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Failure Modes and Effects Analysis
of the Four Leaf Vertical Lift Doors
Located at the SSDIF Cleanroom and the Building 10/29 Interface

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Table of Contents

List of Figures ii
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 Hazards Identified 2
1.5 Critical Flexhoses 2
1.6 Critical Orifices 2
1.7 Critical Filters 2
1.8 End-to-end Areas of Concern 2
1.9 Sneak Circuits Identified 2
2.0 Failure Modes and Effects Analysis 2
2.1 Ground Rules and Definitions 2
2.2 Door Description 2
2.3 System Criticality Assessment 3
2.4 Mechanical FMEA and Block Diagram 5
2.5 Electrical Critical Items 10
2.6 Critical Flex Hoses 10
2.7 Critical Orifices 10
2.8 Critical Filters 10
2.9 Criticality Category 1R Items 10
3.0 Critical Items Lists 10
3.1 Critical Items Acceptance Rationale 10
Critical Item 1 – Door Safety Devices 11
Critical Item 2 - Upper Limit Switch 13
Critical Item 3 - Lower Limit Switch 15
Critical Item 4 – Solenoid Disc Brake 17
3.2 Criticality Category 1R Items 19
4.0 Controls, Verifications 22
5.0 Rationale For Criticality Category Downgrade 22
6.0 Control Logic Analysis 22
7.0 End-To-End Analysis 22
8.0 Sneak-Circuit Analysis 23
9.0 Recommendations 23
10.0 Conclusion 23

List of Figures

Figure		Page
1	Four Leaf Vertical Door, Door No. 130^{L},	4
2	Risk Assessment Code Matrix for the Four Leaf Vertical Lift Doors	21

References

The following documents were used in completing this analysis:

Document/Drawing No.	Title
1. 87-1D-583, Sheet Nos. A1, A2, and E1	Four Leaf Vertical Lift Door; Double Skin Insulated-Motor Operated; Door Nos. 130^L and $134C^L$, respectively
2. NSTS 22206	Requirements for Preparation and Approval of Failure Modes and Effects Analysis (FMEA) and Critical Items List
3. NPR 8715.3	NASA Safety Manual, January 24, 2000

1.0 Summary of Findings

1.1 System Criticality

The four leaf vertical lift doors (International Door) are assessed as critical because failure of these doors could cause the loss of life and/or critical flight hardware.

1.2 Mechanical Critical Items

The Mechanical Critical Items identified are summarized below. The Rationale for Acceptability is documented as part of the Critical Items List (reference Section 3.0). The Rationale for Criticality Category Downgrade is presented in Section 5.0 in consideration of defined and approved controls and verifications.

No.	Critical Item	Original Criticality	Downgraded Criticality	Risk
1	Door Safety Devices	1R	3	Controlled
2	Upper Limit Switch	2	3	Controlled
3	Lower Limit Switch	2	3	Controlled
4	Solenoid Disc Brake	2	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 vehicle.
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 load.
2	Single failure which could result in loss (damage) of a vehicle system.
3	All others.

1.3 Electrical Critical Items

See Table 1, Section 1.2.

1.4 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 Reference 3 determined the risk acceptable/controlled for the retention of the above critical items.

1.5 Critical Flexhoses

There were no critical flexhoses identified in this lifting device.

1.6 Critical Orifices

There were no critical orifices identified in this lifting device.

1.7 Critical Filters

There were no critical filters identified in this lifting device.

1.8 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.

1.9 Sneak Circuits Identified

There was no sneak circuit analysis performed on the four leaf vertical lift doors.

2.0 Failure Modes and Effects Analysis

2.1 Ground Rules and Definitions

This analysis has been developed in accordance with Reference No. 2 and the following additional ground rules and assumptions.

a. Roller chain and sprocket are considered as passive components.

2.2 Door Description

Two four-leaf vertical lift doors are located in the Building 29 and 10 complex. One door is located at the west entrance to the Building 29 Cleanroom; the other is located at the Building 29/10 interface.

The motor operator power is supplied by a 1-1/2 HP motor - 3∅, 60 Hz. Torque is applied to the hoist drum assembly via a chain/sprocket/reduction assembly. The hoisting/lowering of the right and left door edges is accomplished via wire rope (5/16 inch diameter, 6x37, imp plow steel), running in concealed cable sheaves with sealed ball bearings. Door alignment is provided by multiple door side rollers. Door position, open/closed, is controlled by the use of upper and lower single acting counter balance limit switches. Door design includes 6,000 lbs. of counterweights, each door leaf weighs 2,400 lbs. There is a total of four (4) leafs.

