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CLARK FORKLIFT, MODEL C-500Y155D
FAILURE MODES AND EFFECTS ANALYSIS (FMEA)
AND CRITICAL ITEMS LIST (CIL)

NSI Document No.

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1 NSI Document #40-06-341, Periodic Inspection Report for Forklift, S/N Y015-0143-7014.

2 NSI Memo 4002-6.4-001, "Certification of 15,000-lb. Capacity Forklift, Code 750," December 1, 1994.

3 Engineering Services Division Incident Report, September 6, 1994.

4, 5 Potomac Industrial Trucks, Inc. correspondence dated a) September 14, 1994, and November 17, 1994.

6 Analysis of Oil and Filter from Fork Lift Failure, 313/Materials Branch

1.0 SUMMARY OF FINDINGS

1.1 System Criticality

The Clark forklift, Model C-500Y155D, is assessed as critical. A catastrophic failure of this forklift could cause loss of life and/or 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. The vehicle is powered with a PERKINS DIESEL, Model 4.236. (The engine drives the hydraulic pump. Engine failure would result in loss of lift capability. Controlled lowering would, however, be maintained.)

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

There are no filters identified to be a Critical Item.

1.7 Criticality Category 1R Items

There are 16 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:

- Inspection Procedures
  Inclusion of Category 1R Items
- Operator Certification and Annual Refresher Interval, and
- Restriction of Fork Lowering Rate.

1.11 Risk Assessment

Risk assessment was performed in accordance with RECERT-42-011. The Clark forklift is considered safe to operate. The overall risk assessment is arrived as follows:

Hazard Severity Level: Catastrophic
Likelihood: Remote
Risk: Acceptable (Uncertainties Controlled/Managed)

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

2.0 SYSTEM SUMMARY

2.1 Specifications

See Section 2, pages 5 and 6.

2.2 Documentation List

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

1. Clark; Planned Maintenance and Adjustment Procedures; PMA403 3rd Rev.; C500 Y110 135 & 155, (Perkins Diesel);

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. NSI Memo 4002-6.4-001, "Certification of 15,000-lb. Capacity Forklift, Code 750," December 1, 1994.

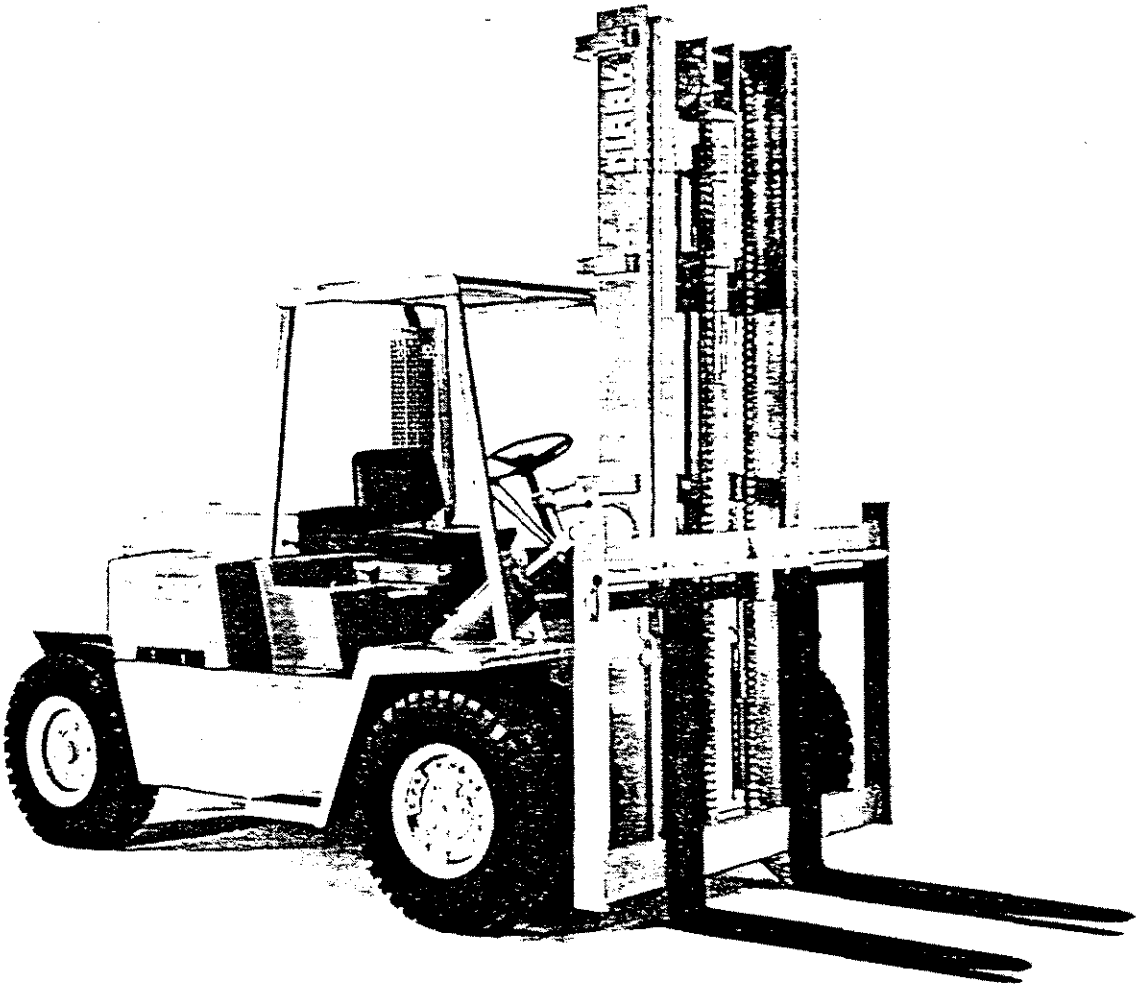
5. Engineering Services Division Incident Report, September 6, 1994.

