Procedures and Guidelines (PG)

DIRECTIVE NO.	540-PG-8719.1.1-A	**APPROVED BY Signature:**	Original signed by:
EFFECTIVE DATE:	02/16/2010	**NAME:**	Ken Hinkle
EXPIRATION DATE:	02/16/2015	**TITLE:**	Division Chief

COMPLIANCE IS MANDATORY

Responsible Office: Code 540

Title: Lift Sling Design

PREFACE

P.1 PURPOSE

The purpose of this work instruction is to document the design and certification requirements for all slings designed by the Mechanical Systems Division (MSD). It is also intended to act as a guideline for proper use. Excerpts from NASA-STD-8719.9 are included as a convenience to the user. It is the user's responsibility to check for the most recent revision.

P.2 APPLICABILITY

This document applies to the Mechanical Systems Division; Code 540

P.3 AUTHORITY

This work instruction applies to all MSD slings for critical and non-critical use at Goddard Space Flight Center. Deviations from this document shall be approved by the MSD Chief Engineer.

P.4 REFERENCES

Document Number	Document Title
NASA STD 5005B	Ground Support Equipment
NASA STD 8719.9	Standard for lifting devices and equipment
GPR 8719.1	Certification and Recertification of Lifting Devices and Equipment
AFSPCMAN 91-701 Vol. 3	Range Safety Users Requirements, Launch Vehicles, Payloads & GSE
ASTM B 30.20	Below the hook lifting devices
ASTM B 30.9	Slings
OSHA 29 CFR 1910.184	Alloy Steel Chain Slings Proof Testing
500-PG-8715.1.2	AETD Safety Manual
GPR 8834.1	Lifting Operations Requirements
15-01-422	Analysis Procedure for Spreader Bar Lift Stability
04DE-WI02	Design of Non-Flight Fixtures
No Reference Number	Wire Rope Users Manual
No Reference Number	Bob's Overhead Crane and Rigging Handbook
No Reference Number	Rigging Manual

P.5 CANCELLATION

N/A

P.6 SAFETY

N/A

P.7 TRAINING

N/A

P.8 RECORDS

Record Title	Record Custodian	Retention
Stress Analysis	Sling Owner	5 Yrs or until Project Completion
Stability Analysis	Sling Owner	5 Yrs or until Project Completion
Proof Test	Sling Owner	5 Yrs or until Project Completion
NDT Report	Sling Owner	5 Yrs or until Project Completion

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

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

Strength Requirements:

All hardware shall be designed with the minimum design factors listed in table 1. For slings that will be utilized at other sites (i.e. Kennedy Space Center, Marshall Space Center, etc.) the design requirements from these operational centers must be identified early in the sling design process

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

Note:

Item	Design Load Factor G's		Factor of Safety		Proof Test Factors	
	Vertical	Lateral	Ultimate	Yield	Initial	Periodic
Alloy Steel Chain	1.0	0.0	5.0		2	1
Wire Rope	1.0	0.0	5.0		2	1
Metal Mesh	1.0	0.0	5.0		2	1
Synthetic Rope	1.0	0.0	10.0		2	1
Synthetic Web	1.0	0.0	5.0*		2	1
Linear Fiber	1.0	0.0	5.0*		2	1
Shackles, D-Rings, Turnbuckles, Eye Bolts, Hoist Rings	1.0	0.0	5.0		2	1
Structural Slings	1.0	0.0	5.0	3.0	2	1
S/C MGSE I/F**	1.6	0.25	1.4	1.25	1.25	N/A

(*) If the sling is used at the Eastern or Western Range, the factor of safety shall be 10.0. Ref. AFSPCMAN 91-701 V3 (Range Safety Users Requirements, Launch Vehicles, Payloads & GSE)

(**) This requirement applies to the spacecraft hardware at its lift-sling attachment points and constitutes an additional spacecraft load case beyond those required for launch loads, test loads, operational loads, etc. The vertical and lateral design load factors are applied simultaneously.

Strength Analysis

A stress analysis shall be prepared and documented for all lifting assemblies designed by MSD. Strength analysis of multiple leg lift assemblies shall assume a worst case load condition of two legs sharing the load. A waiver to this requirement will be considered if analysis shows that worst case loading conditions always will share the load between more than two legs. The loads reacted by each leg shall be calculated based on the actual center of gravity location for each lift configuration and the worst case loads shall govern. 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. For a flight project, the strength analysis shall be approved by the by the Product Design Lead (PDL), otherwise Branch Head approval shall be required.

MS=[Allowable Strength(or Load) /(F.S. x Actual Stress (or Load))] – 1

Stability Analysis

A stability analysis shall be prepared and documented for each lifting configuration.
Each configuration shall meet the stability and flip over criteria defined in Appendix B. (Analysis Procedure for Spreader Bar Lift Stability). Appendix B includes the recommended stability and flip over analysis technique.
The analysis starts with the categorization of the lift arrangement, continues with checking the stability and flipping criteria, and concludes with a look at the energy or force to cause tip over. Both elevation views for each lift shall be considered.
It is important to insure the actual lift arrangement matches the stability analysis. For a flight project, the stability analysis shall be approved by the by the Product Design Lead (PDL), otherwise Branch Head approval shall be required.

Lift Sling Components

Any lifting equipment that contains an OEM warning of “not recommended for lifting” shall not be used.
All Lift Equipment hardware components shall be traceable to a credible source of information, such as OSHA, OEM, etc., for certifiability.

Turnbuckles:

Turnbuckles that contain an OEM warning of “not recommended for lifting” shall not be used.

All Turnbuckles shall be used in a straight line pull without any bending forces.

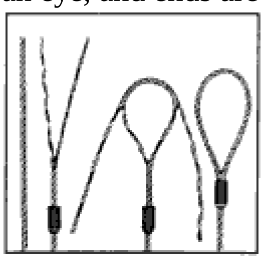
If jam nuts are present on turnbuckles, do not tighten them

Turnbuckles are made for adjustment up to the tension produced by the Safe Working Load (SWL). They are not however, designed for repeated adjustment at high loads. Torqueing the threads at high load may cause binding due to the galvanizing flaking off. The preferred method of turnbuckle adjustment under load is to unload the turnbuckle sufficient to minimize any potential galling. Removal of at least 75% of the load is recommended for repeated adjustment under load.
If at all practical turnbuckles should be avoided in the design of critical lift slings.

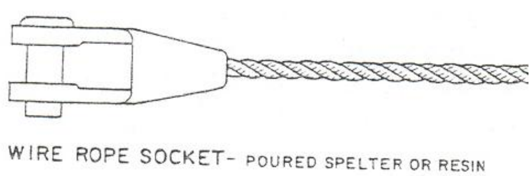
Wire rope assemblies

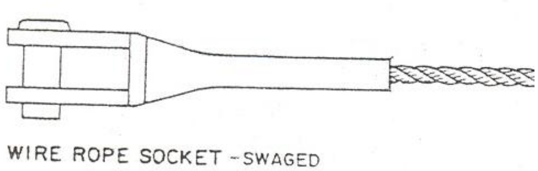
Flemish eyes are the preferred termination method of wire rope assemblies. Other acceptable types of wire rope terminations are wire rope socket and wire rope socket swaged.(refer to Wire Rope Users Manual, American Iron and Steel Institute, 1979, Pages 26-27. and Bob's Overhead Crane and Rigging Handbook, Second Edition, Page 112.)

Flemish Eye Splice
In the standard flemish eye mechanical splice, rope is separated into two parts - 3 adjacent strands, and 3 adjacent strands and core. These two parts are then re-laid back in opposite directions to form an eye, and ends are secured with a pressed metal sleeve.

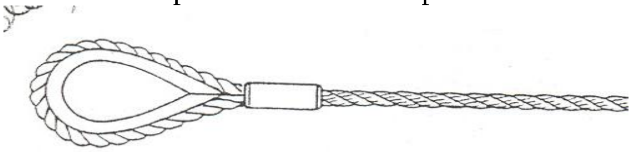


Flemish Eye Splice



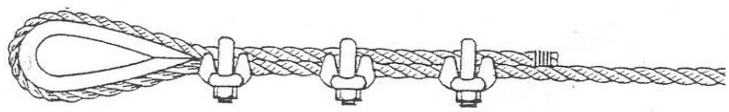


Mechanical spliced ends are not permitted.



MECHANICAL SPLICE – LOOP OR THIMBLE

Mechanical clips are not permitted in wire rope end fittings. (refer to Rigging Manual, D.E. Dickie, 1975, Page 46-47.)



CLIPS - NUMBER OF CLIPS VARIES WITH ROPE SIZE AND CONSTRUCTION

Eye bolts

Eye bolts shall not be used in applications that impart bending loads into the eye bolt.
Eye bolts shall only be used in purely axial (along the center line of the eye bolt) loading conditions.
Swivel hoist rings and safety hoist rings shall be used in all non-axial loading applications.