Two modes of door operation are provided: the first, motor operator, as discussed above, and second, hand operation via a hand operation shift lever. The auxiliary hand chain operator has a maximum pull of 15 lbs.

In addition to the safety devices mentioned above, the following safety features are included in operation of the door.

- If the door should strike an obstruction while closing, it will reverse and return to the full open position.
- A failure of any component within the fail-safe safety edge control circuit will prevent the door close cycle from being initiated.

2.3 System Criticality Assessment

The system functions are identified and assessed on the following Criticality Assessment summary sheets.

System Criticality Assessment Summary Sheet				
System: Four Leaf Vertical Lift Doors			No. 130^L and $124C^L$	
Location: SSDIF Cleanroom and the Building 10/29 interface			Prepared By: M. Crompton	
Output	Function	Effect of Loss/Failure	Criticality Category	Notes
Controls passage of flight hardware, negates degradation of cleanroom pressure and controls contamination input.	Provides output function on critical path from Building 7 to the Building 29 SSDIF Cleanroom.	Doors may drop resulting in possible loss of life or injury to personnel, loss of/potential damage to critical flight hardware.	Critical	See FMEA worksheets.

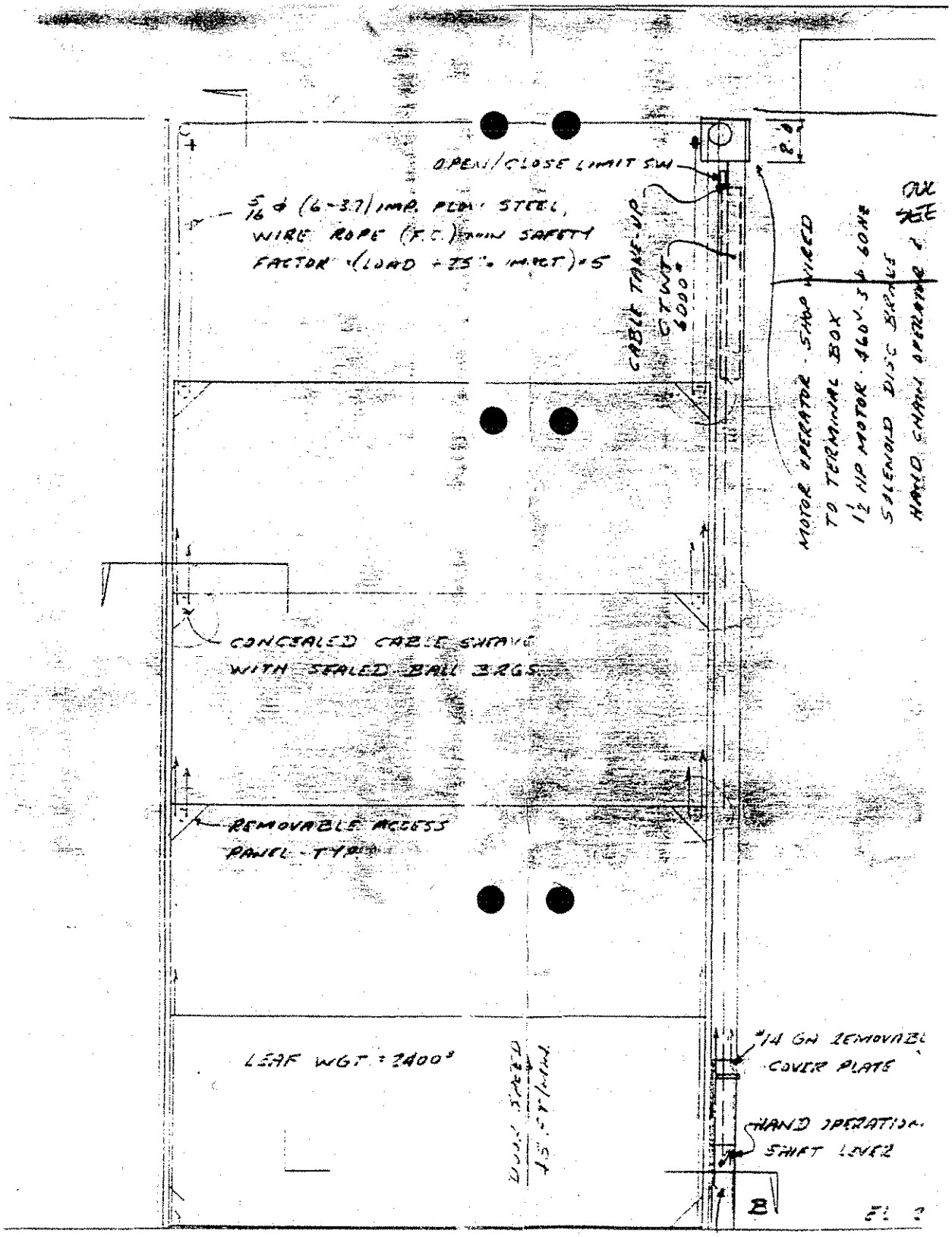
OPEN/CLOSE LIMIT SW
5/16 ϕ (6-3.7) IMP. PLOW STEEL, WIRE ROPE (F.C.) MIN SAFETY FACTOR (LOAD + 25% IMPACT) × 5
CABLE TAKE-UP
CTWT 6000#
MOTOR OPERATOR - SHOP WIRED TO TERMINAL BOX
1½ HP MOTOR - 460V - 3 ϕ - 60HZ
SOLENOID DISC BRAKE
HAND CHAIN OPERATOR
CONCEALED CABLE SHEAVE WITH SEALED BALL BRGS.
REMOVABLE ACCESS PANEL - TYP.
LEAF WGT = 2400#
#14 GA REMOVABLE COVER PLATE
HAND OPERATION SHIFT LEVER
B

