Procedures and Guidelines (PG)

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EXPIRATION DATE:	08/16/2018	**TITLE:**	Associate Head/Mechanical Engineering Branch

COMPLIANCE IS MANDATORY

Responsible Office: Code 540/Mechanical Systems Division

Title: Design of Dollies, Stands, and Spacecraft Shipping Containers

PREFACE

P.1 PURPOSE

The purpose of this PG is to document the design, fabrication and certification requirements for all Dollies, Stands, and Shipping Containers designed by the Mechanical Systems Division (MSD). Requirements for similar Commercial Off The Shelf (COTS) hardware procured by the MSD are also included.

P.2 APPLICABILITY

This work instruction applies to all Mechanical System Division (MSD) Mechanical Ground Support Equipment (MGSE) Dollies, Stands, and Spacecraft Shipping Containers for uses at the Goddard Space Flight Center (GSFC).

P.3 AUTHORITY

NASA-STD-5005, Standard for the Design and Fabrication of Ground Support Equipment

P.4 REFERENCES

Document Number	Document Title
NASA STD 5005	Standard for the Design and Fabrication of Ground Support Equipment
540-PG-8715.1.2	GSFC MSD Safety Manual
500-PG-8715.1.2	AETD Safety Manual
541-PG-8072.1.2	GSFC Fastener Integrity Requirements
AFSPCMAN 91-701 Vol. 3	Range Safety Users Requirements, Launch Vehicles, Payloads & GSE
MIL-HDBK-1791	Designing for Internal Aerial Delivery in Fixed Wing Aircraft

P.5 CANCELLATION

N/A

P.6 SAFETY

N/A

P.7 TRAINING

N/A

P.8 RECORDS

** NRRS – NASA Records Retention Schedule (NPR 1441.1)*

Record Title	Record Custodian	Retention
Stress Analysis	Lifting Device Equipment Manager (LDEM)	5 Yrs or until excessed
Tipping Analysis	LDEM	5 Yrs or until excessed
Proof Test	LDEM	5 Yrs or until excessed
NDI Report	LDEM	5 Yrs or until excessed

P.9 METRICS

N/A

PROCEDURES

In this document, a requirement is identified by "shall," a good practice by "should," permission by "may" or "can," expectation by "will," and descriptive material by "is."

DESIGN/ANALYSIS

D.1 Load Requirements:

All applicable hardware (here after referred to as "hardware") shall be designed with the minimum design factors listed in Table 1. For hardware that will be utilized outside GSFC at other sites (i.e. Kennedy Space Center, Vandenberg, etc.) the design requirements from these operational centers shall be identified early in the design process. It should be noted that if the requirements from these other sites are more restrictive than those contained herein, then they take precedence.

The bottom portion of Table 1 also includes the factors that are to be applied to the flight hardware when interfacing to the various MGSE elements. As can be seen, the factors used for the flight hardware are much less than the factors used for the MGSE. This is due to the extreme weight penalty that would be incurred if the higher MGSE factors were to be used.

Table 1. Design Load Factors, Factors of Safety and Test Factors

Item	Design Limit Loads (DLL) G's[9]				Factor of Safety		Initial Test Factors	Periodic Test Factors
	Vertical[10]	Lateral	Long.	Tipping[6]	Ultimate	Yield		
MGSE								
Dolly[1] (rolling on casters/air pads)	-1.0	± 0.1	± 0.1	0.5	5	3	2 x Payload	1 x Payload
Static Stand/Dolly[1] (Stationary on casters, jacks)	-1.0	± 0.1	± 0.1	0.5	5	3	2 x Payload	1 x Payload
Turnover Dolly[1] (Stationary on casters, jacks)	-1.0	± 0.1	± 0.1	0.5	5	3	2 x Payload	1 x Payload
Transportation Dolly and S/C Shipping Container(C-5)[7]	-3.6/+1.6[2]	±1.0[3]	+2/-1[3]	N/A[4]	3	2	1.25 x DLL	N/A
Transportation Dolly and S/C Shipping Container[8] (Air-ride van)	-2.5/+0.5	± 0.75	± 1.0	N/A[4]	3	2	1.25 x DLL	N/A
Personnel Stationary Work Stand[1,5]	-1.0	± 0.1	± 0.1	0.5	5	3	2 x Payload	1 x Payload
FLT Hardware								
Dolly[1] (rolling on casters)	-1.6	± 0.25	± 0.25	N/A	1.4	1.25	1.25 x DLL	N/A
Static Stand/Dolly[1] (Stationary on jacks)	-1.0	± 0.1	± 0.1	N/A	1.4	1.25	1.25 x DLL	N/A
Transportation Dolly and S/C Shipping Container[7] (C-5)	-3.6/+1.6[2]	± 1.0[3]	+2/-1[3]	N/A	1.5	1.25	1.25 x DLL	N/A
Transportation Dolly and S/C Shipping Container[8] (Air-ride van)	-2.5/+0.5	± 0.75	± 1.0	N/A	1.4	1.25	1.25 x DLL	N/A