Materials not Permitted

Natural rope and wire rope clips shall not be used in slings or rigging hardware to hoist personnel or loads. The fold back metal pressed sleeve or clip technique also shall not be used in slings or rigging hardware (refer to NASA Std 8719.9 section 10.7.g).
Due to cleanliness concerns and brittle characteristics at low temperatures, sling components made from plain carbon steel materials shall not be used if the sling will be utilized inside a thermal vacuum chamber during test (refer to 04DE-WI02 "Design of Non-Flight Fixtures" section 6.2.1).

H. Single Point Failure Weld

All critical welds shall have a surface NDT (magnetic particle or dye penetrant) performed after the initial proof test and after the periodic proof test. The following table 2.clarifies the inspection methods for critical welds in structural slings.

TABLE 2
Nondestructive Testing and Load Testing Requirements for Lifting Equipment Certification and Recertification

EQUIPMENT	POST-PROOF NDT2	POST-PERIODIC NDT2
Alloy Steel Chain Slings	Visual	Visual
Wire Rope Slings	Visual	Visual
Metal Mesh Slings	Visual	Visual
Synthetic Rope Slings	Visual	Visual
Synthetic Web Slings	Visual	Visual
Linear Fiber Slings	Visual	Visual
Structural Slings	Critical Welds: Surface Noncritical Welds: Visual	Critical Welds: Surface Noncritical Welds: Visual
Shackles, D-rings, Turnbuckles, Lifting Lugs, Safety Hoist Rings. Etc.	Single and Non-Single Failure Load Path: Surface	Single and Non-Single Failure Load Path: Surface

Lifting lugs, including eyebolts. which are permanently affixed to the load are considered to be part of the load and are exempt from load testing and NDT, but must be qualified by calculation by the owning organization.

POST-PROOF = After the initial, first-time proof load test of new or extensively modified items.

POST-PERIODIC = After the annual rated load test of the item.

With the exception of thimbles and tapered end fittings, metallic fittings that are integral to slings are included. Thimbles and tapered end fitting are subject to visual NDT only.

Best Practices

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

a. Thin plate structural slings with little out of plane inertia should be avoided due to buckling susceptibility.
b. Align structural sling load line to avoid local induced moments. Lines of action should intersect at the neutral axes of the sling members.
c. 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.
d. Bird Cage lifts- The Bird Cage lift configuration is the least stable due to its kinematics. Efforts should be made to change the lift points to obtain a parallel type lift. Refer to Page 3 of Appendix B for Bird Cage Lift description.
e. Umbrella Lifts- The Umbrella lifts are the most stable due to their kinematics. Refer to page 4 of Appendix B for Umbrella Lift description.
f. During the process of a lift, the risks to equipment and personnel increases as the lift is raised or as the speed increases. For this reason, should large traversals of the bridge crane or trolley be required, the load should be kept as close to the floor as practical, taking into account possible swinging due to crane jogs.
g. When practical, design in castors for transporting heavy lifting frames and spreader bars.
h. To prevent the inadvertent contamination of sensitive flight hardware by an overhead oil leak, consider incorporating a drip guard or dust cover into the sling design.
i. If the sling will be utilized inside a thermal vacuum chamber during test, box beams 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.
j. When designing a lift sling using a spreader bar it is preferred to use upper wire rope assemblies that connect the spreader bar to the crane rather than just connecting the crane directly to the spreader bar. This increases the dimension "b" called out in the stability criteria in appendix B, thereby increasing the stability of the lift. In other words avoid using a strongback.

Proof Testing

When slings are composed of major components that fall into more than one of the categories listed in table 1., the components shall be tested individually according to applicable requirements and then as a system to the lowest proof test factor.

All lifting equipment shall be proof tested and certified prior to use in accordance with Table 1:

K. Periodic Load Testing

Slings shall undergo periodic load tests at least every 4 years in accordance with Table 1. Slings used for critical lifts shall be load tested at least once per year in accordance with Table 1.

L. Certification and Tagging of Slings

Certification/ re-certification tags are required as described in NASA-STD-8719.9 section 10.3.5. A system has been developed to identify slings used in critical lift applications. Completely assembled slings that are critical lift certified are marked conspicuously so that the operator and quality assurance personnel can identify them as such.

Disassembly of the sling shall void the proof test certification unless items/components are identified such that reassembly is identical to the original proof test configuration.

Only the Recertification Program Manager's Office (or his designee) can certify, and tag lift slings for use at GSFC.

Pre-Use Sling Inspection

Daily Inspections- These inspections shall be performed by the user prior to first use each day the sling is to be used and shall include the following:

a) Check for defects such as cracks, deformations, gouges, galling, kinks, crushed areas and corrosion.

b) Check for proper configuration (the lifting assembly and associated hardware, as proof load tested).

Periodic Inspections- The following inspections shall be performed at least once a year:

<u>Alloy Steel Chain Slings</u>- Visually inspect in accordance with NASA-STD-8719.9 section 10.4.5.a (refer to Appendix A)

<u>Wire Rope Slings-</u> Visually inspect in accordance with NASA-STD-8719.9 section 10.4.5.b (refer to Appendix A)

<u>Metal Mesh Slings</u>- Visually inspect in accordance with NASA-STD-8719.9 section 10.4.5.c (refer to Appendix A)

<u>Synthetic Rope Slings</u>- Visually inspect in accordance with NASA-STD-8719.9 section 10.4.5.d (refer to Appendix A)

Synthetic Web and Linear Fiber Slings- Visually inspect in accordance with NASA-STD-8719.9 section 10.4.5.e (refer to Appendix A)

Structural Slings- Visually inspect and NDT in accordance with NASA-STD-8719.9 section 10.4.5.f (refer to Appendix A)

Rejected Slings- All slings rejected during inspection shall be removed from service.

Personnel Certification

Only certified (licensed) crane operators/riggers are authorized to perform rigging tasks for lifting assemblies, equipment and/or operations. Crane operators/riggers shall be certified by RECERT in accordance with NASA-STD-8719.9 and GPR 8719.1 requirements.

Personnel performing NDT shall be qualified and certified in accordance with section 1.9 of NASA-STD-8719.9.

Excerpts from

STANDARD FOR LIFTING DEVICES AND EQUIPMENT NASA-STD-8719.9

(These excerpts are listed for convenience. Be sure to check for the latest revision)

1.9 Personnel Performing Nondestructive Testing. Personnel performing lifting devices and equipment nondestructive testing (NDT), including visual inspections, shall be qualified and certified in accordance with written practices meeting the requirements contained in American Society for Nondestructive Testing (ASNT) Recommended Practice No. SNT-TC-1A, Personnel Qualification and Certification in Nondestructive Testing.

10.3 Testing. The following proof load and periodic load tests apply to slings except as noted in paragraph 10.3.3. Turnbuckles shall be tested at the open position as a minimum. It is recommended that turnbuckles be tested at the open, closed, and midway positions. These tests shall be performed by qualified personnel according to written (specific or general) technical operating procedures. The acceptable tolerance for load test accuracy is +5/-0 percent. When slings are composed of major components that fall into more than one of the categories listed in Table 10-2, the components shall be tested individually according to applicable requirements and then as a system to the lowest test value (if practical). An inspection shall be performed after each load test and prior to release for service to ensure there is no damage. A periodic load test requirement can be fulfilled by a concurrent proof load test. The load shall be held for a minimum of 3 minutes for load tests.

10.3.1 Proof Load Test. Before first use, all new, extensively modified, repaired, or altered slings shall undergo a proof load test at a specified factor of the rated load according to Table 10-2. Proof load tests performed by the manufacturer prior to delivery are acceptable, if the necessary load test papers are provided to verify the extent and thoroughness of the test on the specific item. A proof load test also may be performed at a prescribed time when there is a question in design or previous testing. All components shall be tested together as a system, if practical. Prior to first use, all lifting interfaces such as eyebolts, D-rings, and lifting lugs permanently attached to the load shall be proof load tested if feasible. For lifting interfaces, when deemed unfeasible by the responsible design organization and accepted by the user organization, based on possible overloading of structural members not required during lifting or other considerations, this proof load test can be eliminated. However, design analysis and inspection shall be used to verify the integrity of the interface.

Table 10-2 Proof Load Test Factors
(Based on Manufacturers' Rated Load)

Equipment	Proof Load Test Factor
Alloy Steel Chain Slings	2.0
Wire Rope Slings	2.0
Metal Mesh Slings	2.0
Synthetic Rope Slings	2.0
Synthetic Web Slings	2.0
Linear Fiber Slings	2.0
Structural Slings	2.0*
Shackles, D-rings, Turnbuckles, Eye Bolts, Lifing Lugs, Safety Hoist Rings, etc.	2.0

* Unless otherwise specified by design, due to material characteristics, geometry, design factors, etc., but in any case, at least 125 percent of the sling's rated capacity.

