**********
* ManTech *
*  *
*Document # 40-01-730 *
**********

ADDENDUM TO FMEA
from Philadelphia Tramrail Crane & Hoist Service

Failure Modes and Effects Analysis (FMEA)
and Critical Items List (CIL) for
Crane 10-1 Located in Building 10

ManTech Document Number

40-01-730

March 2005

PREPARED BY: Mel Crompton 4.19.05
M. Crompton, Project Engineer, Recertification Function — Date

APPROVED/
REVIEWED BY: Warren Thomas 05/09/05
W. Thomas, Manager, Recertification Function — Date

APPROVED BY: 5/10/2005
S. Chan, RECERT 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

Preface ..... ii
List of References ..... iii
1.0 Summary of Findings ..... 1
1.1 System Criticality ..... 1
1.2 Mechanical Critical Items ..... 1
1.3 Electrical Critical Items ..... 2
1.4 Critical Control/Monitor Functions ..... 2
1.5 Hazards Identified ..... 2
1.6 Critical Flex-hoses ..... 2
1.7 Critical Orifices ..... 2
1.8 Critical Filters ..... 2
1.9 End-to-End Areas of Concern ..... 2
1.10 Sneak Circuits Identified ..... 2
2.0 Failure Mode and Effects Analysis ..... 2
2.1 System Description ..... 2
2.2 Passive Components ..... 4
2.3 Shaft Attachment Points ..... 4
2.4 Drum and Shaft Bearings ..... 4
2.5 Crane Criticality Assessment ..... 5
2.6 Failure Modes and Effects Analysis Worksheets and Diagrams ..... 6
2.7 Critical Items List (CIL) ..... 6
2.8 Critical Items List Acceptance Rationale ..... 7
Critical Item 1 – Drum Gear ..... 8
Critical Item 2 – Hoist Gearbox ..... 10
Critical Item 3 – Motor Coupling ..... 14
Critical Item 4 – Motor Coupling ..... 16
Critical 1R Item 5 – Initial Hoist Upper Limit Switch ..... 18
Critical 1R Item 6 – Final Hoist Upper Limit Switch ..... 20
Critical 1R Item 7 – Initial Hoist Brake ..... 22
Critical 1R Item 8 – Final Hoist Brake ..... 24
2.9 Criticality Category 1R Items ..... 26
3.0 Risk Assessment ..... 27
3.1 Risk Assessment Code (RAC) and Closure ..... 28
4.0 Controls, Verifications ..... 29
5.0 Rationale for Criticality Category Downgrade ..... 29
6.0 Critical Control/Monitor Functions ..... 30
7.0 End-to-End Analysis ..... 30
8.0 Sneak Circuit Analysis ..... 30
9.0 Recommendations ..... 30
10.0 Conclusion ..... 30

# Preface

This document is provided as a supplement to the vendor-performed Failure Modes and Effects Analysis (FMEA). This document includes the following:

- Critical Items List (CIL)
- Rationale for retaining the Critical Items
- Controls and verifications
- Recommendations

This document is compliant with the general methodology of NSTS 22206, "Requirements for Preparation and Approval of Failure Modes and Effects Analysis and Critical Items List."

List of References

The following documents were used in completing this analysis:

1. Requirements for Preparation and Approval of Failure Modes and Effects analysis (FMEA) and Critical Items List (CIL); NSTS 22206, Revision D; December 10, 1993.
2. NASA-STD-8719.9, NASA "Standard for Lifting Devices and Equipment," May 2002.
3. GPR 8719.1, "Certification and Recertification of Lifting Devices and Equipment," November 23, 2004.
4. NSI Document No. 40-09-284, "Crane Specification to Retrofit Crane 10-1 with Flux Vector Drives Inverter Duty Motors, and Radio Control in the High Bay of Building 10 to Flux Vector Drives at the Goddard Space Flight Center Greenbelt Maryland."
5. Inspection and Maintenance Manual, Spare Parts; Crane America Services; July 1996.
6. NPR 8715.3, "NASA Safety Manual," March 31, 2004.
7. Retrofitted 15-Ton Shaw Box Crane; Operation Manual; Electromotive Systems, Inc.
8. Failure Modes Effect Analysis, Crane 10-1 Retrofit, Bldg. 10, Philadelphia Tramrail Crane and Hoist Service.

## 1.0 Summary of Findings

### 1.1 System Criticality

Crane 10-1 (a 15-ton bridge crane, retrofitted with flux vector drives, inverter duty motors, and radio control) is assessed as critical because failure of the crane could cause the loss of life and/or critical hardware. The crane functions are identified and assessed on the Criticality Summary Sheet (see Section 2.5).