6. Analysis of Oil and Filter from Fork Lift Failure, 313/Materials Branch.

7. Potomac Industrial Trucks, Inc., correspondence dated a) September 14, 1994, and b) November 17, 1994.

8. RECERT-42-011, "A Standard Operating Procedure for Preparation of a Request for a Waiver/Deviation to the Mandatory Requirements of NSS/GO-1740.9B," "NASA Safety Standard for Lifting Devices and Equipment."

9. NHB 1700.1(V1-B), "NASA Safety Policy and Requirements Document," June 1993.



C500Y 110-135-155
PERKINS DIESEL

NOTE: Picture above depicts the standard model. Modification of the vehicle fork system to provide side shifting capability was completed by Potomac Industrial Trucks, Inc., the local equipment dealer.

SPECIFICATIONS:

NOTE: Clark products and specifications are subject to improvements and changes without notice.

MACHINE: C500Y 110, 135, 155

ENGINE: PERKINS DIESEL

Model: 4.236, 4 Cylinders
Governed No-Load r/min: 2600
Idle r/min: 650-700
Firing Order: 1-3-4-2
Crankcase Capacity: [7,5 L] or 2 gal. (with filter)
Thermostat: open @ 168 deg., full open @ 197 deg. F.
Fan Belt Deflection: [9,5 mm] .375"
Fan Belt Tension: New, [63,4 Kg] or 140 lbs.
In operation for 10 min. [49,9 Kg] or 110 lbs.
Fuel Tank Capacity: [114 L] or 30.0 gal.
Cooling System Capacity: [14,2 L] or 15 qts.
Radiator Press. Cap.: [48 kPa] or 7 PSI

ELECTRICAL SYSTEM:

Alternator

Rated Hot Output @ [26,7 ° C] or 80° F.
Ambient - 37 Amps.
Cold Output When Alternator Temp. is [26,7° C] or 80° F.:
22 Amps @ 2000 r/min.
33 Amps @ 5000 r/min.

TRANSMISSION: HYDRATORK

Cap. (w/filter): [17,0 L] or 18 qts.
Cap. (w/o filter): [16,1 L] or 17 qts.
Fluid Type: DEXRON

Starter (Bench Test)

9 VOLTS
60 amps min. to 85 amps max. @ 6800 rpm to 10300 rpm
Rotation: Clockwise

Battery

Ground: Negative
Volts: 12
AMP Hour: 72
Capacity @ 20 HR. RATE, 72 AMP. HRS.

BRAKE SYSTEM

Pedal Free Travel: [3-4,6 mm] or .12-.18"

STEER AXLE:

Axle Alignment

Toe In ..... 0 deg.
Camber ..... 5 deg.
Caster ..... 0 deg.

Right Hand Turn Angle

Left Wheel: .. 48 deg., 20 min.
Right Wheel: .. 72 deg.

Left Hand Turn Angle

Right Wheel: .. 48 deg., 20 min.
Left Wheel: .. 72 deg.

HYDRAULIC SYSTEM:

Main Pump (Priority Sys. for Steer)
Type: Gear
Capacity: [60,6 L/min] or 16 GPM @ 2400 r/min & [17237 kPa] or 2500 PSI
Priority Sys.: Controlled [24,6 L/min] or 6.5 GPM with relief valve setting @ [15513 kPa] or 2250 PSI
Sump Tank Filter: 10 micron
Hyd. Valve Press. Relief: [17237 kPa] or 2500 PSI

Hydraulic Tank

Standard System Requires [75,7 L] or 20 Gal.

