following is an example of Probability Estimation:

A - Likely to occur immediately. ($X > 10^{-1}$)

B - Probably will occur in time. ($10^{-1} \geq X > 10^{-2}$)

C - May occur in time. ($10^{-2} \geq X > 10^{-3}$)

D - Unlikely to occur. ($10^{-3} \geq X > 10^{-6}$)

E - Improbable to occur. ($10^{-6} \geq X$)
(derived from Mil Std 882-System Safety Program Requirements)

	Probability Estimate				
Severity Class	A	B	C	D	E
I	1	1	2	3	4
II	1	2	3	4	5
III	2	3	4	5	6
IV	3	4	5	6	7

Figure 3.2 Risk Assessment Code Matrix