### 1.2 Mechanical Critical Items

The Mechanical Critical Items identified by the Philadelphia Tramrail Crane & Hoist Service. are summarized below. The Rationale for Acceptability is documented as part of the Critical Items List Acceptance Rationale, Section 2.8.

| No. | Critical Item | Original Criticality | Downgraded Criticality | Risk |
|---|---|---|---|---|
| 1 | Drum Gear | 1 | 3 | Controlled |
| 2 | Hoist Gearbox | 1 | 3 | Controlled |
| 3 | Motor Coupling | 1 | 3 | Controlled |
| 4 | Motor Coupling | 1 | 3 | Controlled |
| 5 | Initial Hoist Upper Limit Switch | 1R | 3 | Controlled |
| 6 | Final Upper Limit Switch | 1R | 3 | Controlled |
| 7 | Disc Hoist Brake | 1R | 3 | Controlled |
| 8 | Shoe Hoist Brake | 1R | 3 | Controlled |

The Criticality Category of the critical items was downgraded from the original 1/1R criticality to a "3" due to the implementation of defined and approved operational controls.

Table 1
GSE Criticality Category Definitions

| Criticality | Potential Effect or Failure |
|---|---|
| 1 | Single failure, which could result in loss of life or load. |
| 1R | Two redundant hardware items, which if both failed, could result in loss of life or load (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 that could result in loss of life or load. |
| 2 | Single failure, which could result in loss (damage) of a load. |
| 3 | All others. |

1.3 Electrical Critical Items

See Table 1, Section 1.2.

1.4 Critical Control/Monitor Functions

There were no critical control/monitor functions identified in this analysis.

1.5 Hazards Identified

Justification for retaining the critical items listed above was based on the data elements provided in the Rationale for Acceptability. This Rationale included the following information: Design, Test, Inspection, Failure History, and Operational Use. Risk assessment, based on the criteria identified in the Reference 1, determined the risk of critical item retention to be acceptable.

1.6 Critical Flex-hoses

There were no critical flex-hoses identified in this lifting device.

1.7 Critical Orifices

There were no critical orifices identified in this lifting device.

1.8 Critical Filters

There were no critical filters identified in this lifting device.

1.9 End-to-End Areas of Concern

There were no areas of concern identified that are the design responsibility of other contractors and/or NASA centers.

1.10 Sneak Circuits Identified

There was no Sneak Circuit Analysis performed on Crane 10-1.

2.0 Failure Mode and Effects Analysis

2.1 System Description

General

Crane 10-1, located in the high bay of Building 10, has been converted to Flux Vector Drives. This crane supports the loading, unloading, assembly, and handling of critical payloads and space flight hardware. The crane is radio controlled with backup pendant control. The retrofit provides variable microspeed control of all crane motions to facilitate the precision integration of flight hardware and the placement of critical hardware into the Space Environment Simulation test chamber.

Those components pertinent to the retrofit plus the 1R items only, are addressed in this Addendum.

Hoist Assembly

The hoist is composed of:

Main Hoist

The hoist unit is provided with two means of braking: two electro-magnetic brakes, a hoist motor brake, and a shoe brake, each capable of bringing a rated load to zero speed and holding it (with and without power).

The hoist motor control brake is capable of holding the capacity load of the hoist at any point independent of the second holding brake and, in addition to stopping and safely holding 125 percent of the rated load from any operating speed, has been statically tested (under no load) with 150 percent of the rated load hoisting torque at the point of brake application. This brake, in conjunction with the second holding brake, allows for the manual lowering of a load without power.

Dual upper limit switches are provided; a geared and weighted limit, so that the primary switch has a back up. Actuation of the initial upper limit switch does not inhibit movement in the lower direction. Activation of the final upper limit switch requires resetting of the limit switch prior to movement of the load. The movement of the bridge and trolley is not inhibited after the final upper limit switch has been activated.

A lower limit switch is provided to prevent reverse winding of the wire rope.

Trolley

Replacement trolley motor is an inverter duty motor with electric brake and Lakeshore encoder.

The trolley festoon system, approximately 100 feet, is consistent with the requirements for the flux Vector Drive.

Limit switches for maximum trolley travel in the East/West direction are in place. In addition, a third exists to prevent interference with two crane monorails at a lower level. A pushbutton at the radio transmitter permits bypass of this limit by the operator when necessary.

Bridge

Replacement bridge motors are constant torque inverter duty motor with the Lakeshore encoder and motor brake. Bridge limits for maximum bridge travel are in place.

## 2.2 Passive Components

Passive components will not be analyzed in the FMEA. The current list of passive components includes the hook, load block, wire rope, sheaves, and rope drum. However, the shafts shall be analyzed as to the attachment method.

## 2.3 Shaft Attachment Points

Shaft attachment methods are analyzed for shafts located between the drum and brake. Shaft attachment points are considered passive, in accordance with NSTS 22206, if the shaft is welded or physically attached to the drum by a method approved by the hoisting standards. The shafts so identified, by Reference 1, are listed below.

| Shaft | Method of Attachment | Standard |
|---|---|---|
| Drum | Key | CMAA/ANSI |
| Drum Pinion | Spline | CMAA/ANSI |
| Brake | Spline | CMAA/ANSI |
| Motor Pinion | Key | CMAA/ANSI |

Analysis results of the shaft attachment points meet the criteria of NSTS 22206 and are, therefore, considered passive and acceptable as they are.