10.3.2 Periodic Load Test. Slings shall undergo periodic load tests at least every 4 years at a specific load test factor of the design rated load as given in Table 10-3. All components shall be tested together as a system, if practical. Slings used for critical lifts shall be load tested at least once per year. Slings used infrequently for critical lifts shall be load tested before each critical lift if it has been over a year since the last load test. Lifting interfaces such as eyebolts, D-rings, and lifting lugs permanently attached to the load are exempt from periodic load testing.

Table 10-3 Periodic Load Test Factors
(Based on Manufacturers' Rated Load)

Equipment	Periodic Load Test Factor
Alloy Steel Chain Slings	1.00
Wire Rope Slings	1.00
Metal Mesh Slings	1.00
Synthetic Rope Slings	1.00*
Synthetic Web Slings	1.00
Linear Fiber Slings	1.00
Structural Slings	1.00
Shackles, D-rings, Turnbuckles, Eye Bolts, Lifting Lugs, Safety Hoist Rings, etc.	1.00

* Critical lift rope slings of synthetic material shall not be used beyond 50 percent of the manufacturer's rating to maintain an equivalent design factor in the load system.

10.3.3 Non-Load Test Slings. Due to unique design and usage requirements, a sling may be designated as a non-load test sling by the LDEM, with concurrence from the affected/responsible program/project office, the responsible safety, design engineering, systems engineering, operations, and maintenance organizations. Such slings do not require periodic load tests. Inspections shall be conducted in accordance with paragraph 10.4. This non-load test designation shall be formally documented by each installation and the sling marked accordingly to designate it as a non-load test sling

10.3.4 Sling Rated Load. Rated loads for slings shall be based on the periodic load test weight divided by the periodic load test factor (see Table 10-3). For metal mesh slings, the rated capacity will be noted for vertical basket and choker hitch configurations. For synthetic rope slings, used in noncritical lifts, a 50-percent derating for use is recommended. For synthetic rope slings used in critical lifts, a 50-percent derating is required.

10.3.5 Test Reports and Periodic Recertification Tags.
a. Written, dated, and signed reports shall be prepared after each test. Inadequacies shall be documented and, if determined to be a hazard, corrected prior to further use. These reports shall be kept on file by the owner organization for a minimum of two test cycles and shall be made readily available.

b. Following the load test, all slings shall be given a permanently affixed tag identifying the equipment (part number) and stating the rated capacity based on the load test value and the next periodic load test due date or load test expiration date. For alloy steel chains, size, grade, and reach shall be stated along with the rated load. For synthetic rope slings used for critical lifts, the marked rated load shall be 50 percent of the manufacturer's rated load. The type of material shall also be stated. All load bearing components shall be traceable to the most recent load test. This may be accomplished by clearly marking/coding or tethering all components of the assembly, through configuration control, or other procedures. (NOTE: Load bearing components not traceable to load test will invalidate the load test of the whole assembly.)

10.4 Inspection.
810.4.1 Inspections, as described below, shall be performed on all slings. Inspections shall be performed according to this section, the manufacturers' recommendations, and ASME B30.9. Visual inspections for cracks, deformations, gouges, galling, kinks, crushed areas, corrosion, and proper configuration shall be performed each day the sling is used, prior to first use. An indepth inspection shall be performed annually or when a sling is suspected to have even a small loss of strength or is repaired. Inspections shall be performed by qualified personnel according to approved technical operating procedures. Inadequacies shall be documented and, if determined to be a safety hazard, tagged out and corrected prior to further use.

10.4.2 All new, extensively repaired, or modified slings shall be given a daily and a periodic inspection prior to first use. For component repair on slings, only the inspections that apply to the repaired portion need to be performed prior to first use unless a periodic inspection interval expires during the downtime (see paragraph 10.4.5).

10.4.3 Slings in regular service (used at least once a month) shall be inspected as required in paragraphs 10.4.4 and 10.4.5. Idle and standby slings shall be inspected according to paragraph 10.4.6.

10.4.4 Daily Inspections. These inspections shall be performed prior to first use each day the sling is used and shall include the following:
a. Check for defects such as cracks, deformations, gouges, galling, kinks, crushed areas, and corrosion.
b. Check for proper configuration (the lifting assembly and associated hardware, as proof load tested).

10.4.5 Periodic Inspections. The following inspections shall be performed at least once a year, unless otherwise specified below. The need to replace or repair slings shall be determined by a certified or otherwise qualified person based on an evaluation of inspection results. Any discrepancy (deterioration or damage) is sufficient reason for questioning continued use of the sling (see Wire Rope Users Manual for additional information on wire rope inspections):

a. Alloy Steel Chain
(1) Inspect each link individually to ensure every link hangs freely with adjoining link.
(2) Ensure that wear, corrosion, or deformities at any point on chain do not exceed 20 percent of original dimensions.
(3) Ensure that master links are not deformed.

b. Wire Rope Slings
(1) Ensure that there are fewer than 10 randomly distributed broken wires in one rope lay or 5 broken wires in 1 strand in 1 lay.
(2) Ensure wear or scraping is less than 1/3 the original diameter of outside individual wires.
(3) Inspect for kinking, crushing, bird caging, or any other distortion of the rope structure.
(4) Inspect for excessive heat damage.
(5) Inspect for cracked, deformed, or worn end attachments.
(6) Inspect for significantly corroded rope or end attachments.

c. Metal Mesh Slings
(1) Ensure that there are no broken welds or brazed joints along the sling edge.
(2) Ensure that reduction in wire diameter does not exceed 25 percent due to abrasion or 15 percent due to corrosion.
(3) Inspect for lack of flexibility due to distortion of the fabric.
(4) Ensure that there is no more than a 25 percent reduction of the original cross-sectional area of metal at any point around handle eyes.
(5) Inspect for distortion of either handle out of plane, more than 10-percent decrease in eye width, and more than 10-percent increase in the receiving handle slot depth.

d. Synthetic Rope Slings
(1) Inspect for abnormal wear.
(2) Ensure that there is no powdered fiber between stands.
(3) Inspect for broken or cut fibers.
(4) Ensure that there is no rotting or acid or caustic burns.
(5) Inspect for distortion of associated hardware.

e. Synthetic Web and Linear Fiber Slings
(1) Ensure that there are no acid or caustic burns.
(2) Inspect for melting or charring of any part of surface.
(3) Inspect for snags, punctures, tears, and cuts.
(4) Inspect for broken or worn stitches and rotting.
(5) Ensure that wear or elongation does not exceed amount recommended by the manufacturer.
(6) Perform all inspections provided for by the sling manufacturer. This may include red fibers used as a wear indicator, or a fiber optic sling damage indicator, or some other NDT method designed into the sling.

f. Structural Slings
(1) Verify overall that there is no evidence of damage, gouges in metal, loose bolts, rivets, connections, or deformations such as galling or gouges in pins, eyes, and end connections.
(2) Ensure that there are no bent, deformed, cracked, or excessively corroded support or main members.
(3) Without disassembly, inspect load bearing bolts for evidence of deterioration. Verify that assemblies are intact and that there has been no shifting or relative motion of parts.
(4) Inspect attachment and lifting lugs for visual deformation and evidence of local yielding.
(5) Ensure that there are no elongated attachment or lifting holes.
(6) Inspect around fasteners for local yielding and deformation.
(7) Remove and inspect load bearing slip pins for deformation, evidence of bending, abnormal defects such as galling, scoring, brinelling, and diameters not within design tolerances. Verify that there are no cracks by performing a surface NDT.
(8) Inspect pin bores for deformation, local yielding, scoring, galling, brinelling, and diameters not within design tolerances. Verify that there are no cracks by performing a surface NDT.
(9) Inspect welds for cracks, evidence of deformation, deterioration, damage, or other defects by:
(a) Visual inspection of all welds.
(b) Ultrasonics, radiography, magnetic particle, liquid penetrant, or eddy current as appropriate for critical welds as identified on the design drawings. Inspect a minimum of 1/2 inch on each side of the weld to ensure the heat affected zone is included. Verify that there are no cracks.
(10) Inspect all parts, particularly bare metal, for corrosion. Corrosion-protect all surfaces that are not to be painted, lubricated, or coated with strippable vinyl. Do not paint over uninspected areas, or cracks, deformations, deterioration, or other damage until engineering assessment has been made.
(11) Inspect hooks for deformations or cracks (see Section 7).
g. Rejected Slings. All slings rejected during inspection shall be marked. An engineering assessment will be made to determine if the sling is repairable. Non-repairable slings will be destroyed as soon as possible to avoid unintentional use.

10.4.6 Idle and Standby Slings. Idle and standby slings shall be inspected prior to first use according to the requirements in paragraphs 10.4.4 and 10.4.5 unless these daily and periodic inspections were performed at required intervals during the idle/standby period.

10.4.7 Inspection Reports. Written, dated, and signed inspection reports shall be prepared after each periodic inspection. Inadequacies shall be documented and, if determined to be a hazard, corrected prior to further use. These reports shall be filed and made readily available by the organizational element responsible for inspecting sling(s).