[1] Vertical load should be combined simultaneously with lateral then longitudinal loads (Vertical DLL + Lateral DLL, Vertical DLL + Longitudinal DLL)

[2] The Vertical load factors defined as -4.5/+2 g's in MIL-HDBK-1791are yield load factors

[3] The Lateral and Longitudinal load factors defined as +/- 1.5 and +3/-1.5 in MIL-HDBK-1791 are Ultimate Load Factors and contain a 1.5 ultimate Factor of Safety. Also, the "+" for Longitudinal direction denotes forward and "-" denotes the aft direction.

[4] Dolly is assumed to be secured to the base frame while shipping container is assumed to be secured to the tractor trailer/C-5.

[5] A minimum load of a) 250 lb per person shall be used or b) an evenly distributed load of 50 pound per square foot over the total area of the stand.

[6] For tipping, analysis an ultimate Factor of Safety of 1.0 may be used.

[7] Loads to be applied independently, single direction at a time

[8] Loads to be applied in each direction independently. Gravity loading shall be combined with lateral and longitudinal load cases as shown in the table below.

Load Case (Ex: Dolly Air-ride)	Vertical load (g)	Lateral Load (g)	Long. Load (g)
1	-2.5	0	0
2	+0.5	0	0
3	-1	± .75	0
4	-1	0	± 1.0

[9] Design limit loads applied through system Center of Gravity

[10] Minus sign denotes downward for vertical load. Vertical loads include gravity (-1g)

D.2 Strength Analysis

A stress analysis shall be prepared for all Dollies, S/C Shipping Containers and Personnel Work Stands. The analysis shall calculate stress and/or load levels in all loaded components and tabulate margins of safety (MS) based on material allowable strengths or load capability.

MS = [Allowable stress (or Load) / (F.S. x Induced Stress (or Load)] - 1

The stress analysis of the dolly must include the dolly's own weight, not just the added payload weight

D.3 Tipping Analysis

A tipping analysis shall be prepared for all dollies and work stands. The tipping DLL shown in Table 1 shall be applied to the Center of Gravity (CG) of the system in the worse case configuration. For the analysis, a Factor of Safety of 1.0 may be used in the tipping MS calculation.

D.4 Seismic Analysis

Hardware that will be used outside Goddard in areas susceptible to earthquakes such as the Western Range (WR, Vandenberg Air Force Base), seismic loading shall be considered. The current seismic loading requirements for the WR are specified in AFSPCMAN 91-710 V3 are: 0.4g's vertical and 2.0 g's lateral. This requirement is intended for dollies which are grounded/secured to a building. The .5g tipping load specified in D.3 shall be used to cover possible seismic input for an ungrounded structure.

D.5 Single Point Failure (Critical) Weld

All critical welds shall have a surface NDT (i.e. magnetic particle or dye penetrant) performed before and after the initial proof test and after the periodic proof test. During the detail design of the hardware, critical welds should be avoided where possible. If critical welds are present in the design, they should not be painted so that surface NDT may be performed.

Though not required, a safe life analysis should be considered for all S/C shipping containers and transportation dollies due to their high cyclic loading. More consideration should be given to performing this analysis on hardware that is being reused by a program that didn't actually develop the hardware in the first place. When performing this analysis a 4X service life shall be demonstrated.

D.6 Critical Fasteners

All critical fasteners used on the hardware need to be identified and are subjected to the GSFC Fastener Integrity Requirements (541-PG-8072.1.2). During the detail design of the hardware, critical fasteners should be avoided and fail safe fastener patterns used where possible.

D.7 Load Testing Frequency

All new or modified hardware shall be proof tested to the levels specified in Table 1. The hardware shall be re-proofed every 4 years unless adequate documentation is provided to the GSFC LDEM verifying the appropriate handling, storage, and maintenance of the hardware.

Following all proof testing and prior to use, all hardware shall be visually inspected for any damage or anomalous conditions.

D.8 Commercial Off The Self (COTS) Hardware Requirements

In general, each program/project has the responsibility to define its own policy for the acceptance of Commercial-Off-The Shelf (COTS) handling Mechanical Ground Support Equipment (MGSE) that will be used for flight hardware and critical MGSE. There are a few types of COTS handling MGSE though that shall meet a minimum set of testing requirements. The COTS hardware listed below fall into this category.

