COLUMBIA SCIENTIFIC BALLOON FACILITY

BALLOON OPERATIONS SUPPORT
NASA BALLOON PROGRAM
CONTRACT NO. NAS5-03003

STRUCTURAL REQUIREMENTS AND RECOMMENDATIONS FOR BALLOON GONDOLA DESIGN

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NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION

Approved by: Hugo Franco

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NOTICE

This document supersedes the following:

- OF-605-00-P CSBF Payload Safety Process
- OF-600-22-P Payload Pressure Vessels Certification
- OF-600-21-P Structural Requirements for Balloon Gondolas

CHANGE LOG

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INTRODUCTION

Presently, the Columbia Scientific Balloon Facility (CSBF) requires mechanical certification of all gondolas. Gondola certification helps to ensure that containment frames and suspension systems supplied by scientists are mechanically capable of withstanding the stresses placed on them during testing, launch, flight, termination, and impact.

The scientist is responsible for the design and analysis of the gondola. The CSBF Engineering Department uses the scientist's design information and stress analysis to assess a gondola's suitability and to certify the structure. The gondola stress analysis must be performed by an engineer whose qualifications must be provided to the CSBF in the form of a brief resume. The primary point of contact is the CSBF Engineering Manager who can be contacted through the Administrative Assistant at 903-723-8002. The Engineering Manager will assign a staff engineer to interface with each payload group.

Although CSBF engineers are available to answer questions concerning design problems or unusual projects, the CSBF certifying engineer's primary role is to identify critical structures, determine whether the analysis has examined these structures, and spot-check pertinent calculations. Based on the stress analysis provided, the gondola is given an overall rating and the weight that can be safely accommodated by the structure is determined. The certifying engineer will notify the scientist of the certification based on his design and stress analysis.

This document establishes hard requirements as well as some very general guidelines for gondola design, and points out common design problems which are peculiar to ballooning.

These guidelines will be most helpful during the early gondola development stage when critical design decisions are being made. Initial design development is especially important, because it can impose restrictions on the experiment that only become evident as the plan matures. Well before a design is finalized, the CSBF should be contacted for specific information on weight restrictions, ballast weight, flight train rigging, and other factors that influence gondola design.

To supplement the discussion of gondola design, this document includes information on materials and parts that have been used successfully in gondola construction.

TYPICAL GONDOLA STRESS CONDITIONS

It is impractical to design the gondola to withstand all known flight hazards. The experimenter must identify the hazards which are likely to affect the payload and then address those hazards in the gondola's design. Thus, it is important for gondola designers to be familiar with the typical conditions to which a gondola is subjected before, during, and after flight.

STAGING AREA

MECHANICAL

The gondola is usually assembled in a CSBF staging bay at the launch site or at CSBF in Palestine during integration and compatibility testing prior to a long-duration balloon (LDB) flight. Each work area is equipped with an electric hoist with which the gondola can be lifted. The various hoists have a lineal range up to 35 feet and have maximum lifting capacities from 3000 to 10,000 pounds. The gondola should be equipped so that it can be lifted in the staging area.