10.5 Maintenance. A maintenance program based on manufacturers' recommendations, integrating proactive, reactive, preventive, and predictive maintenance shall be established to increase the probability the sling will function in the required manner over its design life cycle with a minimum of maintenance. The program shall include procedures and a scheduling system for normal periodic maintenance items, adjustments, replacements, and repairs. The program shall also ensure that records are kept and unsafe test and inspection discrepancies are documented and corrected. Any sling found in an unsafe operating condition shall be tagged out and removed from service until repaired. All repairs shall be made by qualified personnel in accordance with the manufacturers' instructions. The need to repair or replace slings shall be determined by a certified or otherwise qualified person based on an evaluation of inspection results.

10.6 Personnel Certification.

10.6.1 Program. Only certified (licensed) and trained riggers are authorized to perform rigging tasks for lifting devices, equipment, and/or operations. A comprehensive training, examination, and licensing program shall be established or made available. For those NASA installations/initiatives or sponsored programs and activities that do not have a training program, these requirements may be provided by a third party that is proficient in the principles of rigging. The rigging certification program will be reviewed at least annually to assure that the contents, training material, testing, and examination elements are up-to-date with current methods and techniques; and that any "lessons-learned" are adequately addressed. Personnel performing NDT shall be qualified and certified in accordance with paragraph 1.9. Training shall be provided to observers and flagmen. All participants in the lifting operation shall have clearly defined roles and responsibilities.

10.6.2 The certification program for rigging operations shall include the following and may be included in the operator training for the individual lifting device training and certification . If the general rigging is included in the specific lifting device certification and training program, sufficient rigging details shall be included in the training, testing and "hands-on" examination portion of that lifting device training program to assure that each individual understands and demonstrates proficiency in the required rigging techniques and methods.

The following shall be addressed in the qualification of individuals for "rigging certification."

a. Training
(1) Classroom training in rigging safety, techniques, and methods, pre-use inspection, slings, and attachment devices (for initial certification and as needed).
(2) Hands-on training (for initial certification and as needed).
(3) An annual review by supervision or other designated personnel of each individual's performance as a rigger or operator/rigger to assure adequate proficiency in performing the necessary rigging tasks in a manner consistent with the principals, methods, and techniques associated with safe rigging practices.

b. Examination
(1) Physical examination (criteria to be determined by the cognizant medical official based upon the related requirements associated with performing rigging tasks).
(2) Written examination.
(3) Operational (practical) demonstration test (for initial certification only or to address new techniques or methods as required). Each individual shall demonstrate the ability to adequate determine and/or apply load weight, center of gravity and apply special articulating devices essential to the safe and successful lift operation. Riggers must demonstrate the ability to apply proper rigging principals, methods, and techniques using simulated loads of various weights, sizes, and configurations.

c. Rigger Licensing/Certification
An organization element shall be designated to issue rigger licenses/certifications. Provisions shall be made to suspend/revoke licenses or certifications for violation of safety requirements, failure to meet medical requirements, or acts of negligence in rigging. A program element to assure current rigger certification status of persons performing rigging tasks shall be established and implemented. The method of licensing is the responsibility of the organization element that is designated to issue the rigger licenses/certifications. Generally this will involve the use of "License/Certification Cards" issued to each individual or maintaining a master list of licensed/certified riggers that is readily available to assurance and supervisory personnel.

(2) Renewal of all rigger licenses/certifications shall require demonstration of proficiency or approval of supervision that proficiency is adequate and current. Licenses/certifications will expire at least every 4 years. Renewal procedures and requirements will be established by the organizational element responsible for issuing rigger licenses/certifications and will include those requirements established in paragraphs 10.6.2 a. and 10.6.2 b.

MANAGEMENT TECHNOLOGY NSI

* N S I *
DOCUMENT NO. 15-01-422

Analysis Procedure
for
Spreader Bar Lift Stability

NSI Document Number
15-01-422

April 6, 1993

Prepared By: Edward L. May
Project Engineer, NSI, Code 750.5

Edited: Mark J. Ramsey
Structural Engineer, NSI, Code 750.5

Approved By: *E Hemminger* — *4-6-93*
Ed Hemminger, Supervisor, NSI, Code 750.5 — Date

David H. Orbock — *4/6/93*
David H. Orbock, Manager, NSI, Code 750.5 — Date

Stan Wojnar — *10/7/93*
Stan Wojnar, NASA Section Head, Code 754.1 — Date

Russ Springham — *10-7-93*
Russ Springham, NASA Branch Head, Code 754 — Date

Launch Environment and Simulation Support
NSI Technology Services Corporation
Aerospace Technology Applications Center, A ManTech International Company
Goddard Space Flight Center
Greenbelt, Maryland 20771

Background

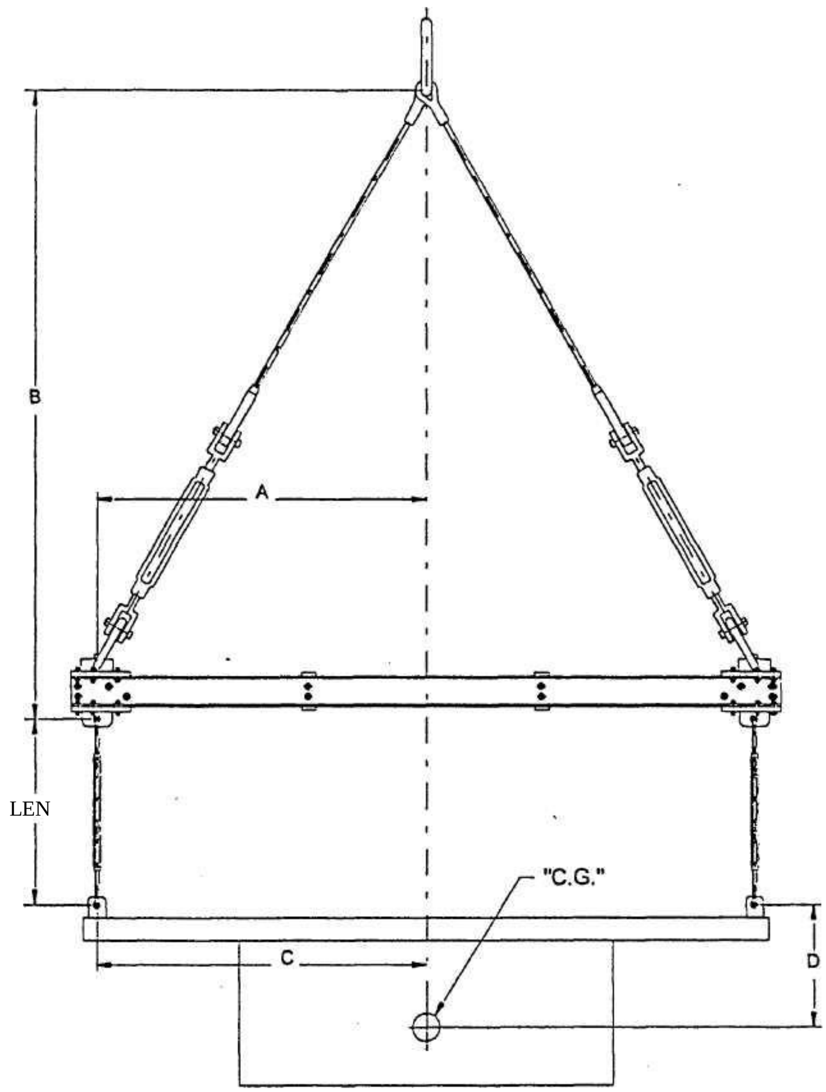
This specification is intended to aid the analyst in determining whether a spreader bar lift is stable. In general if the lowest lift attachment point is above the payload's center of gravity then the lift is deemed stable. If the lowest lift attach point is below the center of gravity, then further analysis is required. This procedure is intended to expand on the JPL spreader bar lift stability specification found in appendix G of JPL Document #D6904 Dated February 1990. Additional analysis methods are offered. A further analysis shows that we must limit the lifts from being very tall and thin, even though they meet the JPL specification. Alternative methods to obtaining stability for these types of lifts are discussed. Tag Line usage, placement, and operational considerations with respect to lift height are also covered.

Classification of Spreader Bar Lifts

Spreader bar lifts fall into two major categories. The first is those in which the load center of gravity is below the lowest lift attach point of the lift arrangement. These lifts are inherently stable. For any angle of the spreader bar, the load raises. The other category, which is the subject of this procedure, are lifts in which the load center of gravity is above the lowest attach points of the lift arrangement. These lifts must be analyzed to determine if they will be stable under all conditions. In some configurations of these lifts, they may be marginally stable, however, experience shows that one must ensure stability under all lift conditions to prevent injury or damage. It is the intention of this specification to aid in the development of the analysis for these latter type lifts.

