Michoud Assembly Facility

Rigging Crane Rails Employee Injury

Type B Mishap

NMIS Case Number: 23-101175

Date of Mishap: September 22, 2023

Date of Report: November 17, 2023

WARNING: This document is Controlled Unclassified Information (CUI)

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Acknowledgments

The Mishap Investigation Team wishes to thank the personnel of the prime contractor, subcontractor, and NASA Michoud Assembly Facility personnel for their help and cooperative support throughout the time of the accident investigation. The Team gratefully acknowledges the contributions made by the following individuals and organizations:

Name	Responsibility	Organization
Wilbert Wheeler	Ex Officio	MSFC/QD
Christi Dame	Legal Advisor	MSFC/LS
Molly Porter	Public Affairs	MSFC/CS
Bonnie Sanders	Mishap Interim Response	MAF/S3
Marcus Sanchez/Jared Sweatman	Mishap Interim Response	MAF/Bastion
Security Personnel	MAF Protective Services	MAF/AS
David Howitt/Lykanta Wilson	MAF Safety	MAF/QD
St. Bernard Fire Department	Emergency Medical Services	Chalmette, LA
Acadian Air Med	Emergency Medical Services	Lafayette, LA
Kristie French	NSC Support	MSFC/NSC
Jennifer Hanselman	Technical Writer	GRC/NB

1.0 Charter and Response

1.1 Signature Pages

Investigating Authority Signatures

To the best of my knowledge, the report contents are accurate and complete, and I concur with the documented findings and recommendations.

RUTH JONES Digitally signed by RUTH JONES
Date: 2023.12.18 14:34:12 -06'00' 12.18.2023

Signature Date

Dr. Ruth Jones, Chair
Deputy Division Chief, Avionics—ES30
NASA Marshall Space Flight Center

To the best of my knowledge, the report contents are accurate and complete, and I concur with the documented findings and recommendations.

Milford Olinger Digitally signed by Milford Olinger
Date: 2023.12.18 14:28:34 -06'00' 12/18/2023

Signature Date

M. Frank Olinger, ASP, Member
System Safety, Mishap Manager, Human Factors POC — QA10
SSC Safety and Mission Assurance

To the best of my knowledge, the report contents are accurate and complete, and I concur with the documented findings and recommendations.

Geoffrey Card Digitally signed by Geoffrey Card
Date: 2023.12.20 10:25:58 -06'00' 12.20.2023

Signature Date

Geoff Card, Member
Safety Specialist, Safety and Mission Assurance — QD12
Fall Protection Subject Matter Expert
MSFC Safety and Mission Assurance

To the best of my knowledge, the report contents are accurate and complete, and I concur with the documented findings and recommendations.

James Polk Digitally signed by James Polk Date: 2023.12.18 17:55:57 -05'00' 12/18/2023

Signature Date

Dr. J.D. Polk, Member
Medical Doctor — Subject Matter Expert
HQ-QA000

Ex Officio Signature

I assure the following:

The investigation was conducted in conformance with NASA policy and NASA Procedural Requirements 8621.1.

a. The investigation process is fair, independent, and non-punitive.

b. The mishap report contains all the required elements.

c. Adequate facts have been gathered and analyzed to substantiate the findings.

d. The mishap report accurately identifies the proximate cause(s), root cause(s), and contributing factor(s).

e. The recommendations reasonably address the causes and findings.

f. Each recommendation can be tied to a finding.

I also concur with this report.

Wilbert Wheeler Digitally signed by Wilbert Wheeler Date: 2023.12.20 10:33:40 -06'00' 12/20/2023

Signature Date

Wilbert Wheeler, Ex Officio
Safety Engineer, Industrial Safety — QD12
Marshall Space Flight Center, Safety and Mission Assurance

Advisors' Signatures

I sign this report indicating that any privileged or proprietary information, ITAR information, EAR information, or material subject to the Privacy Act has been identified and marked as non-releasable to the public (e.g., NASA CUI); and that volumes/appendices that are releasable to the public are marked releasable. Additionally, this report is consistent with the policies and procedures in my functional area.

CHRISTI DAME Digitally signed by CHRISTI DAME Date: 2024.01.16 11:42:46 -06'00' 01.16.2024

Signature Date

Christi Dame
Legal Advisor
Office of Chief Counsel
MSFC

I sign this report indicating that any privileged or proprietary information, ITAR information, EAR information, or material subject to the Privacy Act has been identified and marked as non-releasable to the public (e.g., NASA CUI); and that volumes/appendices that are releasable to the public are marked releasable. Additionally, this report is consistent with the policies and procedures in my functional area.

MOLLY PORTER Digitally signed by MOLLY PORTER Date: 2023.12.18 14:41:55 -06'00' 12.18.2023

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Molly Porter
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Office of Strategic and Communications
MSFC

I sign this report indicating that any privileged or proprietary information, ITAR information, EAR information, or material subject to the Privacy Act has been identified and marked as non-releasable to the public (e.g., NASA CUI); and that volumes/appendices that are releasable to the public are marked releasable. Additionally, this report is consistent with the policies and procedures in my functional area.

KRISTIE FRENCH Digitally signed by KRISTIE FRENCH
Date: 2024.01.16 14:06:40 -06'00'

Signature

1.16.2024

Date

Kristie French
Mishap Investigation Specialist
NASA Safety Center

1.2 Transmittal Letter

November 17, 2023

QD01

TO: Joseph Pelfrey, Acting Director, Marshall Space Flight Center

FROM: Dr. Ruth Jones, Chairperson, MAF Rigging Crane Rails Employee Injury, Type B Mishap, Mishap Investigation Team

SUBJECT: Final Mishap Investigation Team Report of the Rigging Crane Rails Employee Injury (NMIS Case 23-101175), Type B Mishap, at Michoud Assembly Facility, September 22, 2023

Pursuant to your letter of October 3, 2023, which established the Mishap Investigation Team (MIT) for the Rigging Crane Rails Employee Injury (NMIS Case 23-101175) at Michoud Assembly Facility on September 22, 2023, I am pleased to inform you that the MIT concluded its investigation into circumstances surrounding this Type B Mishap. All activities were concluded in accordance with NPR 8621.1, "NASA Procedural Requirements for Mishaps, Close Calls Reporting, Investigation and Record Keeping."

This letter transmits the final report of the Rigging Crane Rails Employee Injury Investigating Authority for the Type B mishap that occurred on September 22, 2023.

Dr. Ruth Jones
Mishap Investigation Board Chair

1.3 Appointment Letter

National Aeronautics and Space Administration

George C. Marshall Space Flight Center
Marshall Space Flight Center, AL 35812

October 3, 2023

Reply to Attn of: DA01

TO: Distribution

FROM: DA01/Director (Acting)

SUBJECT: Appointment of Type B Mishap Investigation Team, Rigging Crane Rails Employee Injury (NMIS Event 23-101175)

REF: NPR 8621.1, NASA Procedural Requirements for Mishap Reporting, Investigating, and Recordkeeping

This memorandum establishes the Mishap Investigation Team (MIT) to investigate the injury to an employee at the Michoud Assembly Facility (MAF), Building 103, on September 22, 2023. While completing the rigging of a crane rail for a lift, the employee was climbing down, a different rail became dislodged and fell on the employee's leg. Because of the potential for a permanent disability, I am classifying this mishap as a Type B in accordance with NPR 8621.1.

I am appointing Dr. Ruth Jones/ES30 as the Chair of this Mishap Investigation Team; the remaining Team members are listed in the enclosure.

The MIT Chair will report to me on all aspects regarding the investigation. In accordance with the NPR, the MIT will complete the following actions:

· Obtain and analyze evidence, facts, and opinions it considers relevant.

· Conduct tests and any other activity it deems appropriate.

· Impound property, equipment, and records as considered necessary (consistent with the agreements with the international partners and contractors).

· Determine the root cause, proximate causes, intermediate causes, and contributing factors relating to the mishap.

· Develop recommendations that are clear, verifiable, and achievable in order to prevent recurrence or similar mishaps from occurring.

· Provide a final written report to me that will conform to all requirements in the referenced

Enclosure:

Mishap Investigation Team (MIT) for Building 103 Rigging Crane Rails (rail fell on employee's leg), Type B Mishap.

The following individuals are the members of the MIT:

Name	Organization	Responsibility
Dr. Ruth Jones	MSFC-ES30	Chairperson
M. Frank Olinger	SSC-QA10	Mishap Investigator – Human Factors
Geoff Card	MSFC-QD12	Mishap Investigator – Subject Matter Expert
Dr. J. D. Polk	HQ-QA000	Medical Doctor

The following individual will serve as the Ex Officio to the MIT and will complete applicable tasks as outlined in NPR 8621.1D:

Name	Organization	Responsibility
Wilbert Wheeler	MSFC-QD12	Ex Officio

The following individuals are considered support staff to the MIT:

Name	Organization	Responsibility
Christi Dame	MSFC-LS01	Legal Advisor
Molly Porter	MSFC-CS80	Public Affairs Advisor
Kristie French	MSFC-NC00	Mishap Investigation Specialist

1.4 Executive Summary

On Friday, September 22, 2023, at approximately 8:54 a.m. Central Daylight Savings Time (CDST), a construction worker, herein referred to as the injured party (IP), was injured while performing construction work at Building 103 at the NASA Michoud Assembly Facility (MAF) campus.

An upgrade of the steel structure in Building 103 was being undertaken to allow a crane to run along the rails to move and assemble flight hardware throughout the facility. The subcontractor was awarded a contract on October 17, 2022, to replace cranes and runways in Building 103 with 20-foot and 40-foot steel beams that measured 12.5 inches in height.

Steel beams were stacked five high (~6'8") including dunnage (4"x4" wood) under each beam in the G5-G6 area of Building 103-1 in what is termed a "lay-down area." Each steel beam is 12.5 inches high, 20 feet or 40 feet long, weighs 900 pounds or 1,800 pounds respectively, and dunnage is approximately 3.5 inches in height. During the activity, the construction subcontractor employees, herein referred to as subcontractor, had to change their method of lifting the steel beams because their temporary storage space for the lay-down area was reduced. Previously, the subcontractor had a larger temporary lay-down area and the beams were only stacked one to two beams high (~16 to 32 inches), which did not require workers to climb or mount the beams to attach rigging. During this activity, a beam was removed from the stack, placed on the floor, rotated 180 degrees with the wide portion of the beam facing upward, and then transported to the work area and raised into place for welding and installation into the rafters.

At the time of the mishap, the IP had just placed a beam clamp and hand tightened the jack screw on a beam on the fifth level (~6'8") of the stack, while standing on the fourth level (~5'4") of the stack atop the beams. The IP then stepped down with their right foot onto dunnage that was located between the third and fourth levels of the beam stack. Upon stepping on the dunnage, the dunnage broke, sending beams from the level above the dunnage to plummet straight down, and causing the IP to fall. During the fall, the IP's left foot contacted a beam on the fifth level, which caused the beam to fall onto a second beam on the fifth level, sending both beams tumbling down the stack toward the floor. The IP impacted the ground and remaining stack with right arm, and one of the tumbling beams from the fifth level impacted and entrapped IP's right lower extremity. The fall was above 4 feet, but below 6 feet. The steel beam that impacted IP's leg from a height and entrapped IP weighed at least 900 pounds.

IP's working team, which consisted of the forklift driver, spotter, and additional personnel, lifted the steel beam by hand off the IP's right leg and placed cribbing under the beam to allow the IP to lift right lower extremity out from under the beam. The right lower extremity sustained an obvious compound fracture with profuse arterial bleeding. A security officer placed a makeshift tourniquet on the IP shortly after arrival. The fire department personnel placed additional tourniquets on the limb to stop the bleeding. The IP was taken by ambulance to a landing zone to await an emergency services helicopter. The IP was airlifted to the trauma center for definitive care. The IP required surgery and ultimately suffered the loss of the right lower extremity, resulting in a permanent partial disability.

The Mishap Investigation Team (MIT) was officially appointed by Joseph Pelfrey, the Acting Center Director at Marshall Space Flight Center, on Tuesday, October 3, 2023. The MIT was instructed to gather information, analyze facts, identify proximate and root causes, and contributing factors relating to the mishap, and to recommend appropriate actions to prevent a similar mishap from reoccurring. The investigation, initiated on Thursday, October 5, 2023, and the team deployed to MAF on October 10, 2023, to evaluate the mishap site, review evidence and data, and to conduct interviews. The Mishap Investigation Team (MIT) employed the Agency's investigation process as prescribed in NASA Procedural Requirements for Mishap and Close Call Reporting, Investigating, and Recordkeeping, NPR 8621.1 (NASA Procedural Requirements, 8621.1).

The NASA Mishap Information System (NMIS) case number assigned to this mishap is 23-101175, classified as Type B. The incident did not result in any property damage or mission failure. The hazards present on the day of the mishap were classified as Fall and Human Consequence Hazards.

The Interim Response Team (IRT) provided the MIT with evidence collected during their construction site/mishap site visit and from the formal interviews of subcontractor and MAF personnel. Other sources of the MIT's evidence included Project documentation, the Office of Safety and Health Administration (OSHA) steel erection regulations and construction safety requirements, the IP's medical records, and interviews with the subcontractor's personnel and MAF personnel.

The MIT's analysis was accomplished through NASA Root Cause Analysis (RCA) methodology. RCA enabled the MIT to identify the underlying causes of the IP's fall, the construction safeguards, and MAF's organizational factors or root causes that could have indirectly contributed to the mishap, along with MIT's recommendations. The recommendations, if implemented, could prevent similar types of mishaps from occurring during future stacked steel or steel beam projects.

The subcontractor was found to have violated OSHA standard 29 Code of Federal Regulations (CFR) 1910, Occupational Safety and Health Standards and 1926, Safety and Health Regulations for Construction: 1910.176(b), 1926.20(b)(2), 1926.250(b)(9) (Occupational Safety and Health Administration (OSHA), 1910.176; Occupational Safety and Health Administration (OSHA), 1926.20; Occupational Safety and Health Administration (OSHA), 1926.250). OSHA representatives were present at MAF on September 22, 2023, and their report is not available.

The MIT requested a copy of the OSHA Form 301–Injuries and Illnesses Incident Report, from the subcontractor. The report was received on October 26, 2023.

Proximate Causes

The MIT identified two proximate causes, which directly resulted in the IP’s injury because of a fall from the stacked steel beams. If either one of these two causes were not present, or had been properly modified, the accident could have been averted.

ECFT-1: Steel beam impacted IP's right leg.

Supporting Evidence

MIT learned through interviews that the steel beam impacted the IP's right leg once the dunnage broke and the IP fell from the level 4 (~5’4” in height) beams. The MIT was provided video footage of the incident from a camera located in building 103 at column E4. The steel beam weighed a minimum of 900 pounds. Several beams tumbled from level 5 (~6’8” high) when the IP was trying to exit the stack of beams.

ECFT-2: Steel beams weighed 900 pounds each.

Supporting Evidence

MIT learned from the interviews and data evidence that the beams had a minimum weight of 900 pounds. The subcontractors were working with 20-foot and 40-foot beams, which weighed 900 pounds and 1,800 pounds respectively, and the height of each beam was 12.5 inches. Interviews indicated a 20-foot beam struck the IP's right leg.

Root Causes

The MIT established the following as a root cause:

ECFT-1.1.2.2.1.2.1.1.1: MAF does not have written requirements for requesting space.

Supporting Evidence

Interviews indicated that all requests for space allocations for temporary floor space were verbal and there was no formal process to request temporary floor space. MIT learned through interviews that several verbal requests were made to the prime contractor that more space was needed to store the beams. The subcontractor never got a response if the request was approved or denied from the prime contractor. In order to stay on schedule, beams were placed in the assigned temporary storage area, which resulted in the beams being stacked at a height of five beams high (~6’8”) instead of maximum height of two beams high (~2’8”). Organizational Issuance MAF AS60 Facility Utilization Policy (AS60-OI-008) (NASA, MPD 5340.1/AS60-OI-008) does not address the process to request temporary or permanent manufacturing floor space. The document only addresses allocating office space. There is no formal process to request temporary floor space and/or it is not communicated to the contractors within the plant the process to request more temporary floor space.

Contributing Factor

One contributing factor was determined. The MIT established the following as a contributing factor:

ECFT-1.3.1: IP's left foot contacted upper beam.

Supporting Evidence

Interviews indicated IP was working on level 4 (~5’4”) to attach clamps to beams on level 5 (6’8”). As IP climbed down the beams, he stepped on dunnage located on level 3 (~4’3.5”) and the dunnage broke. As the IP was falling, IP's foot contacted the beams on level 5 (~6’8”). With limited information and video footage taken far away from the mishap site, MIT concluded IP’s foot contact with beam may be a contributing factor to the beams falling.

2.0 Narrative Description and Facts

2.1 Events Prior to the Mishap

The NASA Michoud Assembly Facility (MAF) is one of the largest manufacturing plants in the United States, encompassing over 832 acres. MAF is located in New Orleans, Louisiana. Organizationally, it is part of NASA's Marshall Space Flight Center (MSFC) and is a multi-tenant complex, housing both contractors and federal agencies, with over 4,200 employees.

Originally built during World War II to support the war effort, it was adapted to support the manufacture of the S1 stage of the Saturn V rocket during the Apollo Program in the 1960s. Following Apollo, the facility was used to build all external tanks for the space shuttle, completing the last tank in 2010. With over 43 acres under a single roof, it is a world-class, multi-tenant manufacturing facility, currently employing over 4,200 persons working for various companies. MAF is manufacturing and assembling the largest rocket stage ever constructed, the Space Launch System (SLS) core stage, which will return NASA astronauts to the Moon.

Figure 1: Aerial View of Michoud Assembly Facility

An upgrade of the steel structure in Building 103 was being undertaken to allow a crane to run along the rails [Twin City (T/C) American rail type] in order to move and assemble flight hardware throughout the facility. The subcontractor was awarded a contract on October 17, 2022, to replace cranes 34, 35, 36 and runways in Building 103 with 20-foot and 40-foot (Figure 2) steel beams that measured 12.5 inches in height.

Figure 2: 20- and 40-foot beams.

The subcontractor who was installing the steel beam rails had previously had a temporary large square footage of “lay-down” area for the steel beams, which allowed beams to be placed directly on the floor or stacked two high (~2’8”) at most. At that time, the temporary lay-down area was located in the approximate area to the steel beams being replaced in the ceiling structure, such that minimal to no transport was required of the beams. They would be hoisted and elevated directly to the area of assembly.