TORQUE SPECS:

Counterweight Bolt: [650,7-786,3 N·m] or 480-580 lb. ft. (DRY)

C500:

Steer Wheel Lug Nuts: [610-678 N·m] or 450-500 lb. ft.

Drive Wheel Lug Nuts: [142-163 N·m] or 105-120 lb. ft. See GROUP 22 for tightening sequences.

STEER AND DRIVE TIRES:

Tire Pressure: [724 kPa] or 105 PSI

COUNTERWEIGHT:

Weight:	C500Y110	[2449 Kg] or 5400 lbs.
	C500Y135	[3123 Kg] or 6885 lbs.
	C500Y155	[3613 Kg] or 7965 lbs.

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 is 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 redundance, could result in loss of life or loss of flight hardware or damage to 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 Noncritical.

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 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 performed to determine whether the GSE is Critical or Noncritical 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 flight hardware or damage to 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 Noncritical.

SYSTEM CRITICALITY ASSESSMENT SUMMARY WORKSHEET				
System Clark Forklift Model C-500Y155D	Drawing See Figures 1 and 2	Location Building 7 Truck Lock	Prepared by M. Crompton, 10/19/94	
INPUT/OUTPUT	FUNCTION	TIME PERIOD	EFFECT OF LOSS/FAILURE	CRIT. CAT.
Lift System	Provides ability to raise/lower loads up to 14.4K 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 flight hardware. Multiple failure is required.	Crit.
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. Multiple failure is required. Delay in operations.	3
Side shift system	Provides the ability to pick up and deposit a load laterally.	Pick up, transport, and deposit of the load.	Failure of the side shift system could cause delay for repairs. Multiple failure is required. Delay in operations.	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.	Crit.

5.0 FAILURE MODES AND EFFECTS ANALYSIS AND CIL

5.1 Mechanical FMEA Worksheets

The mechanical components of the Clark forklift, Model C-500Y155D are identified from documents referenced in the Documentation List and are analyzed on the following worksheets.

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET

SYSTEM: Clark Fork Lift Model No. C500Y165D
SUBSYSTEM: Lift
PROGRAM: Side Shift Hose Damage
REFERENCE: Planned Maintenance and Adjustment Procedures: Clark, January 1981 Revision

DATE: November 29, 1994
PREPARED BY: M. Crompton
R. Gayo

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	Lift cylinder	Impeded movement of lift 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 failure.	LT	1R
2	Lift cylinder rod	Surface debris or scratches	Intermittent fork hang-up and resultant upright unloading.	Uncontrolled fork movement/dropping the load. Requires multiple failure.	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 failure.	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 failure.	LT	1R
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 or 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

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET

SYSTEM: Clark Fork Lift Model No. C500Y165D
SUBSYSTEM: Lift
PROGRAM: Side Shift Hose Damage
REFERENCE: Planned Maintenance and Adjustment Procedures: Clark, January 1981 Revision

DATE: November 29, 1994
PREPARED BY: M. Crompton
R. Gayo

NO.	PART NAME	FAILURE CAUSE	FAILURE EFFECT ON SYSTEM PERFORMANCE	FAILURE EFFECT ON CRITICAL HARDWARE AND/OR PERSONNEL SAFETY	TIME TO EFFECT	CRIT CAT
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 failure.	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
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 failure.	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
15	Load back rest	Damage due to load	Premature replacement.	Shortened life. Delay for repairs.	LT	3
16	Cylinder base/ anchor bolts	Misalignment	Chain wear.	Delay for repair.	LT	3

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET

SYSTEM: Clark Fork Lift Model No. C500Y165D
SUBSYSTEM: Lift
PROGRAM: Side Shift Hose Damage
REFERENCE: Planned Maintenance and Adjustment Procedures: Clark, January 1981 Revision

DATE: November 29, 1994
PREPARED BY: M. Crompton
R. Gayo

NO.	PART NAME	FAILURE CAUSE	FAILURE EFFECT ON SYSTEM PERFORMANCE	FAILURE EFFECT ON CRITICAL HARDWARE AND/OR PERSONNEL SAFETY	TIME TO EFFECT	CRIT CAT
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
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: Clark Fork Lift Model No. C500Y165D
SUBSYSTEM: Tilt
PROGRAM: Side Shift Hose Damage
REFERENCE: Planned Maintenance and Adjustment Procedures: Clark, January 1981 Revision

DATE: November 29, 1994
PREPARED BY: M. Crompton
R. Gayo

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: Clark Fork Lift Model No. C500Y165D
SUBSYSTEM: Hydraulic
PROGRAM: Side Shift Hose Damage
REFERENCE: Planned Maintenance and Adjustment Procedures: Clark, January 1981 Revision