Figure 1

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET					
Four Leaf Vertical Lift Door, No. 130[L] Building No. 29, Cleanroom West Entrance and the Building 29/10 Interface				Prepared by: M. Crompton	
Part Name	Part Function	Failure Mode and Cause	Failure Effect on System Performance	Failure Effect on Flight Hardware and/or Personnel Safety	RAC
1-1/2 HP Motor	Provides power to drive cable take-up.	Inoperative open, shorted windings.	None. Solenoid disc brake will set. Door lift inoperative.	Degradation of cleanroom pressure/contamination control if door stops in open position. Delay due to repair.	5
Leaf Clip, terminal stop	Stops individual leafs, nos. 2, 3, or 4, in the correct position when lowering.	Weld/clip failure. Faulty component overload.	Affected leaf would lower to the next lower position and the lift clip on the affected leaf would engage the next lower leaf.	Degradation of cleanroom pressure/contamination control. Delay due to repair.	5
Solenoid Disc Brake	When de-energized, stops, hold load.	Disc(s) failure Spring(s) failure Faulty component Wear, fatigue	Effect is a function of number of failed components. Brake failure in the "up" direction would cause the leaf to actuate the upper limit switch, securing electrical power. Safety devices would actuate in the event of slack rope.	Degradation of cleanroom pressure/contamination control. Delay due to repair.	5
	When energized, brakes release and door is operative.	Fails to energize brakes hold the door. Faulty component.	Motor current overloads – will secure power. Door is inoperative.	Degradation of clean-room pressure/ contamination control if door stops in open position. Delay due to repair.	5

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET					
Four Leaf Vertical Lift Door, No. 130[L] Building No. 29, Cleanroom West Entrance and the Building 29/10 Interface				Prepared by: M. Crompton	
Part Name	Part Function	Failure Mode and Cause	Failure Effect on System Performance	Failure Effect on Flight Hardware and/or Personnel Safety	RAC
Wire Rope	Provides for door lift.	Rope failure. Broken wires, wear. Cracked, etc., end attachment.	Activates door safety device. If one wire rope fails, in the down direction, the safety device will actuate. The remaining rope will attempt to hold the door. If both ropes fail, both safety devices actuate, stopping descent. If one wire rope fails in the up direction, the remaining rope will attempt to lift possibly causing jamming. Overload would secure power. If both wire ropes fail in the up direction, safety devices actuate, stopping descent.	Degradation of cleanroom pressure/contamination control if door stops in open position. Delay due to repair.	5
Door Safety Devices	Stops bottom/engaged leafs.	Faulty component.	None. Delay due to repair.	Delay in operation.	5
Leaf Clips, Lift	Provides for lift of individual leafs, nos. 2, 3, and/or 4.	Weld/clip failure.	Unable to raise leaf(s) with failed clip(s).	Inability to relocate flight hardware as a function of leaf no. failure versus flight hardware height. Delay due to repair.	5