Prior to this incident, the square footage of the temporary lay-down area for storing the steel beams was curtailed (Figure 6) due to the tenant needing that additional space to store flight hardware. The temporary lay-down area was significantly reduced from the yellow highlighted plus orange highlighted area to only the orange highlighted area in Building 103 (Figure 6), such that the steel beams now had to be stacked. In this case, the beams were stacked five beams high, which is approximately 6 feet and 8 inches including the dunnage.

Dunnage are 4”x4” wood beams that were repurposed following their use in transportation of the steel beams to MAF (Figure 3); the wood beams are used to separate each level in the stacks of steel beams. Dunnage has a height of 3.5 inches. Beams are always stacked with dunnage placed under them starting at the floor level.

Figure 3: Dunnage between beam stacks.

The subcontractor moving the beams was told by the prime contractor's safety personnel to no longer use the forks of the forklift to remove steel from the stack; therefore, the subcontractor opted to use a beam clamp to move beams and have a more secure load. Since the beams were stacked to a height of approximately five high (~6'8"), a subcontractor employee needed to walk on the steel beam stack and manually use the beam clamp to tighten the jack screw to secure the clamp prior to that beam being lowered to the ground and the beam clamp removed (Figure 4).

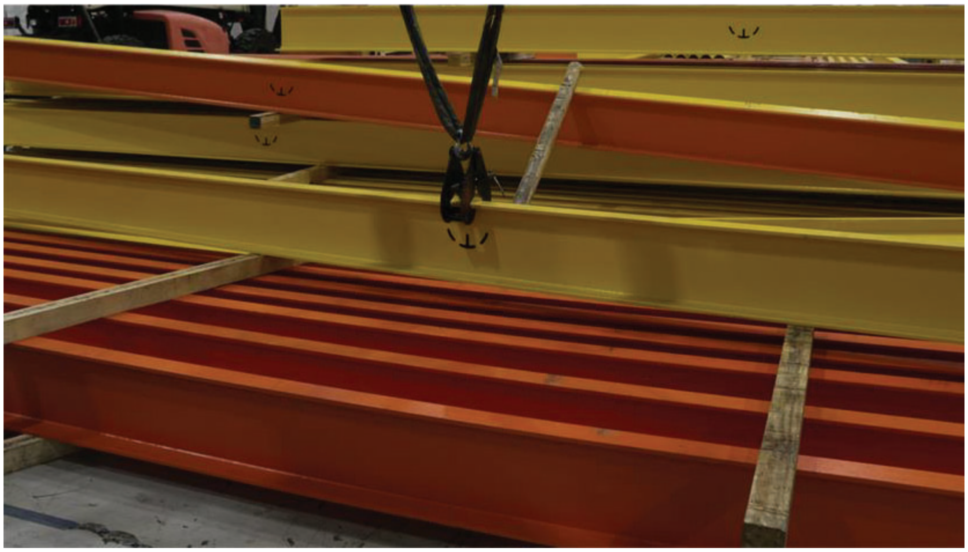


Figure 4: Beam clamp attached to the beam.

The beam would then be flipped 180 degrees (Figure 5), such that the wider portion of the beam was facing the rooftop for assembly into the ceiling beam matrix, and placed on the forklift in preparation for moving the beam into position prior to being installed. The subcontractor raised concerns about the lack of square footage of the lay-down stack (Figure 6). The MIT learned from interviews the subcontractor requested more floor space from the prime contractor, but the subcontractor never received a response that approved or denied their request. In order to meet the scheduled deadline, the subcontractor allowed the beams to be stacked above the normal maximum height of a 2-beam stack, which is approximately 32 inches. The previously site-specific health and safety plan was not updated after the change in procedure.

Figure 5: Beam flipped 180 degrees on forklift.

There were two lengths of steel beams in the stack. The majority (levels 1-4 of the stack) were the longer 40-foot beam types, weighing approximately 1,800 pounds each. The beams on the fifth level (~6’8”), which were in the process of being moved, were the lighter 20-foot beam types, with a weight of approximately 900 pounds each.

(b) (7)(F)

Figure 6: Initial storage area and reduced storage area of beams in Building 103 (yellow + orange is the initial temporary storage area; orange is the reduced temporary storage area).

2.2 Events on the Day of the Mishap

On the morning of Friday, September 22, 2023, subcontractor employees in the immediate area in Building 103, G5/G6 consisted of the forklift driver, the spotter, and the rigger, who is the IP. Additional subcontractor employees were located nearby in the machine shop in Building 103 in preparation for raising the steel beams in that location. From video footage evidence, taken with a camera located at E4, at 8:46 a.m., the forklift driver positions the lull (with the clamp attached) while the spotter directs the forklift driver for clearance; the IP climbs up the stack of beams and clamps the beam. After the IP successfully clamped the beam at 8:48 a.m., the forklift driver lifted and lowered the beam to the floor. After the beam was lowered to the floor, IP walked to the end of the beam to exit down the stack of beams to the floor level and unclamp the beam, which was lowered to the floor, rotated 180 degrees, and placed on the forklift (Figure 7).

Figure 7: Different angle of beam flipped 180 degrees on forklift.

At approximately 8:53 a.m., IP climbed the stack of beams to level 4, which is approximately 64 inches above the floor, and began rigging the next beam on level 5 (~6’8”). At 8:54:03 a.m., the forklift driver lifted a beam from level 5 and lowered the beam to the floor. At 8:54:16 a.m., the IP exited down the stack of beams from the side instead of walking to the end of the beams, which was the normal procedure to exit the beam. When exiting down the stack of beams, IP stepped on dunnage to get to the next level, but the dunnage broke and IP fell to the floor. The IP can be seen in the video footage falling from the stack of beams with the beams rolling off the stack. Interviews indicated IP stepped down onto the dunnage with their right foot, and the dunnage broke and gave way (Figure 8).

Figure 8: View of broken dunnage under beam.

The steel supported by the dunnage on the fourth level plummeted, and in the act of falling, the IP’s left foot contacted the steel beam on the fifth level, causing it to fall into another beam and roll off the stack (Figure 9).

Figure 9: View of collapsed beams.

The IP impacted ground/beam with right arm and a steel beam fell upon IP's right leg, instantly causing right leg to be crushed and fractured.

2.3 Events Immediately Following the Mishap

After witnessing the IP fall from the stack of beams, the forklift driver stopped and exited the lull. The multiple beams falling made a loud noise (Figure 10) and got several workers' attention.

Figure 10: View of collapsed beams and broken dunnage.

The forklift driver ran to get help from coworkers located in the machine shop area to help assist. The spotter, forklift driver, and additional workers lifted the steel beam from IP's leg by hand and placed cribbing under the beam to prevent it from falling back onto the IP's leg. IP picked up right leg by the pants leg and moved it out from under the beam. At 8:55 a.m., calls were received by 911 dispatch. Security was en route to Building 103 (Figure 11) and arrived at 8:56 a.m.

Figure 11: MAF security at the mishap site.

2.3.1 Emergency Response

The IP remained conscious; exposed bone and bright red blood issuing from the right lower extremity was evident at this time.

At 8:58:40 a.m., two MAF security officers responded to the mishap site. Security Officer 1 recognized the bright red arterial bleeding and extent of the injury and subsequently used a bystander's belt and their own police baton to devise a makeshift tourniquet. The tourniquet was placed above the injury, but below the knee, and was tightened until the bleeding slowed. Bleeding was slowed substantially but continued. Upon arrival of the St. Bernard Fire Department at 9:07 a.m. (Figure 12), emergency personnel replaced the makeshift tourniquet with a commercial medical tourniquet device. Bleeding continued, so a second tourniquet was placed just above the knee. A third tourniquet, higher up the thigh, was utilized and bleeding ceased.

Figure 12: St. Bernard Fire Department at the mishap site.

The injury to the right arm was unknown at this time, most likely due to the distracting extensive right lower extremity injury, so no splint was applied. IP was placed on a “man-bag,” a soft-sided stretcher with handles used to extricate patients from difficult terrain or areas, in order to remove IP from the scene and load them onto a cot. The IP was loaded into an ambulance (Figure 13), which then transported them to the designated helicopter landing area.

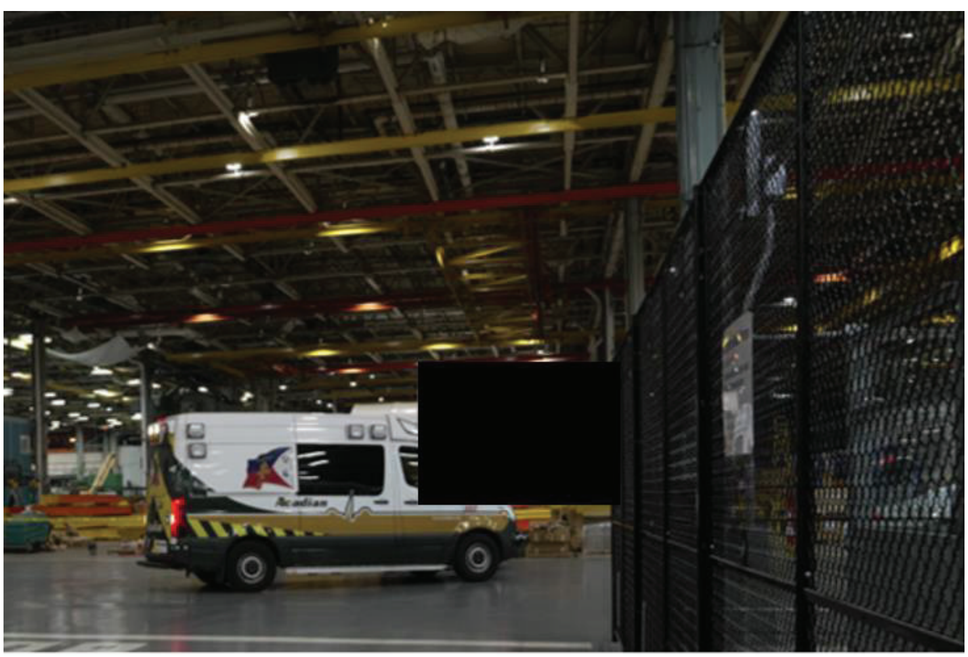


Figure 13: Ambulance arriving to the mishap site.

Because of the extent of trauma and injuries, onsite personnel called for Helicopter Emergency Medicine Services (HEMS) to take the IP to a Level 1 trauma center, as opposed to the local hospital. The helicopter landed at 9:33 a.m. and evacuated the IP to the trauma center. En route, the IP received intravenous fluids and pain medication by HEMS personnel and remained alert and oriented. The IP was evaluated by the trauma team after arrival. Since pain medications were taken by the IP, no drug test was conducted. IP had several surgeries and lost the extremity of their lower right leg, which is a permanent partial disability. Several days after the incident, IP had additional surgery on their right arm.

Thanks in part to their combat training, Security Officer 1's calmness and quick action in making a makeshift tourniquet saved the IP's life.

2.3.2 Interim Response Team (IRT) Actions

The security officers who arrived at the mishap site assumed the role of the Incident Commander (IC) and ensured the site was secured. IC transferred responsibility of the mishap site to the IRT lead at approximately 9:36 a.m. The IRT lead met with the subcontractor employees and facility personnel. The IRT lead then directed facility personnel to instruct the subcontractors to take the necessary actions to assure the safety of the mishap site and steel beam stack. The subcontractors detached the beam from the rigging and lowered additional beams that had partially fallen. The IRT collected witness statements, coordinated obtaining site photographs, collected evidence pertaining to the IP's Personal Protective Equipment (PPE), took measurements of the weather and air quality, and secured key documents. The Occupational Health lead worked to clean up biohazardous material (blood) from the mishap site.

Information gathered included training records, the Health and Safety Plan (HASP) for the work site, and the roles and responsibilities as well as placement of personnel. MAF's Safety contractor personnel entered the event into NMIS, and the IRT lead notified NASA Headquarters of the mishap in accordance with mishap guidelines. The IRT lead maintained control of the site and assisted the MAF's Safety Office to transfer the site and evidence collected to the investigating authority. The OSHA investigator contacted the subcontractor and began creating their report.

3.0 Mishap Investigation

3.1 Investigation Preparation

NASA has established specific requirements for reporting, investigating, and documenting mishaps, close calls, and any newly identified workplace hazards. The role of the MIT is to conduct a comprehensive investigation of the mishap, including gathering evidence, conducting witness interviews, and creating a timeline of the events before, during, and after the mishap. The MIT describes the mishap as it took place, verifies the time the mishap occurred, and determines the reason the mishap occurred. To achieve this, the MIT analyzes the data and the information collected throughout the investigation. The objective of the MIT's investigation is to reduce the number, severity, and recurrence of similar accidents.

The MIT initiated its investigation on October 5, 2023, at 10:00 a.m. The MIT chair met with the entire MIT and supporting staff for introductions, overview of the mishap process, dates of availability, daily schedule, and travel dates. Briefing materials were received by the IRT that included a general overview of the accident, evidence and witness statements collected by the IRT, and a description and photographs of the construction site conditions. At this point, the IRT had transferred responsibility for the mishap site and evidence in-hand to the MIT for use in its investigation.

On Tuesday, October 10, 2023, the MIT deployed to MAF to survey the mishap site, took additional photographs, and began interviewing witnesses on Wednesday, October 11, 2023, at 8:00 a.m.

3.2 Site Safety and Evidence Retention

The MIT first visited the construction/mishap site in Building 103 on October 10, 2023, at 2:30 p.m., met with several NASA MAF personnel, and requested site maps and additional documentation. The site tour and overview, led by MAF Safety and Health Manager, allowed the MIT to assess the construction site and take additional photographs. The site had already been safed post-accident, and the steel beam stack was no longer in the same configuration as it was during the accident, with beams now stacked only four high. Some of the dunnage had been moved to assist with the removal of the steel beam from IP's leg. The broken dunnage was still in place between the beams on level 3 and level 4.

During the site visit, after the mishap site was safed, the MIT and MAF's Safety and Health Manager identified that a beam was stacked incorrectly or upside down with the narrow portion on the bottom (Figure 14), and this was brought to the attention of the subcontractor safety officer for them to remedy this situation to keep the work area safe. The correct stacking of the beams is with the wide edge down.

Figure 14: Beam upside down in stack.

3.3 Data Collection and Development

3.3.1 Approach

The MIT conducted Root Cause Analysis (RCA) of the mishap by using the Root Cause Analysis Tool (RCAT) software in accordance with NPR 8621.1, NASA Procedural Requirements for Mishap and Close Call Reporting, Investigating, and Recordkeeping (NASA, MCP 8621.1). Using data gathered, the MIT initiated the construction of the timeline. A data-gathering tool, referred to as the Four-Column List, was used to categorize the evidence and determine what information was still required to best support the mishap investigation. The software, hardware, environment, liveware-team, liveware-individual, and documents (SHELL-D) technique was used to ensure the MIB considered a broad range of scenarios. After gathering data, the MIT developed a Fault Tree (FT) outlining possible causes of the mishap.

As data were gathered and analyzed, elements of the FT with sufficient data were ruled in, whereas potential causal factors with no identified supporting data or evidence were ruled out. Potential causal factors supported by data and/or evidence are reflected in the Event and Causal Factor Tree (ECFT).

A significant amount of information was collected over the investigation phase. A witness list was generated, which encompassed a list of personnel that the IRT interviewed or listed as being at the scene, and additional personnel the MIT wished to interview during the course of their investigation. Photographs, contracts, the HASP, witness statements, dispatch call log, video footage, training records, previous mishap reports, and additional documents were reviewed as part of the investigation. The medical member of the team reached out to the IP, first responders, and the trauma team to ascertain medical data pertinent to the investigation.

The MIT collected and reviewed a significant amount of information regarding the OSHA regulations for steel erection, as well as whether any regulations or standards existed for stacking of steel. In addition, the Internet was used extensively to locate health and safety standards held by other construction companies or hardware facilities that store or stack steel.

Throughout this investigation, the MIT determined what happened (direct evidence, witness statements), when it happened (timeline), and why it happened (proximate causes, root causes, and contributing factors). The MIT then developed recommendations to address the proximate causes identified for this mishap to ensure a similar mishap does not happen again. As required, the recommendations have been identified and presented in a form the team considers clear, achievable, and verifiable.

3.3.2 Witness and Project Personnel Interviews

The MIT was provided a list of individuals who were either at or near the construction area when the mishap occurred or responded to the mishap. This information became the initial interview list, and it included emergency and interim response personnel and the subcontractor employees (including the IP) who were in the area after the mishap occurred. Others were added to the interview list based on their role in the construction project and/or their special knowledge relating to the possible conditions that may have contributed to the mishap.

The MIT developed the questions used during the interviews tailored the questions based on the individual’s role in the mishap and/or the Project, their location at the time of the mishap, and their levels of responsibility for the health and safety of the construction personnel. Nineteen interviews were conducted with employees from the subcontractor, prime contractor, NASA, support contractors, security, and tenant organization. The MIT believes that it acquired sufficient data and information to adequately assess the circumstances of the mishap and provide sound recommendations to the Appointing Official.

3.3.3 Data Analysis

The MIT carefully constructed a timeline based on video photographic evidence that was time and date stamped, security dispatch reports, fire department dispatch reports, EMS reports, and additional data and interviews.

In addition, the dunnage was inspected, and the broken/fractured piece of dunnage was married to its remaining part to show the exact position of the dunnage when the accident occurred. The large knot, with the fracture pattern along the knot, was also photographed and evaluated. Greater than 85% of the width of the dunnage was encompassed by the knot, and the depth of the knot extended well beyond 50% of the 4”x4” board. The fracture pattern of the wood was along the knot line as indicated in the figures below (Figure 15 and Figure 16). In addition, from interviews, it was found that it was common to reuse dunnage that had been used to secure the load on the delivery truck. When using dunnage on the delivery truck, the load is typically ratcheted down for transport, which may in turn cause additional wear and tear on the dunnage. The dunnage was also not lined up vertically in the stack to dissipate the weight load and avoid potential issues from cantilevering.

Figure 15: Fractured dunnage to show the extensive knot and fracture pattern along the knot.