DATE: November 29, 1994
PREPARED BY: M. Crompton
R. Gayo

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: Clark Forklift Model No. C500Y165D
SUBSYSTEM: Lift
PROGRAM: Side Shift Hose Damage
REFERENCE: NSTS 22206, Revision D

DATE: November 30, 1994
PREPARED BY: M. Crompton
R. Gayo

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: Uncommanded lowering.	A B C		• Operator inspection prior to first use daily. • Frequent inspection monthly. • Periodic inspection annually.
2	Lift cylinder rod	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. • Frequent inspection monthly. • Periodic inspection annually.
3	Cylinder rod seals	Surface debris	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. • Frequent inspection monthly. • Periodic inspection annually.
4	Roller uprights	Clearance change	Intermittent fork hang-up and resultant unloading.	A B C		• Operator inspection prior to first use daily. • Frequent inspection monthly. • Periodic inspection annually.

CRITICALITY CATEGORY 1R WORKSHEETS

SYSTEM: Clark Forklift Model No. C500Y165D
SUBSYSTEM: Lift
PROGRAM: Side Shift Hose Damage
REFERENCE: NSTS 22206, Revision D

DATE: November 30, 1994
PREPARED BY: M. Crompton
R. Gayo

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 daily. • Frequent inspection monthly. • 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. • Frequent inspection monthly. • 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. • Frequent inspection monthly. • 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. • Frequent inspection monthly. • Periodic inspection annually.

CRITICALITY CATEGORY 1R WORKSHEETS

SYSTEM: Clark Forklift Model No. C500Y165D
SUBSYSTEM: Lift
PROGRAM: Side Shift Hose Damage
REFERENCE: NSTS 22206, Revision D

DATE: November 30, 1994
PREPARED BY: M. Crompton
R. Gayo

NO.	PART NAME	FAILURE CAUSE(S)	FAILURE EFFECT	REDUNDANCY SCREENS		TEST AND INSPECTION REQUIREMENT(S)
				PASS	FAIL	
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. • Frequent inspection monthly. • Periodic inspection annually.
11	Uprights	Twisted	Intermittent fork hang-up and resultant unloading.	A B C		• Operator inspection prior to first use daily. • Frequent inspection monthly. • Periodic inspection annually.
12	Stop blocks	Misalignment	Unequal stop block loading.	A B C		• Operator inspection prior to first use daily. • Frequent inspection monthly. • Periodic inspection annually.
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. • Frequent inspection monthly. • Periodic inspection annually.

CRITICALITY CATEGORY 1R WORKSHEETS

SYSTEM: Clark Forklift Model No. C500Y165D
SUBSYSTEM: Lift
PROGRAM: Side Shift Hose Damage
REFERENCE: NSTS 22206, Revision D

DATE: November 30, 1994
PREPARED BY: M. Crompton
R. Gayo

NO.	PART NAME	FAILURE CAUSE(S)	FAILURE EFFECT	REDUNDANCY SCREENS		TEST AND INSPECTION REQUIREMENT(S)
				PASS	FAIL	
14	Flex hose retainer	Overloading	Unrestrained hose. Hydraulic oil leak. Upright unloading.	A B C		• Operator inspection prior to first use daily. • Frequent inspection monthly. • Periodic inspection annually.
17	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. • Frequent inspection monthly. • Periodic inspection annually.
18	Lift chains wear	Uneven wear, tension	Intermittent fork hang-up/upright unloading. Uncontrolled fork movement/could result in dropping the load. Requires multiple failures.	A B C		• Operator inspection prior to first use daily. • Frequent inspection monthly. • Periodic inspection annually.
21	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. • Frequent inspection monthly. • Periodic inspection annually.

CRITICALITY CATEGORY 1R WORKSHEETS

SYSTEM: Clark Forklift Model No. C500Y165D
SUBSYSTEM: Tilt
PROGRAM: Side Shift Hose Damage
REFERENCE: NSTS 22206, Revision D

DATE: November 30, 1994
PREPARED BY: M. Crompton
R. Gayo

NO.	PART NAME	FAILURE CAUSE(S)	FAILURE EFFECT	REDUNDANCY SCREENS		TEST AND INSPECTION REQUIREMENT(S)
				PASS	FAIL	
3	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. • Frequent inspection monthly. • 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. Recent service, performed by the equipment Dealer, Potomac Industrial Trucks, Inc., included the fabrication and installation of improved hose guards to prevent flex hoses from coming off the hose sheaves in the event the upright becomes unloaded.

6.2 Test and Inspection

- Operator inspection prior to first use daily.
- Frequent inspection monthly.
- Periodic inspection annually.

NSI Document #40-06-341, "Periodic Inspection Report for Forklift, Serial Number Y015-0143-7014," is provided as an example of the report presently in effect. (See Attachment No. 1.)