1. Positioning tables (such as Koiki/Aronson)
2. Holding/Turnover Fixtures (such as Flotron)

Other MGSE hardware that supports flight hardware and critical MGSE such as handling carts, furniture dollies, tables, bonded storage mobile shelving, etc. shall be proof tested as defined by each project's policies. It is recommended that Product Design Lead (PDL) responsible for the hardware include the policy of acceptance of COTS MGSE when developing the MGSE handling plan. For those items that are identified by the project as requiring proof testing, it is suggested that the requirements noted below in sections D.9.17 - .18 be used if no policy is available.

D.9 Hardware Tests

D.9.1 Dolly (rolling on casters/air pads) Vertical Proof Test

The vertical strength of the dolly while on its casters/air pads shall be demonstrated through a vertical proof test performed with 2 times the payload mass attached to the interface. With the proof masses attached, the dolly shall be moved around the facilities while on its castors/air pads.

D.9.2 Dolly (rolling on casters/air pads) Lateral Proof Test

The strength of the dolly while on its castors/air pads in the lateral and longitudinal directions shall be demonstrated through test or analysis using the DLL and Factors of Safety specified in Table 1.

D.9.3 Static Stand/Dolly (Stationary on jacks) Vertical Proof Test

The vertical strength of the Static Stand/Dolly (stationary on its jacks) shall be demonstrated through a vertical proof test performed with 2 times the payload mass attached to the interface plane.

D.9.4 Static Stand/Dolly (Stationary on jacks/wheels) Lateral Proof Test

The strength of the dolly while on its castors/air pads in the lateral and longitudinal directions shall be demonstrated through test or analysis using the DLL and Factors of Safety specified in Table 1.

D.9.5 Static Stand/Dolly (Stationary on jacks/wheels) Tipping Proof Test

The resistance of the Static Stand/Dolly (stationary on its jacks/wheels) to tipping in the highest cg orientation shall be demonstrated through test or analysis using the DLL and Factors of Safety specified in Table 1. For the analysis, a Factor of Safety of 1.0 may be used in the tipping MS calculation.

D.9.6 Turnover Dolly (Stationary on jacks) Dynamic Rotational Proof Test

The strength of the rotational mechanism of the dolly while on its jacks shall be demonstrated through a proof test with 2 times the payload mass attached to the interface plane at the same cg location as the payload (twice the interface moment). The rotational mechanism shall be operated through the full range of motion and at the maximum operational rotational speeds.

D.9.7 Turnover Dolly (Stationary on jacks) Lateral Proof Test

The strength of the dolly while in the lateral and longitudinal directions shall be demonstrated through test or analysis using the DLL and Factors of Safety specified in Table 1.

D.9.8 Turnover Dolly (Stationary on jacks) Tipping Proof Test.

The resistance of the turnover dolly and payload to tipping while on its jacks in the highest cg orientation shall be demonstrated through test or analysis using the DLL and Factors of Safety specified in Table 1. For the analysis, a Factor of Safety of 1.0 may be used in the tipping MS calculation.

D.9.9 Transportation Dolly and S/C Shipping Container (C-5) Proof Test

The Transportation Dolly and Shipping Container while supported at their transport interfaces shall be proof tested to the system mass (payload + dolly) times the DLLs specified in Table 1 with a test factor of 1.25. For the test, the maximum payload mass shall be assumed. As a minimum, a test demonstrating the strength in the vertical direction shall be performed. The lateral and longitudinal strength may be demonstrated by analysis if positive Margins of Safety using higher Factors of Safety of 3 on yield and 5 on ultimate can be shown.

D.9.10 Transportation Dolly and S/C Shipping Container (Air-ride van) Proof Test

The Transportation Dolly and Shipping Container while supported at their transport interfaces shall be proof tested to the system mass (payload + dolly) times the DLLs specified in Table 1 with a test factor of 1.25. For the test, the maximum payload mass shall be assumed. As a minimum, a test demonstrating the strength in the vertical direction shall be performed. The lateral and longitudinal strength may be demonstrated by analysis if positive Margins of Safety using higher Factors of Safety of 3 on yield and 5 on ultimate can be shown. In addition to the static proof testing, the Transport Dolly and Shipping Container shall be road tested (with a maximum payload mass attached) over similar roads that the flight payload will be transported over. For the road test, three axis acceleration responses at the base of the container and on the isolated Transportation Dolly shall be recorded.