Analysis indicated the bearings to be acceptable. No further discussion is provided on these items.

## 2.4 Drum and Shaft Bearings

NSTS 22206, see Reference 1, requires that bearings on drums and shafts be analyzed only to determine if the bearings can fail and drop the load. The following bearings and effect of failure were identified.

| ITEM | EFFECT OF FAILURE |
|---|---|
| Drum Bearings | Loss of Function |
| Intermediate Gear Bearings | Loss of Function |
| Trolley Wheel Bearings | Impaired Function |

Rationale for Acceptability follows:

- The bearings are double row, roller bearings
- Lubricant: grease
- Tests and inspections were performed post retrofit in accordance with Acceptance Test Procedures defined in the Crane Specification (see Reference 4).
- The crane typically operates at low speeds.
- Crane 10-1 was designed for Moderate Service (Class C) and operates at Light Service (Class B).
- The crane operates in a controlled environment.

## 2.5 Crane Criticality Assessment

The crane functions are identified and assessed on the following Criticality Assessment Sheets:

| CRANE CRITICALITY ASSESSMENT SUMMARY SHEET | | | | |
|---|---|---|---|---|
| Crane 10-1 | | | Prepared By: M.Crompton | |
| Location: Building 10 | | | Date: March 2005 | |
| **OUTPUT** | **FUNCTION** | **EFFECT OF LOSS/FAILURE** | **CRIT CAT** | **NOTES** |
| Hoist System | Provides ability to lift/lower loads up to 15 tons. | Failure of the hoist system could cause the load to drop. Loss of life and/or loss of flight hardware. | Crit | See FMEA worksheets. |
| Hoist Braking System | Provides ability to hold a load suspended with or without power. | Failure of both hoist braking systems could cause the load to drop. Loss of life and/or loss of flight hardware. | Crit | See FMEA worksheets. |
| Trolley System | Provides ability to move load left or right the width of the bridge. | Failure of the trolley system could cause the load to contact facility and/or other flight hardware. Loss of life and/or loss of flight hardware. | Crit | See FMEA worksheets. |
| Trolley Brake System | Provides ability to stop and hold trolley in required position. | Failure of the trolley brake could cause impact with facility structure and/or other flight hardware. Loss of life and/or loss of flight hardware. | Crit | See FMEA worksheets. |
| Bridge System | Provides ability to traverse entire length of the facility. | Failure of the bridge system could cause flight hardware to contact facility structure and/or other flight hardware, loss of life and/or flight hardware. | Crit | See FMEA worksheets. |
| Bridge Brake System | Provides ability to stop and hold bridge in required position. | Failure of the bridge brake system could cause flight hardware to contact facility structure and/or other flight hardware, loss of life and/or flight hardware. | Crit | See FMEA worksheets. |

2.6 Failure Modes and Effects Analysis Worksheets and Diagrams

The mechanical components of pertinent equipment are identified in the vendor-performed Failure Modes and Effects Analysis (FMEA). See Reference 8.

2.7 Critical Items List (CIL)

| No. | Critical Item |
|---|---|
| 1. | Drum Gear |
| 2. | Hoist Gearbox |
| 3. | Motor Coupling |
| 4. | Motor Coupling |
| 5. | Initial Hoist Upper Limit Switch |
| 6. | Final Hoist Upper Limit Switch |
| 7. | Disc Hoist Brake |
| 8. | Shoe Hoist Brake |

## 2.8 Critical Items List Acceptance Rationale

The justification for retaining the identified critical items is presented here. The rationale is comprised of the following elements:

- Design
- Test
- Inspection
- Failure History
- Operational Use

The individual CIL sheets follow.

Critical Item 1 – Drum Gear

| Item Number | Contents |
|---|---|
| 1. | Item Identification: Drum Gear, Part No. HL70A-23<br>See Illustration No. HLT-70A, Reference 8. |
| 2. | Criticality Category: 1 |
| 3. | Function: Transmits lifting torque and gear reduction.. |
| 4. | Failure Mode: Excessive load |
| 5. | Cause: Exceeding hoist capacity |
| 6. | Failure Mode Number: N/A |
| 7. | Failure Effect: Loss of critical hardware/personnel safety |
| 8. | Critical Items List Acceptance Rationale includes the following items. |

A. Design

The hoist is designed to meet all the OSHA requirements cited in OSHA CFR 1910.179 and 1910.306 and CMAA 70. The drum gear meets all the requirements for Class C (moderate service) and is manufactured to AGMA quality Class 5 or better.

The drum gear is attached to the drum shaft via splines.