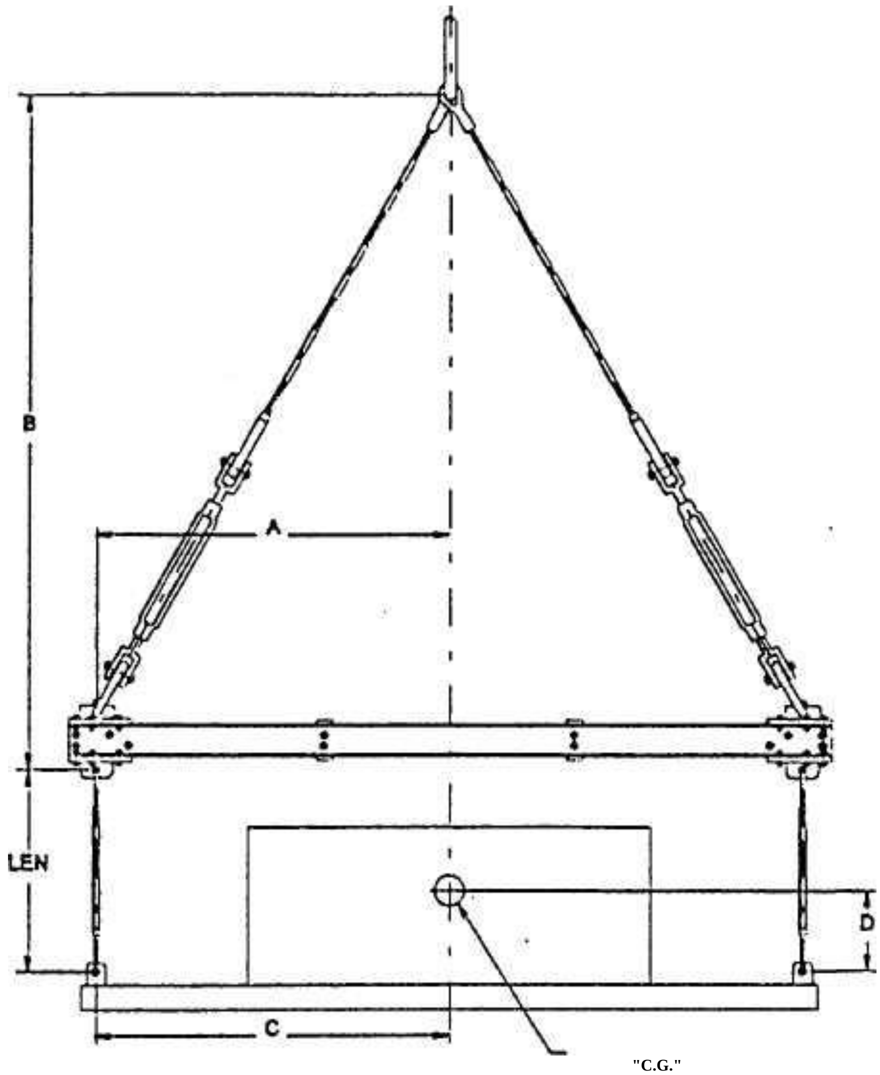
Once a lift is determined to be of the type that the load center of gravity is above the lowest lift point of the lift arrangement, we must further determine if it is a parallel lift. Each of the main two sub-categories of lifts, symmetric and asymmetric, can have parallel lifts. Both symmetric and asymmetric lifts further have three sub-categories, parallel, bird-cage, and, umbrella lifts. Asymmetric lifts are those in which the center of gravity of the load does not fall along a perpendicular bisector of the upper spreader bar. The lifts typically have different length slings or wires from the spreader bar up to the hook lift point

Load Center of Gravity Below Attach Points



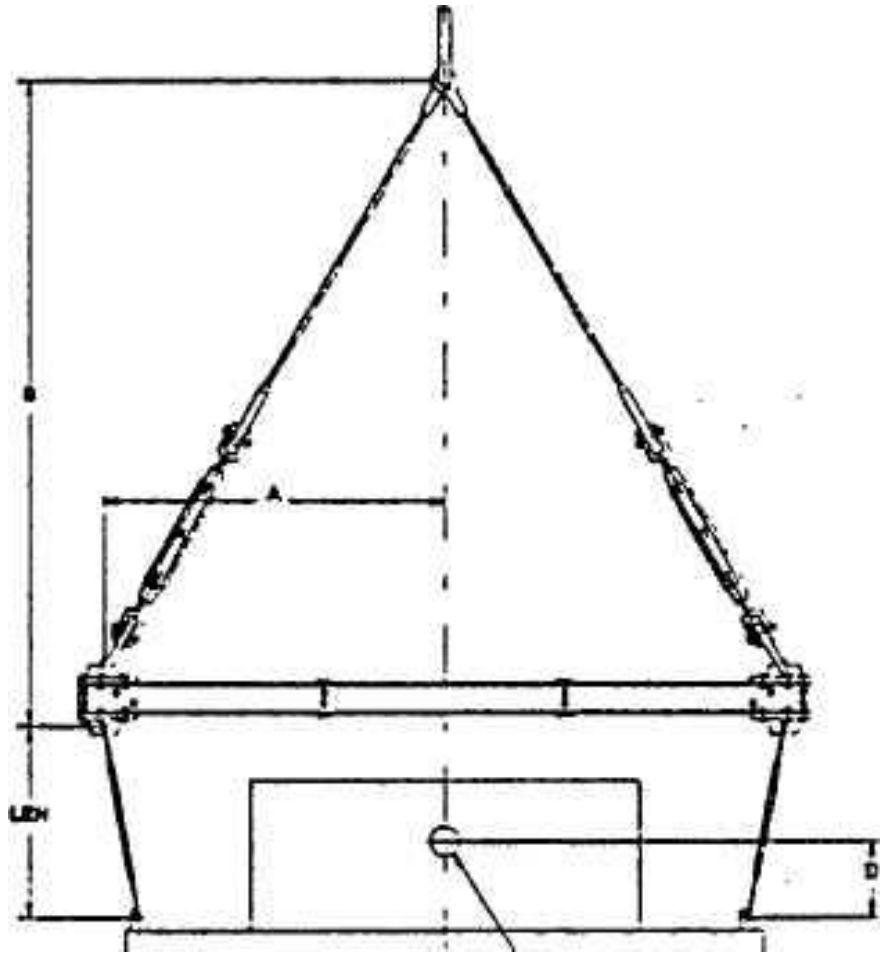
Load Center of Gravity Above Attach Points

Symmetric Parallel Spreader Bar Lifts



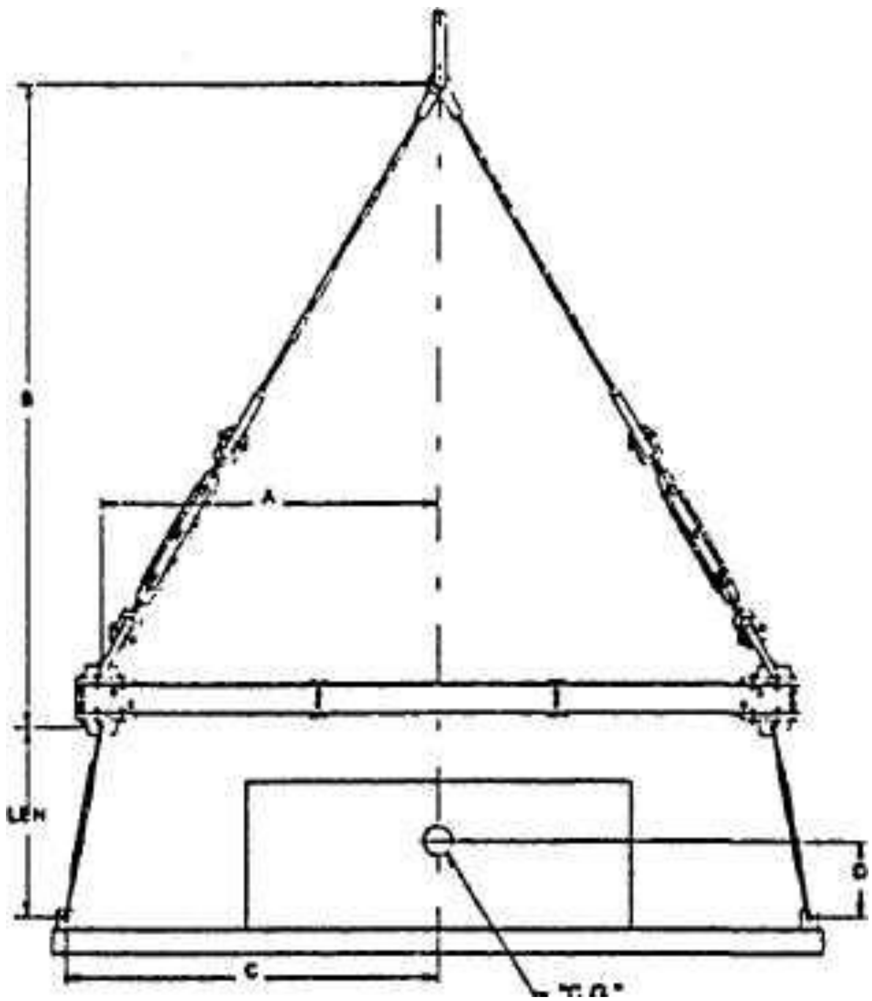
These lifts are defined as lifts using a spreader bar where the load center of gravity falls on the perpendicular bisector of the spreader bar, is located above the lowest sling attach point, and where the slings between the spreader bar and the lower platform fall vertically and thus are parallel.