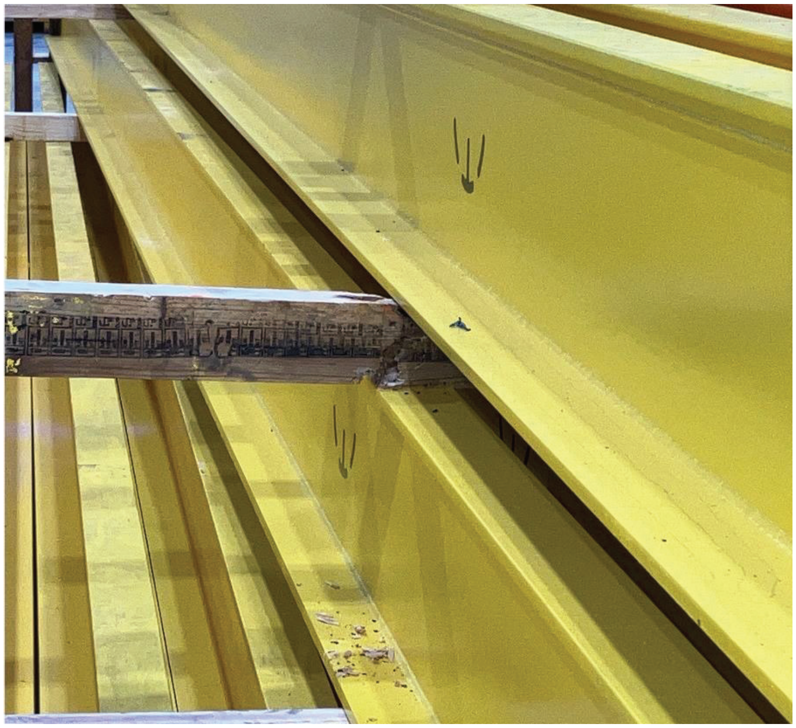


Figure 16: Fractured dunnage is re-mated to show position and fracture site.

A review of the literature on structural integrity of wood versus knot size was undertaken. In their work examining wood strength and elasticity, Rocha et al. (2018) showed that there is clearly a relationship between the size of the knot and the modulus of elasticity. Additionally, Koman et al. (2013) showed that the increase in the proportions of knot areas results in a significant decrease of the modulus of elasticity (MOE), with changes in structure and tensile strength differing from that of normal wood. The effect of a knot on the mechanical strength of the wood depends on the proportion of wood occupied by the knot; the number of knots; the nature, size and distribution of the knot; and the area encompassed throughout the load section (Hossein, Shahverdi, & Roohnia, 2011; Zhou, Zhou, Zhou, & Zhang, 2016).

For this case, the knot was significant in size, encompassing almost the entirety of the width and greater than 50% of the depth of wood dunnage. In addition, it is unknown what forces this dunnage was subjected to previously, such as from being ratcheted down for transport. Thus, in addition to the data from the literature showing that this dunnage was at risk for breaking due to the size of the knot, it is not known what additional stress factors or cracks may have occurred as a result of the dunnage being subjected to previous forces when loaded and used for transport and then subsequent reuse.

Additional research showed that the Occupational Safety and Health Administration has a regulation for stacked materials (Occupational Safety and Health Administration (OSHA), 1926.250), such as wood, brick, etc., but the regulation is general in nature. OSHA does not prohibit items such as steel from being stacked, but merely states that the items should be secured in such a way as to prevent slippage.

Although I-beams and H-beams can be stacked on their side in alternating patterns, T/C American-style beams cannot, owing to their differing sizes on each end. In addition, T/C American-style rail beams should have their widest portion as the base when stored, to avoid easily toppling over. However, there is no regulation or standard that specifically covers the nuances of the shape of this type of steel beam in regard to storage.

3.3.4 Timeline of Events

While gathering data, the MIT developed and maintained a timeline of events leading up to the incident. As the root cause analysis (RCA) progressed, the timeline was expanded to include events that were related to intermediate and proximate causes. All times listed are in Central Daylight Savings Time. The summary timeline is shown in Table 1.

Table 1: Timeline of Events

Overall Timeline		
DATE	**TIME**	**Notes**
10/17/2022	8:00:00 a.m.	Subcontractor awarded contract
10/25/2022	8:00:00 a.m.	Construction meeting started
10/25/2022	8:00:00 a.m.	Subcontractor submitted submittals for crane and trolley
11/7/2022	8:00:00 a.m.	Pre-construction meeting started
1/10/2023	8:00:00 a.m.	Subcontractor submitted control drawings
1/24/2023	8:00:00 a.m.	Subcontractor rails, crane, and trolleys delivery estimated
2/7/2023	8:00:00 a.m.	Subcontractor completed removal of Crane 36
2/7/2023	8:00:00 a.m.	Subcontractor started removal of Crane 35
2/28/2023	8:00:00 a.m.	Subcontractor removed all three cranes
3/28/2023	8:00:00 a.m.	Subcontractor received rails for Crane 35
5/2/2023	8:00:00 a.m.	Subcontractor received Bridge 35
5/23/2023	8:00:00 a.m.	Subcontractor received rails and bridge for Crane 36
5/30/2023	8:00:00 a.m.	Subcontractor received all rails for entire project
5/30/2023	8:00:00 a.m.	Subcontractor started stacking rails as received
5/30/2023	8:00:00 a.m.	Subcontractor received Bridge for 34
6/19/2023	8:00:00 a.m.	Subcontractor removed old crane rails
7/3/2023	8:00:00 a.m.	Subcontractor lay-down area configuration changed (subcontractor estimated)
8/29/2023	8:00:00 a.m.	Subcontractor received trolleys
9/19/2023	8:00:00 a.m.	Subcontractor started installing crane rails
9/22/2023	8:45:00 a.m.	Subcontractors began operation
	8:47:00 a.m.	Injured party (IP) climbed up on beam stack, forklift operator repositioned lull, IP placed clamp on first beam lifted
	8:47:50 a.m.	Spotter entered work area
	8:48:10 a.m.	Using the lull, forklift operator lifted and repositioned first beam from top of stack to floor

	8:48:30 a.m.	IP got off beam stack to disconnect clamp from first beam, exited the beams at the end of the beam stack
	8:49:30 a.m.	Spotter stepped up on first level of beam
	8:49:55 a.m.	Spotter assisted IP to reposition first beam
	8:50:30 a.m.	Forklift operator began to lift first beam again
	8:50:54 a.m.	IP and spotter walked first beam to forklift (to control the movement of the beam without tag lines and only waist high)
	8:52:30 a.m.	First beam was placed on the tines of the forklift
	8:52:40 a.m.	Forklift operator repositioned lull to lift next beam
	8:52:50 a.m.	IP and Spotter adjusted first beam on tines of forklift
	8:52:58 a.m.	IP climbed back up on beam stack, spotter remained on floor
	8:54:00 a.m.	Forklift operator began to lift second beam
	8:54:14 a.m.	IP began to climb down from beam stack IP stepped over beams to lower-level dunnage
	8:54:15 a.m.	Dunnage broke under IP's right foot, causing him to fall
	8:54:16 a.m.	IP's left foot contacted upper beam, which caused beams to tumble
	8:54:16 a.m.	One beam impacted IP's right leg, and IP impacted right arm with ground or beam
	8:54:17 a.m.	Spotter witnessed the incident, IP remained conscious
	8:54:25 a.m.	Bike rider diverted to the mishap site
	8:54:28 a.m.	Forklift operator saw IP and stopped work with the lull
	8:54:38 a.m.	Bike rider stopped at the mishap site
	8:54:39 a.m.	Bike rider appeared to be on phone potentially calling security
	8:54:53 a.m.	Forklift operator exited lull and left work area to get assistance from coworkers
	8:55:00 a.m.	Officers routed to mishap site
	8:56:00 a.m.	MAF Security 3 arrived at column S3 door at Building 103
	8:57:00 a.m.	New Orleans, LA 911 operator was called and fire department dispatched
	8:58:00 a.m.	Coworkers responded to mishap site and manually removed beam from IP's leg
	8:58:40 a.m.	MAF Security Officers 1 and 2 arrived at mishap site (video time stamp)
	9:03:24 a.m.	First tourniquet placed on IP's right leg by security (belt and baton)
	9:07:00 a.m.	Fire department arrived on the mishap site
	9:12:47 a.m.	Additional tourniquets placed on IP's right leg by fire department
	9:13:07 a.m.	Prime contractor safety arrived at mishap site
	9:13:13 a.m.	Emergency medical services arrived on mishap site
	9:29:47 a.m.	Helicopter approved to land at MAF
	9:31:37 a.m.	Security 4 arrived on helipad
	9:33:09 a.m.	Security 5 led emergency medical services to the helipad
	9:33:25 a.m.	Emergency medical services helicopter landed on the helipad
	9:37:13 a.m.	Mishap site had been blocked off, and security handed off incident command to MAF safety
	9:45:05 a.m.	Mishap site determined to be all clear by incident commander
	9:48:23 a.m.	IP routed to University Hospital in New Orleans via helicopter

9/22/2023	1:34:00 p.m.	Mishap was entered into NASA Mishap Information System (NMIS) and entered as a Type C Mishap
10/3/2023	8:00:00 a.m.	Mishap Investigation Team appointed to investigate Type B Mishap (Appointment letter was issued)
10/4/2023	8:00:00 a.m.	Mishap reclassified as a Type B Mishap in NMIS
10/10/2023	7:00:00 a.m.	MIT traveled to MAF and gathered evidence and visited mishap site
10/11-13/2023	7:00:00 a.m.	MIT conducted witness interviews (19 total)
10/13/2023	8:00:00 a.m.	Award ceremony for security personnel who were instrumental in saving IP's life.
10/13/2023	9:00:00 a.m.	MIT departed from MAF and returned to MSFC
10/16/2023	7:00:00 a.m.	MIT continued investigation work

3.3.5 Types of Data Gathered

The IRT provided the MIT with a significant portion of the direct evidence and data including results from measurements of the environmental conditions on the work site taken by an IRT member. In addition, the MIT collected numerous types of relevant, pre-existing documentation. Documents included those used in the procurement process for establishing the contract with the prime contractor, Project documents developed by NASA or submitted by the prime contractor and subcontractor, NASA requirements, and OSHA regulations associated with construction and steel erection. Table 2 contains the full list of documents and other forms of information used in conducting the investigation.

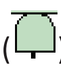
Table 2: Type of Data Gathered – List of Documents

Table 2a. NASA MAF Data/Documents
MAF 103 building map
NASA safety Interim Response Team briefings
Photographs taken on the day of the accident, September 22, 2023, by NASA safety
Photographs taken on the day of mishap site visit by Mishap Investigation Team
Witness statements (two)
MAF safety investigation presentation (Type C Mishap 09/22/2023 at Building 103-1-G5/G6)
Fire department Incident Report #230003727
911 dispatch log
MAF Protective Services video footage (E4 Camera)
MAF Protective Services video footage (G1 Camera)
MIT team interviews (IP, subcontractor, prime contractor, NASA safety, NASA facilities, MAF security, tenant); total of 19 interviews
Audio files from interviews; total of 19 interviews
MAF Facility Utilization Policy (AS60-OI-008)

IP's medical report
List of people (3) working on construction site on September 22, 2023
Time stamp documentation – video footage provided by MAF Protective Services
Project management timeline
Four Column List to identify – what we know, what we don't know, what we think we know, what data we need
Mishap site visit on October 10, 2023 (obtained evidence – broken dunnage)
MSFC Form 4515 submitted into NASA Mishap Information System (NMIS)
Table 2b. Subcontractor Data/Documents
Prime contractor interim response team briefings
Prime contractor space allocation request form
Prime contractor safety alert safety sharing & lessons learned 2023-04
Prime contractor photos taken on the day of the incident on September 22, 2023
FINAL construction subcontract
Subcontractor training certifications forklift
Subcontractor training certifications for aerial boom lift
Subcontractor safety plan
Subcontractor OSHA rate
Subcontractor demolition work plan (replace castellated beams demolition plan)
Subcontractor job hazard analysis (replace castellated beams)
Subcontractor Safe Plan of Action (SPA)
Subcontractor forklift pre-use inspection checklist
Subcontractor inspections and findings
Subcontractor submitted OSHA serious event report online form
Subcontractor workers compensation experience rating

3.4 Event and Causal Factor Tree (ECFT)

NASA's root cause analysis (RCA) was used as the data analysis method for assessing the data and evidence accumulated during this investigation. This method has become the standard analysis technique used in all NASA mishap investigations. The NASA RCA Tool (RCAT), Version 3.1.0.1, and user support were provided to the MIT by the NASA Safety Center (NSC). For readability, the following Event and Causal Factors Tree (ECFT) diagram is divided into several sections. As data was gathered, elements on the Fault Tree (FT) were ruled out with refuting data or ruled in if there were sufficient supporting data. All of the substantiated causal events, conditions, and contributing factors that were ruled in are reflected on an ECFT. The ECFT was expanded by continually asking why until the data was exhausted.

An event and causal factor analysis was accomplished as part of the RCA. Once all the causal events, conditions, and contributing factors were determined on the FT and supported with data, an ECFT was produced. The tree was expanded by continually asking "why" for the elements located above. This process ended when sufficient data were no longer available or when the answer to the "why" question reached a root cause or was found to be outside of NASA control. The full ECFT diagram is included in the NMIS record. Segments of the ECFT are provided in Section 4, with events symbolized with a green rectangle and conditions represented with a blue oval. Boxes with a circle beneath identify where the MIT determined that an event or condition was not anomalous or reached a root cause. A diamond indicates that no more data existed to identify "why." The And () gate means that all the factors below it had to occur for an event or condition to occur.

4.0 Findings

A discussion of the analysis of proximate, intermediate, and root causes with supporting evidence is presented in this section. Accompanying figures are also shown for ECFT branches of closely related causes.

4.1 Undesired Outcome

The MIT defined the Undesired Outcome (UO) as **MAF Subcontractor (IP) sustained permanent partial disability.**

4.2 Proximate Cause

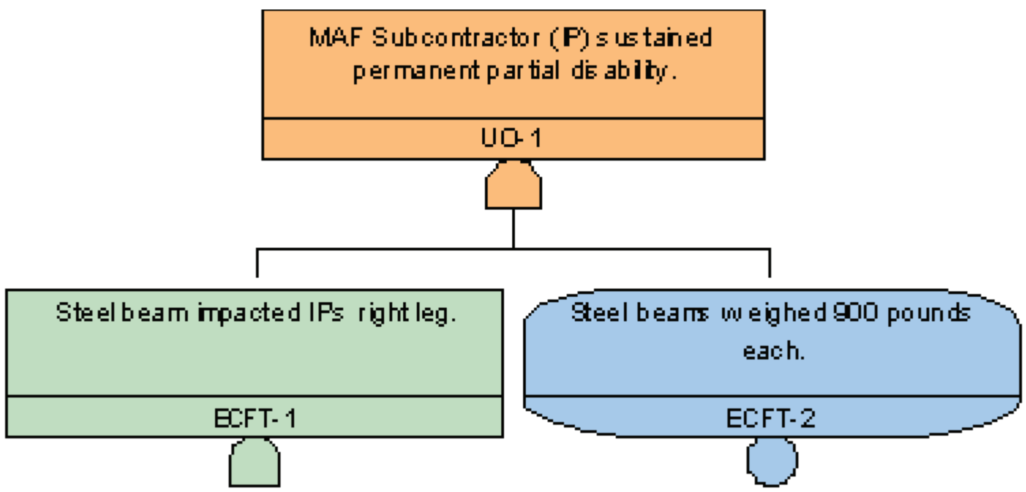


Figure 17: Proximate Causes

ECFT-1 - Steel beam impacted IP's right leg.

Supporting Evidence: MIT learned through interviews that the steel beam impacted the IP's right leg once the dunnage broke and the IP fell from the level 4 beams (~5’4”). The MIT was provided video footage of the incident from a camera located in building 103 at column E4. Several beams tumbled from level 5 (~6’8”) when the IP was trying to exit the stack of beams.

ECFT-2 - Steel beams weighed 900 pounds each.

Supporting Evidence: MIT learned from the interviews and data evidence that the beams had a minimum weight of 900 pounds. The subcontractors were working with 20-foot and 40-foot beams, which weighed 900 pounds and 1,800 pounds respectively. The height of each beam is 12.5 inches. Interviews indicated a 20-foot beam struck IP's right leg.

4.3 Intermediate Causes

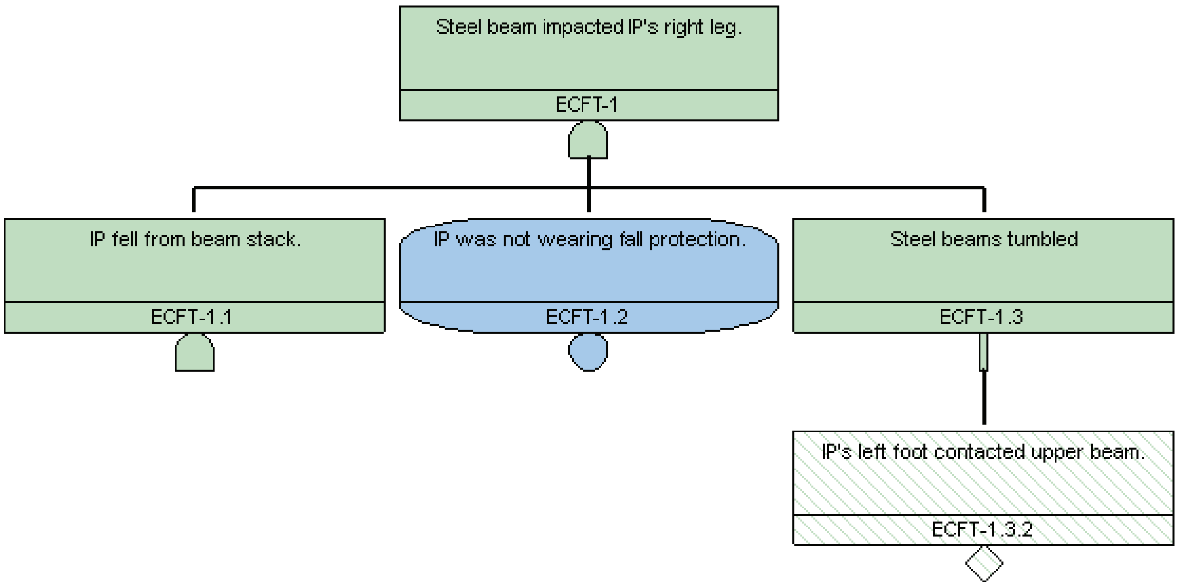


Figure 18: Proximate Cause 1 breakdown.

ECFT-1.1 - IP fell from beam stack.

Supporting Evidence: MIT learned through interviews, witness statements, and video footage provided from MAF Protective Services that the IP fell from level 4 (~5' 4" high above the floor) beams due to the dunnage breaking. IP was on the stack of beams to attach clamps to beams because the beams were stacked five high (~6' 8") instead of two high (~2'8").

ECFT-1.2 - IP was not wearing fall protection.