6.3 Failure History

A mishap involving Clark forklift S/N Y105-0143-7014 occurred on September 6, 1994. The lift was fully raised and was being lowered under a no-load condition. The forks dropped approximately 16 feet unexpectedly. A careful examination of the lift system was made by the local Clark dealer. No indication of any problem was found. (See Attachments 2 through 5.)

A sample of the original hydraulic fluid and filter and a sample of new oil were provided to Code 313/Materials Branch for analysis. No irregularities were found. (See Attachment 6.)

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.

6.4.2 Restriction of the lowering rate has been proposed. See Attachment 5. It would appear that a restricted lowering rate would increase the time for upright unloading to occur and, in turn, increase the time for the operator to perform corrective action and preclude failure.

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 be continued and performed by qualified, designated personnel;

7.1.2 the sixteen (16) Criticality Category 1R items identified during this analysis be included in the Periodic inspection annually; and,

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

7.2 No critical items were identified as a result of this analysis. There are numerous redundant hardware items. All are capable of checkout during normal operations. The time for failure to occur for 11 of the 29 components analyzed herein was, however, determined to be "Short Term," i.e., months. Implementation of the aforementioned scheduled test and inspections are recommended to mitigate the 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 two years, based on the recommendations of both the forklift manufacturer and the National Safety Council. However, the Goddard Space Flight Center RECERT Program requires that crane operators attend annual refresher training. It is, therefore, recommended that forklift operators performing critical lifts be similarly required to achieve renewal via annual recertification training.

7.3 It is recommended that the option of restricting the lowering fork rate be evaluated to further assess the level of protection against the aforementioned failure causes. Acceptance of this design feature would provide an additional level of protection to correct or negate the risk before the effect is manifested.

7.4 It is recommended that appropriate, pertinent portions of this analysis pertaining to:

- operator training and annual refresher interval, and
- the significance of operator inspections prior to first use daily, Frequent monthly inspection and Periodic inspection annually

be included in the next revision of the Engineering Services Division Safety Manual.

7.5 The act of stacking loads or setting forks on other surfaces has been identified (see Attachment 4) as the cause of upright unloading and resultant hose damage. It is recommended that means of detecting reverse fork loading be considered to alert the operator as to possible unloading of the uprights.

8.0 RISK ASSESSMENT

Risk assessment was performed in accordance with Figure 2, reproduced from RECERT-42-011, see Section 2.2, Documentation List, No. 8. The rationale for retaining the critical systems was developed based on:

- Consideration of the aforementioned parameters: Design, Test, Inspection, Failure History and Operational Use.

Definitions of the "Hazard Severity Levels" and "Likelihood of Occurrence" are self-explanatory (see Figure 2).

Hazard Severity Level : Catastrophic
Likelihood : Remote
Risk : Acceptable (Uncertainties Controlled/Managed)

GSFC RECERTIFICATION
HAZARD SEVERITY LEVELS VERSUS LIKELIHOOD OF OCCURRENCE FOR RISK ASSESSMENT*

		HAZARD* SEVERITY LEVELS		
		MARGINAL (COULD RESULT IN MINOR INJURY OR MINOR FLIGHT HARDWARE DAMAGE)	CRITICAL (COULD RESULT IN SERIOUS INJURY OR SIGNIFICANT FLIGHT HARDWARE DAMAGE)	CATASTROPHIC (COULD RESULT IN FATALITY OR LOSS OF FLIGHT HARDWARE)
LIKELIHOOD	*PROBABLE (EXPECTED TO HAPPEN)*	UNACCEPTABLE RISK (UNCERTAINTIES EXIST)	UNACCEPTABLE RISK (UNCERTAINTIES EXIST)	UNACCEPTABLE RISK (UNCERTAINTIES EXIST)
	OCCASIONAL (COULD HAPPEN)	ACCEPTABLE RISK (MINOR UNCERTAINTIES EXIST)	UNACCEPTABLE RISK (MINOR UNCERTAINTIES EXIST)	UNACCEPTABLE RISK (MINOR UNCERTAINTIES EXIST)
	REMOTE (NOT EXPECTED TO HAPPEN)	ACCEPTABLE RISK (UNCERTAINTIES CONTROLLED/ MANAGED)	ACCEPTABLE RISK (UNCERTAINTIES CONTROLLED/ MANAGED)	ACCEPTABLE RISK (UNCERTAINTIES CONTROLLED/ MANAGED)

* THIS GSFC RECERT RISK ASSESSMENT MATRIX IS A MODIFIED VERSION OF FIGURE G-1, APPENDIX G, IN NHB 1700.1(V1-B), "NASA SAFETY POLICY AND REQUIREMENTS DOCUMENT," JUNE 1993.