Symmetric Bird-Cage Spreader Bar Lifts



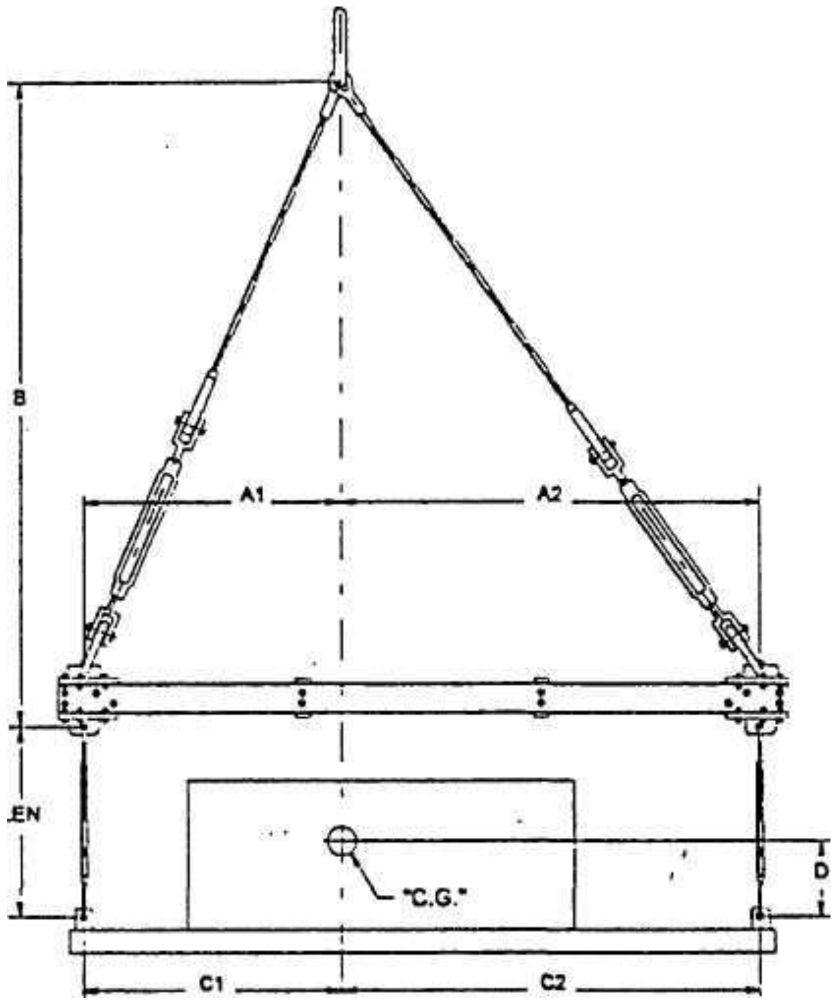
These lifts are defined as lifts using a spreader bar where the load center of gravity falls on the perpendicular bisector of the spreader bar, is located above the lowest sling attach point, and where the spreader bar is longer than the lower platform so that the lower ends of the slings are closer together than their top ends.

Symmetric Umbrella Spreader Bar Lifts



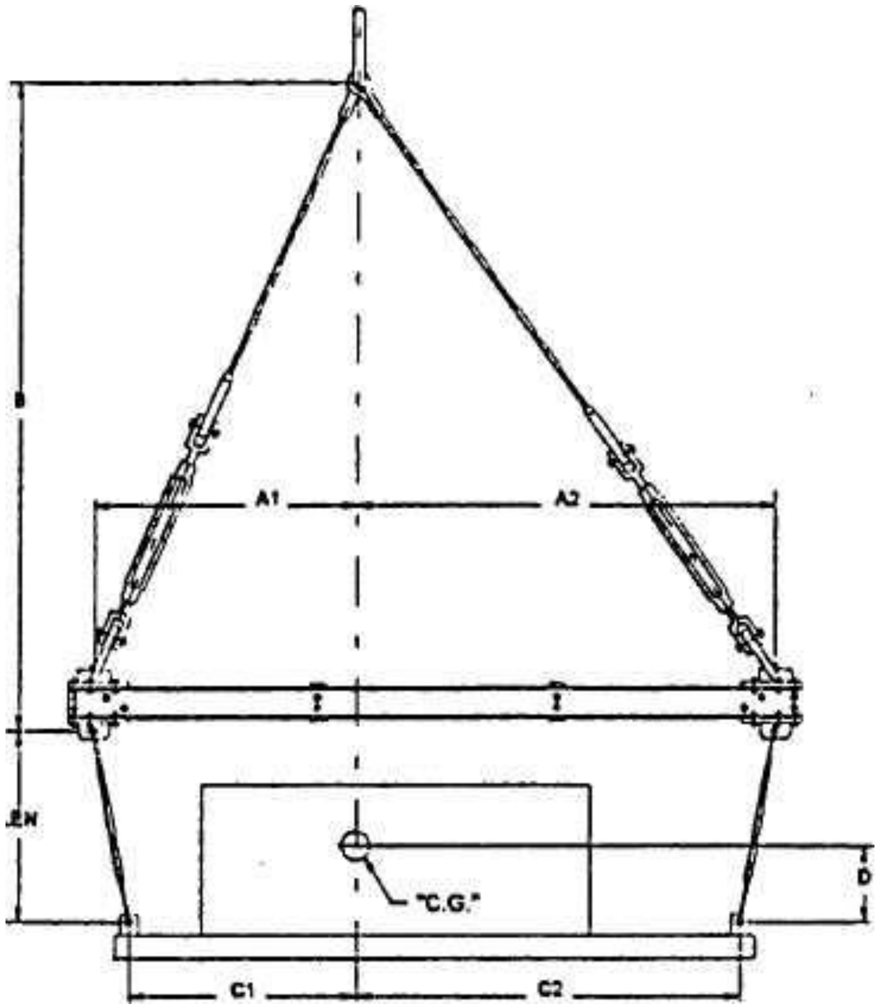
These lifts are defined as lifts using a spreader bar where the load center of gravity falls on the perpendicular bisector of the spreader bar, is located above the lowest sling attach point, and where the spreader bar is shorter than the lower platform so that the lower ends of the slings are farther apart than their top ends.

Asymmetric Parallel Spreader Bar Lifts



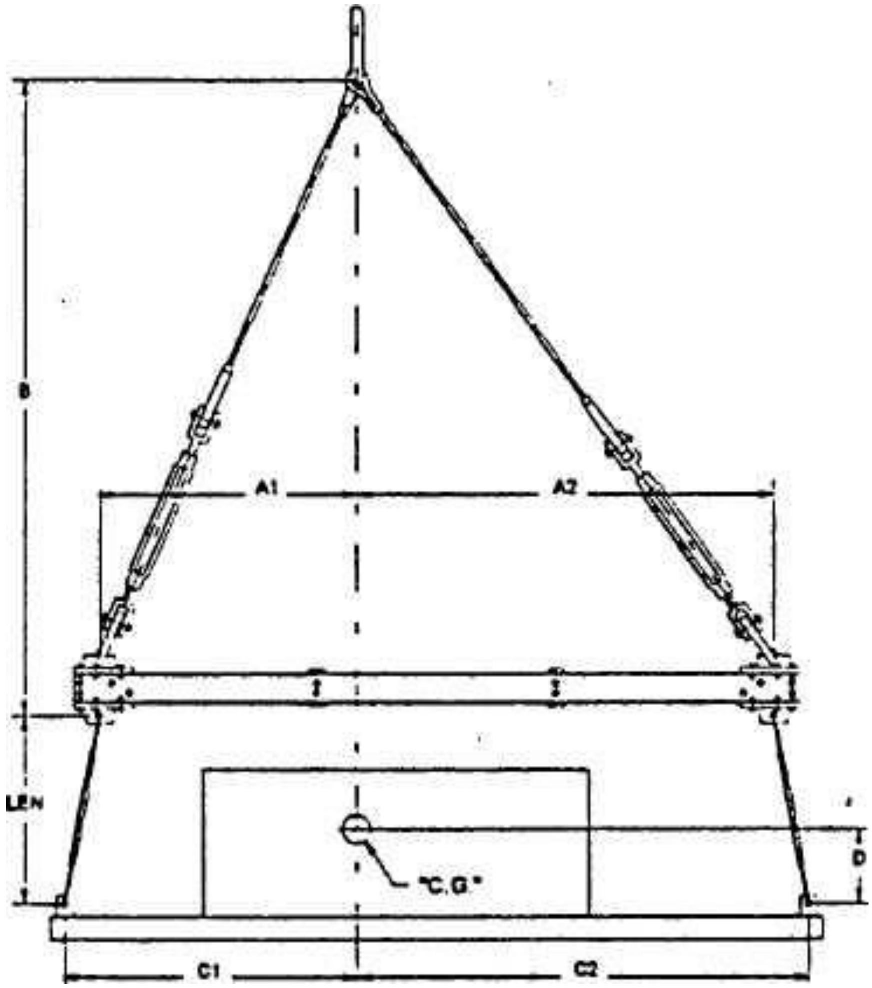
These lifts are defined as lifts using a spreader bar where the load center of gravity does not fall on the perpendicular bisector of the spreader bar, is located above the lowest sling attach point, and where the slings between the spreader bar and the lower platform fall vertically and thus are parallel.