Supporting Evidence: MIT learned through interviews and standards that fall protection protective equipment was not required due to the height of the walking working surface. The subcontractor was working on level 4 (~5'.4") beams, which was under six feet high. The OSHA standard for construction requires fall protection on any work done at the height of six feet or more. Since this was not an anomalous condition, no further analysis was done in this event.

ECFT-1.3 - Steel beams tumbled

Supporting Evidence: Interviews indicated IP made contact with the beams either with their hands and/or foot, which may have contributed to the beams tumbling. MIT also learned from video footage and a visit to the mishap site that when IP stepped on dunnage, the beams began to tumble. Several factors contributed to the beams tumbling, such as contact with beams, misalignment of beams and dunnage, and dunnage breaking.

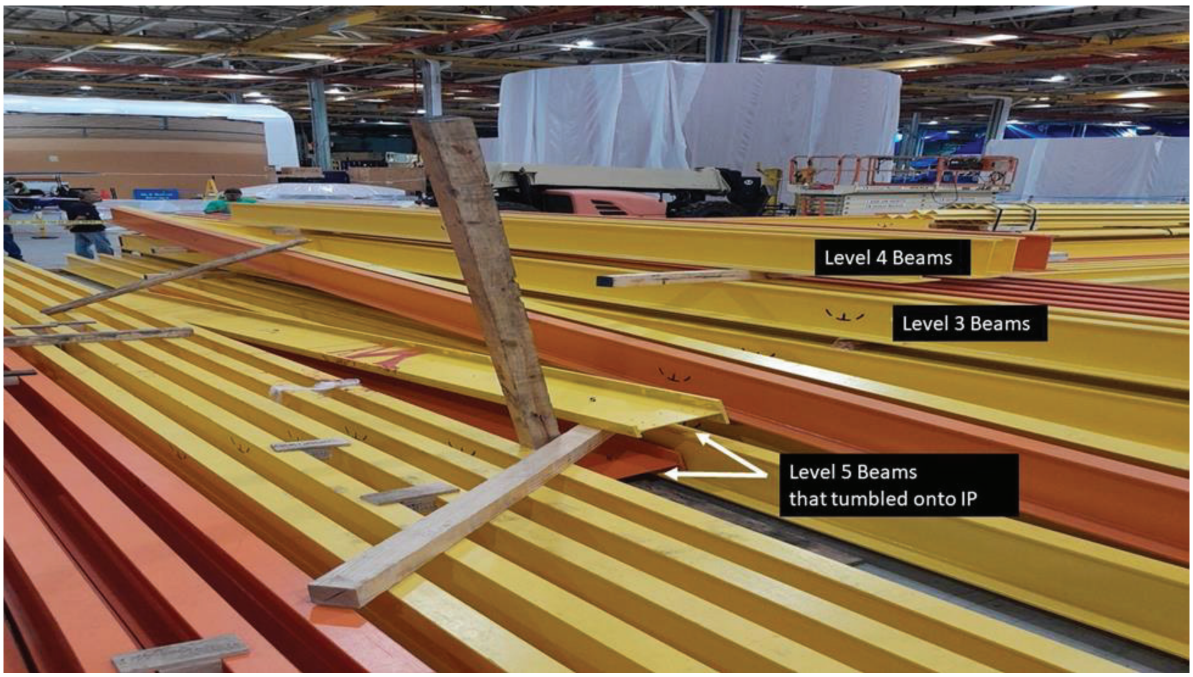


Figure 19: Beams from level 5 that tumbled onto IP, and beams that collapsed with breakage of dunnage.

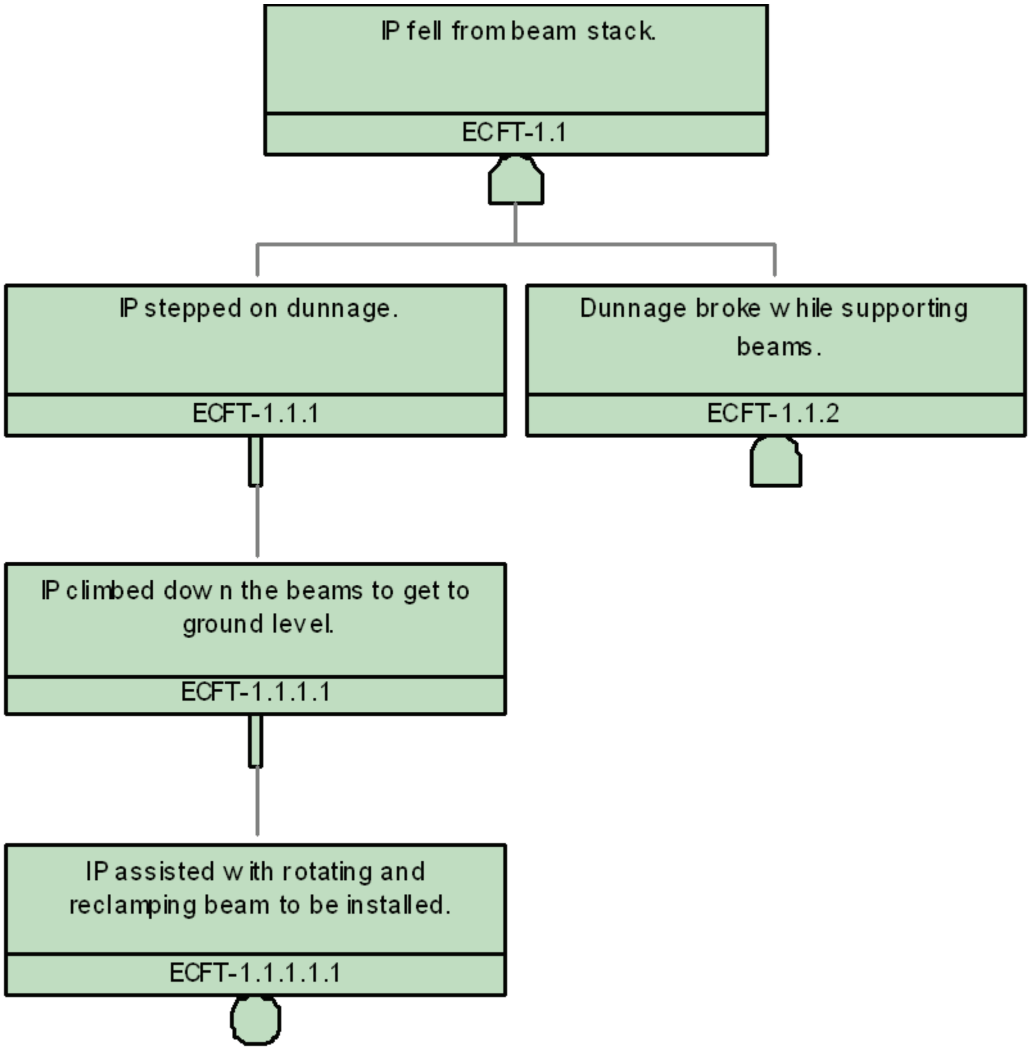


Figure 20: Causes of the IP falling from beam stack.

ECFT-1.1.1 - IP stepped on dunnage.

Supporting Evidence: MIT learned from interviews, witness statements, and video footage that the IP stepped on dunnage to get down from the stacked beams. The IP normally would walk to the end of the beams to exit, but in this particular incident, IP decided to exit at the side of the beams.

ECFT-1.1.1.1 - IP climbed down the beams to get to ground level.

Supporting Evidence: MIT learned from the mishap site, witness statements, and interviews that the IP was standing on level 4 (~5' 4" high above the floor) beams and climbed down the beams to exit the beams. It was also noted that walking down the beams was a norm and was done often. Interviews indicated that ladders, scaffolds, and/or aerial lifts are infeasible and unsafe methods to go up or down the unsecured beams.

ECFT-1.1.1.1.1 - IP assisted with rotating and reclamping beam to be installed.

Supporting Evidence: MIT learned through interviews that the beams had to be rotated 180 degrees from the stacked orientation to be installed in the final location. The IP clamped the narrow edge of the beam and lowered the beam to the floor, then rotated the beam 180 degrees so the wide edge could be clamped in the lifting configuration. After the mishap site was safed, MIT observed the beams were stacked with the wide edge down with the exception of one beam during the mishap site visit. MIT notified the prime contractor and subcontractor safety personnel, who informed the MIT that the unsafe stacking would be corrected. MIT learned through interviews that the reclamping was performed due to the height of the stacked unsecured beams.

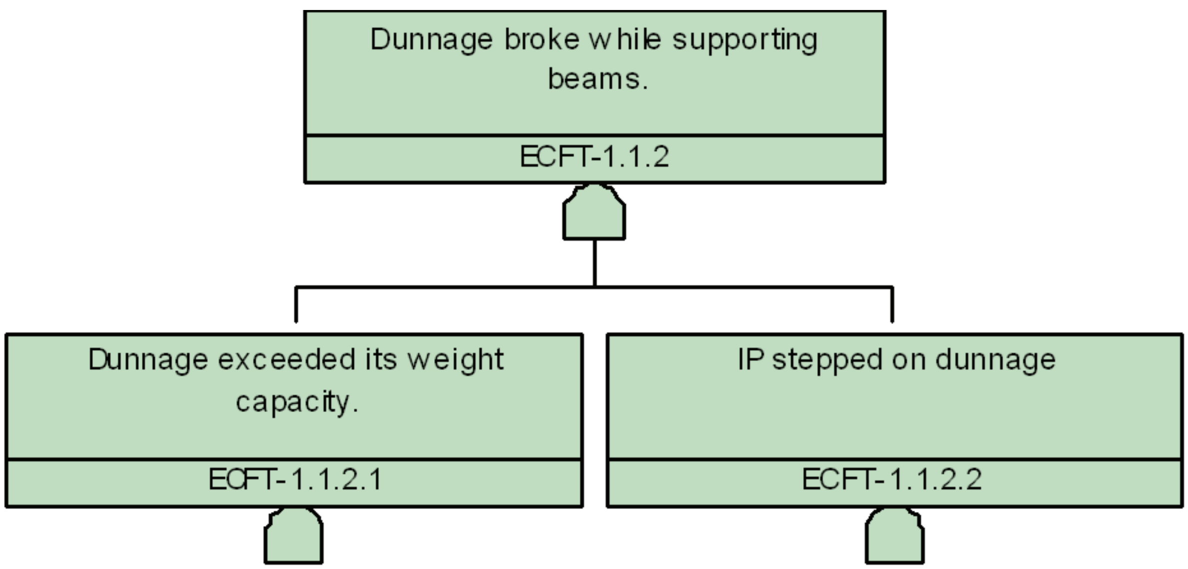


Figure 21: Causes to the dunnage breaking.

ECFT-1.1.2 - Dunnage broke while supporting beams.

Supporting Evidence: MIT learned through interviews and witness statements that the IP stepped on dunnage to exit the beam stack and the dunnage broke. During the visit to the mishap site, MIT saw the broken dunnage still in place under a beam and the end that broke off. In this case, there were several factors that contributed to the dunnage breaking, such as exceeded weight capacity, misaligned beams, misaligned dunnage, and condition of the dunnage such as old or aging wood, cracks, or knots.

For this case, the knot was significant in size, encompassing almost the entirety of the width and greater than 50% of the depth of the 4”x4” wood dunnage. In addition, it is unknown what forces this dunnage was subjected to previously, such as from being ratcheted down for transport. Thus, in addition to the data from the literature showing that this dunnage was at risk for breaking due to the size of the knot, it is not known what additional stress factors or cracks may have occurred as a result of the dunnage being subjected to previous forces when loaded and used for transport and then subsequent reuse.

Figure 22: Broken dunnage and one of two beams that it supported.

ECFT-1.1.2.1 - Dunnage exceeded its weight capacity.

Supporting Evidence: MIT learned through interviews and witness statements that the IP stepped on dunnage and the dunnage broke. During the visit to the mishap site, MIT saw the broken dunnage still in place under a beam and the end that broke off. In this case, there were several factors that contributed to the dunnage breaking, such as exceeded weight capacity, misaligned beams, misaligned dunnage, and condition of the dunnage, such as old and aging wood, cracks, or knots.

ECFT-1.1.2.2 - IP stepped on dunnage.

Supporting Evidence: MIT learned from interviews that IP stepped on dunnage to get down from the stacked beams. The IP normally would walk to the end of the beams to exit, but in this particular incident, the IP decided to exit at the side of the beams.

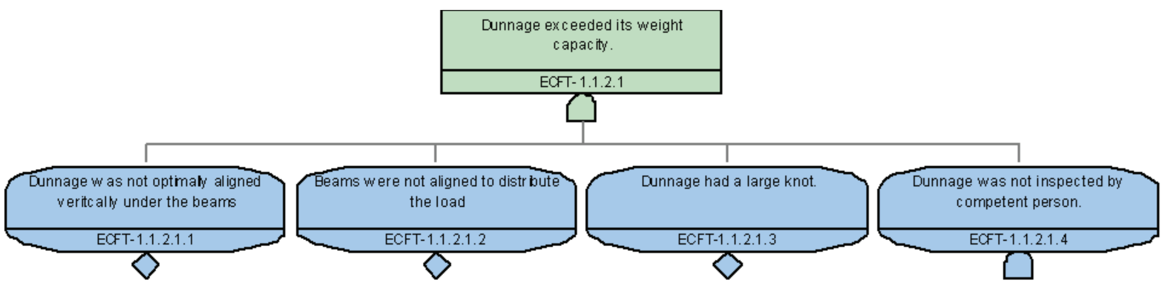


Figure 23: Causes to the dunnage exceeding its weight capacity.

ECFT-1.1.2.1.1 - Dunnage was not optimally aligned vertically under the beams.

Supporting Evidence: MIT learned from the timeline that on May 30, 2023, all beams were received for the installation of the castellated beam project. MIT witnessed that the dunnage was aligned in a staggered fashion when visiting the mishap site. Pictures of the dunnage misalignment were provided to the MIT for evidence.

Figure 24: Misaligned dunnage supporting steel beams.

ECFT-1.1.2.1.2 - Beams were not aligned to distribute the load.

Supporting Evidence: MIT learned from the timeline that on May 30, 2023, all beams were received for the installation of the castellated beam project. MIT was provided pictures that showed beams weren't properly supported. MIT also observed at mishap site that dunnage and beams were not aligned to support the load.

ECFT-1.1.2.1.3 - Dunnage had a large knot.

Supporting Evidence: MIT learned through interviews that the dunnage used to support the beams had knots in them. MIT observed at the mishap site the dunnage that broke had a significantly large knot in it which may have contributed to the dunnage breaking.

A review of the literature on structural integrity of wood versus knot size was undertaken. In their work examining wood strength and elasticity, Rocha et al. (2018) showed that there is clearly a relationship between the size of the knot and the modulus of elasticity. Additionally, 21.1
et al. (2013) showed that the increase in the proportions of knot areas results in a significant decrease of the modulus of elasticity (MOE), with changes in structure and tensile strength differing from that of normal wood. The effect of a knot on the mechanical strength of the wood depends on the proportion of wood occupied by the knot; the number of knots; the nature, size and distribution of the knot; and the area encompassed throughout the load section (Hossein, Shahverdi, & Roohnia, 2011; Zhou, Zhou, Zhou, & Zhang, 2016).

For this case, the knot was significant in size and encompassed almost the entirety of the width and greater than 50% of the depth of the 4”x4” wood dunnage. In addition, it is unknown what forces this dunnage was subjected to previously, such as from being ratcheted down for transport. Thus, in addition to the data from the literature showing that this dunnage was at risk for breaking due to the size of the knot, it is not known what additional stress factors or cracks may have occurred as a result of the dunnage being subjected to previous forces when loaded and used for transport and then subsequent reuse.

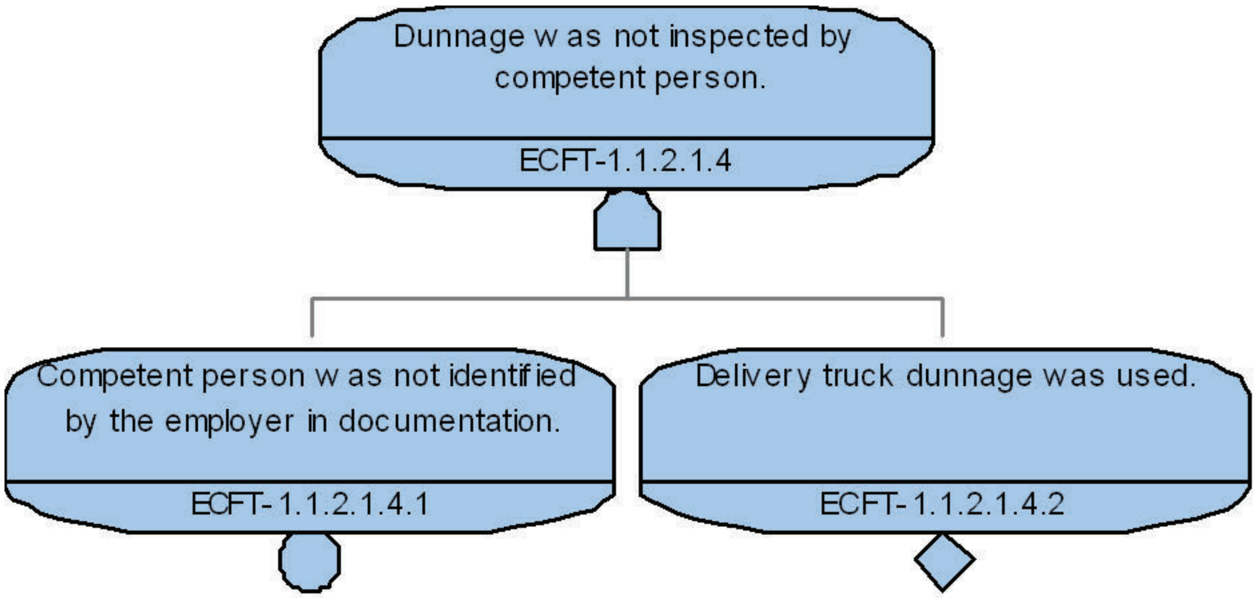


Figure 25: Additional causes of the dunnage breaking.

ECFT-1.1.2.1.4 - Dunnage was not inspected by competent person.

Supporting Evidence: MIT learned through interviews the dunnage used to support the beams were not inspected before use. The dunnage was used previously to deliver the beams to the storage area. The beams and dunnage were removed in 2-3 stacks from the delivery truck using a forklift. The stack of beams and dunnage were placed in the storage area, and the dunnage was not inspected by anyone, including the competent person.

ECFT-1.1.2.1.4.1 - Competent person was not identified by the employer in documentation.

