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5-5

ADDENDUM TO FMEA
from Century Crane and Hoist, Inc.

Failure Modes and Effects Analysis (FMEA)
and Critical Items List (CIL) for Crane 5-5
Located in the Building 5 Machine Shop

ManTech Document Number

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Preface

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

- Critical Items List (CIL)
- Rationale for Acceptability
- Recommendations

This document is compliant with the methodology of NSTS 22206, "Requirements for Preparation and Approval of Failure Modes and Effects Analysis and Critical Items List" (Reference 2).

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List of References

The following documents were used in completing this analysis:

1. Failure Mode and Effects Analysis; Century Crane and Hoists; June 11, 2001

2. Requirements for Preparation and Approval of Failure Modes and Effects Analysis (FMEA) and Critical Items List (CIL); NSTS 22206, Revision D; December 10, 1993.

3. Crane Specification to Revamp Crane 5-4 with Radio Control, New Drives, Hoist and Trolley, and Bridge Motors and Crane 5-5 With Radio Control in the Machine Shop Area of Building 5; NSI Document 40-09-309; November, 1999.

4. Operation, Service and Part Manual; Series 700 Shaw-Box; September 1997.

5. NASA-STD-8719.9, NASA "Standard for Lifting Devices and Equipment" May 2002.

6. Specifications for Electric Overhead Traveling Cranes; CMAA Specification #74, 1994.

7. Inspection and Preventive Maintenance Procedure for Bridge Crane 5-5 Procedure 25-06-051-9; March 1996.

8. NPG 8715.3, "NASA Safety Manual," January 24, 2000.

9. Appendix I, Periodic Inspection/Maintenance Report for Bridge Crane 5-5, Building 5, Hi-Bay, NSI Report Number 25-06-051-9, March 1996.

10. "Lifting Device Operator Daily Crane and Hoist Inspection and Limit Switch Test," RECERT 42-001, latest revision.

11. GPR 8719.1, "Certification and Recertification of Lifting Devices and Equipment."

1.0 Summary of Findings

1.1 System Criticality

This analysis includes the changes to crane 5-5 listed below:

- Converted to radio control with back-up pendants
- Bridge and trolley festoon collector systems
- Safety cable added to the bridge runway
- An anti-collision warning system

The 20-ton Main Hoist and 3-ton Auxiliary Hoist support Machine Shop operations in the handling of flight hardware and one-of-a-kind articles. Crane 5-5 functions are identified and assessed on the Criticality Summary Sheet (see Section 2.2).

1.2 Mechanical Critical Items

The Mechanical Critical Items identified by Century Crane and Hoist analysis (Reference 1) are summarized below. The Rationale for Acceptability for retaining the critical items is documented as part of the Critical Item Acceptance Rationale.

No.	Critical Item	Original Criticality	Downgraded Criticality	Risk
1	Compound Internal Gear	1	3	Controlled
2	Compound Planet Gear	1	3	Controlled
3	Bridge Beam	1	3	Controlled
4	Bridge Axles	1	3	Controlled

1.3 Electrical Critical Items

The electrical items identified in this analysis are summarized below:

No.	Critical Item	Original Criticality	Downgraded Criticality	Risk
5	Initial Upper Limit Switch	1R	3	Controlled
6	Final Upper Limit Switch	1R	3	Controlled
7	Hoist Motor Brake,	1R	3	Controlled
8	Mechanical Load 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

GSC 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.

1.4 Critical Control/Monitor Functions

There are no critical control/monitor functions associated with this hoist.

1.5 Hazards Identified

Justification for retaining the critical items listed above was based on the data elements provided in Section 3.0. This justification included the following information: Design, Test, Inspection, Failure History, and Operational Use. Risk assessment, based on the criteria identified in the Reference 8, determined the risk to be acceptable/controlled for the retention of the above critical items.

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 this system.

2.0 Failure Mode and Effects Analysis

2.1 System Description

General

This analysis addresses the retrofit of Crane 5-5. Crane 5-5 consists of a 20-Ton Main and a 3-ton auxiliary Shepard Niles Crane, located in the East High Bay of Building 5. The retrofit includes:

- Radio-control with a back-up pendant
- Flat cable festoon system on the trolley and bridge
- Circuit breaker having a shunt trip
- Installation of a safety cable on the West Side of the crane runway
- An anti-collision warning system indicating when Crane 5-5 is in the working envelope of Crane 5-4
- A strobe light on the crane bridge, indicating power-on

Component Description

Century Crane and Hoist provided a detailed component description (Reference 1). Parts were identified for the Main Hoist, Auxiliary Hoist, Trolley and Bridge. This convention will be continued in this Addendum.