Asymmetric Bird-Cage Spreader Bar Lifts



These lifts are defined as lifts using a spreader bar where the load center of gravity does not fall on the perpendicular bisector of the spreader bar, is located above the lowest sling attach point, and where the spreader bar is longer than the lower platform so that the lower ends of the slings are closer together than their top ends.

Asymmetric Umbrella Spreader Bar Lifts

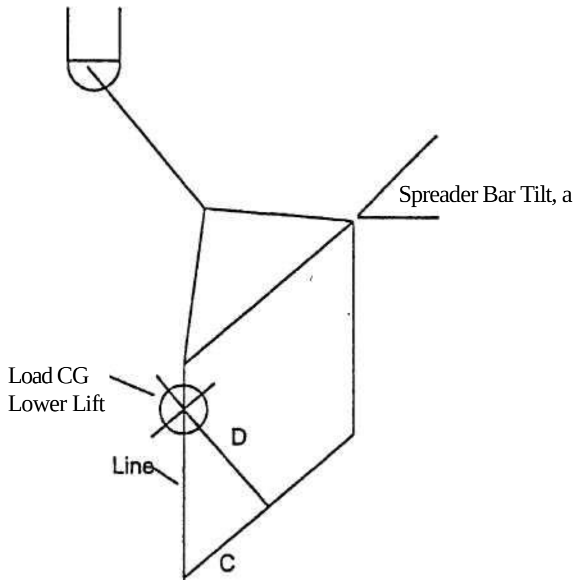


These lifts are defined as lifts using a spreader bar where the load center of gravity does not fall on the perpendicular bisector of the spreader bar, is located above the lowest sling attach point, and where the spreader bar is shorter than the lower platform so that the lower ends of the slings are farther apart than their top ends.

<u>Discussion</u>

Stability

A spreader bar lift is stable, when the Load Center of Gravity (LCG) raises with spreader bar tilt. However, a lift can meet the stability criterion but will flip over with only a small angular excursion of the spreader bar. This occurs when D is large compared to C. Whenever the LCG passes outside the lower lift lines, a tipping moment. is created that will allow the load to flip over. This will occur especially if the load is tall, thin and is lifted using the spreader bar arrangement. Therefore, a flipping criterion must also be met.



Impending Flip-over

The bird cage lifts are the least stable due to their kinematics. Efforts should be made to change the lift points to obtain a parallel type.

The umbrella lifts are the most stable due to their kinematics. The extreme of an umbrella lift is one in which the slings from the hook form a straight line to the lower platform attach points. In these cases and especially those in which the spreader bar is smaller than a straight line between the hook and the lower platform, the spreader should be removed and slings attached from the lower platform directly to the hook. This lift without the spreader bar will then be stable as long as the center of gravity falls within the lifting lines.

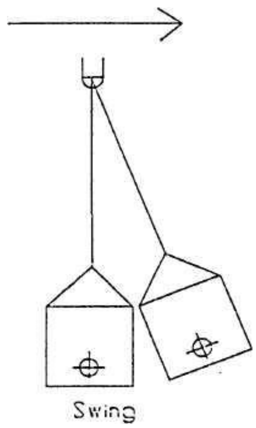
Energy Considerations

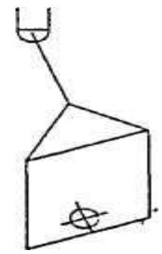
Various procedures can cause energy to 'move' the center of gravity to an area that would cause instability. Handling can input enough energy into the system to cause it to flip. Tag lines used during handling impart force into the lift system. A 3001b tag line operator hanging on an inappropriate placed tag line would significantly change the load center of gravity and the corresponding spreader bar tilt determined using standard static analysis. Irresponsible tag line operator can get a load oscillating enough to topple almost any load. One solution to this is to place the tag lines below the load center of gravity and minimize vertical loading on the payload. Fortunately, trained tag line operators are responsible, not negligent, and will not use the tag line to impart excessive energy into the lift system.

Another method of imparting energy into the load is through the crane itself. A worst-case scenario is when the crane abruptly stops after traversing at full speed. The kinetic energy of the load can then be enough to impart enough energy into the load to cause it to flip. An abrupt crane stoppage could occur when the power is lost and the brakes lock on, or if the crane hits an obstruction or an end-stop. Thus, we calculate the energy of the load traveling at full speed, and compare that kinetic energy with the energy it will take to tip the spreader bar enough to cause the center of gravity to pass outside the lower sling lines and topple the load.

This calculation is conservative since it neglects the energy which would be imparted to cause payload lift sling swinging motion, and assumes all energy to be taken by spreader bar tipping or racking. Because of the very conservative estimate of the tipping energy, no factor of safety is required.

Crane Motion





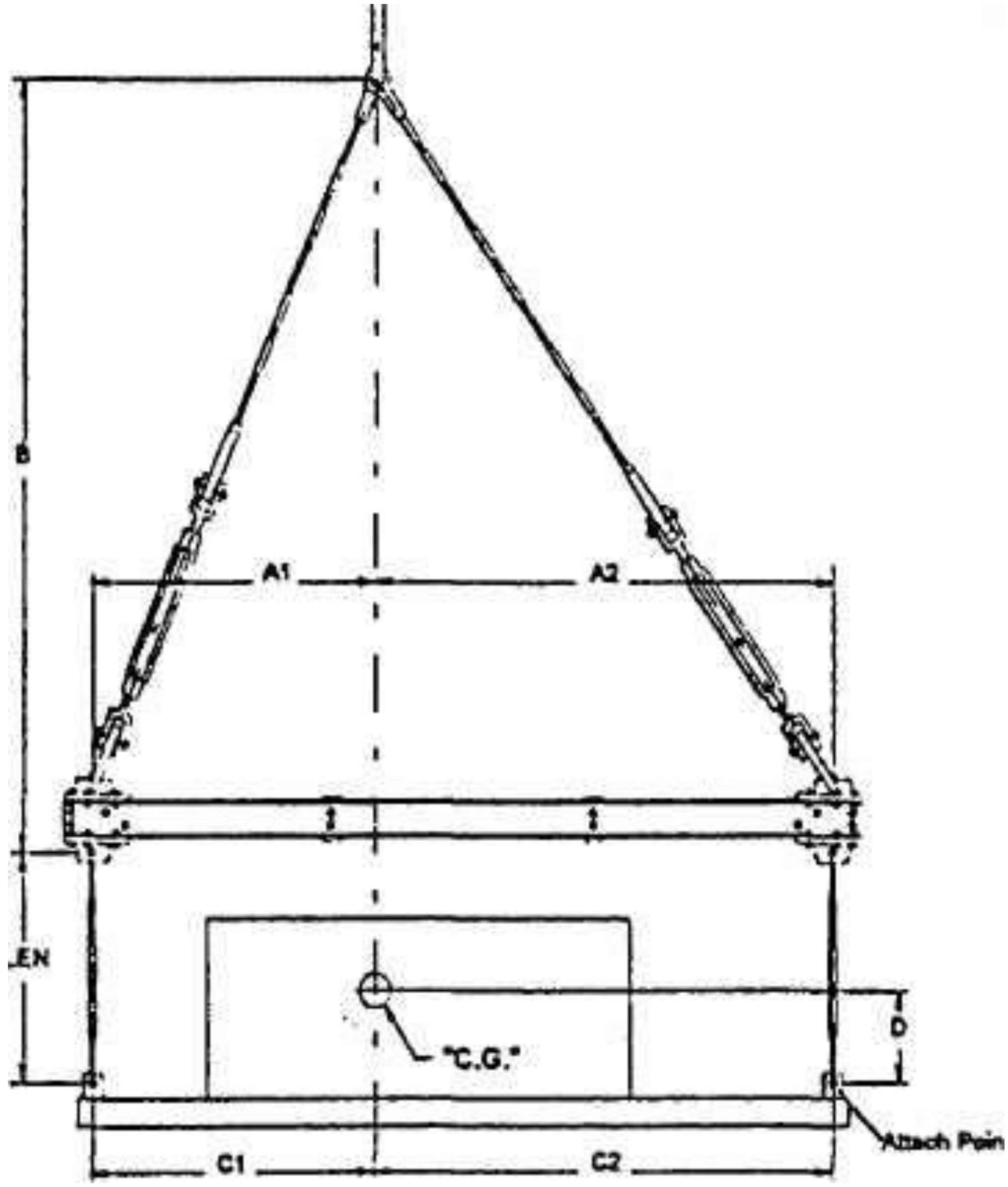
Tipping or Racking

It is further noted that tipping or racking is more likely for crane motion with the payload at maximum height. It is therefore strongly recommended that, if at all possible, crane motion should be minimized with the payload in the full height position.