D.9.11 Personnel Work Stand (Stationary) Vertical Proof Test

A vertical proof test of the Personnel Work Stand shall be performed to the levels specified in Table 1.

D.9.12 Personnel Work Stand (Stationary) Tipping Proof Test

Tipping resistance of Personnel Work Stands shall be demonstrated by test or through analysis using the DLL and Factors of Safety specified in Table 1. For the analysis, a Factor of Safety of 1.0 may be used in the tipping MS calculation.

D.9.13 Spacecraft/Dolly Interface (Rolling on casters/air pads) Proof Testing
The S/C side of the S/C-Dolly interface shall be tested to the levels specified in Table 1. If the spacecraft side of the interface is not test verified then positive Margins of Safety must be demonstrated with higher Factors of Safety of 2.0 on yield and 2.6 on ultimate. GSE interfaces that utilize bonded joints as part of the load path must be proof tested and cannot show verification by analysis only.

D.9.14 Spacecraft/Dolly Interface (Stationary) Proof Testing
The S/C side of the S/C-Dolly interface shall be tested to the levels specified in Table 1. If the spacecraft side of the interface is not test verified then positive margins of safety must be demonstrated with higher factors of safety of 2.0 on yield and 2.6 on ultimate. GSE interfaces that utilize bonded joints as part of the load path must be proof tested and cannot show verification by analysis only.

D.9.15 Spacecraft/Transportation Dolly (C5) MGSE Interface Proof Testing.
The spacecraft interface that attaches to the Transportation Dolly (C5) shall be proof tested to the levels specified in Table 1 with a test factor of 1.25. If the spacecraft side of the interface is not test verified then positive margins of safety must demonstrated with higher factors of safety of 2.0 on yield and 2.6 on ultimate. GSE interfaces that utilize bonded joints as part of the load path must be proof tested and cannot show verification by analysis only.

D.9.16 Spacecraft/Transportation Dolly (Air-ride) MGSE Interface Proof Testing
The spacecraft interface that attaches to Transportation Dolly (Air-ride) shall be proof tested to the DLL specified in Table 1 with a test factor of 1.25. If the spacecraft side of the interface is not test verified then positive margins of safety must demonstrated with higher factors of safety of 2.0 on yield and 2.6 on ultimate. GSE interfaces that utilize bonded joints as part of the load path must be proof tested and cannot show verification by analysis only.

D.9.17 COTS Proof Testing
When COTS proof testing is performed, all new hardware shall be proof tested to a minimum of 125 percent of the items "nameplate rating" or the manufacturers specified Safe Working Load (SWL) or Working Load Limit (WLL). If the COTS hardware has been modified or repaired in any way that would bring into question its capability to safely perform its intended functions, the COTS MGSE shall be reproofed to 125%.

Following proof testing and prior to use, all hardware shall be visually inspected for any damage or anomalous conditions.

D.9.18 COTS Load Testing Frequency
COTS MGSE hardware requiring load testing shall be re-tested every 4 years to 100% of the rated load unless adequate documentation is provided to the LDEM verifying the appropriate handling, storage, and maintenance of the hardware. Also, any required maintenance specified by the manufacturer shall be performed according to the manufacture's recommended maintenance schedule.

Following all load testing and prior to use, all hardware shall be visually inspected for any damage or anomalous conditions.

D.9.19 Separable Assemblies

Any portion of the hardware assembly that will be disassembled after Proof Testing shall be tagged/marked in some manner so that it shall be reassembled identically to the tested configuration.

D.10 Best Practices

The following guidelines for the selection of materials, components and use of design rules for dollies and work platforms assemblies are recommended.