B. Test

Specific tests to detect failure modes and causes during acceptance and certification tests were performed, i.e.:

- Factory tests before shipments, and
- Crane acceptance test procedures.

For details, reference Critical Items List, Item 2: Hoist Gearbox

C. Inspections

Cranes used frequently for critical lifts are load tested annually. If inspection indicates problems, then gearing is inspected for wear or cracks. NDT techniques are used if indication of problems are suspected.

Inspections are performed in accordance with paragraph 4.4 of Reference 2 (NASA-STD-8719.9).

Operational tests are performed together with rated load tests. Test reports are documented, dated, and signed. The inspection reports are maintained on file and made readily available by the Recertification Program Manager.

D. Failure History

Loss of load due to loss of the hoist drum gear has not been experienced since the inception of the RECERT Program.

E. Operational Use

Critical lift operators are trained in the specific hazards and special procedures associated with the lift. Emergency procedures are addressed for contingency actions or other emergencies.

Critical Item 2 – Hoist Gearbox

| Item Number | Contents |
|---|---|
| 1. | Item Identification: Hoist Gearbox. See Reference 8. |
| 2. | Criticality Category: 1 |
| 3. | Function: Transmits power from high-speed hoist motor to low-speed drum. |
| 4. | Failure Mode: Gear disengagement |
| 5. | Cause: Structural failure of components |
| 6. | Failure Effect: Loss of load |
| 7. | Critical Items List Acceptance Rationale includes the following items. |

A. Design

The design features that minimize the probability of occurrence of the critical failure mode and causes are listed here:

- Gear/shaft attachment methods are approved by hoisting standards.
- Gearing is designed/manufactured in accordance with AGMA standards.
- Two drum pinion gears distribute tooth face pressure resulting in a high durability factor and low fatigue.

The hoist encoder, maintain a watchdog status on the mechanical integrity of the gears and shafting of the motor. A deviation greater than the cumulative angular allowances for backlash and machining tolerances will result in a major failure. The failure will be noted on the control via a fault finding circuit.

B. Test

Reference 4 addresses in detail the specific test to detect failure modes and causes during acceptance and certification tests that was performed:

Factory tests before shipment

Provide documentation of tests performed at the supplier's plant prior to shipment.

The Examination

Examined the equipment for compliance with the requirements of this specification. This element of inspection encompasses all visual examination and dimensional measurements. Noncompliance with any specified requirements, or presence of one or more defects preventing or lessening

maximum efficiency, constituted cause for rejection. Any redesign or modification of the manufacturer's standard product was permitted after receiving approval of the required deviation request as submitted by the Contractor and approved by NSI. A drawing of the modified part wais required with sufficient detail that it could be remanufactured by a competent machinist.

Acceptance Test Preparation

After the completed job was in place, adjusted, lubricated, and otherwise made ready for operation, it was tested by the Contractor, in the presence of NSI. Hoisting tests for speed were made after mechanisms attained essentially steady state, prior to taking data. The Contractor furnished the labor. Slings and weights required for the acceptance tests were provided by NSI.

Crane Acceptance Test Procedures

The Contractor prepared a complete set of hoist acceptance test procedures. These procedures were written such that the crane was required to:

- Demonstrate its ability to traverse the entire working envelope with no load, 50% of rated load, and 100% of rated load.
- Raise and lower 0%, 50%, and 100% of the rated load at the maximum specified speed.
- Hold 50%, 100%, and 125% of the rated load approximately six inches above the floor for a period of three minutes without appreciable lowering.
- Bring 0%, 50%, and 100% of the rated load to a stop in the lowering mode at the maximum specified speed without dropping the load.
- Demonstrate its ability to bring the hook to a stop at the initial upper limit switch at full speed with no load and then automatically lower the hook.
- Demonstrate its ability to bring the hook to a complete stop at the final upper limit switch at full speed with no load.
- Demonstrate its ability to stop the hook from being lowered beyond the setting of the lower limit switch.
- Demonstrate proper functioning of all pendant controls, including the emergency stop button at any speed under all loads.
- Demonstrate the minimum speed of 0.50 inch per minute when in micro speed at full load.
- Demonstrate that when in load float, the hook will not raise or lower more than .005 inch at full load for ten seconds.
- Record the amperage readings during each phase of the first two tests specified above.
- Demonstrate the crane's ability to meet Class C as defined by CMAA #70.
- Demonstrate that operating the system in load float for one hour does not create excessive heating of the hoist motor.

Crane Electrification System Factory Tests

Factory tests on crane electrification systems and associated fittings were made in accordance with the applicable provisions of the referenced standards. Dielectric tests were in accordance with ANSI/U 857. Voltage-drop and short-circuit tests were in accordance with "Testing Standards" of NEMA BU 1.

Routine tests shall include dielectric tests on crane electrification system. Certification of dielectric tests shall be submitted and shall show compliance with the referenced standard.