Passive Components

Passive components are not analyzed in the FMEA. The current list of passive components includes the hook, load block, wire rope, sheaves, and rope drum.

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 Attachment Points

Shaft	Method of Attachment	Standard	Criticality
Motor Pinion Shaft	Spline	CMAA	3
Rotor Shaft	Spline, Keys, & Snap Ring	CMAA	3
Air Cooled Brake Shaft	Key	CMAA	3
Motor Shaft Extension	Splined	CMAA	3

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

Drum and Shaft Bearings

NSTS 22206 (see Reference 2) 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
Motor End Frame Bearing	Loss of function
Gear Cage and Drum Bearing	Loss of function
Trolley Axle Bearings	Loss of function
(2) per wheel	Loss of function

In addition to the bearings addressed above, it is similarly noted that the brake ratchet bearings (Main Hoist) may wear, causing binding. Attention to unusual noises and mechanical inspection would prevent loss of load.

Rationale for Acceptability follows:

- Lubricant: manufacturer's recommended or approved equivalent
- The crane typically operates at low speeds
- Crane was designed for Moderate Service (Class C) and operates at Light Service (Class B)

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

2.2 Crane Criticality Assessment

The crane functions are identified and assessed on the following Criticality Assessment Summary Sheet.

CRANE CRITICALITY ASSESSMENT SUMMARY SHEET				
Crane 5-5, East High-Bay Machine Shop Location: Building 5				Prepared By: M.Crompton Date: October 2002
Output	**Function**	**Effect of Loss/Failure**	**Crit Cat**	**Notes**
Handling of Project Flight Hardware	Raises/lowers and provides lateral north/south or east/west direction movement of critical equipment	Load may drop resulting in possible loss of life or injury to personnel, loss of/potential damage to Flight Hardware or both.	Critical	See FMEA Worksheets; Reference 1

3.0 Critical Items List (CIL) Acceptance Rationale

The justification for retaining the critical items identified in Reference 1 (see also Section 1.2) is presented here. The rationale is comprised of the following data elements:

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

The individual CIL sheets follow.

Critical Item 1 – Compound Internal Gear

No.	Contents
1.	Item Identification: Compound Internal Gear, Part No. X-51 Sub-System Series 700, Shepard Niles See Bulletin Sheet No. 2527-A
2.	Criticality Category: 1
3.	Function: Allows the compound gear cage to rotate within the ring gear
4.	Failure Mode: Gearing wear could cause backlash
5.	Cause: Exceeding hoist capacity
6.	Failure Mode Number: N/A
7.	Failure Effect: Loss of critical hardware/personnel safety
8.	Rationale for Acceptability:

Rationale for acceptance 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 intermediate gear meets all the requirements for Class C, "moderate service" and is manufactured to AGMA quality Class 5 or better.

The intermediate 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
- Crane acceptance test procedures

Section 4.0 of Reference 3 addresses in detail the above tests.

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.

Operational tests and inspections 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 intermediate 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 – Compound Planet Gear

No.	Contents
1.	Item Identification: Compound Planet Gear, Part No. X-54 Sub-System Series, Shepard Niles Hoist See Bulletin Sheet No. 2527-A
2.	Criticality Category: 1
3.	Function: Transmits lifting torque and speed 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.	Rationale for Acceptability:

Rationale for acceptance 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 planetary gear meets all the requirements for Class C, "moderate service," and is manufactured to AGMA quality Class 5 or better.

The planetary 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 shipment
- Crane acceptance test procedures

Section 4.0 of Reference 3 addresses in detail the above tests.

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.

Operational tests and inspections 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 planetary 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 3 – Bridge Beam

No.	Contents
1.	Item Identification: Bridge Beam
2.	Criticality Category: 1
3.	Function: Carries the trolley and travels along the runway
4.	Failure Mode: Failure of the lower flange
5.	Cause: Excessive wear
6.	Failure Mode Number: N/A
7.	Failure Effect: Loss of critical hardware/personnel safety
8.	Rationale for Acceptability:

Rationale for acceptance includes the following items.