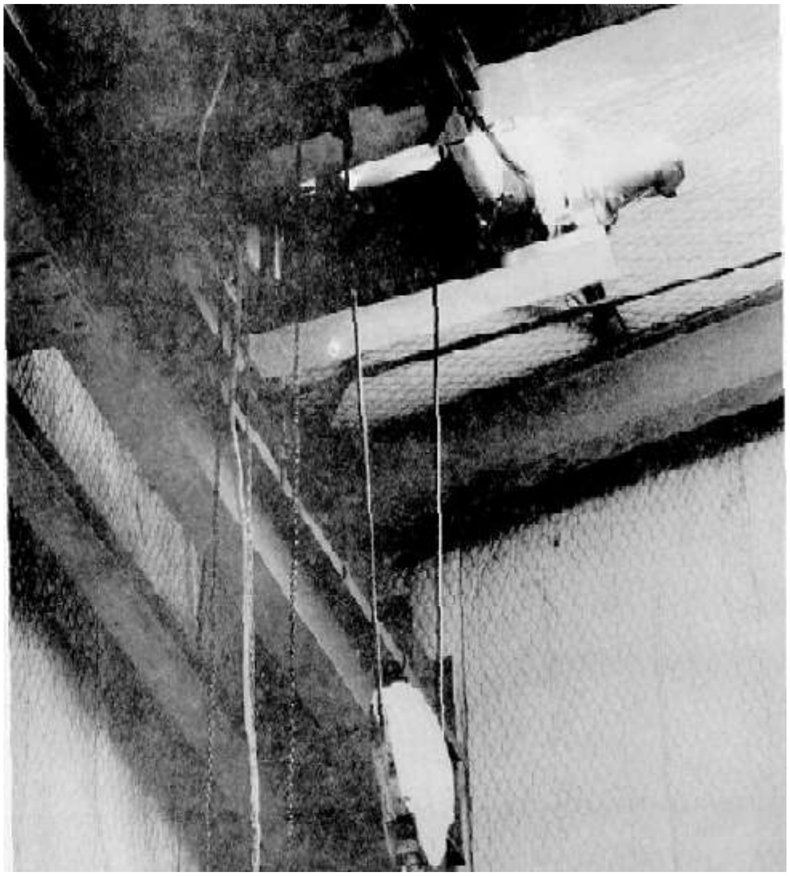


Figure 1 Staging area hoist

THERMAL

There is little thermal stress on the gondola while in the staging area because work areas are heated or cooled as necessary.

In the summertime, a cool gondola taken out to the flight line on a warm, humid day may be affected by condensation. This problem can be avoided by dry gas purging of critical enclosures or by warming the gondola before it leaves the work area.

FLIGHT LINE

MECHANICAL

The package is carried from the staging bay to the launch pad by the launch vehicle. It hangs from the vehicle by the launch pin, and on the trip to the pad it can bounce with a force of up to .25-g. It is also subject to high frequency, low amplitude vibration from the vehicle's engine.

The ride to the launch pad is much less stressful than flight termination, so the components of the gondola that are designed to withstand flight conditions and termination will survive the ride to the pad easily. Rarely, a flight component that will withstand normal flight conditions is sensitive to the high frequency vibration of the launch vehicle.

NOTE

Experimenters often place devices on the gondola package which are removed before launch. These devices must be attached securely to the gondola during the ride to the pad.

THERMAL

Extreme temperatures on the flight line can affect thermally sensitive equipment in the gondola.

For example, summertime temperatures in Palestine, TX may reach 50°C a few inches above the launch pad, and temperatures at the gondola's height several feet above the pad may exceed 40°C. Temperatures in Antarctica can range from 5°C to -15°C during the campaign (October-January).

The gondola may also sit in direct sun during the flight line checkout period before launch, which can compound overheating problems.

ELECTRICAL

During package pickup and launch, the gondola is suspended within 10 feet of the launch vehicle's electrically driven motors).

The vehicle usually runs during package pickup, the trip to the launch pad, and during the launch. The launch arm motor is only run during launch. The CSBF is not aware of any interference of these motors with electrically sensitive equipment, but they do create significant electrical fields as well as transfer potential unwanted vibrations to the gondola.

LAUNCH

MECHANICAL

The gondola experiences a jolt of about 0.5-g when the balloon is released from the spool.

A similar shock is incurred when the gondola is released from the launch vehicle onto the ascending balloon train. These jolts rarely exceed 2-g.

ASCENT

MECHANICAL

During the ascent phase of flight, the gondola is commonly jolted by wind shears with up to 0.5-g of force. Structurally, a gondola that is properly designed to survive termination will withstand the stresses of ascent. However, problems may occur when high-quality data collection is required during ascent. If data collection during ascent is critical to the experiment, these forces must be considered in the gondola's design.

The balloon may rotate as much as two revolutions per minute during ascent. To maintain accurate positioning, pointing systems must work harder during this phase of balloon flight than during any other.

The balloon system typically ascends on average at approximately 800 ft/min, with maximum ascent rates of 1200 ft/min and minimum ascent rates as low as 400 ft/min depending on many factors (balloon size, weight, location). Thus, the gondola may spend as much as 3 hours in the ascent stage to reach an altitude of 130,000 feet.

THERMAL

On ascent, the gondola passes through the coldest layer (troposphere) from about 40,000 to 70,000 feet. For as long as 60 minutes, the gondola is exposed to temperatures below −70°C. Frozen condensation formed during ascent through the troposphere usually sublimates before the gondola reaches 70,000 feet.