Spporting Evidence: Interviews indicated the competent person was identified verbally and the employee who was designated as competent person was unsure they were the competent person. The subcontractor's employees wore several hats and various employees involved in this work took on the competent person role, but no individual was identified as the competent person in any documentation. Since the competent person was not identified in any documentation, no further analysis was done in this event.

ECFT-1.1.2.1.4.2 - Delivery truck dunnage was used.

Supporting Evidence: According to interviews, the dunnage from the delivery truck was used to stack the beams. MIT wasn't provided information to determine if beams were moved in bundles or individual beams, but was told the dunnage from the delivery truck was reused. MIT observed at the mishap site some dunnage was bowed upward, and this may be a result of the weight of the beams as well as the misalignment of the beams.

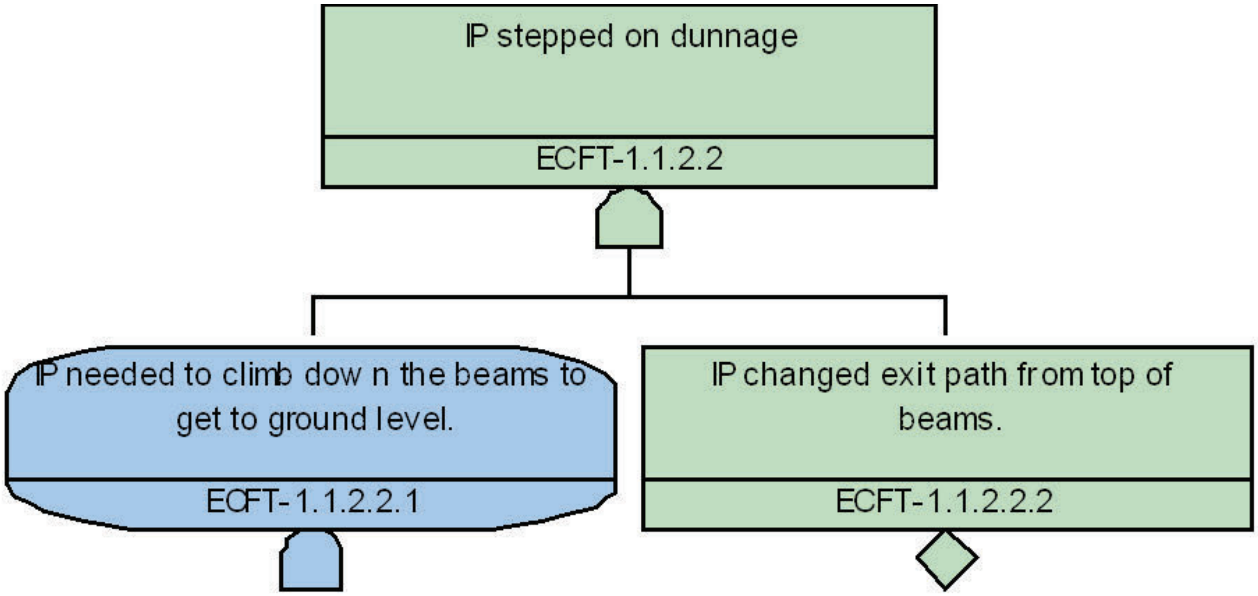


Figure 26: Causes to the IP stepping on dunnage.

ECFT-1.1.2.2.1 - IP needed to climb down the beams to get to ground level.

Supporting Evidence: MIT learned from mishap site, witness statements, and interviews, IP was standing on level 4 beams to clamp attachment to beams and climbed down the beams to exit the beams. It was also noted that walking down the beams was a norm and it was done often. Interviews indicated that ladders, scaffolds, and/or aerial lift are infeasible and unsafe methods to go up or down the unsecured beams.

ECFT-1.1.2.2.2 - IP changed exit path from top of beams.

Supporting Evidence: Video footage illustrated that IP walked to the end of beams on previous movement on beams. However, MIT learned from the mishap site, witness statements, and interviews, IP was standing on level 4 beams and climbed down the beams to exit the beams. It was also noted that walking down the beams was a norm and it was done often. Interviews did not indicate why IP changed his exit path off the beams. Interviews indicated that ladders, scaffolds, and/or aerial lift are infeasible and unsafe methods to go up or down the unsecured beams.

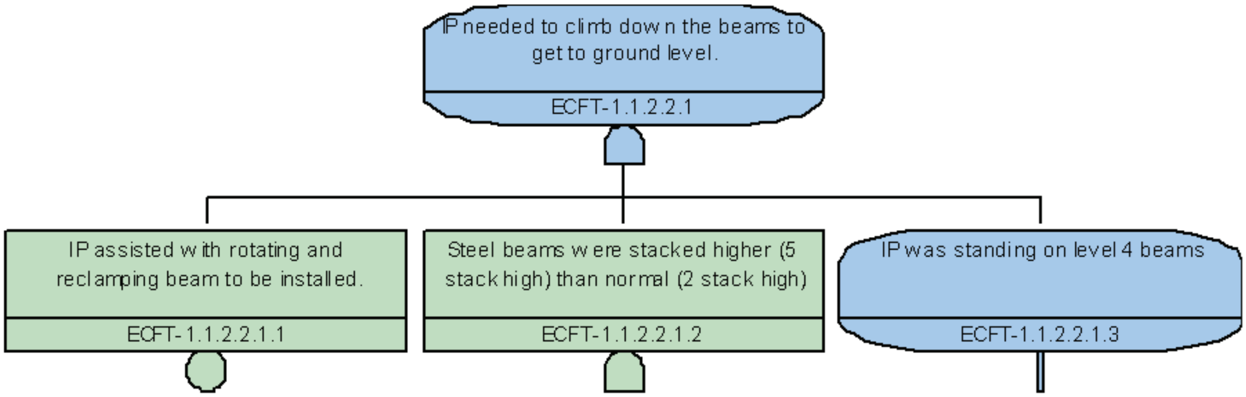


Figure 27: Causes why the IP needed to climb down to ground level.

ECFT-1.1.2.2.1.1 - IP assisted with rotating and reclamping beam to be installed.

Supporting Evidence: MIT learned through interviews that the beams had to be rotated 180 degrees from the stacked orientation to be installed in the final location. The IP clamped the narrow edge of the beam, lowered it to the floor, and rotated the beam 180 degrees so that the wide edge could be clamped in the lifting configuration. After the mishap site was safed, the MIT visited the lay-down area and observed the beams were stacked with the wide edge down with the exception of one beam that was stacked with wide edge up. MIT notified the prime contractor and subcontractor safety personnel of the beam stack in the wrong configuration, and safety personnel informed MIT that the unsafe stacking would be corrected. Interviews indicated that the reclamping was performed due to the height of the stacked unsecured beams.

ECFT-1.1.2.2.1.2 - Steel beams were stacked higher (five stack high) than normal (two stack high).

Supporting Evidence: MIT learned through interviews, video, and site visit that the beams were stacked five high instead of maximum height of two high (~2’8”).

ECFT-1.1.2.2.1.3 – IP was standing on level 4 beams.

Supporting Evidence: MIT learned from video footage, witness statements, and interviews, the IP was working with beams stacked five high and stood on level 4 (~5’4” from floor level) beams to clamp attachment to beams.

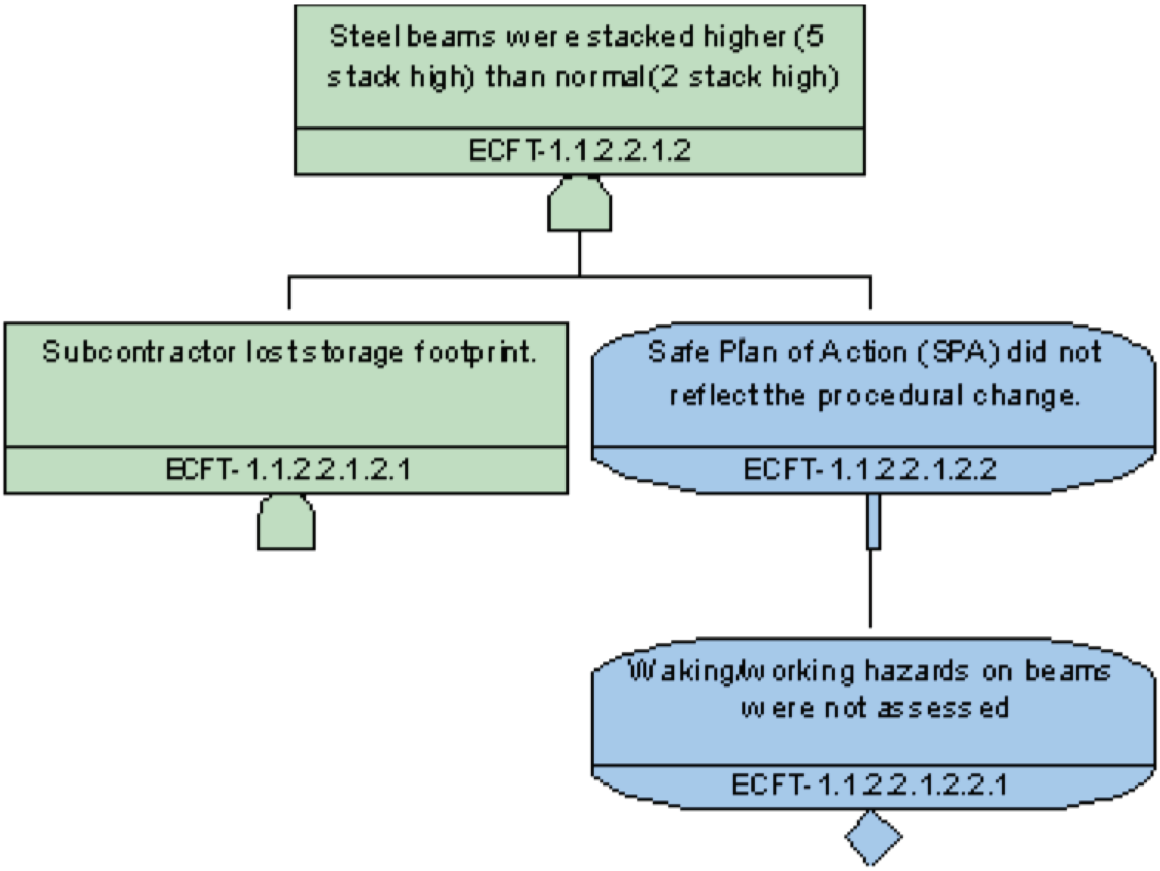


Figure 28: Additional causes to why IP was on stack of beams.

ECFT-1.1.2.2.1.2.1 - Subcontractor lost storage footprint.

Supporting Evidence: MIT learned through interviews that the subcontractor lost floor space to store beams, resulting in the stacking of beams at a height of five (~6'8") high instead of maximum height of two (~2'8") high when they had appropriate space to store beams. Floor space was given to subcontractor to do work for the tenant who owned the space. Once the subcontractor completed the job, the tenant wanted their space back to store flight hardware. Therefore, the subcontractor's storage footprint decreased tremendously. The subcontractor still had to install beams in the plant in various areas, which meant beams were being delivered. Since their storage footprint had decreased, the subcontractor stacked the beams higher than normal. Lay-down area was curtailed due to contract restraints.

ECFT-1.1.2.2.1.2.2 - Safe Plan of Action (SPA) did not reflect the procedural change.

Supporting Evidence: MIT received the Safe Plan of Action (SPA) and Job Hazard Analysis (JHA) as evidence. MIT reviewed both documents and concluded both documents lacked details of the hazards and mitigations/controls for this specific job. Neither the SPA nor the JHA stated a procedural change. MIT learned through interviews the procedure change was done verbally.

ECFT-1.1.2.2.1.2.2.1 - Walking/working hazards on beams were not assessed.

Supporting Evidence: Interviews indicated walking the beams was a norm, and subcontractors did not see it as a hazard. MIT reviewed the SPA and JHA and did not see any hazards related to walking on the beams identified.

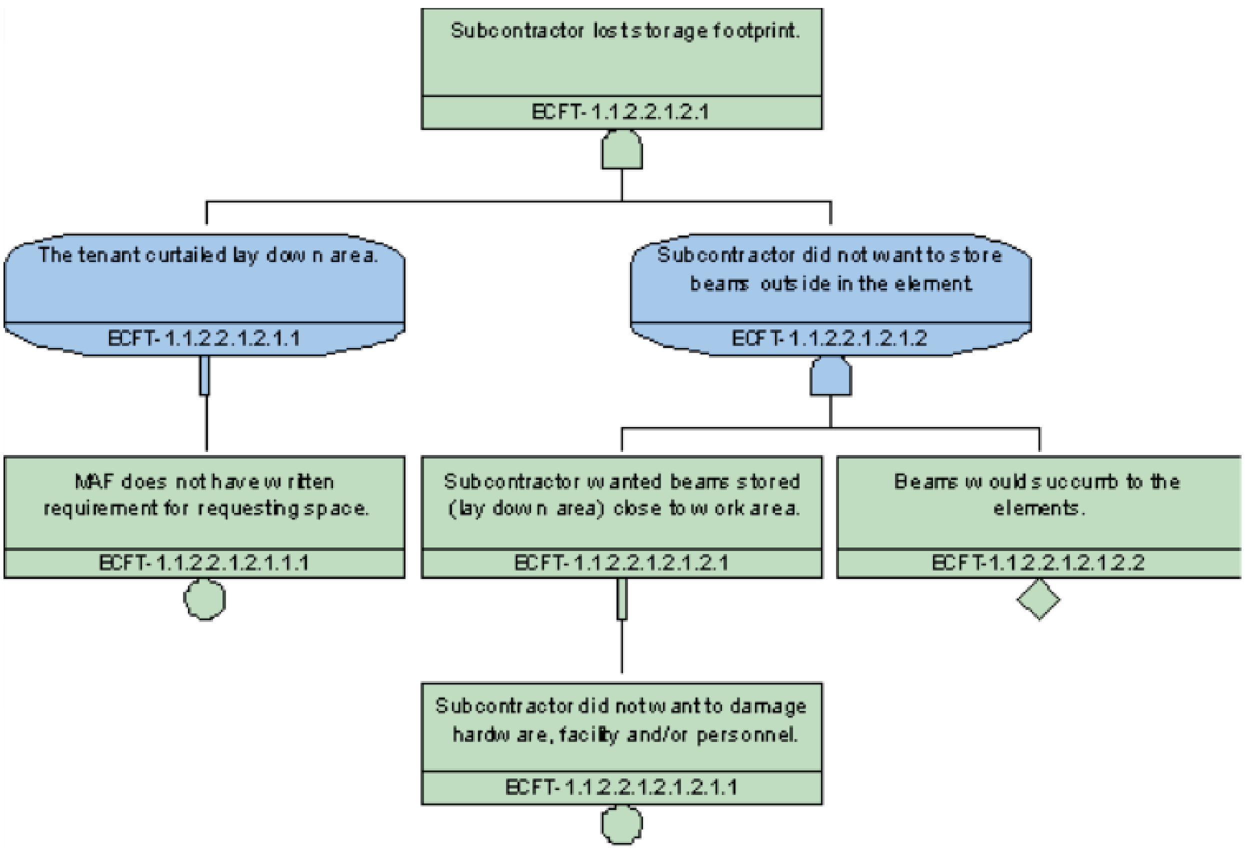


Figure 29: Causes to why the beams were stacked higher than 2 beams.

ECFT-1.1.2.2.1.2.1.1 - Tenant curtailed lay-down area.

Supporting Evidence: MIT learned through interviews the subcontractor lost floor space to store beams resulting in the stacking of beams at a height of five (~6’8”) high instead of maximum height of two (~2’8”) high when they had appropriate space to store beams. Floor space was given to subcontractor to do work for the tenant who owned the space. Once the subcontractor completed the job, the tenant wanted their space back to store flight hardware. Therefore, the subcontractor's storage footprint decreased tremendously. The subcontractor still had to install beams in the plant in various areas, which meant beams were being delivered. Since their storage footprint had decreased, the subcontractor stacked the beams higher than normal. Lay-down area was curtailed due to contract restraints. Interviews indicated the subcontractor made a request verbally for more storage space, but the subcontractor never got a response if the request was approved or denied. In order to stay on schedule, beams were stacked in the assigned storage area. There is no formal process to request floor space and/or it is not communicated to subcontractors within the plant how to request more floor space.

ECFT-1.1.2.2.1.2.1.2 - Subcontractor did not want to store beams outside in the elements.

Supporting Evidence: MIT learned through interviews that the subcontractor did not want to transport beams through the facility over long distances, which would increase the probability of damaging hardware, the facility, and personnel within the plant. The subcontractor stated the beams would rust if stored outside in the elements and would then need to be sandblasted and repainted, which would require more work, time, and money.

ECFT-1.1.2.2.1.2.1.2.1 - Subcontractor wanted beams stored (lay-down area) close to work area.

Supporting Evidence: MIT learned through interviews that the subcontractor wanted to store the beams close to their work area.

ECFT-1.1.2.2.1.2.1.2.1.1 - Subcontractor did not want to damage hardware, facility, and/or personnel.

Supporting Evidence: MIT learned through interviews that the subcontractor wanted to store the beams close to their work area and did not want to transport beams through the facility over long distances, which would increase the probability of damaging hardware, the facility, and personnel within the plant. The subcontractor was working with beams that were 20 feet and 40 feet long. Beams with that length have a greater chance of damaging something in the process of being transported.

ECFT-1.1.2.2.1.2.1.2.2 - Beams would succumb to the elements.

Supporting Evidence: Interviews indicated beams will rust quickly if stored in the Louisiana atmosphere and would then need to be sandblasted and repainted, which would require more work, time, and money.