Figure 2

ATTACHMENTS

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**********************
*        N  S  I     *
*                    *
* DOCUMENT NO. 40-06-341 *
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PERIODIC INSPECTION REPORT
FOR
FORKLIFT, S/N Y1015-0143-7014
CLARK 15,500#

NSI Report Number

40-06-341

January 1994

INSPECTED BY: J. P. McDonough RR 1/5/94
R. Gayo, Lifting Device Inspector, NSI — Date

INSPECTED BY: E Wieneke 1-5-94
E. Wieneke, Lifting Device Inspector, NSI — Date

APPROVED BY: A. G. Zorn 2/3/94
A. Zorn, Manager, Recertification Support, NSI — Date

RECERT Support
NSI Technology Services Corporation
A Subsidiary of ManTech International Corporation
Goddard Space Flight Center
Greenbelt, Maryland 20771

Attachment 1

PERIODIC INSPECTION REPORT
FOR CLARK 15,500#
S/N Y1015-0143-7014

1/5/94
DATE

	OK - ✓	Needs Maint.
Tires - Condition/Pressure	✓	
Overhead Guard	✓	
Load Back Rest - Attached	✓	
Finger Guards - Attached	✓	
Capacity Plate - Attached	✓	
Battery Capacity Plate - Attached	N/A	
Hour Meter Functioning	✓	
Horn	✓	
Lights	✓	
Shifting Linkage	✓	
Accelerator/Control Linkage	✓	
Service Brake	✓	
Parking Brake	✓	
Steering Operation	✓	
Hoist and Lowering Operation	✓	
Tilt Control - Forward and Back	✓	
Hydraulic Tank Level	✓	
Hoist Cylinder for Leaks	✓	
Tilt Cylinder for Leaks	✓	
Main Relief Valve Setting	✓	
General Leaks - Hoses/Cuts/Abrasions/Fittings	✓	
Mast and Carriage Safety Stops	✓	
Mast Flange Wear	✓	
Mast Rollers and Thrust Buttons	✓	
Carriage Rollers and Thrust Buttons	✓	
Tension Rods	✓	
Forks - Top Clip - Pin - Heel	✓	
Forks - Bend - Twist	✓	
Forks - Fatigue Cracks (NDT)	✓	
Parking/Seat Switch	✓	
Direction Switch	✓	
Battery Condition	✓	
Battery Box and Connectors	✓	
All Wire Connections	✓	
Interlock Switches	✓	
Valve Hoist and Tilt Switches	✓	
Gasoline/LP Gas Leaks	✓	

Comments:

Annual PM Performed

40-06-341

INSPECTION REPORT
FOR CLARK 15,500#
S/N Y1015-0143-7014

INSPECTOR J. McDonough — E. Wienecke DATE 1/5/94

ITEM	DESCRIPTION OF DISCREPANCY	ACTION
15,500# Clark Forklift		
	PM & Load Test @ 15,500#	OK

The complete report is available for review. It is filed with Lifting Device Maintenance and Inspection Section of NSI.

This forklift has been inspected and load tested and (is) ~~is not~~ liftworthy.

Inspector Jon P. Phly Inspector E. Wienecke

MANAGEMENT TECHNOLOGY NSI

Memorandum

NSI Technology Services Corporation
Aerospace Technology Applications Center, A ManTech International Company

To: Distribution
VIA S. Chan/750

From: A. G. Zorn

Subject: Certification of 15,000-lb. Capacity Forklift, Code 750

Date: December 1, 1994

Copies: M. Viens/313
Files 4002, 6.4(Clark forklift S/N Y1015-0143-7014)

In reply refer to: NSI-4002-6.4-001

Subsequent to Dealer repair, and after an extensive series of tests and inspections, the 15,000-lb. capacity Clark forklift has been recertified and released for service.

Immediately following the mishap (Attachment 1, Incident Report) in which the forks dropped unexpectedly, this forklift was returned to the local Clark dealer, Potomac Industrial Trucks. Potomac inspected the entire forklift (not just the lift mechanism). The lift hydraulic hoses and hose rollers were replaced and a factory-designed hydraulic hose guard was installed over the hose rollers. The hydraulic fluid along with the filter element was changed. New hydraulic fluid and a new filter element were installed. A pressure gage was installed in the hydraulic circuit and the lift pressure was checked against specification.

A careful examination was made of the lift carriage, carriage rollers, and the lift channels in which the rollers move. No indication of any problem was found.

A sample of the old hydraulic fluid along with the old filter and a sample of the new oil were provided to Code 313/Materials Branch for analysis. No unexpected irregularities were found (Attachment 2).