A. Design

The bridge is designed to meet all the requirements of CMAA 74 (Reference 6). The crane is designed for Class C – Moderate Service. This service covers cranes that may be used in machine shops or paper mill machine rooms, etc., where service requirements are moderate. In this type of service, the crane will handle loads that average 50 percent of the rated capacity with 5 to 10 lifts per hour, averaging 15 feet, not over 50 percent of the lift at rated capacity.

B. Test

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

- Factory tests before shipments
- Crane acceptance test procedures

Section 4.0 of Reference 3 addresses in detail the above tests. Specifically, reference:

4.2 Factory Tests Before Shipment

4.5.1 Crane Acceptance Test Preparation
4.5.2 Crane Acceptance Test Procedures
4.6 Crane Electrification System Factory Tests
4.7 On-Site Complex Electrification System Tests

C. Inspections

Inspections are performed in accordance with Para. 303 of NASA-STD 8719.9 (Reference 5), Inspection and Preventive Maintenance Procedure (Reference 7), and Inspection and Maintenance Report (Reference 9). Operational tests and inspections 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 bridge beam 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 4 – Bridge Axles

No.	Contents
1.	Item Identification: Bridge Axles: (2) per truck Sub-System Shepard Niles Main Hoist See Bulletin Sheet #2276-A, Reference 1
2.	Criticality Category: 1
3.	Function: Shares bridge wheel loads
4.	Failure Mode: Exceeded allowable stress
5.	Cause: Overload
6.	Failure Mode Number: N/A
7.	Failure Effect: Loss of load
8.	Rationale for Acceptability:

Rationale for Acceptability includes the following items.

A. Design

The bridge axles are designed in accordance with Section 3.6, Bridge End Truck of Reference 6 (CMAA Specification #74, 1994).

B. Test

Specific tests to detect failure modes and causes during acceptance and certification tests were performed

- Factory tests before shipments
- Crane acceptance test procedures

Section 4.0 of Reference 3 addresses in detail the above tests. Specifically, reference:

4.2 Factory Tests Before Shipment
4.5.1 Crane Acceptance Test Preparation
4.5.2 Crane Acceptance Test Procedures
4.6 Crane Electrification System Factory Tests
4.7 On-Site Complex Electrification System Tests

C. Inspections

Inspections are performed in accordance with Para. 303 of Reference 5 (NASA-STD 8719.9), Inspection and Preventive Maintenance Procedure (Reference 7), and Inspection and Maintenance Report (Reference 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 bridge axle 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 1R Item 5 – Initial Upper Limit Switch

No.	Contents
1.	Item Identification: Initial Hoist Upper Limit Switch, Geared, Item No. HL 74, Crane 5-5
2.	Criticality Category: 1R
3.	Function: Crane 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 to engage b. Failure mechanism
5.	Cause: a. Corroded contacts b. Contacts fused together
6.	Failure Mode Number: N/A
7.	Failure Effect: a. Hoist will stop and brakes will set if moving up b. No effect. Two limit switches are used
8.	Rationale for Acceptability:

Critical Items List Acceptance Rationale includes the following items.

A. Design

Operational redundancy 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 Crane 5-5. Limit switches/limit switch trip is checked for attachment, position, alignment, and effectiveness.

C. Inspection

Checkout and verification of each limit switch is performed annually during formal Periodic Inspection. Daily inspections, performed by the certified operator, do not include verification 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 Upper Limit Switch

No.	Contents
1.	Item Identification: Final Hoist Upper Limit Switch, Shepard Niles Hoist, Crane 5-5
2.	Criticality Category: 1R
3	Function: All hoisting motion is precluded after the limit switch is encountered.
4	Failure Mode: a Fails open b. Fails closed
5	Cause: a. Corroded contacts b. Contacts fused together
6	Failure Mode Number: N/A
7	Failure Effect: a. Hoist unable to operate b. Hook block does not stop at limit switch.
8.	Rationale for Acceptability:

Rationale for Acceptability 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 5-5 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 25-06-051-9, Inspection and preventive maintenance procedure for Bridge Crane 5-5. 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 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 7 – Hoist Motor Brake

No.	Contents
1	Item Identification: Hoist Motor Brake, Crane 5-5
2	Criticality Category: 1R
3	Function: Hold load after hoisting or when de-energized
4	Failure mode: Fails to engage
5	Cause: Worn brake pads/springs
6	Failure Mode No.: N/A
7	Failure Effect: a. Hoist motor brake fails b. Mechanical load brake will hold the load
8	Rationale for Acceptability:

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

A Periodic Inspection is performed annually for recertification of Crane 5-5. Testing is performed in accordance with Paragraph 4.3 of NASA-STD-8719.9 (Reference 2). The Operational Test includes a demonstration of <u>each</u> brake's ability to stop and hold a load.