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET					
Four Leaf Vertical Lift Door, No. 130[L] Building No. 29, Cleanroom West Entrance and the Building 29/10 Interface				Prepared by: M. Crompton	
Part Name	Part Function	Failure Mode and Cause	Failure Effect on System Performance	Failure Effect on Flight Hardware and/or Personnel Safety	RAC
Reduction Coupling	Provides connection between reduction side and wire rope drums.	Loss of coupling. Sheared keys. Broken chain.	All leafs drop.	Both safety devices activate stopping descent.	5
Cable Drum	▪ Stores wire rope during the hoisting operation. ▪ Provides rope anchor.	▪ Allowable stress exceeded, causing crushing. ▪ Non-Code design. ▪ Non-uniform material properties.	Slack in both ropes would cause both safety devices to actuate, stopping descent.	Degradation of cleanroom pressure/ contamination control if door stops in open position. Delay due to repair.	5
Hoist drum assembly including shaft, pillow block, & bearing mounts.	Transmits torque for hoisting/ lowering operation.	▪ Faulty shaft attachment. ▪ Excessive loads. ▪ Insufficient design safety standard. ▪ Faulty component.	Slack in both ropes would cause both safety devices to actuate, stopping descent.	No effect. Delay due to repair.	5
Limit Switches	Limits up/down position of the counter weight.	Fails open/corroded contacts. Fails closed/ contacts fused together.	No door motion. Motor overload, loss of power, brake will set	No effect. Delay due to repair.	5
Door Side Rollers	Maintains door alignment.	Misalignment due to bearing failure – lack of lubrication.	Eight rollers are provided per leaf. The degree of misalignment would be a function of the number of failed rollers.	No effect. Delay due to repair.	5

FAILURE MODE AND EFFECTS ANALYSIS (FMEA) WORKSHEET					
Four Leaf Vertical Lift Door, No. 130[L] Building No. 29, Cleanroom West Entrance and the Building 29/10 Interface				Prepared by: M. Crompton	
Part Name	Part Function	Failure Mode and Cause	Failure Effect on System Performance	Failure Effect on Flight Hardware and/or Personnel Safety	RAC
Cable Sheave	Provides mechanical advantage for the hoisting/ lowering operation.	The size and condition of the sheave groove determine rope life.	Sheave wear may alter rope alignment or may result in excessive rope wear.	No effect. Delay due to repair.	5
Drive Sprockets.	Transmits torque to the drive train.	Disengagement. Faulty component.	Torque for holding the leaf will be lost. Leaf will drop.	Both ropes fail, both safety devices actuate, stopping descent.	5

2.5 Electrical Critical Items

The limit switches, LS1 and LS2, are identified as electrical critical items.

2.6 Critical Flex Hoses

There are no flex hoses associated with this equipment.

2.7 Critical Orifices

There are no orifices associated with this equipment.

2.8 Critical Filters

There are no filters associated with this equipment.

2.9 Criticality Category 1R Items

There were two Criticality 1R items identified in the critical output functions in Section 2.4.

3.0 Critical Items Lists

No.	Critical Item
1	Door Safety Devices
2	Upper Limit Switch
3	Lower Limit Switch
4	Solenoid Disc Brake

3.1 Critical Items Acceptance Rationale

The justification for retaining the identified critical items 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 – Door Safety Devices

Number	Contents
1	Item Identification: Safety Devices
2	Criticality Category: 1R
3	Function: The function of the safety devices is to lock the doors in the event that the cable breaks.
4	Failure Mode: Faulty component
5	Cause: Structural failure of components
6	Failure Effect:

Safety devices are located at the bottom left and right of the lower leaf. The most likely failure mode would be failure of a single safety device, causing the leaf to stop and possibly tilt. Door operation would subsequently be delayed for repair. Failure of both safety devices, i.e., multiple failures, would be required to drop the door leafs. The probability of this latter event occurring would be many times greater than a single failure.