FLOAT

MECHANICAL

Float is mechanically the least stressful portion of the gondola’s flight. The gondola altitude is fairly stable except for the variations that occur at sunrise and sunset. Balloon rotation is usually less than 1 rpm.

THERMAL

During daytime flights, the gondola has little protection against direct sun and marked temperature differences occur between shaded and unshaded areas.

TERMINATION AND DESCENT

MECHANICAL

At termination, the gondola and parachute are separated from the balloon. As part of the flight train, the parachute is under tension during flight. The stored energy released at termination causes the parachute to recoil toward the payload (Figure 2). The gondola falls for 4 to 6 seconds until parachute opening, at which time the gondola’s fall is slowed with a deceleration of approximately 2-g to 5-g.

The current flight configuration includes a shock attenuator device (“rip stitch”) which has eliminated most, if not all, of the recoil, thus reducing the shock loads to more manageable levels. However, the design requirements still apply since there can never be any guarantee that the device will work every time. Additionally, ballast must be included as part of the weight in the design analysis (see the *Weight* section on page 9).

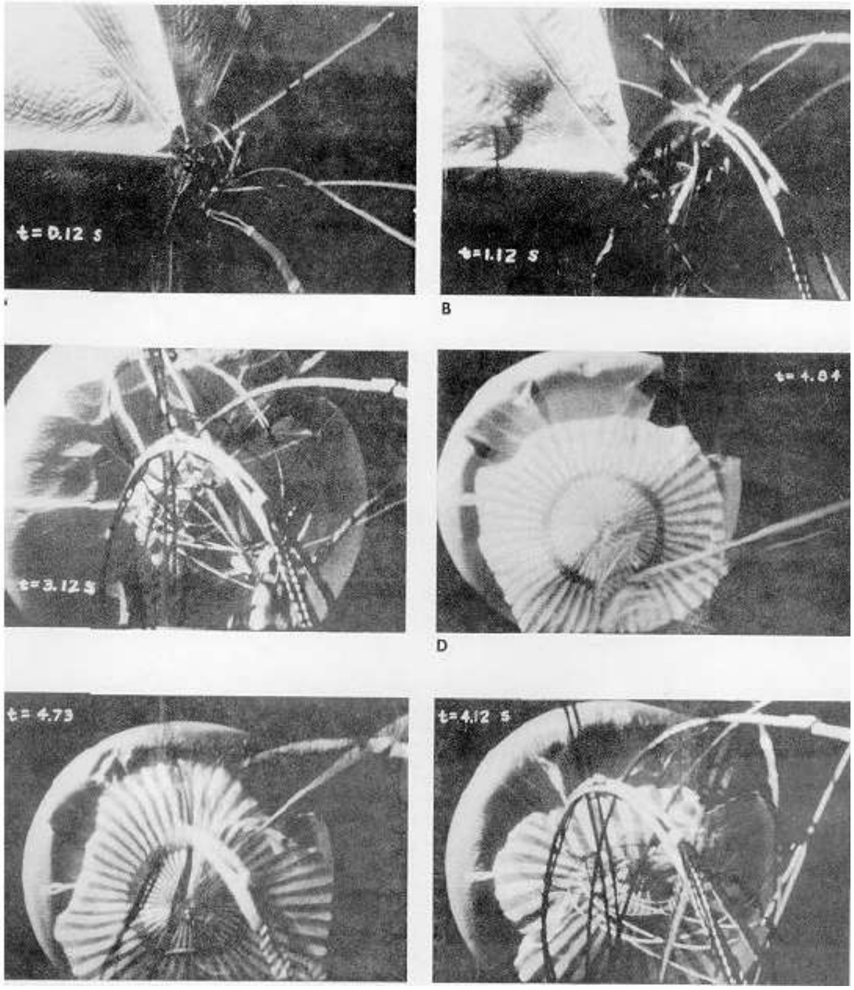


Figure 2 Parachute recoil following termination

The flight train may become misaligned during free-fall. In such cases, off-axis loading may occur in the suspension system. This problem is discussed in the *Suspension Systems* section on page 14.