C. Inspection

Inspections are performed to a) detect whether or not critical failure modes have occurred and b) to minimize the probability of occurrence of the failure mode and cause. The following inspections are pertinent to the Hoist Motor Brake:

Daily test and inspection: performed by the certified crane operator prior to first use, each day the crane is used. (See RECERT 42-001, April 1991, Revised August 1995, Reference 10).

Functional operating and control mechanisms are checked for maladjustments that could interfere with normal operations.

Frequent and Periodic Inspections are performed in accordance with Reference 7, based on Reference 5 (NASA-STD-8719.9). Periodic inspections are performed annually to identify wear in brake system parts that are readily accessible without major disassembly beyond an acceptable limit.

D. Failure History

Loss of load due to hoist motor brake failure 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 addressed for contingency actions.

Critical 1R Item 8 – Mechanical Load Brake

No.	Contents
1	Item Identification: Mechanical Load Brake Shepard Niles Hoist, Main & Auxiliary Hoist
2	Criticality Category: 1R
3	Function: Used for controlling load speed in the lowering direction, prevents the load from overhauling the motor.
4	Failure mode: Fails to engage
5	Cause: Loss of friction
6	Failure Mode No.: N/A
7	Failure Effect: a. Mechanical load brake fails b. Hoist motor brake will hold the load
8	Rationale for Acceptability:

Rationale for Acceptance includes the following items:

A. Design

Mounted on shaft in the hoist gear train as close to the drum as possible.

B. Test

Periodic testing is performed annually for recertification of Crane 5-5. Load testing is performed in accordance with NSI Reports No. 25-06-051-9 (see Reference 7).

C. Inspections

Checkout and verification of each brake is performed during formal periodic inspection. Details of the periodic inspection are documented in Reference 7. Daily inspections, performed prior to first use each day is addressed in Reference 11, RECERT 42-001.

D. Failure History

Loss of load due to brake failure 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.

3.1 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 5-5, Machine Shop Location: Building 5, 20/3 Ton Bridge Crane					Date: September 2002 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	
Hoist Motor Brake	Loss of electrical power	Unable to operate. Brakes will set	C	A/B	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.			
Mechanical Load Brake	Loss of electrical power	Unable to operate. Brakes will set	C	A/B	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			
Initial Hoist Upper Limit Switch	Fails open/ corroded contacts	No up motion.	A/C	B	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.			
		Final limit switch available.			
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	Two blocks. Shuts down crane.			
		Initial limit switch available			

3.2 Risk Assessment

The following risk assessment evaluation was performed in accordance with Reference 8, NPG 8715.3. A Risk Assessment Matrix is included (see Table 2). The severity, Probability Estimates and Risk Assessment Code (RAC) number 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 of operation, and affected population. The following is an example of Probability Estimation:

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

(Derived from Mil Std 882-System Safety Program Requirements)

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

Risk Assessment Code (RAC)

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

Critical Item	Severity Class	Probability	RAC No.
1. Compound Internal Gear*	Class II Critical	Improbable (E)	5
2. Compound Planet Gear*	Class II Critical	Improbable (E)	5
3. Bridge Beam*	Class II Critical	Improbable (E)	5
4. Bridge Axle*	Class II Critical	Improbable (E)	5
5. Initial Upper Limit Switch*	Class II Critical	Improbable (E)	5
6. Final Upper Limit Switch*	Class II Critical	Improbable (E)	5
7. Hoist Motor Brake*	Class II Critical	Improbable (E)	5
8. Mechanical Load Brake*	Class II Critical	Improbable (E)	5

	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

Table 2
Crane 5-5 Risk Assessment Code Matrix

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.

4.1 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 Table 2).

5.0 Control Logic Analysis

There is no control logic associated with this lifting device.

6.0 End-to-End Analysis

There were no areas of concern identified during this analysis.

7.0 Sneak Circuit Analysis

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

8.0 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.

9.0 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.