Looking at the equations for the kinetic and potential energies, the mass of the load can be divided into both sides, and thus is eliminated. Now, we have the massless
kinetic energy of the load, 1/2 • V2, and the massless potential energy, g • □cg, wrt change in height of the Load Center of Gravity(LCG) caused by tilting the spreader bar from horizontal. The maximum crane velocity is directly calculated.

The analysis starts with the categorization of the lift arrangement, continues with checking the stability and flipping criteria, and concludes with a look at the energy or force to cause tipover. It is important that the lift arrangement be carefully documented with each part labeled to insure the actual lift arrangement matches the stability analysis.

Lift Stability Analysis Summary



For All Lift Configurations

$B>1.5(A^2/C^2)*D$

Parallel Symmetric Lifts

$\alpha_{flipover}=\text{Tan}^{-1}C/D$

$\Delta cg=B(1-\cos\alpha)-D(1-\cos\alpha)$

If cg is below Attach Point, Stable

All non-parallel and Asymmetric Lifts

Graphical Solution to determine Δcg and α

Maximum Crane Velocity

$V_{flip}= (2*\Delta cg*\text{gravity})^{1/2}$

Procedure

Stability Criterion

For all Lift Configurations determine of the values of Al, A2, B, Cl, C2, D, and Length as shown on Figure 1.

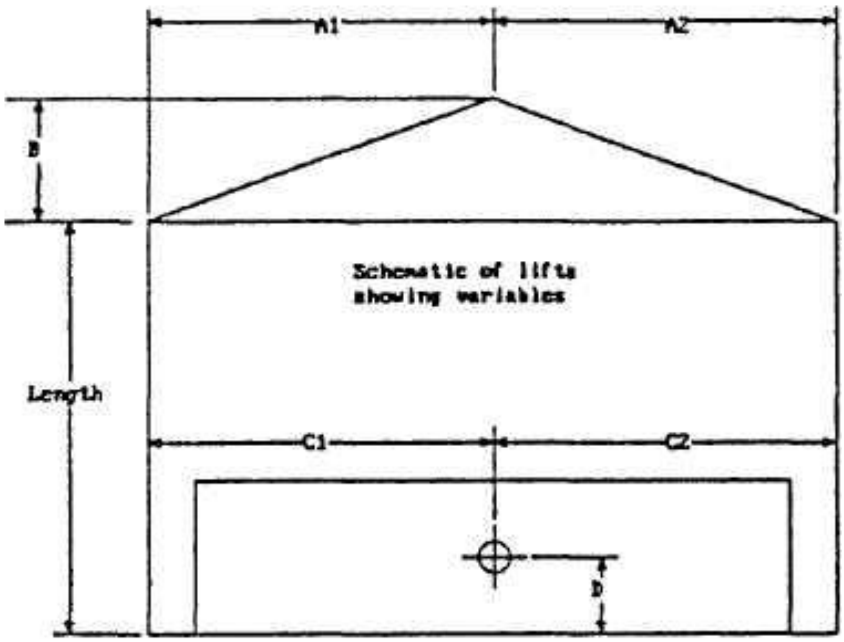


Figure 1 - Diagram of Variables (from program)

Both of the pairs, A1 & C1 and A2 & C2, should be checked for asymmetric lifts. The following criterion shall be met for a lift configuration to be considered stable.

$$B \geq 1.5(A_i^2/C_i^2)D$$

Flipping Criterion

The angular excursion that causes the load to flip-over should also be checked. The following formula describes the Flipping Angle in terms of the lift geometry for parallel lifts only.

$$\alpha \; \textit{Flip-over} = TAN^{-1}(C_i/D)$$

The Flipping Angle should be some reasonable large number so the lift has a large tolerance for handling. A good rule of thumb to ensure that the crane will not impart enough energy to reach the flip-over angle is $C > 2 \bullet D$. (This rule of thumb yields: α Flip-over= 63º)

Maximum Crane Velocity
Using the set of Cl & D or C2 & D which gives the smallest ratio C/D.

1. For parallel lifts, the flip-over angle can be calculated directly.

$$\alpha \; \textit{Flip-over} = TAN^{-1}(C_i/D)$$

In the case of non-parallel lifts, the angular excursion of the spreader bar when the LCG passes outside of the lift lines must be determined graphically or by numeric iteration.

2. At the Flip-over angle, determine the vertical movement of the LCG and calculate the crane velocity which imparts enough energy to flip the load using the following.

$$V_{flip} = (2 \bullet \Delta cg \bullet gravity)^{1/2}$$

3. The bridge or trolley velocity shall not be operated faster than *Vflip.* Note that the available speeds are limited to the discrete steps corresponding to the crane speeds, and the reduced speed must be one obtainable by the crane being used.

<u>Solutions to an Unstable Lift Situation</u>

The easiest way to increase lift stability is to increase the vertical distance of the hook from the upper spreader bar; dimension B. In some cases due to limited ceiling heights or tall obstacles, this is not possible. The next solution is to lower the vertical distance between the load center of gravity and the lowest lift points. This can be done by building a rigid structure onto the lower platform and re-installing the lower lift point attachments. A re-analysis is necessary to ensure that stability is achieved. A third way to ensure stability is to essentially make the lower platform rigid to the spreader bar by use of cross bracing or cross members.

The stability requirements described herein shall be followed regardless of the Lift Classification or the analysis method chosen. Cross bracing will change the classification of the lift. The problem becomes one for structural analysis, rather than strictly a stability analysis. The structural analysis must ensure that each member can take the load in all possible load tilt conditions.

Other Considerations

Tag Lines

Tag lines should be documented as part of the Lift Configuration. The tag lines should be attached to the spreader bar or the lower platform such that vertical loads on either of these members are minimized. The tag lines should be used only for the dampening of load swinging or gentle rotation about the lift axis. The tag lines should never be used for vertical adjustment of the load's tilt. Tag line operators must notify the lift engineer if they notice that vertical loads are needed for any reason, since a shift in center of gravity may have occurred, or the lift has become unstable from another cause.

Lift Height

During the process of a lift, the risks to equipment and personnel increase as the lift is raised or as the speed increases. For this reason, should large traversals of the bridge crane or trolley be required, the load should be kept as close to the floor as is practical, taking into account the possible swinging of the load due to crane jogs. Safety is not increased if the load is lifted so that the hoist is close to its upper limit, in fact, all this does is increase the amount of energy that the crane imparts into tipping as the bridge or trolley is jogged, started or stopped. In addition, it increases the potential energy of the load thus increasing the damage should the load fall in a worst case scenario. At all times, personnel must be kept clear of the load and as the lift is increased. The space of clearance from the load should be increased to approximately 1.5 times the height of the load.

Appendix A – Definitions

Critical Lift	A lift where failure /loss of control could result in loss of life, loss of or damage to flight hardware, or a lift involving special, high dollar items, such as spacecraft, one of kind articles, or major facility components, whose loss would have serious programmatic or institutional impact.
Critical Weld	A weld where the single failure of which could result in injury to personnel or damage to property or flight hardware by dropping or losing control of the load.
GSFC	Goddard Space Flight Center
NDT	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.
OEM	Original Equipment Manufacturer
Sling	A lifting assembly and associated hardware used between the actual object being lifted and hoisting device hook.
Spreader Bar	A structural horizontal beam used between the object being lifted and the hoisting device hook. Spreader bar is attached to the hoisting device hook from or near its ends. This allows for a more stable lift.
Strong Back	A structural horizontal beam used between the object being lifted and the hoisting device hook. Strong back is attached to the hoisting device hook from its middle.
Structural Sling	A rigid or semi-rigid fixture that is used between the actual object being lifted and hoisting device hook. Examples are spreader bars, equalizer bars and lifting beams.

Appendix B - Acronyms

MS	Margins of Safety
MSD	Mechanical Systems Division
NDT	Non Destructive Testing
OEM	Original Equipment Manufacturer
PDL	Product Design Lead
SWL	Safe Working Load

CHANGE HISTORY LOG

Revision	Effective Date	Description of Changes
Baseline	04/17/2006	Initial Release
A	02/16/2010	Asterisk removed from Table 1 to add clarity. Revised format.