On-Site Complex Electrification System Tests

Hoist complex electrification system was given continuity and insulation tests after the installation was completed before equipment was energized.

The Contractor provided all necessary test equipment, labor, and personnel to perform the tests specified.

Test data was recorded and included location and identification of busway and megohm readings versus time.

Final acceptance depended upon satisfactory performance under test. No electrification system was energized until recorded test data was approved.

A factory representative from the Flux Vector Drive manufacturer made a final on-site checkout of the drive programs and adjustments to the system as required by NSI and provided four hours of operating instructions to crane operators.

Operational tests were conducted from ground level to identify abnormal audio/visual indication. Gearbox lubricant was sampled for freedom from water, metal particles, sludge, or other contamination.

Daily tests are performed prior to first use each day the crane is used. These tests verify the functional operation of the crane mechanisms. Tests pertinent to proper gearbox function consist of hoist start, raising/lowering, smooth travel and audio indication of excessive wear.

C. Inspections

Periodic Inspections are performed annually to determine whether or not critical failure modes have occurred. Gearbox lubricant is inspected as described above. In-depth inspection is performed as warranted.

D. Failure History

Loss of load due to loss of the hoist gearbox has never been experienced.

E. Operational Use

Gear teeth would have to be lost to effectively impair the mechanical integrity of the load path. The certified crane operator would receive an audio indication of such an abnormal condition. Critical Lift Operators are trained in the specific hazards and special procedures to mitigate the effects of failure once it has occurred.

Critical Item 3 – Motor Coupling

| Number | Contents |
|---|---|
| 1 | Item Identification: Motor Coupling, Item 443462-5 |
| 2 | Criticality Category: 1 |
| 3 | Function: Transmits torque from the motor to the motor pinion shaft |
| 4 | Failure Mode: Excessive load |
| 5 | Cause: Exceeding design load |
| 6 | Failure Mode No: N/A |
| 7 | Failure Effect: Coupling failure would occur. The shoe brake would hold the load. There would be no effect on the flight hardware nor personnel safety. Delay in operation. |
| 8 | Critical Items List Acceptance Rationale includes the following: |

A. Design

The design features that minimize the causes and probability of the critical failure mode occurring are listed here:

Coupling attachment methods are approved by hoisting standards (i.e., ANSI compliant).

B. Test

Crane acceptance testing is previously described, with reference to the Hoist Gearbox. The tests demonstrate the hoist's ability of meet the Class C service classification.

A Daily test is performed prior to first use each day the crane is used. This test verifies the functional operation of the hoist, i.e., hoist start/stop, raising/lowering, and initial limit switch operation, etc., smooth travel and audio indication of excessive wear.

C. Inspection

A Periodic Inspection is performed annually for recertification and to determine whether or not critical failure modes have occurred. In-depth investigation is performed as warranted.

D. Failure History

Loss of load due to loss of the motor coupling on a properly maintained hoist has never been experienced.

E. Operational Use

Shaft/splines would have to be lost to effectively impair the mechanical integrity of the load path. The certified crane operator would receive an audio indication of such an abnormal condition. Critical lift operators are trained in the specific procedures to mitigate the effects of failure once it has occurred.

Critical Item 4 – Motor Coupling

| Number | Contents |
|---|---|
| 1 | Item Identification: Motor Coupling, Item 3836-54 |
| 2 | Criticality Category: 1 |
| 3 | Function: Transmits torque from the motor to the motor brake |
| 4 | Failure Mode: Excessive load |
| 5 | Cause: Exceeding design load |
| 6 | Failure Mode No: N/A |
| 7 | Failure Effect: Coupling failure would occur. The disc brake would hold the load. There would be no effect on the flight hardware nor personnel safety. Delay in operation. |
| 8 | Critical Items List Acceptance Rationale includes the following: |

A. Design

Operational redundancy minimizes the probability of occurrence of the critical failure mode and causes. The redundant hardware items are energized during the crane operating cycle. Upon failure of the holding brake, the remaining redundant brake will continue to perform the holding function.

B. Test

Periodic testing is performed annually for recertification of Crane 10-1. Limit switches/limit switch trip is checked for attachment, position, alignment and effectiveness.

C. Inspection

Checkout and verification of each motor coupling is performed annually during formal Periodic Inspection. Details of the periodic brake testing are documented in NSI Procedure 25-06-021, Inspection and Preventive Maintenance Procedure for Bridge Crane 10-1. Daily inspections performed by the certified operator, do not include verification of the functional operation of each coupling, but rather are limited to checking the initial brake coupling.

D. Failure History

Loss of load due to loss of the motor coupling on a properly maintained hoist has never been experienced.

E. Operational Use

Shaft/splines would have to be lost to effectively impair the mechanical integrity of the load path. The certified crane operator would receive an audio indication of such an abnormal condition. Critical lift operators are trained in the specific procedures to mitigate the effects of failure once it has occurred.