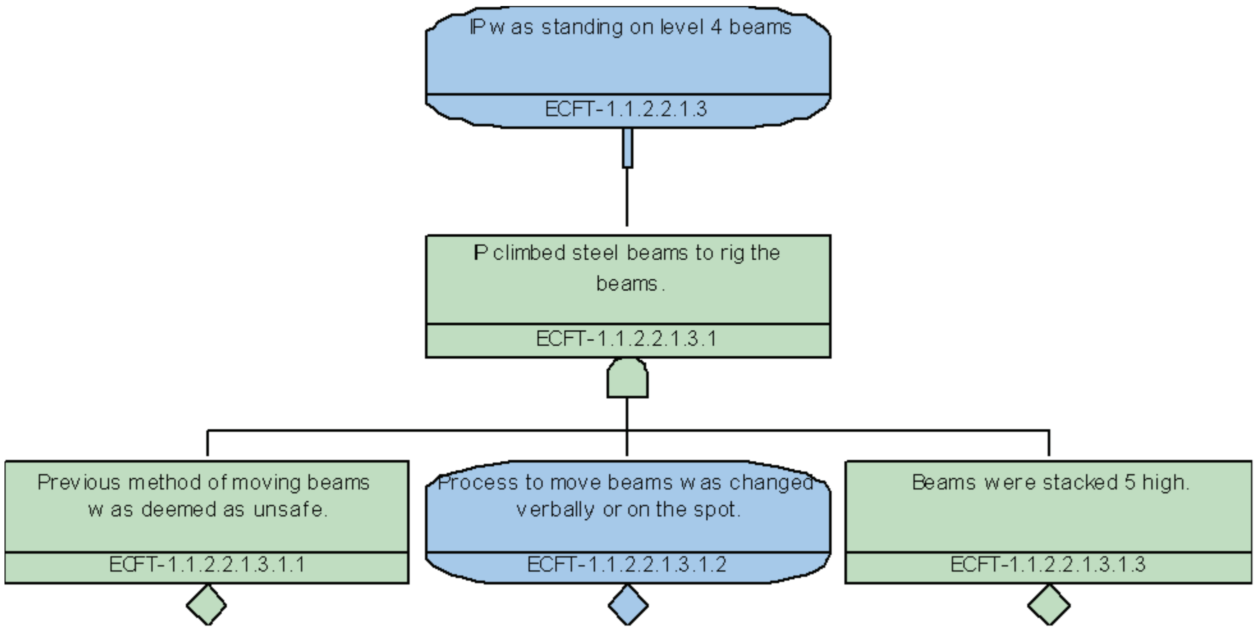


Figure 30: Causes as to why the IP was on the beams.

ECFT-1.1.2.2.1.3.1 - IP climbed steel beams to rig the beams.

Supporting Evidence: MIT learned through interviews and video that IP climbed the beam to secure it with forklift clamps, rigging, and beam clamp. MIT learned from video footage, witness statements, and interviews tht the IP was working with beams stacked five high and stood on level 4 (~5’4” from floor level) beams to clamp attachment to beams.

ECFT-1.1.2.2.1.3.1.1 - Previous method of moving beams was deemed unsafe.

Supporting Evidence: MIT learned from interviews that the IP was installing castellated beams. Initially, the IP was moving the beams with a forklift without securing them and was told by the prime contractor that this method was unsafe. The IP then used the free rigging method and beam clamp but was told by the prime contractor that this method was unsafe as well.

NOTE: Free rigging is the direct attachment to or placement of rigging equipment (slings, shackles, rings, etc.) onto the tines of a powered industrial truck for a below-the-tines lift. This type of lift does not use an approved lifting attachment.

ECFT-1.1.2.2.1.3.1.2 - Process to move beams was changed verbally or on the spot.

Supporting Evidence: Interviews indicated that all requests for space allocations were verbal and there was no formal process to request space. MIT learned through interviews that several verbal requests were made to the prime contractor for more space to store the beams. The subcontractor never got a response from the prime contractor if the request was approved or denied. In order to stay on schedule, beams were stacked in the assigned storage area, which resulted in the beams being stacked at a height of five high (~6’8”) instead of maximum height of two high (~2’8”). There was no formal documentation to note a change in the process to move the beams. When the beams were stacked at a height of two high, there was no need to climb the beams to attach the clamp to the beams because the attachment occurred on the floor.

ECFT-1.1.2.2.1.3.1.3 - Beams were stacked 5 high.

Supporting Evidence: MIT learned through interviews that the subcontractor lost floor space to store beams, resulting in the stacking of beams at a height of five high (~6’8”) instead of maximum height of two high (~2’8) when they had appropriate space to store beams. Floor space was given to the subcontractor to do work for the tenant who owned the space. Once the subcontractor completed the job, the tenant wanted their space back to store flight hardware. Therefore, the subcontractor's storage footprint decreased tremendously. The subcontractor still had to install beams in the plant in various areas, which meant beams were being delivered. Since their storage footprint had decreased, the subcontractor stacked the beams higher than normal. Lay-down area was curtailed due to contract restraints. Interviews indicated that the subcontractor made a request verbally for more storage space, but the subcontractor never got a response if the request was approved or denied. In order to stay on schedule, beams were stacked in the assigned storage area. There is no formal process to request floor space and/or it is not communicated to the subcontractors within the plant how to request more floor space.

4.4 Contributing Factor

ECFT-1.3.2 - IP's left foot contacted upper beam.

Supporting Evidence: Interviews indicated IP was working on level 4 (~5'4" from ground level) to attach clamps to beams on level 5 (~6'8"). As IP was climbing down the beams, IP stepped on dunnage located on level 3 (~4' from ground level) and the dunnage broke. As the IP was falling, IP reached for the beams to stabilize the fall and IP's left foot contacted the beams on level 5. With limited information and video footage taken far away from the mishap scene, MIT concluded foot contact with a beam may be a contributing factor to the beams falling.

4.5 Root Cause

ECFT-1.1.2.2.1.2.1.1.1 - MAF does not have written requirements for requesting space.

Supporting Evidence: Interviews indicated that all requests for space allocations were verbal and there was no formal process to request space. MIT learned through interviews that several verbal requests were made to the prime contractor for more space to store the beams. The subcontractor never got a response from the prime contractor if the request was approved or denied. In order to stay on schedule, beams were stacked in the assigned storage area, which resulted in the beams being stacked at a height of five high (~6'8") instead of maximum height of two high (~2'8"). There is no formal process to request floor space and/or it is not communicated to the subcontractors within the plant the process to request more floor space.

4.6 Observations

O-1: There was lack of clarity in the procedure for transferring Interim Response Team (IRT) responsibilities from MAF Protective Services and Occupational Health/AS60 to MAF Facility Safety/QD12.

Supporting Evidence: Although an Interim Response Team (IRT) was implemented in accordance with NPR 8621.1 (NASA Procedural Requirements, 8621.1) and the Program Mishap Preparedness and Contingency Plan (MPCP), there was confusion regarding establishing the point at which the Incident Commander (IC) relinquished control to the NASA IRT, which is led by the Industrial Safety Branch per MWI 8621.1 (NASA MPR 1860.1) and MCP 8621.1 (NASA, MCP 8621.1). This lack of clarity also occurred in the 2017 High Visibility Close Call, Inadvertent Radiation Exposure mishap (NMIS 17-101755). Although corrective action was implemented, a reoccurrence of lack of IRT duties and handoff from IC also occurred in this mishap.

O-2: The availability of the video footage taken by the camera located in Building 103/E4-Camera 1 and used to monitor the activities in the building proved to be invaluable in understanding the activities occurring at the work site during the time of the IP's fall from the beams.

Supporting Evidence: The MIT's use of the time-lapse video proved to be very helpful in understanding the incident and occurrence of events.

O-3: The MIT reviewed the timeline and description of activities that occurred during this mishap emergency response. It was noted that the IP received medical care from Protective Services, who arrived on the scene first within minutes. Security Officer 1 immediately made a makeshift tourniquet out of a bystander's belt and their own baton and applied it to the IP's upper leg. This quick action and the ability to remain calm is commendable and saved the IP's life. It was also noted that a medical flight was called by senior security personnel, and this too contributed to saving IP's life by rapid referral to a trauma center.

Supporting Evidence: The MIT learned when the response activity occurred through interviews and emergency dispatch logs with description and times.

4.7 Medical Outcomes

The IP sustained a fracture of the right forearm as a result of the fall, which required surgical fixation. In addition, the IP sustained partial limb amputation (a right below-knee amputation), after multiple attempts at limb salvage surgery for the right lower extremity failed, and the risk versus reward for continued efforts was deemed no longer viable or sustainable.

Regarding the level of disability or impairment, the State of Louisiana utilizes *The American Medical Association Guides: Current Medicine for Permanent Impairment Ratings* (6th Edition 2023). This is a published and regularly updated guideline used by physicians to ascertain the impairment or disability of an individual. The guidelines provide impairment grids for lower and upper extremity amputations, which are divided into five impairment classes (0 through 4), and each impairment class is further divided (except class 0) into five grades (A through E), each with its respective impairment rating that is expressed as a percentage of the extremity. In the case of the IP, the injury is too acute to ascertain the remaining or residual impairment. An individual's proximal problems or medical/surgical complications, revisions, surgeries, grafts, prosthetics, skin breakdown, infection, phantom limb pain, or proximal joint issues may lead to an increase in the impairment value because of the application of grade modifiers. In addition, crush injuries may have delayed healing and typically require additional orthopedic and plastics repair or modifications. The IP will at the very least have a permanent partial disability due to the loss of the right lower extremity, but the percentage and residual impairment or level of impairment will not be known for some time until complete healing, prosthetics fitting and use, and chronic residual conditions can be assessed at a much later date.

5.0 Recommendations

Several recommendations have been identified as a result of the MIT's work. Recommendations addressing the root cause, RCA findings, and other recommendations are listed here in priority order, starting with the highest-priority recommendation. MIT has created a Mishap Warning-Action-Response (MWAR) to suggest Best Practices for the Agency to consider.

5.1 Root Cause

R-ECFT-1.1.2.2.1.2; R-ECFT-1.1.2.2.1.2.1; R-ECFT-1.1.2.2.1.2.1.1; ECFT-1.1.2.2.1.2.1.1.1; R-ECFT-1.1.2.2.1.2.1.2; R-ECFT-1.1.2.2.1.3.1.3- MAF does not have written requirements for requesting space.

Recommendation 1: The MAF Facility Utilization Organizational Issuance, AS60-OI-008 (NASA, MPD 5340.1/AS60-OI-008), allocates office space and not floor space on the manufacturing floor to store hardware, tools, equipment, etc. NASA MAF Facility Utilization Policy, AS60-OI-008 (NASA, MPD 5340.1/AS60-OI-008), should be updated by NASA AS60 for space allocation to include manufacturing floor space. The updated policy should include a flowchart of the process and point of contacts.

5.2 Recommendations from RCA Findings

R-ECFT-1.1.2.1.4.1- Competent person was not identified by the employer in documentation.

Recommendation 1: NASA MSFC Safety should create a checklist to verify that contractors adhere to NASA, MSFC, and/or OSHA requirements per job area (construction, lifting devices, explosives, etc.). The organization/contractor performing the work/operations shall designate an employee within their organization to serve as the competent person in accordance with 29 CFR pt. 1926.32(f).

5.3 Other Recommendations

O-1: There was lack of clarity in the procedure for transferring Interim Response Team (IRT) responsibilities from MAF Protective Services and Occupational Health/AS60 to MAF Facility Safety/QD12.

R-O1: NASA MSFC Industrial Safety Branch/QD12, NASA MSFC Environmental Engineering and Occupational Health Office/AS10, and NASA MSFC Protective Services/AS60 should jointly and collaboratively define more specifically the sequence of hand-offs from IRT to IC to MIT in all

Centers' Mishap Preparedness Contingency Plans (MPCPs). All Centers should do a mishap simulation where the roles and responsibilities of the IC and IRT would be demonstrated so when a mishap occurs, there will be no confusion on who oversees the mishap. In addition to MPCP requirements (NPR 8621.1, section 1.3.1, paragraph e), this should include a life-threatening simulation at a level of Type A or B mishap.

O-2: The availability of the video footage taken by the camera located in Building 103/E4-Camera 1 and used to monitor the activities in the building proved to be invaluable in understanding the activities occurring at the work site during the time of the IP's fall from the beams.

R-O2: NASA MSFC Protective Services/AS60 management should consider installing time-lapse cameras as a requirement for all activity, especially where construction and flight hardware activities are performed.

O-3: The MIT reviewed the timeline and description of activities that occurred during this mishap emergency response. It was noted that the IP received medical care from Protective Services, who arrived on the scene first within minutes. Security Officer 1 immediately made a makeshift tourniquet out of a bystander's belt and their own baton and applied it to the IP's upper leg. This quick action and the ability to remain calm is commendable and saved the IP's life. It was also noted that a medical flight was called by senior security personnel, and this too contributed to saving IP's life by rapid referral to a trauma center.

R-O3: NASA Protective Services and Office of Chief Health and Medical Officer (OCHMO) should ensure that all security personnel have medical tourniquets in their first aid kit. Tourniquets should be available in all NASA buildings near AEDs and/or with indoor first aid kits as appropriate. "Stop the Bleed" training should be required for all NASA Security Personnel.

Protective Services should ensure that all members of their staff complete the "Stop the Bleed" training. In addition to training, NASA Centers should develop live simulations to be performed in high-risk areas to practice applying tourniquets, being the IRT, and to ensure training and competence of personnel in communicating and responding to emergencies.

5.4 Mishap Warning Action Response (MWAR)

MIT suggests the following Best Practices for all NASA Centers to consider for future construction work that involves steel erection, working at unprotected edges, and/or working at heights of 4 feet or more:

1. All NASA Fall Protection Program Administrators should implement a Best Practice for their respective Center that a personal fall arrest system should be worn when working at an unprotected edge greater than 4 feet. When feasible, the fall protection user

should anchor above their head. Another Best Practice suggested is workers should not walk on unsecured beams, no matter the height of the beam stack.

2. The NASA SMA appropriate branch/department should verify that the contractor's Job Hazard Analysis (JHA) includes the inspection of the dunnage by the competent person. The JHA should identify the mitigation or control plan if deficiencies (warps, cracks, splits, etc.) are observed in the dunnage to be used.
3. The NASA SMA appropriate branch/department should verify the contents of all contractors' SPAs and JHAs to ensure all hazards, mitigations, and controls have been identified for each job assigned and reflect any procedure changes. SPAs and JHAs should be reviewed and signed according to the company/Center's process.
4. Construction training should be required for all resident contractors as well as NASA personnel engaged in construction projects involving steel erection. MSFC SMA (QD) should obtain a steel erection standards awareness course (training), incorporating OSHA, ANSI, and MSFC requirements for steel erection. All resident contractors and NASA civil servants assigned to a construction project should attend this training immediately upon assignment. MSFC Center Operations (AS) should ensure Project team members complete the steel erection awareness training.

6.0 HFACS Analysis and Discussion

In the following section, the applicable text is from the Human Factors Analysis and Classification System (HFACS) handbook, NASA-HDBK-8709.25, V1.4, describing each classification. Red text indicates the events and conditions that contributed to the event and falls under those categories, and green text indicate positive conditions that took place.

ACTS: These influences or factors describe behavioral omissions and commissions committed by an individual or team and contribute to an event.	
Decision-Making Events: When actions based on conscious choices contribute to an event.	
AD101 Incorrect action selection. A factor when an individual mis-prioritizes and executes the wrong course of action to accomplish a task and this contributes to an event.	**ECFT-1.1.1 – IP stepped on dunnage.** **ECFT-1.1.1.1 – IP climbed down the beams to get to ground level.** **ECFT-1.1.2.2 – IP stepped on dunnage.** **ECFT-1.1.2.2.1 – IP needed to climb down the beams to get to ground level.** **ECFT-1.1.2.2.1.3 – IP was standing on level 4 beams (~5'4" from floor level).** **ECFT-1.1.2.2.1.3.1 – IP climbed steel beams to rig the beams.** **ECFT-1.1.2.2.2 – IP changed exit path from top of beams.** Beams were being stacked higher than two beams high (~2'8") due to beam storage footprint being reduced, thus requiring an employee to climb and walk on stack of beams. IP had previously exited stack of beams at the end of the stack; this time IP climbed down the side of the stack. **Correct Action Taken:** Medical airlift was requested to transport IP to trauma center, which contributed to saving the life of the IP.
AD103 Inadequate real-time assessment. A factor when an individual fails to adequately evaluate the risks associated with a course of action, and this contributes to an event.	**ECFT- 1.1.2.2.1.2.2.1 – Walking/working hazards on beams were not assessed.** **ECFT-1.1.2.2.2 – IP changed exit path from top of beams.** Employee did not recognize the hazards of walking/working on beams or climbing down the side of the stack of beams. **Correct Real Time Assessment:** Arriving security personnel was trained as a combat medic, immediately assessed the incident, and applied a temporary tourniquet to stem the flow of blood.

RECONDITIONS: When environmental factors or conditions of individuals affect performance.	
ENVIRONMENTAL FACTORS: When physical, technological, spatial, or informational factors affect the practices, conditions, and actions or inactions of an individual or team.	
Physical Environment: When weather, climate, buildings, natural surroundings, or "housekeeping" create conditions affecting the actions of an individual or team and contribute to an event.	
PE207 Housekeeping. A factor when upkeep or organization of workspaces, equipment, and materials contributes to an event.	**ECFT-1.1.2.1.3 – Dunnage had a large knot.** **ECFT-1.1.2.1.4 – Dunnage was not inspected by competent person.** **ECFT-1.1.2.1.4.2 – Delivery truck dunnage was used.** **ECFT-1.1.2.2.1.2.1 – Subcontractor lost storage footprint.** **ECFT-1.1.2.2.1.2.1.1 – Tenant curtailed lay-down area.** **ECFT-1.1.2.2.1.2.1.2 - Subcontractor did not want to store beams outside in the elements.** **ECFT-1.1.2.2.1.2.1.2.1 – Subcontractor wanted beams stored (lay-down area) close to work area.** **ECFT-1.1.2.2.1.2.1.2.1.1 Subcontractor did not want to damage hardware, facility, and/or personnel.** The dunnage from the delivery truck was reused to stack beams; this dunnage was not inspected by a competent person and had a large knot in the wood. The subcontractor had lost the storage footprint due to the job in the area being completed and the tenant needing the space to store flight hardware. The subcontractor did not want to store beams outside in the weather and did not want to move the beams long distances through the building, which could possibly increase the number of damage or injury incidents. The size of the lay-down area had been greatly reduced, requiring the beams to be stacked higher than two beams high (~2'8"); the beams were being stacked up to five beams high (~6'8").
Information Environment: When interactions among individuals, crews, and teams create conditions that influence the preparation and/or performance of a mission.	
PI203 Risk assessment during event or mission. A factor when a team member's ability to adequately communicate changes during mission execution and adjust their work accordingly contributes to an event.	**ECFT- 1.1.2.2.1.2.2.1 – Walking/working hazards on beams were not assessed.** **ECFT-1.1.2.2.2 – IP changed exit path from top of beams.** The hazards of walking/working on the stacked steel beams were not addressed in the Job Hazard Analysis.