Forces affecting the gondola during the descent on the parachute are very similar to those discussed in the *Launch*, *Ascent*, and *Float* sections on the previous page. However, during descent, the gondola/parachute combination swings in a circular pattern at several rpm. Antenna orientation at termination and during descent can result in significant data loss. Experimenters concerned with good data transmission during the descent phase of a flight should contact the CSBF about procedures for minimizing data loss.

THERMAL

On descent, the gondola encounters the same thermal conditions as during ascent (page 4) for about 10 minutes. As external components cool during descent, water may condense and freeze on the gondola. Moisture accumulation usually begins below 50,000 feet on descent and may damage sensitive, unprotected components of the payload or may start corrosion if the gondola is not disassembled and cleaned soon after flight.

LANDING

MECHANICAL

The factors affecting the gondola most at landing are surface winds and the terrain at the impact site.

Typically the gondola will be traveling at approximately 15 knots vertically; horizontal wind speeds at the impact site can vary greatly. Wind speeds of 15-20 knots can be encountered on landings.

Impact conditions for flights will vary considerably depending on the direction of flight. Summer (westward) flights often impact in West Texas where the gondola may land in hard, open ground; in gullies; or on rocks. There is also a slight chance that the gondola will land in a small body of water such as a farm pond.

Typical impact sites for spring or fall turnaround and winter (eastward) flights include open fields, densely wooded areas, swamps, and farm ponds. An open field is the most desirable site and is preferred for landing when possible. However, landings in trees or shallow water are not uncommon when flying over the southeastern United States. In wooded areas, the parachute or gondola may become entangled in branches, suspending the payload above the ground.

Upon impact, the tracking plane pilot releases the parachute from the gondola by radio command to prevent a re-inflated parachute from dragging the payload. The pilot can only fire the parachute cutaway after sighting and verifying that the gondola is on the ground. For this reason, the parachute cutaway is almost never fired during nighttime terminations. When the parachute cannot be cut away after impact, it may re-inflate and tip the gondola over. In extreme cases, the parachute may drag the gondola.

RECOVERY

MECHANICAL

Flights are terminated so that the gondolas will land in sparsely populated, rural areas. Recovery procedures vary depending on the actual impact location. For instance, although the CSBF uses specialized recovery vehicles, it is often impossible to reach payloads via a maintained road. Crews must often negotiate with landowners to enter private property or to cut roads into inaccessible spots. These conditions can delay recovery of the entire package from a few hours to a few days.

If the recovery process has been taken into consideration during the design stage, the gondola is less likely to incur damage during a difficult recovery. The gondola should be easy to disassemble using conventional tools. Sensitive detectors which are easily removable can be recovered quickly, even if the entire recovery process is lengthy.

Batteries must be easily accessible for removal by recovery crews because expended batteries and powered-up equipment pose fire hazards.

Gondolas are transported on open trailers, and the road trip from the impact site back to the launch facility can be rough. The gondola typically experiences jolts of 5-g to 7-g throughout the ride and unprotected sensitive equipment may return to the facility covered with dust.

GONDOLA DESIGN RECOMMENDATIONS

A typical gondola is a box-like or spherical framework equipped with a suspension system for attachment to the flight train. Surrounding the bottom and sides of the gondola is an impact absorption system which cushions the gondola on landing. The design of these structural elements is discussed in the following sections.

These requirements generally apply to all launch locations, but have particular importance for Antarctic flights due to the uniqueness and remoteness of the area, as well as environmental challenges not found at other launch facilities.

MODULAR COMPONENT DESIGN

GENERAL

In the initial design stage the experimenter should consider arranging the gondola in components, particularly if it is very large, while maintaining appropriate weights and sizes for individual components. Modular component designs facilitate ease of payload assembly and disassembly. This is encouraged for all structures and locations, but is highly emphasized for Antarctic and Canadian recoveries (see *Appendix J – Aircraft Recovery Options* on page 53). A well-designed gondola arranged in components provides for experiment adaptation on subsequent flights without requiring redesign of the basic gondola structure.

RECOVERY OPERATIONS

The designer can avoid many field recovery problems by adopting a modular design and by limiting the size and weight of the gondola or of individual components. A gondola that can be broken down into smaller units is easier to recover from inaccessible landing sites and to transport on field recovery vehicles.