Critical 1R Item 5 – Initial Hoist Upper Limit Switch

| Number | Contents |
|---|---|
| 1 | Item Identification: Initial Hoist Upper Limit Switch Geared, Item No. HL-74 |
| 2 | Critical Category: 1R |
| 3 | Function: Hoist movement in the raise direction is precluded after the limit switch is encountered. Movement in the "lower" direction is not inhibited. |
| 4 | Failure Mode: a) Fails open<br>b) Fails closed |
| 5 | Cause: a) Corroded contacts<br>b) Contacts fused together |
| 6 | Failure Mode Number: N/A |
| 7 | Failure Effect: a) Hoist will stop and brakes will be set if moving up.<br>b) No effect. Two limit switches are used. |
| 8 | Critical Items List Acceptance Rationale includes the following items. |

A. Design

Operational redundancy is the primary design feature, which minimizes the probability of loss of the load due to contact failure. Redundancy, is "unlike" in that non-identical hardware items, e.g., initial and final upper limit switches, perform the same function.

B Test

Periodic testing is performed annually for recertification of the crane 10-1 limit switches. Limit switch trip is checked for attachment, position, alignment, and effectiveness.

C. Inspections

Checkout and verification of <u>each</u> limit switch is performed annually during formal Periodic Inspection. Details of the periodic limit switch testing are documented in NSI Procedure 25-26-021, Inspection and Preventive Maintenance Procedure for Bridge Crane 10-1. Daily inspections, performed by the certified operator, do not include recertification of the functional operation of the final upper limit switch, but rather are limited to checking the availability of power to the limit switch.

D. Failure History

Loss of load due to initial hoist upper limit switch malfunction has not been experienced since the inception of the RECERT Program.

E. Operational Use

Critical Lift Operators are trained in the specific hazards and special procedures associated with the lift. Emergency procedures are addressed for contingency actions.

Critical 1R Item 6 – Final Hoist Upper Limit Switch

| Number | Contents |
|---|---|
| 1 | Item Identification: Final Hoist Upper Limit Switch, Paddle type |
| 2 | Critical Category: 1R |
| 3 | Function: All hoisting motion is precluded after the limit switch is encountered. |
| 4 | Failure Mode: a) Fails open<br>b) Fails closed |
| 5 | Cause: a) Corroded contacts<br>b) Contacts fused together |
| 6 | Failure Mode Number: N/A |
| 7 | Failure Effect: All hoisting motion precluded |
| 8 | Critical Items List Acceptance Rationale includes the following items. |

A. Design

Operational redundancy is the primary design feature, which minimizes the probability of loss of the load due to contact failure. Redundancy, is "unlike" in that non-identical hardware items, e.g., initial and final upper limit switches, perform the same function.

B. Test

Periodic testing is performed annually for recertification of the crane 10-1 limit switches. Limit switch trip is checked for attachment, position, alignment, and effectiveness.

C. Inspections

Checkout and verification of <u>each</u> limit switch is performed annually during formal periodic inspection. Details of the periodic limit switch testing are documented in NSI Procedure 25-06-021, Inspection and preventive maintenance procedure for Bridge Crane 10-1. Daily inspections, performed by the certified operator, do not include recertification of the functional operation of the final upper limit switch, but rather are limited to checking the availability of power to the limit switch.

D. Failure History

Loss of load due to initial hoist upper limit switch has not been experienced since the inception of the RECERT Program.

F. Operational Use

Critical Lift Operators are trained in the specific hazards and special procedures associated with the lift. Emergency procedures are addressed for contingency actions.

Critical 1R Item 7 – Disc Hoist Brake

| Number | Contents |
|---|---|
| 1 | Item Identification: Disc Brake (located behind the gearbox)<br>See Illustration HL-72B, Reference 8 |
| 2 | Criticality Category: 1 |
| 3 | Function: Hold load after hoisting or when de-energized. |
| 4 | Failure mode: a) Fails to engage<br>b) Fails to disengage |
| 5 | Cause: a) Structural failure of components<br>b) Failure mechanism |
| 6 | Failure Mode No.: N/A |
| 7 | Failure Effect: a) Disc brake fails; one of the two brakes will set<br>b) Shoe brake will hold load |
| 8 | Critical Items List Acceptance Rationale includes the following items: |

A. Design

Operational redundancy minimizes the probability of occurrence of the critical failure mode and causes. The redundant hardware items are energized during the crane operating cycle. Upon failure of the brake, the remaining redundant brake will continue to perform the holding function.

B. Test

Periodic testing is performed annually for recertification of Crane 10-1. Testing is performed in accordance with Section 202 of NASA-STD-8719.9 (Reference 2). The Operational Test includes a demonstration of each brake's ability to stop and hold a load.