PI204 Communication. A factor when information is misspoken, misread, or misheard, and this condition contributes to an event. This includes putting forth with proper persistence. Examples: Lack of assertiveness; information not entered in maintenance logbook, engineering order, or work card; poor shift turnover.	**ECFT-1.1.2.2.1.2.1.1.1 - MAF does not have a written requirement for requesting space.** Subcontractor made a request to the prime contractor that additional floor space was needed. The communications requesting additional space from the subcontractor were not adequately addressed by prime contractor to the tenant where area was being requested.

SUPERVISION: Factors in a mishap if the methods, decisions, or policies of the supervisory chain of command directly affect practices, conditions, or individual actions and contributes to an event.	
Oversight: When supervision such as guidance, oversight, training, and/or management are associated with preconditions and/or actions related to an event.	
SO302 Local Training Issues/Programs. A factor when one-time or recurrent training programs, upgrade programs, transition programs, or any other local training contributes to an event. *(Note: The failure of an individual to absorb the training material in an adequate training program does not indicate a training program problem; see Precondition - Psychological category).*	**ECFT-1.1.2.2.1.2.2 - Safe Plan of Action (SPA) did not reflect the procedural change.** The subcontractor was performing work and was told that it was unsafe. The subcontractor changed the method of lifting the rails, but never documented the change in the SPA.
Accountability: When supervisory attention to known deficiencies among personnel, equipment, processes, and/or procedures influence conditions related to an event.	
SA301 Personnel Management. A factor when a supervisor is aware of pre-existing conflicts between operators, maintainers, or aviators who exhibit recognizable risky behaviors or unsafe tendencies and fails to institute remedial actions.	**ECFT- 1.1.2.2.1.2.2.1 – Walking/working hazards on beams were not assessed.** **ECFT-1.1.2.2.2 – IP changed exit path from top of beams.** Oversight was lacking as the safety personnel walked by but never addressed the issue of walking/working on the beams or the beams stored up to five beams high (~6'8") without constraints.

<table>
<tr><td colspan="2">ORGANIZATION: When the shared attitudes, values, beliefs, or contractor relationships within an organization impact operation and/or operational risk.</td></tr>
<tr><td colspan="2">Climate/Culture: When the attitudes, values, beliefs, or morale impact operations and/or operational risk.</td></tr>
<tr><td>OC403 Contractor relations. A factor when relationships, communications, or inter-operability between the organization and contractors (prime or sub) is affected and impacts the working relationship. This includes the oversight and insight.</td><td>ECFT-1.1.2.2.1.2.1.1 – Lay-down area was curtailed to space restraints by the tenant.

The communication requesting additional space from the subcontractor was not adequately addressed by the prime contractor to the tenant where area was being requested.</td></tr>
<tr><td colspan="2">Operations: When the organizational processes and/or procedures (e.g., structure, tempo, risk management, oversight, publications, training) impact operations.</td></tr>
<tr><td>OP404 Program oversight or management. A factor when acquisitions management, design analysis (e.g., design review boards, Safety and Mission Success Review, Flight Readiness Reviews, etc.), and Program oversight or management affect a Program's ability to obtain the correct quantity/quality of equipment.</td><td>ECFT-1.1.2.2.1.2.1.1.1 - MAF does not have a written requirement for requesting space.
ECFT-1.1.2.2.1.3.1.2.1 (should be 1.1.2.2.1.3.1.3)- Beams were stacked five high.

The subcontractor made several requests to obtain additional floor space to accommodate the steel beams, but never received any feedback, which resulting in the beams being stacked more than two high (~2'8").</td></tr>
<tr><td>OP405 Publications/written guidance. A factor when the quality, quantity, acquisition/supply, or updating of publications, procedures, and/or written guidance affect operational risk. Examples: Vehicle operating manuals, instructions, directives, technical manuals, etc.</td><td>ECFT-1.1.2.2.1.2.1.1.1 - MAF does not have a written requirement for requesting space.

The process of requesting additional floor space is not clearly defined in any documentation.</td></tr>
</table>

Resources: When the allocation, availability, or condition of personnel, equipment, facilities, and monetary assets necessary for an organization to accomplish a mission impact operations.	
OR407 Facilities/Buildings & Grounds. A factor when the quality or quantity of facilities, roads, sidewalks, outside training areas, parking lots, common areas, etc., affect operational risk.	**ECFT-1.1.2.2.1.2 - Steel beams were stacked higher (five stack high) than normal (two stack high).** **ECFT-1.1.2.2.1.2.1 - Subcontractor lost storage footprint.** **ECFT-1.1.2.2.1.2.1.2 - Subcontractor did not want to store beams outside in the elements.** **ECFT-1.1.2.2.1.2.1.2.1 - Subcontractor wanted beams stored (lay-down area) close to work area.** **ECFT-1.1.2.2.1.2.1.2.1.1 - Subcontractor did not want to damage hardware, facility, and/or personnel.** The subcontractor had lost the storage footprint due to the job in the area being complete and the tenant needing the space to store flight hardware. The subcontractor did not want to store beams outside in the weather and did not want to move the beams long distances through the building, which could possibly increase the number of damage or injury incidents. The size of the lay-down area had been greatly reduced, requiring the beams to be stacked higher than two beams high (~2’8”); the beams were being stacked up to five beams high (~6’8”).

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Appendix 1: Fault Tree Diagram and Summary

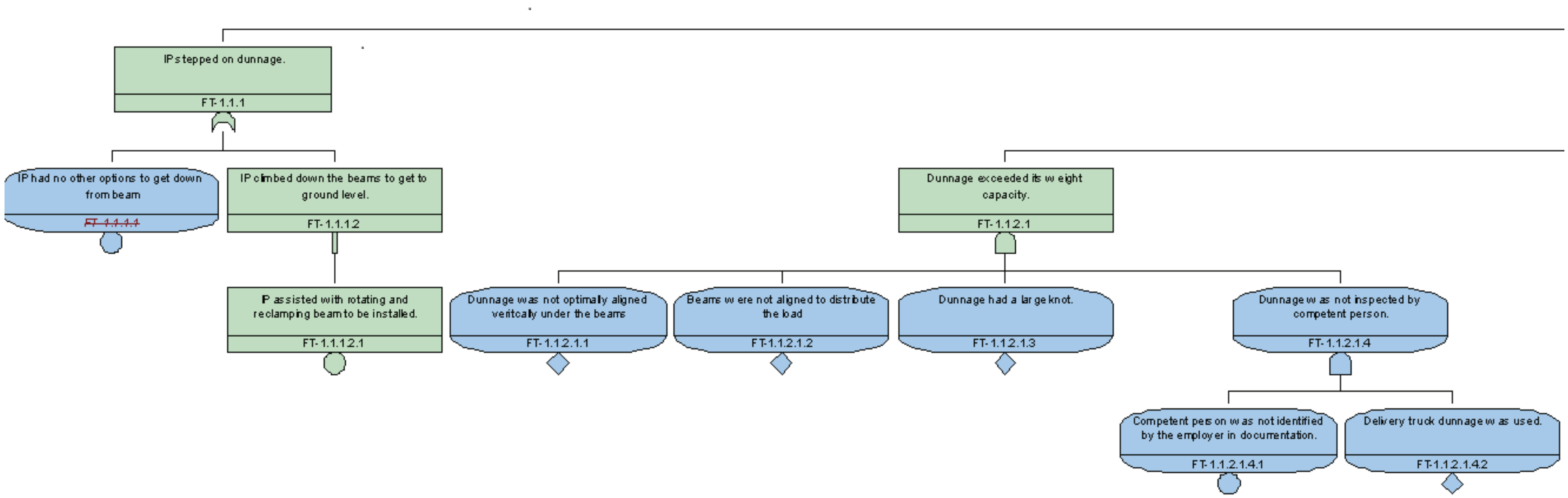

Figure 31: Fault Tree, Section 1

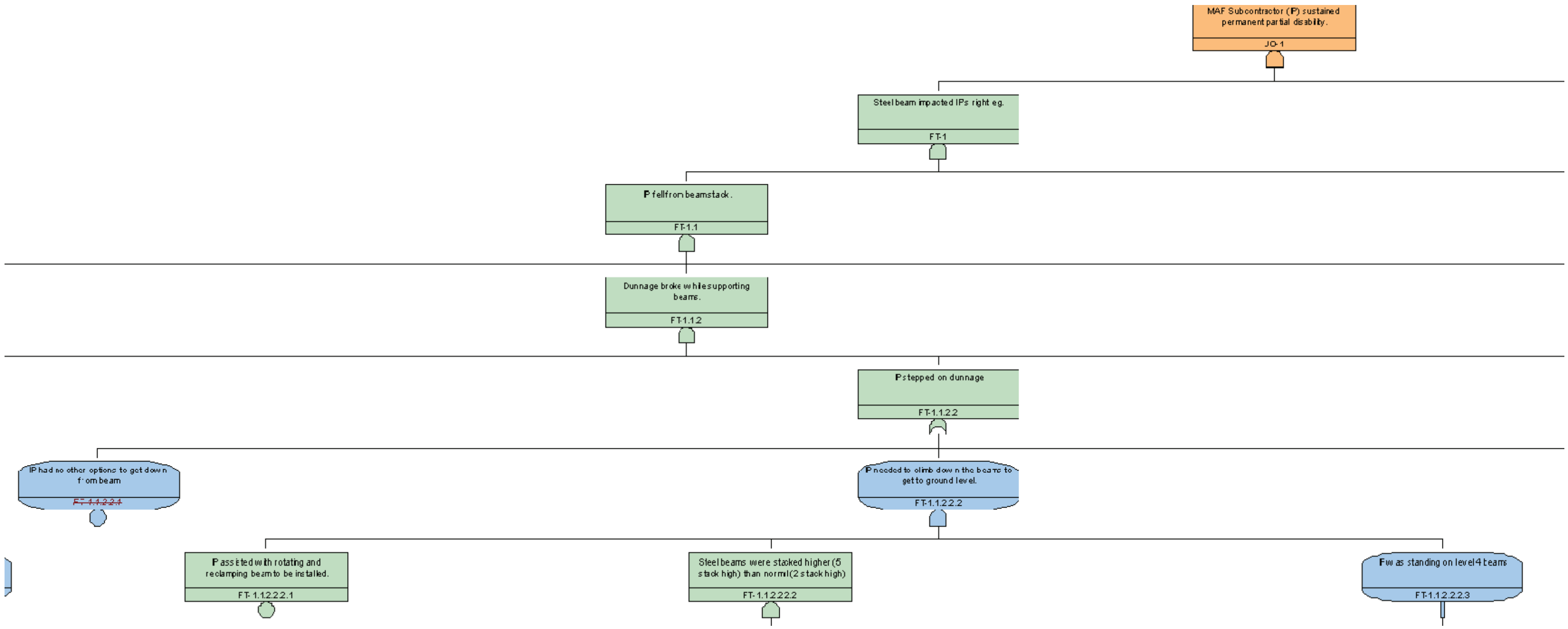

Figure 32: Fault Tree, Section 2

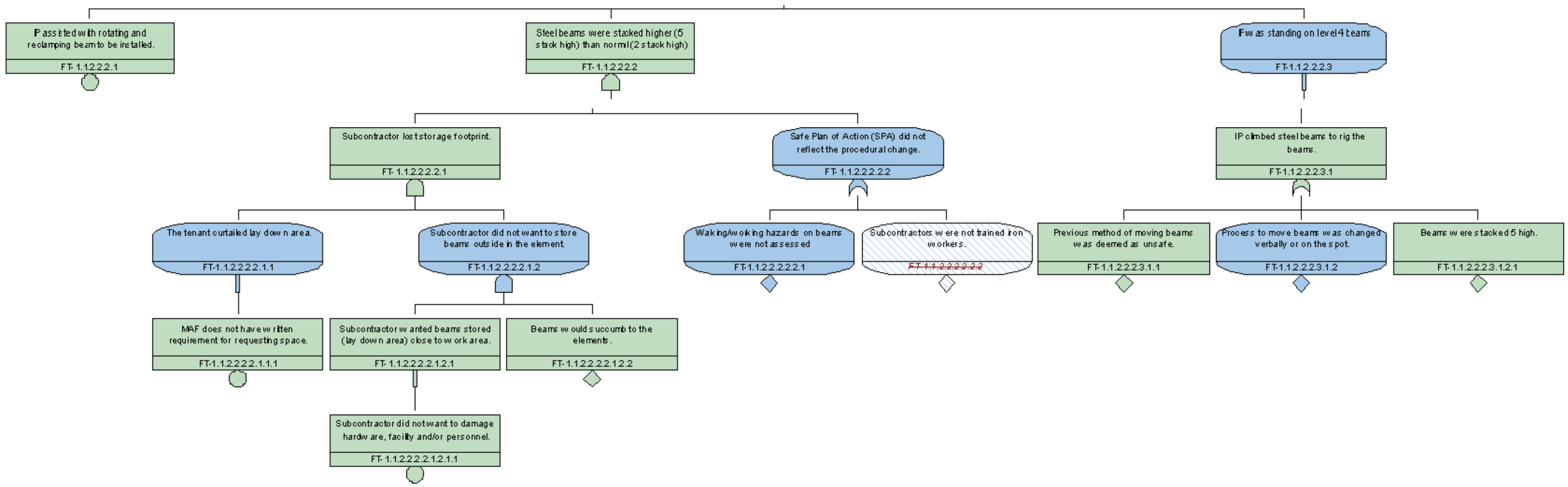

Figure 33: Fault Tree, Section 3

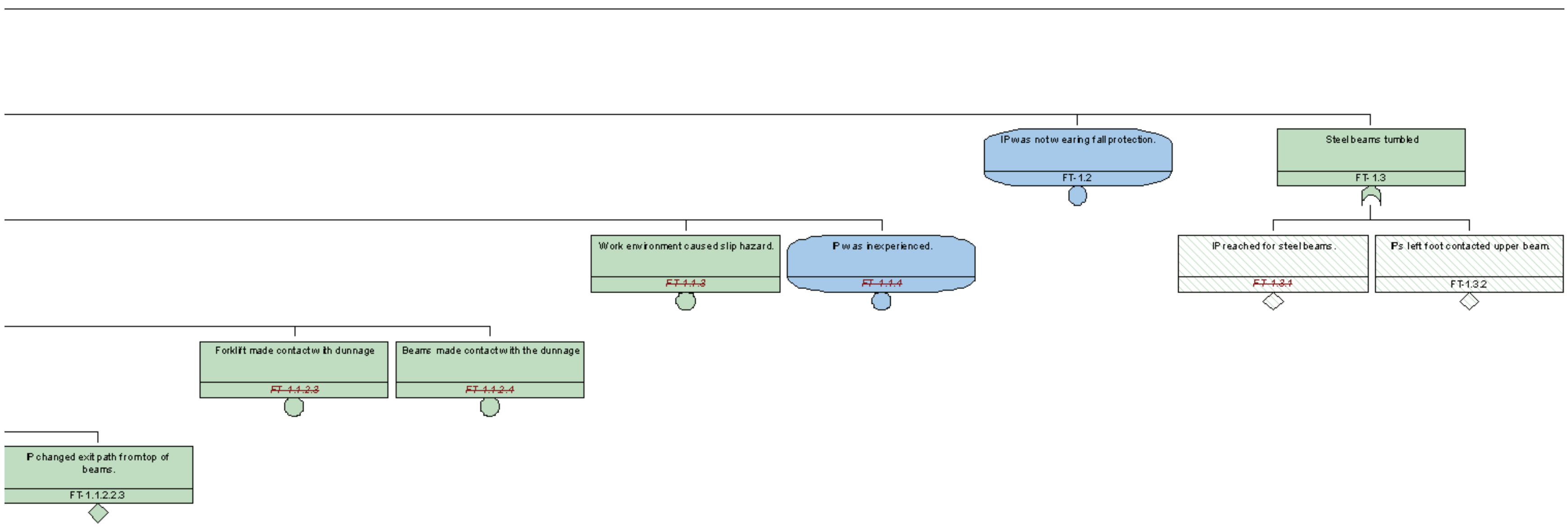

Figure 34: Fault Tree, Section 4

FT-1.1.1.1 and FT-1.1.2.2.1 (Potential Cause - Ruled Out): IP had no other options to get down from beam.

Refuting Evidence: MIT learned from the mishap scene and interviews that ladders, scaffolds, and/or aerial lifts are infeasible and unsafe methods to go up or down the unsecured beams. Therefore, IP either had to walk to the end of the beams or step on dunnage to exit the beams.

FT-1.1.2.2.2.2.2.2 (Potential Contributing Factor – Ruled Out): Subcontractors were not trained iron workers.

Refuting Evidence: MIT learned through interviews that this was a construction job and the employees were experienced in installing beams. According to North American Industry Classification System,an iron worker is a form of construction worker, but they do specialized work such as erecting buildings. There is no specific training for iron working.

FT-1.1.2.3 (Potential Cause - Ruled Out): Forklift made contact with dunnage.

Refuting Evidence: MIT learned from interviews and video footage that the forklift did not make contact with the dunnage.

FT-1.1.2.4 (Potential Cause - Ruled Out): Beams made contact with the dunnage.

Refuting Evidence: MIT learned from interviews and video footage that the beams did not make contact with the dunnage.

FT-1.1.3 (Potential Cause - Ruled Out): Work environment caused slip hazard.

Refuting Evidence: Interviews indicated the work environment had no hazards (proper lighting, no noise, no moisture on beams, etc.) to contribute to the incident. During the mishap site visit, the MIT didn't see any work environment hazards.

FT-1.1.4 (Potential Cause - Ruled Out): IP was inexperienced.

Refuting Evidence: MIT learned from interviews that the subcontractor company was a family-owned business. MIT doesn't know how much experience the IP has in this industry. Interviews indicated IP was knowledgeable of the job and the industry.

FT-1.3.1 (Potential Contributing Factor – Ruled Out): IP reached for steel beams.

Refuting Evidence: MIT learned from interviews, witness statements, and video footage that IP was working on level 4 beams to attach clamps to beams. When IP exited the beams, he stepped on dunnage located on level 3, and when the dunnage broke, IP reached for beams for stability while falling, but was unable to secure himself from falling. IP did not grab the beam when falling.

FT-3 (Potential Cause - Ruled Out): IP was rigging crane beams.

Refuting Evidence: MIT learned from interviews that the IP was installing castellated beams. Initially, the IP was moving the beams with a forklift without securing them and was told by the prime contractor that this method was unsafe. The IP then used the free rigging method and beam clamp, but was told by the prime contractor that this method was unsafe as well. Therefore, IP used forklift clamps, rigging, and beam clamps to secure beams. Rigging was complete and was not causal to his fall.