7 Rationale for Acceptability:

Rationale for acceptance includes the following items.

A. Design

- Cable safety devices are redundant
- Low estimated usage (approximately 56 times per week).
- Safety device operation is contingent on the cable breaking. The cable is inspected annually. Redundant cables are provided for each leaf.
- The safety device RAC No. 5 is estimated to be an IIE (i.e.,Critical – Improbable).

Reference 3 considers a RAC 5 to be a low risk level.

B. Test

- Test and inspections are performed annually.
- Operation and maintenance is performed in accordance with procedures documented by International Door, Inc., designers/manufacturers of the vertical lift doors.

C. Inspections

Documentation of the annual tests and inspections were maintained by the Recertification Function Manager. Worn cast iron components are replaced with steel components on both the door with the worn component and the second door. Associated records are maintained for analysis.

D. Failure History

- Failure of the cable safety devices has not occurred since installation of the vertical lift doors.
- Unexplained anomalies have not/do not exist.

E. Operational Use

- Corrective action post safety device failure would consist of prompt problem identification, repair/replacement of the defective device, as required.
- Door actuation, contingent on the type of problem, would be via the auxiliary hand chain operator to mitigate the effects of failure once it has occurred.
- See also, Item 7.a., "Design," above.

Critical Item 2 - Upper Limit Switch

Number	Contents
1	Item Identification: Limit Switch
2	Criticality Category: 1R
3	Function: Limits up position of the counterweights
4	Failure Mode: Faulty Component
5	Cause: Failure open/closed
6	Failure Effect: Open: No up motion. Failure Effect Closed: The overload will trip, causing the loss of power. The brake will set. Delay in operation.
7	Rationale for Acceptability

Rationale for acceptance includes the following items.

A. Design

The limit switch is adjusted at the time of installation. The reliability of the design is such that the need for further adjustment should not be required.

B. Test

Specific tests performed to detect failure mode and causes consist of running the door through a complete cycle and checking the operation of all components.

C. Inspection

All controls are visually inspected to determine whether or not critical failure modes have occurred. Components are inspected for broken parts and replaced as required.

D. Failure History

- Limit switch failure has not occurred since installation of the vertical lift doors.
- Unexplained anomalies have not/do not exist.

E. Operational Use

The operator will secure door operation and report failure to the RECERT group. The cause of failure will be determined and the on-call door service contractor contacted to inspect/repair deficient components. Door contractor emergency response has been timely.

Critical Item 3 - Lower Limit Switch

Number	Contents
1	Item Identification: Limit Switch
2	Criticality Category: 1R
3	Function: Limits down position of the counterweights
4.	Failure Mode: Faulty Component
5	Cause: Failure open/closed
6	Failure Effect: Open: No down motion. Failure Effect: Closed: The motor overload will trip, causing the loss of power. The brake will set. Delay in operation.
7	Rationale for Acceptability

Rationale for acceptance includes the following items.

A. Design

The limit switch is adjusted at the time of installation. The reliability of the design is such that the need for further adjustment should not be required.

B. Test

Specific tests performed to detect failure mode and causes consist of running the door through a complete cycle and checking the operation of all components.

C. Inspection

All controls are visually inspected to determine whether or not critical failure modes have occurred. Components are inspected for broken parts and replaced as required.

D. Failure History

- Limit switch failure has not occurred since installation of the vertical lift doors.
- Unexplained anomalies have not/do not exist.

E. Operational Use

The operator will secure door operation and report failure to the RECERT group. The cause of failure will be determined and the on-call door service contractor contacted to inspect/repair deficient components. Door contractor emergency response has been timely.

Critical Item 4 – Solenoid Disc Brake

Number	Contents
1	Item Identification: Solenoid disc brakes
2	Criticality Category: 1
3	Function: Hold load after hoisting or when de-energized
4	Failure Mode: a. Fails to engage b. Fails to disengage
5	Cause(s): a. Excessive disc wear b. Lack of power
6	Failure Mode Number: N/A
7	Failure Effect: Safety devices are automatically actuated to hold the doors, in the event of slack cable(s).
8	Rationale for Acceptability

Rationale for acceptance includes the following items:

A. Design

The design features which minimize the probability of occurrence of door failure consist of the aforementioned redundant wire rope attachment points and the redundant safety devices.