C. Inspections

Daily and Periodic safety inspections are performed in accordance with the Section 203 of NASA-STD-8719.9. Functional operating and control mechanisms are checked daily for maladjustments. Inspections for brake wear are performed annually. Details of the Periodic testing and maintenance are documented in NSI Procedure 25-06-021.

D. Risk Control and Mitigation for Critical 1R Items

As presented in the Critical Category 1R Redundancy Screen Table, the risk of the failed item is controlled and mitigated through the implementation of Daily, Monthly, and Periodic Inspections.

E. Failure History

Loss of load due to brake failure has not been experienced, since the inception of the RECERT Program.

F. Operational Use

Critical lift operators are trained in the specific hazards and special procedures associated with the Lift Emergency procedures addressed for contingency actions.

Critical 1R Item 8 – Shoe Hoist Brake

| Number | Contents |
|---|---|
| 1 | Item Identification: Outboard Shoe Brake |
| 2 | Criticality Category: 1 |
| 3 | Function: Hold load when hoist motor is de-energized. |
| 4 | Failure mode: a) Fails to engage<br>b) Fails to disengage |
| 5 | Cause: a) Spring failure<br>b) Internal part failure |
| 6 | Failure Mode No.: N/A |
| 7 | Failure Effect: a) One of the two brakes will set<br>b) Disc brake will hold load |
| 8 | Critical Items List Acceptance Rationale includes the following items: |

A. Design

Operational redundancy minimizes the probability of occurrence of the critical failure mode and causes. The redundant hardware items are energized during the crane operating cycle. Upon failure of the brake, the remaining redundant brake will continue to perform the holding function.

B. Test

Periodic testing is performed annually for recertification of Crane 10-1. Testing is performed in accordance with Section 202 of NASA-STD-8719.9 (Reference 2). The Operational Test includes a demonstration of each brake's ability to stop and hold a load.

C. Inspections

Daily and Periodic safety inspections are performed in accordance with the Section 203 of NASA-STD-8719.9. Functional operating and control mechanisms are checked daily for maladjustments. Inspections for brake wear are performed annually. Details of the Periodic testing and maintenance are documented in NSI Procedure 25-06-021.

D. Risk Control and Mitigation for Critical 1R Items

As presented in the Critical Category 1R Redundancy Screen Table, the risk of the failed item is controlled and mitigated through the implementation of Daily, Monthly, and Periodic Inspections.

E. Failure History

Loss of load due to brake failure has not been experienced, since the inception of the RECERT Program.

F. Operational Use

Critical lift operators are trained in the specific hazards and special procedures associated with the Lift Emergency procedures addressed for contingency actions.

## 2.9 Criticality Category 1R Items

The FMEA is a single failure point analysis and does not address multiple failures with the following clarification:

> The combined effect of failure of two like and/or unlike redundant items that could result in loss of life/load will be evaluated.

These items are classified as criticality category 1R items. 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:

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

Screen B - Loss of the redundant item is readily detectible by the ground crew. (This screen is not applicable to standby redundancy.)

Screen C - Loss of all redundant items cannot result from a single credible cause, such as contamination.

Accordingly, the following items are identified herein as category 1R items. These items are identified as critical items in accordance with Reference 1. A critical item is defined as any one of the following:

1. A Criticality 1, 1S, or 2 Single Failure Point
2. A redundant hardware item where the second failure results in loss of life or load and the item is not capable of checkout during normal ground operations (i.e., a single fault tolerant item which fails Redundancy Screen A).

The 1R items are addressed on the following redundancy screen summary.

| CRITICALITY CATEGORY 1R REDUNDANCY SCREENS | | | | | |
|---|---|---|---|---|---|
| Crane 10-1<br>Location: Building 10 | | | | | Date: March 2005<br>Prepared by: Mel Crompton |
| PART NAME | FAILURE MODE | FAILURE EFFECT ON CRANE PERFORMANCE | REDUNDANCY SCREENS | | TEST AND INSPECTION REQUIREMENTS FOR RISK CONTROL AND MITIGATION |
| | | | Pass | Fail | |
| Disc Hoist Brake | Loss of electrical power | Unable to operate. Brakes will set. | A, B, C | | Requirements for annual, monthly inspection, and daily validation of the brakes in accordance with NASA-STD-8719.9 |
| | Mechanical failure | Unable to operate. Brakes will set. | A, B, C | | |
| Shoe Hoist Brake | Loss of electrical power | Unable to operate. Brakes will set. | A, B, C | | Requirements for annual, monthly inspection, and daily validation of the brakes in accordance with NASA-STD-8719.9 |
| | Mechanical failure | Unable to operate. Brakes will set | A, B, C | | |
| Initial Hoist Upper Limit Switch | Fails open/ corroded contacts | No up motion. | A, B, C | | Requirements for annual, monthly inspection, and daily validation of the limit switch in accordance with NASA-STD-8719.9 |
| | Fails closed/ contacts fused together | Hoist continues "up" motion and will stop by final limit switch. | C | A, B | |
| Final Hoist Upper Limit Switch | Fails open/ corroded contacts | No up motion. | C | A, B | Requirement for annual operational test of the final upper limit switch, including manual verification that all hoist motion is precluded. |
| | Fails closed/ contacts fused together | Initial limit switch failed. Shuts down crane. | C | A, B | |

## 3.0 Risk Assessment

The following risk assessment evaluation was performed in accordance with Reference 6, NPR 8715.3. A Risk Assessment Matrix is included. The severity and probability estimates for each use of the critical items is documented. The controls are considered to be in place to achieve minimum residual risk.