Free rigging is the direct attachment to or placement of rigging equipment (slings, shackles, rings, etc.) onto the tines of a powered industrial truck for a below-the-tines lift. This type of lift does not use an approved lifting attachment.

FT-4 (Potential Cause - Ruled Out): Emergency response increased severity of injury.

Refuting Evidence: MIT learned through interviews that security was the first to arrive on scene and commercial medical tourniquets were not available. Therefore, security accessed and immediately created a makeshift tourniquet out of a belt and baton. Security applied the make shift tourniquet to the IP's right leg to stop the bleeding. EMS arrived about five minutes after security, and they applied three additional tourniquets to the IP's leg before IP was airlifted. As a result of the quick response, there was no increase of severity of the IP's injury.

FT-5 (Potential Cause - Ruled Out): Beams were unstable.

Refuting Evidence: MIT learned through interviews that the beams were stable and that's why IP climbed the beams to perform rigging duties.

Appendix 2: Definitions

Amputation: The removal, either traumatically or surgically, of a body part or limb.

Body Harness: Straps secured about the employee in a manner that will distribute the fall arrest forces over at least the thighs, pelvis, waist, chest, and shoulders, with means for attaching it to other components of a personal fall arrest system.

Beam: A steel girder, which may have one side larger than another or a curved surface to allow a crane to roll along the smoother surface in order to move a large load from one place to another.

Beam Clamp: A device that has a jack screw that ratchets down tightly onto the narrow side of a beam, allowing a crane or lull to pick up the beam for movement or extrication.

Cause: An event or condition that results in an effect. Anything that shapes or influences the outcome.

Chairperson: The individual in charge of a mishap investigation board or mishap investigation team.

Competent Person: One who is capable of identifying existing and predictable hazards in the surroundings, or working conditions which are unsanitary, hazardous, or dangerous to employees, and who has authorization to take prompt corrective measures to eliminate them.

Condition: Any single as-found state, whether or not resulting from an event, that may have safety, health, quality, security, operational, or environmental implications.

Contracting Officer: The person with the authority to enter into, administer, and/or terminate contracts and make related determinations and findings.

Contributing Factor: An event or condition that may have contributed to the occurrence of an undesired outcome but, if eliminated or modified, would not by itself have prevented the occurrence. Contributing factors increase the probability that an event or condition will occur.

Corrective Actions: Changes to design processes, work instructions, workmanship practices, training, inspections, tests, procedures, specifications, drawings, tools, equipment, facilities, resources, or material that result in preventing, minimizing, or limiting the potential for recurrence of a mishap.

Cribbing: Placement of hard surface planking to provide solid platform for prevention of beam slippage or movement.

Deceleration Device: Any mechanism, such as a rope grab, rip-stitch lanyard, specially woven lanyard, tearing or deforming lanyard, automatic self-retracting lifeline/lanyard, etc., which serves to dissipate a substantial amount of energy during a fall arrest or otherwise limit the energy imposed on an employee during fall arrest.

Deck: A floor or hard surface where the beams are lowered onto prior to being flipped or transported to additional sites for lifting or work.

Definitive Care Facility: A hospital with the highest level of cardiac or trauma surgical services and expertise in a regional area.

Dunnage: Dunnage is a term that refers to any material used to support, protect, or separate items during transportation or storage. Often these are solid wood beams, typically 4”x4” and typically six feet or more in length, that are used to space and separate loads for transport on a vehicle or for storage on a deck.

Emergency Medical Services: An official vehicle and responders capable of providing emergency medicine care and transport to a definitive care facility or hospital.

Event: A real-time occurrence describing one discrete action, typically an error, failure, or malfunction.

Event and Causal Factor Analysis: Identifies the time sequence of a series of tasks and/or actions and the surrounding conditions leading to the occurrence of an undesired outcome. The results are displayed in a graphic that provides an illustration of the relationships between the events, conditions, and undesired outcome.

Event and Causal Factors Tree: A graphic representation of the mishap or close call that shows the event (accident) at the top of the tree, depicts the logical sequence of events, illustrates all causal factor(s) (including condition[s] and failed barrier[s]) necessary and sufficient for the mishap or close call occurrence, and depicts the root cause(s) at the bottom of the tree.

Evidence: Everything used to support or refute a hypothesis or finding.

Ex Officio: An individual authorized to participate in all investigation proceedings and tasked to assure that the investigation is conducted in conformance with NASA policy and NPR 8621.1D.

Executive Summary: A top-level summary, which is part of the mishap investigation report, describing the circumstances of a mishap including who, what, when, where, and why, and a description of the proximate and root causes. The executive summary should be worded where possible to meet NASA's Office of Communications' criteria for public release.

Fall-Restraint System: A fall-protection system that prevents the user from falling any distance. The system comprises either a body belt or body harness, along with an anchorage, connectors, and other necessary equipment. The other components typically include a lanyard and also may include a lifeline and other devices.

Fault Tree Analysis: An analytical technique whereby an undesired system state is specified and the system is then analyzed in the context of its environment and operation to find all credible ways in which the undesired event can occur.

Finding: A conclusion, positive or negative, based on facts established during the investigation by the investigating authority (i.e., cause, contributing factor, and observation).

Final Mishap Investigation Report: The signed mishap investigation report with endorsements and comments attached.

Free Rigging: Free rigging is the direct attachment to or placement of rigging equipment (slings, shackles, rings, etc.) onto the tines of a powered industrial truck for a below-the-tines lift. This type of lift does not use an approved lifting attachment.

Hazardous Operation/Work Activity: Any operation or other work activity that, without implementation of proper mitigations, has a high potential to result in loss of life, serious injury to personnel or public, or damage to property due to the material or equipment involved or the nature of the operation/activity itself.

HASP: Health and Safety Plan developed by each contractor describing the specific hazards and safety requirements for their work and how they plan to protect themselves while performing the work.

Hemorrhage: Severe bleeding or blood loss from an artery or vein.

Helicopter EMS: Helicopter-based Emergency Medical Services that can land at the scene of an accident or injury at a designated or unimproved landing site, field, or road with the goal of providing emergency care to a critically ill or injured patient and transporting them to a definitive care facility.

Human Error: Either an action that is not intended or desired by the human or a failure on the part of the human to perform a prescribed action within specified limits of accuracy, sequence, or time that fails to produce the expected result and has led or has the potential to lead to an unwanted consequence.

Human Factor: a. A body of scientific facts about human characteristics, capabilities, and behavior. The term includes, but is not limited to, principles and applications in the areas of human engineering, personnel selection, training, life support, job performance aids, and human performance evaluation.
b. A body of information about human abilities, human limitations, and other human characteristics from a physical and psychological perspective relevant to the design, operations, and maintenance of complex systems.

Human Factors Analysis: The study of how people interact with their environment. Physiological, psychological, and organizational behaviors are evaluated. Human factors analysis is an important component of mishap investigation. Determining why, how, and where human behaviors contributed to mishaps and close calls is key to preventing future mishaps.

Human Factors Investigator: An investigator with expertise in human factors and mishap causation who has primary responsibility to assist in data collection and analysis, determine the manner in which human factors caused or contributed to the mishap or close call, evaluate relevant human error and determine its root causes, and generate recommendations to eliminate or reduce error occurrence or minimize the error's negative effects to prevent the occurrence of a similar mishap.

Incident: An occurrence of a mishap or close call.

Incident Command: A scene commander or person who leads the response to an incident or accident. This may be the first official responder until replaced or relieved by a formal incident commander, such as a law enforcement chief or fire department chief.

Incident Command System: The Incident Command System, or ICS, is a standardized, on-scene, all-risk incident management concept. ICS allows its users to adopt an integrated organizational structure to match the complexities and demands of single or multiple incidents without being hindered by jurisdictional boundaries.

Inspection: A comprehensive survey of all or part of a workplace by qualified personnel. Inspections are normally performed during the regular work hours of the Agency, except as special circumstances may require. Inspections do not include routine workplace surveillance of occupational health conditions. Inspections may also include visual surveillance of materials for use in the construction phase or stacking of beams.

Interim Response Team: A team that arrives at the mishap scene immediately after an incident; secures the scene; documents the scene using photography, video, sketches, and debris mapping; identifies witnesses; collects written witness statements and contact information; preserves evidence; impounds evidence at the scene and other NASA locations as needed; collects debris; implements the chain-of-custody process for the personal effects of the injured and deceased; notifies the Public Affairs Office about casualties, damages, and potential hazards to the public and NASA personnel; advises the supervisor if drug testing should be initiated; and provides all information and evidence to the investigating authority.

Intermediate Cause: An event or condition that existed before the proximate cause, directly resulted in its occurrence and, if eliminated or modified, would have prevented the proximate cause from occurring.

Investigating Authority: The individual mishap investigator, mishap investigation team, or mishap investigation board authorized to conduct an investigation for NASA. This includes the mishap investigation board chairperson, voting members, and ex officio but does not include the advisors and consultants.

Lanyard: A flexible line of webbing, or synthetic or wire rope, that is used to for connecting the body belt or body harness to a deceleration device, lifeline, or anchorage.

Lay-Down Area: An area where beams are placed on a decking or flooring for temporary storage prior to their being worked with, raised, moved, elevated, or engaged.

Lull: A lull is a type of machine used for material handling and is often used in manufacturing. They are also known as telehandlers or tele-loaders. The vehicle has a telescopic boom that can be used or mated with forks. They typically have a lift height of 54 feet and lift capacity of 10,000 pounds.

Mishap Investigation: The members of the appointed board (investigating authority) shall use a structured technique to collect and review all available data, construct a timeline of events, conduct witness interviews, reconstruct the mishap or close call, and analyze the mishap occurrence to determine what happened, when it happened, and why it happened.

Mishap Investigation Report: The mishap investigation report documents the facts associated with an incident as determined by the investigating authority. In the report, the investigating authority identifies primary, or root, causes, and contributing and possible causes and recommends corrective actions to prevent the occurrence of similar mishaps.

Mishap Investigation Team: A NASA-sponsored team tasked to investigate a mishap or close call and generate the mishap investigation report in accordance with the requirements specified in NPR 8621.1D.

Mishap Summary: A formatted presentation prepared by the NASA Safety Center as a public-releasable document to capture the event sequence, findings, and recommendations contained in a NASA Type A, Type B, or high-visibility mishap or close call investigation report.

NASA Employees: Federal civil servants employed and paid by NASA, or on detail from other Federal agencies, and NASA Support Service Contractors.

NASA Mishap: A NASA mishap is an unplanned event resulting in at least one of the following:
a. Occupational injury or occupational illness to non-NASA personnel caused by NASA operations.
b. Occupational injury or occupational illness to NASA personnel caused by NASA operations.
c. Destruction of or damage to NASA, public, or private property, including foreign property, caused by NASA operations or NASA-funded research and development projects.
d. NASA mission failure before the scheduled completion of the planned primary mission.

NASA Mishap Information System: A custom-developed system for capturing mishaps, close calls, and hazards, as required in NPR 8621.1.

Noncompliance: A violation of an OSHA standard or violation of a NASA standard or requirement.

Observation: A factor, event, or circumstance identified during the investigation that did not contribute to the mishap or close call, but, if left uncorrected, has the potential to cause a mishap or increase the severity of a mishap; or a factor, event, or circumstance that is positive and should be noted.

Occupational Injury or Illness: Work-related per 29 CFR pt. 1904.

OSHA Standard 1926, Subpart R: Federal regulations/standards specifically applicable to steel erection construction activities.

Personal Fall-Arrest System: A system used to stop an employee in a fall from a working level. A personal fall-arrest system consists of an anchorage, connectors, and a body harness and may include a lanyard, deceleration device, lifeline, or suitable combination of these. The use of a body belt for fall arrest is prohibited.

Permanent Partial Disability: An injury or occupational illness that does not result in a fatality or permanent total disability, but in the opinion of competent medical authority, results in permanent impairment through loss of use of any body part with the following exceptions: loss of teeth, fingernails, or toenails; loss of tips of fingers or toes without bone involvement; inguinal hernia (if it is repaired); disfigurements; or sprains or strains that do not cause permanent limitation of motion.

Privilege: A level of confidentiality that a NASA (Federal employee) investigating authority or interim response team member may grant to a witness to an incident. Confidentiality means a witness is assured verbally and in writing that information provided during interviews or in a written statement will be protected by NASA to the extent provided by law.

Procedure: A documented description of the sequential actions in performing a given task.

Proximate Cause: The event(s) that occurred, including any condition(s) that existed immediately before the undesired outcome, directly resulted in its occurrence and, if eliminated or modified, would have prevented the undesired outcome. Also known as the direct cause(s).

Qualified Person: One who, by possession of a recognized degree, certificate, or professional standing, or who by extensive knowledge, training, and experience, has successfully demonstrated his ability to solve or resolve problems relating to the subject matter, the work, or the project.

Recommendation: An action developed by the investigating authority to correct the cause or a finding identified during the investigation.

Responsible Organization: The organization responsible for the activity, people, operation, or Program, where a mishap occurs, or the lowest level of organization where corrective action will be implemented.

Rigger: One who's duties include locating the appropriate piece of steel, attaching the cabling or rigging, or attaches the beam clamp and uses the jack screw to tighten the clamp on top of a beam.

Root Cause: An event or condition that is an organizational factor that existed before the intermediate cause and directly resulted in its occurrence (thus indirectly it caused or contributed to the proximate cause and subsequent undesired outcome) and, if eliminated or modified, would have prevented the intermediate cause from occurring, and the undesired outcome. Typically, multiple root causes contribute to an undesired outcome.

Root Cause Analysis: A structured evaluation method that identifies the root causes for an undesired outcome and the actions adequate to prevent recurrence. Root cause analysis should continue until organizational factors have been identified or until data are exhausted.

Self-Retracting Lifeline/Lanyard: A deceleration device containing a drum-wound line which can be slowly extracted from, or retracted onto, the drum under slight tension during normal employee movement, and which, after onset of a fall, automatically locks the drum and arrests the fall.

Site-Specific HASP: A plan developed to identify and ameliorate safety and health hazards at a specific site, such as a construction site; the plan describes hazards that are likely to be encountered and develops procedures to either eliminate or control the hazards.

Spotter: An individual who has the assignment to identify and recognize hazards that may be in the forklift or lull driver's blind spot when in operation and notifies or uses visual cues to notify the driver of the hazard.

T/C American: The type of steel beam that is narrow on one end and wider at the opposite end. The wider end is located toward the ceiling and a monorail crane rolls along the rails of the narrower end.

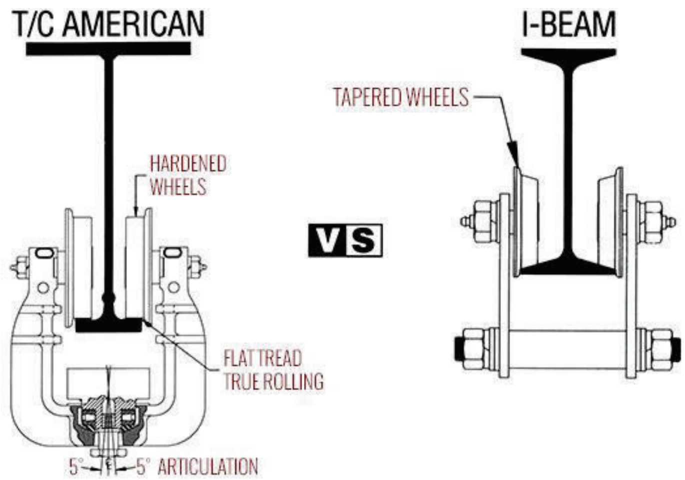

Figure 35: T/C American beam vs. Traditional I-beam.

Timeline: Events and conditions preceding and following a mishap supported by facts and arranged in chronological order.

Tourniquet: A device used to restrict blood flow, especially in cases of traumatic hemorrhage, by tightening around a limb or extremity.

Type B Mishap: A mishap that caused an occupational injury or illness that resulted in a permanent partial disability, the hospitalization for inpatient care of 1-2 people within 30 workdays of the mishap, or a total direct cost of mission failure and property damage of at least $500,000 but less than $2,000,000.

Type C Mishap: A mishap resulting in a non-fatal OSHA-recordable occupational injury or illness causing days away from work, restricted duty, or transfer to another job beyond the day or shift on which the mishap occurred; hospitalization for inpatient care of 1-2 people within 30 workdays of the mishap; or a total direct cost of mission failure and property damage of at least $50,000 but less than $500,000.

Undesired Outcome: An event or result that is unwanted and different from the desired and expected outcome. For mishap investigation, an undesired outcome should describe the loss that determined the mishap classification (i.e., property damage, mission failure, fatality, permanent disability, lost-time case, or first-aid case).

Witness: A person who has information, evidence, or proof about a mishap and provides his or her knowledge of the facts to the investigating authority.

Witness Statement: A verbal or written statement from a witness of his or her account including a description of the sequence of events, facts, conditions, and causes of the mishap.

Violation: An omission or commission, a condition, or a situation that is in conflict with the procedures, standards, and the requirements of safety and health standards.

Appendix 3: Acronyms

AIHA	American Industrial Hygiene Association
AISC	American Institute of Steel Construction
AMA	American Medical Association
ANSI	American National Standards Institute
CAD	Computer-Aided Design
CAP	Corrective Action Plan
CDST	Central Daylight Savings Time
CFR	Code of Federal Regulations
CO	Contracting Officer
COTR	Contracting Officer's Technical Representative
CUI	Controlled Unclassified Information
ECFT	Event and Causal Factors Tree
EAP	Employee Assistance Program
EMS	Emergency Medical Services
ERT	Emergency Response Team
HASP	Health and Safety Plan
HEMS	Helicopter Emergency Medical Services
HFACS	Human Factors Analysis and Classification System
HQ	Headquarters
IC	Incident Commander
IP	Injured Party
IRT	Interim Response Team
JHA	Job Hazard Analysis
MAF	NASA Michoud Assembly Facility
MIT	Mishap Investigation Team
MOE	Modulus of Elasticity
MSFC	NASA Marshall Space Flight Center
NAICS	North American Industry Classification System
NASA	National Aeronautics and Space Administration
NMIS	NASA Mishap Information System
NPR	NASA Procedural Requirements
NSC	NASA Safety Center
OSHA	Occupational Safety and Health Administration
OSMA	Office of Safety and Mission Assurance
PPE	Personal Protective Equipment
RCA	Root Cause Analysis
RCAT	Root Cause Analysis Tool
SLS	Space Launch System
SMA	Safety and Mission Assurance
SPA	Safe Plan of Action
SRL	Self-Retracting Lifeline

SSC	Stennis Space Center
T/C	Twin City
MWAR	Mishap Warning-Action-Response