Whenever possible, delicate instruments should be positioned within the gondola in such a way that they can be removed in the field and packed separately for transportation from the impact site. The experimenter should provide appropriate containers for packing components in the field. Any unprotected components will be exposed to weather and road conditions on the trip back.

Most recoveries will require a device to lift the payload onto the recovery trailer. There is no hard requirement for hoist points on the gondola; however, the designer may wish to provide and/or label hoist points to aid the recovery crew (Figure 1 on page 2).

The payload will be positioned on the recovery trailer in the most secure position, usually on its side.

WEIGHT

In general, as experiments have become more complex, the weight of the average scientific package has increased. As a result, many gondolas are now pushing the upper weight limit of present safety regulations for balloon flight. Thus, gondola weight should be considered a resource to be utilized as efficiently as possible. The weight limits for recovery are no more restrictive than those for flight; however, lighter payloads are easier to recover.

While the package must be sturdy enough to support equipment and withstand flight conditions, a balance must be maintained between structural integrity and gondola weight. To achieve this balance, some experimenters are now using design analysis computer programs and employing sophisticated construction techniques to minimize weight without sacrificing structural strength.

One of the critical elements of early design is the initial weight estimate. It is not uncommon for the gondola's final weight heavier than the original estimate. Therefore, the experimenter must carefully estimate the anticipated weight of all science instruments, science and CSBF electronics, and ballast. Further, the experimenter must build some flexibility into the design to accommodate added weight of experiment modifications. Changes in flight profile—longer flight times, higher altitudes, and flights through sunset—also increase gondola weight by adding ballast weight.

GONDOLA FRAME

GENERAL GUIDELINES

The gondola frame is the structure which contains science detectors and electronics. It must be capable of supporting this equipment and ballast.

One of the most important elements in frame design is the method of attaching members and supporting structures: welding, bolting, or clamping (see the *Attachment Techniques* section on page 13).

The framework may be open or can be covered by walls. Walls are seldom used as structural members, but often serve to protect internal components from direct sun during flight and to protect instruments from dust, rocks, and tree limbs upon landing. Depending on their construction, walls may also provide thermal insulation.

Of course, there are many variations on this basic pattern. As long as the gondola can be launched and recovered by the CSBF, is within the weight restrictions, and meets the CSBF certification requirements (see the *Gondola Design Requirements for Certification* section on page 18), the experimenter has great freedom in designing the actual gondola body.

PRESSURE VESSELS

A common method of accommodating a pressure vessel is to build a supporting cradle within the gondola. The pressure vessel can also be bolted to an encircling flange which is, in turn, attached to the gondola frame.

The pressure vessel is more likely to survive flight and impact without damage if it is not a structural member. In addition, the design is easier to analyze for CSBF certification if the vessel is not a structural member (see the *Pressure Vessel* section on page 24).

FASTENERS

The use of quick-disconnect fasteners is strongly recommended for all gondolas, but for flights from Antarctica and Sweden (Canadian recoveries) in particular. These fasteners can save a significant amount of time on the Ice during integration and compatibility testing and during recovery operations where heavy gloves must typically be worn and ground time is very limited.

HOIST POINTS

The gondola will need to be lifted by hoists during integration and compatibility testing at the launch site and during recovery operations. Having multiple hoist points on the structure will enable the package to be safely moved and lifted during these activities.

METALS

The CSBF typically uses aluminum in most of its flight components due to its low cost and its low weight/strength ratio. Most science gondolas are usually constructed with commercial aluminum and steel alloys, but have on occasions made use of other higher strength steels and titanium alloys. The CSBF does not make any specific recommendations for any particular metal and is only concerned that the design requirement is met.

If there is a doubt s to a metal’s suitability, refer to the *Metallic Materials Properties Development and Standardization Handbook* (MMPDS). The MMPDS Handbook (latest edition) will be used by the CSBF in checking allowable stress limits on the metals used.

INSULATION

Two types of foam insulation are typically used in ballooning – ethafoam (white) and Styrofoam (blue). The insulating values for these foams are listed in Appendix E. White foam is a better insulator but it will be dimensionally deformed after a balloon flight and may have to be replaced. The blue foam is dimensionally stable and is generally preferred for insulating components such as electronics boxes.