1. Load lines should align so that local induced moments are avoided. Lines of action should intersect at the neutral axes of the members.
2. All bolted joints should be designed fail-safe where the highest loaded fastener in the pattern can be removed and the remaining fasteners can carry the load with a 1.0 factor of safety. If the joint is not fail-safe, then some method will be needed to ensure that if the fasteners are removed following the proof test, the bolts are indexed to the appropriate joints.
3. Where possible, all welds should be designed fail safe.
4. For structural elements, materials with good strain properties should be used. It should be noted that the current Range Safety Document (AFSPCMAN 91-710 V3) specifies that, *"materials that have at least 20% ultimate strain need to be used. If the materials selected do not meet this minimum ultimate strain requirement, the design must include a fracture mechanics analysis that shows a service life cycle factor of safety of 100:1 and a detailed NDE surface and/or volumetric requirements."*
5. If the hardware will be utilized inside a thermal vacuum chamber during testing, box beams/closed sections should be avoided. It is difficult to properly clean the inside surfaces of box beams and box beam weldments can result in virtual leaks if not properly vented.
6. Shock Isolation Target Frequency - Target frequency for the shock isolation system should be in the 3 - 7 Hz range to avoid coupling with dynamic inputs from air-ride trucks (<2Hz and >10 Hz) and C5 aircraft (>10 Hz). Where possible, testing of the isolation system with a spacecraft mass (and center of gravity) simulator under transportation conditions should be performed to verify environments and performance of the isolation system prior to use with the flight hardware.
7. Wire rope isolator sizing and loading – It is advisable to consult with the isolator vendor when sizing the isolators. Discussion should include the system frequency requirements, dynamic loading conditions and proof test requirements.
    a. The maximum allowable static displacement should be verified with the vendor. Some vendors prefer to limit the working static displacement of the isolator to a certain percentage of the maximum rated dynamic displacement.
    b. The stiffness values to be used in the selection of the isolator should be verified with the vendor. Testing of isolators indicates that the average stiffness values specified for vibration isolation (as opposed to shock isolation), which are defined based on small deflections of the isolator (10% or less of the maximum rated stroke), most accurately reflect the measured dynamic behavior of the isolated system. Load-deflection curves may be obtained from the vendor to understand the behavior of the isolator under various loading conditions.

8. If alignment measurements are planned on the Dolly, consider incorporating a 3 point leveling jack configuration to aid alignment set-up.
9. Use swivel hoist ringss in place of lifting eyes wherever possible due to the lack of lateral load capability of lifting eyes. Utilize some method of securing nuts so they don't come loose during transportation
10. If lifting lugs are permanently attached (welded), only visual inspection will be applicable.
11. Provide dedicated grounding points (tapped holes) around the Dolly.
12. Dolly Caster Loading**.** To determine the caster loading on a dolly, an assumption of the dolly stiffness needs to be made. If the four wheeled dolly is very stiff out of plane, while the dolly is rolled across an uneven floor, only three wheels will contact the floor at a time and if the cg is close to the center of the footprint of the wheels, only two diagonal wheels will carry load. If the dolly stiffness is not known, the conservative loading assumption that only two diagonal casters carry the load should be made. If this assumption is felt to be too conservative for the dolly configuration, then FEM analysis using worst-case assumptions for payload weight and CG location can be used to determine the load sharing of the casters.

    For example, let's say we have a dolly that has an empty weight of 1000 lbs and is sized to carry a 1000 lbs payload. If the dolly is very stiff out of plane, casters rated for at least 1000 lbs should be used. If the dolly is very flexible out of plane (like a Flotron dolly) casters rated for at least 500 lbs should be used. Please note that for this example the effect of the 0.1g lateral load has not been included for simplicity. The actual castor rated load should account for a combined loading condition as specified in Table 1.

    When sizing the casters, the caster manufacturer should be contacted to determine what Factors of Safety the vendor used in their design. Also, the vendor should be contacted if the proof test will exceed the rated load of the caster for the vendor's concurrence.

Appendix A - Definitions

A.1 **Catastrophic Hazard** - A condition in which a failure can result in disabling or fatal personnel injury, the loss of a spacecraft or launch vehicle.

A.2 **Critical Fastener** - A fastener where the single failure would result in a Catastrophic Hazard

A.3 **Critical Weld** - A weld where the single failure of which could result in disabling or fatal personnel injury or damage to property or flight hardware.

A.4 **NDT (Non-Destructive Test)** - The development and application of technical methods to examine materials or components in ways that do not impair future usefulness and serviceability in order to detect, locate, measure and evaluate flaws; to assess integrity, properties and composition; and to measure geometrical characteristics.

A.5 **Payload** - Any flight hardware supported by MGSE

Appendix B - Acronyms

COTS	Commercial Of The Shelf
DLL	Design Limit Load
FS	Factor of Safety
LDEM	Lifting Device Equipment Manager
GSFC	Goddard Space Flight Center
OEM	Original Equipment Manufacturer
MGSE	Mechanical Ground Support Equipment
MS	Margin of Safety
PDL	Product Design Lead
S/C	Spacecraft

CHANGE HISTORY LOG

Revision	Effective Date	Description of Changes
Baseline	12/10/2007	Initial Release
A	09/28/2009	Revised Table 1. Removed requirement for adding an additional 1x mass equal to the dolly empty weight for the proof test. Added discussion in section D. 9 on caster sizing
B	08/16/2013	Revised transportation DLL in Table 1 and clarified methodology of load combining. Clarified Seismic loading in section D4 Added requirements for COTS hardware in D 8, D.9.17-9.18 Added discussion on wire rope isolator sizing in section D10.