Definitions for Risk Severity Class and Probability Estimate follow.

Risk Severity Class:

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, or loss of personnel, major systems, or load.

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.

Probability Estimate:

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 or operation, and affected population. The qualitative risk assessment method utilized herein uses the likelihood of occurrence, probability, definitions listed below:

A. Likely to occur immediately
B. Probably will occur in time
C. May occur in time
D. Unlikely to occur
E. Improbable to occur

The risk matrix is completed by documenting each hazard cause, severity, and likelihood of occurrence in the appropriate risk assessment code block.

3.1 Risk Assessment Code (RAC) and Closure

| | 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 |

Crane 10-1 Risk Assessment Code Matrix

A summary of the risk assessment criteria for the Critical Items List components follows.

| Critical Item | Severity Class | Probability | RAC No. |
|---|---|---|---|
| 1. Drum Gear* | Critical (II) | Improbable (E) | 5 |
| 2. Hoist Gearbox* | Critical (II) | Improbable (E) | 5 |
| 3. Motor Coupling* | Critical (II) | Improbable (E) | 5 |
| 4. Motor Coupling* | Critical (II) | Improbable (E) | 5 |
| 5. Initial Hoist Upper Limit Switch* | Critical (II) | Improbable (E) | 5 |
| 6. Final Hoist Upper Limit Switch* | Critical (II) | Improbable (E) | 5 |
| 7. Disc Hoist Brake* | Critical (II) | Improbable (E) | 5 |
| 8. Shoe Hoist Brake* | Critical (II) | Improbable (E) | 5 |

It is noted that the effectiveness of the in place controls and verifications is demonstrated by the fact that lifting device failure has not been a contributing root cause since the inception of the lifting device certification program in 1985.

## 4.0 Controls, Verifications

Controls are summarized below:

- Compliance with Hoisting Standards, i.e., CMAA
- Compliance with OSHA Regulations
- Compliance with AGMA Standards
- Documented, signed, and approved test procedures
- Performance of factory tests before shipment
- Acceptance testing
- Requirement for Daily, Monthly, and Periodic tests and inspections
- Performance of rated load tests

Verifications are as follows:

- Certification documentation
- Certified Critical Lift Crane Operators
- Documented, dated, and signed Test Reports
- Signed Lifting Device Operator Daily Crane and Hoist Inspection and Limit Switch Test Log

## 5.0 Rationale for Criticality Category Downgrade

The criticality categorization for the critical items identified herein have been reassessed for credibility and reasonableness on the basis of operational experience with the equipment. The rationale for acceptability of each of these critical items included consideration of the following data elements: Design, Test, Inspection, Failure History, and Operational Use. Controls and verifications are in place to either eliminate the critical item or achieve minimum residual risk.

It is therefore recommended that the Criticality Category, for the identified Critical Items, be downgraded from a "1" to a "3."

A Hazard Assessment of the remaining risks was performed in accordance with NPG 8715.3, "NASA Safety Manual," determined the Risk Assessment Code (RAC) number to be equal to "5" (see Section 3.1).

Controls and verifications are in place to achieve minimum risk. Assessment of the remaining risks was performed in accordance with NPG 8715.3, "NASA Safety Manual." The Criticality Category of the critical items, see Table 1, was downgraded from the original 1/1R criticality to a "3" due to the consideration of defined and approved operational controls.

## 6.0 Critical Control/Monitor Functions

There are no critical control/monitor functions associated with this crane. No critical control/monitor function analysis is, therefore, required.

## 7.0 End-to-End Analysis

There were no areas of concern identified during this analysis.

## 8.0 Sneak Circuit Analysis

There was no sneak circuit analysis performed on this lifting device.

## 9.0 Recommendations

- Continue to certify the lifting device to reflect operational requirements. Continue to perform maintenance of the critical items per OEM requirements.
- Only certified, trained operators shall be authorized to operate lifting devices.
- Maintain documents/approved test and inspection procedures current.
- Review/update this analysis, as required, to reflect any changes in operation or facility improvements that affect the crane system.

## 10.0 Conclusion

Based on the above analysis, the risk hazard with controls and verification in place, is assessed to be acceptable/controlled. With a RAC 5, it is concluded that this crane is in compliance with the requirements set forth in NASA-STD-8719.9 for performing critical lift operations.