B. Test

Periodic testing is performed annually for recertification of the subject doors. Testing is performed by (a) removal of the counter weight loading, (b) causing slack in the leaf wire rope, and (c) verification of safety device actuation.

C. Inspection

Inspections performed during the annual maintenance are described in the attached International Door, Inc., procedure. Operating instructions, maintenance, and lubrication are addressed.

D. Failure History

Current data on annual test, inspection, and maintenance results, including component failures/replacement, are maintained on file at the Recertification Function office. Copies are available upon request.

E. Operational Use

The operator will secure door operation in the event of a malfunction and report failure to the Recertification Function. The cause of failure will be determined and the on-call door service contractor contacted to inspect/repair deficient components. Door contractor emergency response has been timely.

3.2 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 2. 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).

There were two (2) Category 1R items identified during the failure modes and effects analysis, Section 2.

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

CRITICALITY CATEGORY 1R REDUNDANCY SCREENS					
Four Leaf Vertical Lift Doors Located at SSDIF Cleanroom and Building 10/29 Interface					Prepared By: M. Crompton
PART NAME	FAILURE MODE	FAILURE EFFECT ON SYSTEM PERFORMANCE	REDUNDANDY SCREENS		TEST AND INSPECTION REQUIREMENTS FOR RISK CONTROL AND MITIGATION
			PASS	FAIL	
Door Safety Devices	Stops bottom leaf. Faulty component.	Safety device fails causing lower leaf to stop and possibly tilt. Multiple failures would be required to drop the door leaf.	A, C		Test, inspection and maintenance performed in accordance with manufacturer's recommendations.
Upper Limit Switch	Fails open/Corroded contacts.	No up motion.	A, C		Test, inspection, and maintenance performed in accordance with manufacturer's recommendations.
	Fails closed.	Motor overload trips, loss of power brakes set.			
Lower Limit Switch	Fails open/corroded contacts.	No down motion.	A, C		Test inspection and maintenance performed in accordance with manufacturer's recommendations.
	Fails closed. Contacts fused.	Motor overload trips, loss of power, brakes set.			
Solenoid Disc Brake	Loss of electrical power.	Unable to operate. Brakes will set.	A, C		Test, inspection and maintenance performed in accordance with manufacturer's recommendations.
	Mechanical failure.				

3.3 Risk Assessment

The following risk assessment evaluation was performed in accordance with Reference 3, NPR 8715.3. A Risk Assessment Matrix is included, see Figure 2. The severity and probability estimates for each of the critical items are 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 on the ground, or loss of crew, major systems, or vehicle during the mission.

Class II – Critical – A condition that may cause severe injury or occupational illness, or major property damage to facilities, systems, equipment, and 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 personnel 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 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.

Risk Assessment Code Matrix

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

Figure 2

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

	Critical Item	Severity Class	Probability	RAC No.
1.	Door Safety Devices	Class II Critical	Improbable (E)	5
2.	Upper Limit Switch	Class II Critical	Improbable (E)	5
3.	Lower Limit Switch	Class II Critical	Improbable (E)	5
4	Solenoid Disc Brake	Class II Critical	Improbable (E)	5

It is noted that the effectiveness of the in place controls and verifications is demonstrated by the fact that vertical lift door 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:

- Manufacturer's requirement for annual inspection, maintenance and lubrication of the Critical Items.

Verification as follows:

- Documented, dated, and signed inspection/maintenance report.

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 to a "3".

A Hazard Assessment of the remaining risks was performed in accordance with NPR 8715.3, "NASA Safety Manual," determined the Risk Assessment Code (RAC) number to be equal to "5", (see Figure 2.).

6.0 Control Logic Analysis

There is no control logic associated with the vertical lift doors.

7.0 End-To-End Analysis

No areas of concern were identified which are the design responsibility of other contractors or NASA Centers

8.0 Sneak-Circuit Analysis

There was no sneak circuit analysis performed on the vertical lift doors.

9.0 Recommendations

- Continue to perform manufacturer's recommended annual inspection, maintenance, and lubrication.
- Maintain verification documentation current.
- Review/update this analysis, as required, to reflect any changes in operation or improvements that affect the four-leaf vertical lift doors.

10.0 Conclusion

Based on the above analysis, the risk hazard with controls and verification in place, is assessed to be acceptable/controlled.