The collective conclusion arrived at by the equipment Dealer (Attachments 3 and 4) and RECERT was that the anomaly was "most probably" resulted from operator error.

Because of the importance of this equipment and its use in handling flight hardware, a Failure Mode and Effects Analysis (FMEA) is currently being performed to identify all the single failure points. The FMEA completion is anticipated by mid-December 1994. Then, follow-up appropriate equipment modifications and/or enhancement will be implemented by RECERT with the manufacturer's approval to improve forklift reliability.

To Distribution
From A. G. Zorn
NSI-4002-6.4-001

December 1, 1994
2

A. G. Zorn
Manager
Recertification Support

Attachments - 4

Distribution: M. Brown/700
J. Munford/750
A. Simpson/750
J. Stecher/750
S. Wojnar/754
J. Packard/750.5

AGZ/slb

ENGINEERING SERVICES DIVISION
INCIDENT REPORT

DATE :	TIME :	LOCATION :
September 6, 1994	11:00AM	Building 29 High Bay

PERSONNEL INVOLVED :

NAME	AFFILIATION	INJURY
Richard B. Wilson	NSI	None

EQUIPMENT INVOLVED :

Clark Fork Lift
Model: C-500Y155D
Serial No.: Y1015-0143-7014

NARRATIVE :

The loading of palletized GSE had just been completed. The lift was fully raised (approximately 15 ft) and it was being lowered under a no-load condition, when suddenly it collapsed and struck the pavement beneath it. The "tracks" may have been "cocked" and came loose after the piston cylinder had been drained?

Several hydraulic hoses were damaged. An inspection will be performed by the RECERT crew. The fork lift is out of service.

CORRECTIVE ACTION IS/WILL BE TAKEN

An investigation will be made to determine the cause and corrective action will then be taken.

DISTRIBUTION :

Chief, Engineering Services Division/750
Associate Chief, Engineering Services Division/750
Assistant Chief of Operations,
Engineering Services Division/750
Health & Safety Engineering Office/205
Chairman, Safety Committee/750
Branch/NSI Mission
All 750 Section Supervisors

ORIGINATOR :

A. Wolfson
Supervisor
Mechanical Systems Support

REVISED APRIL 1988

Attachment 3

POTOMAC
INDUSTRIAL TRUCKS, INC.

WASHINGTON OFFICE
800 RITCHIE ROAD
CAPITOL HEIGHTS, MD 20743
(301) 336-1700

WINCHESTER OFFICE
P. O. BOX 960
STEPHENS CITY, VA 22655
(703) 509-6100

• SALES • SERVICE
• RENTALS • PARTS
• INSTALLATIONS

SEPTEMBER 14, 1994

NSI TECHNOLOGY SERVICES
GSFC
GREENBELT, MD. 20771

ATTENTION: MR. RAY WHITEHEAD

DEAR MR. RAY WHITEHEAD;

PER YOUR REQUEST, I WILL EXPLAIN THE OPERATION OF YOUR CLARK FORKLIFT TRUCK, S/N: Y1015-0143-7014 AND WHY THE SIDESHIFT HOSES ARE BEING DAMAGED.

ABOVE AND BEYOND NORMAL USE, THE ONLY WAY THE HOSE COULD BE DAMAGED AS THEY ARE IS BY UNLOADING OF THE UPRIGHT CAUSING THE HOSES TO SLACKEN AND COME OUT OF THE HOSE SHEIVES. THIS HAPPENS OFTEN WHEN STACKING LOADS OR SETTING FORKS ON OTHER SURFACES. WHEN THE UPRIGHT UNLOADS, YOU WILL NOTICE THE LIFT CHAINS AND HOSES WILL NO LONGER BE TIGHT. WHEN TENSION IS REAPPLIED BY RAISING THE LIFT CYLINDER, THE HOSES COME DOWN ON TOP OF THE SHEIVES AND ARE CUT.

IF I CAN BE OF ANY FURTHER ASSISTANCE, PLEASE FEEL FREE TO CONTACT ME AT (301) 336-1704.

VERY TRULY YOURS,

John B. Kluberton

JOHN B. KLUBERTON
SERVICE MANAGER

MATERIAL HANDLING SPECIALISTS

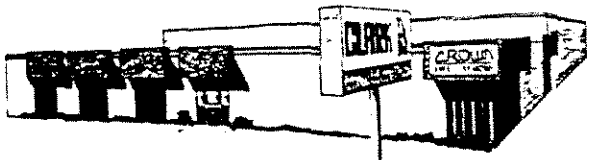
CLARK FORKLIFTS
Marklifts SCISSORS & BOOMS
Interlake RACKS & CONVEYORS
CROWN FORKLIFTS

Attachment 4

POTOMAC
INDUSTRIAL TRUCKS, INC.

WASHINGTON OFFICE
800 RITCHIE ROAD
CAPITOL HEIGHTS, MD 20743
(301) 336-1700

WINCHESTER OFFICE
P. O. BOX 940
STEPHENS CITY, VA 22655
(703) 869-6100



• SALES • SERVICE
• RENTALS • PARTS
• INSTALLATIONS

November 17, 1994

Mr. Albert Zorn, Manager
Recertification Support
NSI Technologies
Goddard Space Flight Center
Code 750.5
Greenbelt, MD 20771

Ref: C500Y155D, serial no. Y1015-0143-7014

Dear Mr. Zorn:

Per your request, I will specify for you the work and tests performed on your above noted Clark forklift truck.

* Replaced 4 hoses in upright and 2 rollers. Fabricated and installed hose guards to prevent hoses from coming off hose sheaves in the event the upright becomes "unloaded".

* Replaced hydraulic oil and filter proved NSI personnel with oil sample for testing.

* Filled all tires to specification.

* Load tested truck. Truck will lift to rated capacity.

* Checked hydraulic pressures all truck pressures are within recommended specifications.

* Visually checked entire unit. Found no discrepancies and truck in acceptable working condition.

Mr. Zorn, you had requested that we restrict the lowering speed of your truck; I have been in contact with Clark engineering on this matter, there are some specific questions that have arised.

1. What lowering speed do you require?
(Feet/inches per minute)

POTOMAC
INDUSTRIAL TRUCKS, INC.

2. Is the lift speed acceptable as it currently is?

3. If engineering at Clark would design the "fix", when would you want it installed? And as this is not a warranty type issue, is NSI willing to except responsibility of payment?

I look forward to your reply. Please feel free to call me with any questions you may have.

Respectfully,

POTOMAC INDUSTRIAL TRUCKS, INC.

John B. Kluberton,
Service Manager

JBK/xlj

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland
20771

ply to Attn. of: 313

November 1, 1994

TO: 750/Engineering Services Division/Mr. Chan

FROM: 313/Materials Branch

SUBJECT: Analysis of Oil and Filter from Fork Lift Failure

INTRODUCTION

The subject analysis was performed in support of an on going failure investigation of the Clark 15,000 pound forklift. The nature of the failure was a rapid uncontrolled lowering of the forks. At some point during this event the hydraulic lines that control the span of the forks were severed. The cause for the event is unknown. This forklift is sometimes used to lift flight hardware and ground support equipment. The occurrence of another such event could adversely impact flight projects. As the forklift is still under warranty, the failure analysis and repair is being performed by a representative of the fork lift manufacturer. The Materials Branch was asked to verify the integrity of the hydraulic oil used in the forklift.

CONCLUSIONS

No difference could be detected between the used and as received oil when analyzed using MS and XRF techniques.

The filter had a considerable amount of debris. When analyzed using EDS it was found to be mostly iron, iron oxide, and aluminum. The shape of many of the particles was spherical. These particles may have been created by a welding process during the manufacture of the forklift, indicating that the filter had not as yet been changed.

No evidence of a failed component was found in the filter. No large particles or shards that appeared to be fragments of components were found in the filter.

DISCUSSION

Three hydraulic oil specimens were submitted for examination. One specimen was taken directly from an oil container and represents the oil intended for use in the hydraulic system, The second oil specimen was taken from the oil reservoir on the forklift. The third specimen was drained from the hydraulic line that controls the lifting ram.

Each oil specimen was examined using x-ray fluorescence (XRF) spectroscopy. The XRF analysis can detect elements with molecular weights greater than aluminum. The level of sensitivity of the XRF should detect elements in concentrations of 1 wt % or greater. No contamination was found in the oil. The spectra for the new and used oil were identical.

The as received oil and oil removed from the forklift reservoir were analyzed using mass spectroscopy by Joseph Petitto (Unisys). Again the spectra were identical, indicating that the oil previously used is the same as that currently being used. It is assumed that the replacement oil is the correct type.

The filter was disassembled and carefully examined for large particles, none were found. The debris in the fold were removed using an alcohol flush that was subsequently filtered. These debris were analyzed examined using a scanning electron microscope (SEM) and analyzed using an energy dispersive spectrometer by Liqin Wang (Unisys). The particles were of varied shapes and sizes. A large percentage of the particles where spherical in nature and thought to be created by a welding process. The composition of the particles was primarily iron with iron oxide on their surface. Some aluminum was also noted.

Questions concerning the mass spectroscopy and SEM analysis can be directed Mr. Petitto and Dr. Wang, respectively. Please feel free to contact me (X-2049), if you have any other questions or concerns.

Michael J. Viens

cc:

313/Staff
313/file
313.2/Petitto
313.1/Wang