IMPACT ATTENUATION SYSTEM

Most systems use paper crush pads or a similar material to absorb gondola kinetic energy at impact. The crush pads are attached to the bottoms and sides of most gondolas. The bottom layers absorb the vertical energy, while the layers on the sides protect the gondola in case of tip-over.

Figure 3 Crush pads on payload

The crush pads can be attached in a number of ways. They should be easily fastened to the gondola and easily replaced after flight. One successful technique is to glue the crush pad to ply board which is then bolted to the gondola. After flight, the member is simply unbolted from the gondola for replacement before the next flight.

It is imperative that the designer make calculations to determine an effective crush pad design. The crush pad must begin crushing under the weight of impact and crush at a rate that dissipates the energy of impact before the material bottoms out. If an arbitrary configuration is attached to a gondola, it is possible for the gondola to destroy itself upon impact, leaving the crush pad undamaged. (See *Appendix H – Example Crush Pad Design* on page 47 for sample calculations of crush pad requirements.)

An inverted pyramid of crush pad has proven to be very successful. Lower layers of the pyramid crush quickly. The payload's descent into the crush pad is then slowed as the layers with greater surface area (and therefore greater crush resistance) are expended.

The CSBF stocks one type of crush pad for use by scientists. The crush pad stocked by the CSBF is a paper honeycomb product (KF-1-80(0)EDF 51 lb) manufactured by International Honeycomb Corp. (Park Forest South, Illinois). It is supplied in 4-ft x 5-ft sheets, 4 inches thick with 1 inch cell size. Each sheet weighs 5 pounds, and has an approximate crush strength of 10 psi.

Reusable Systems

A few gondolas have been constructed with reusable impact systems. Most of these systems use shock absorbers which survive impact without being permanently deformed. Consequently, they do not have to be replaced after each flight. This type of system is used infrequently and, unless carefully designed, it is often unsuccessful at either surviving impact or adequately protecting the payload.

Reusable systems are typically more difficult to design than disposable systems. However, over the span of several flights, a reusable system may save replacement and design time as well as material expenses.

Like disposable systems, reusable impact systems must be able to absorb horizontal and vertical energy and provide protection in the event of tip-over. Therefore, some shock-absorbing members must be positioned on the sides or upper edges of the gondola (Figure 5 on page 12).

BALLAST HOPPERS

The CSBF provides hoppers and rigging for carrying ballast below the gondola. In a typical arrangement, the hoppers are supported by flat, nylon straps that attach to eyebolts (Figure 4). The eyebolt is then inserted in a hole in a gondola member.

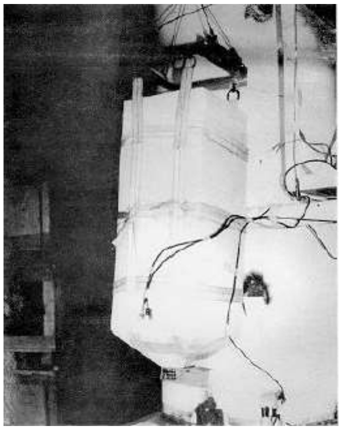


Figure 4 Standard ballast hopper

The CSBF provides AN-45 eyebolts for suspension of the ballast hopper straps, and usually drills holes for the bolts after the payload arrives at the CSBF. Four or more eyebolts are required for one or two hoppers. The scientist must identify the payload's center of gravity for proper positioning of the ballast hoppers and insure that the supporting members are capable of supporting 600 pounds of ballast with 10-g loading.

The scientist may provide ballast hoppers to replace the standard hopper used by the CSBF. Custom hoppers may be side-mounted or may allow special ballast handling that would otherwise be impossible (Figure 5).

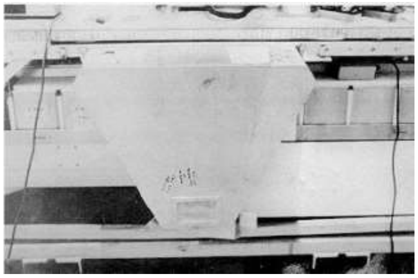


Figure 5 Side-mounted ballast hopper

The CSBF should be contacted for information on hopper design and ballast valves if the scientist intends to construct custom hoppers.

In designing the ballast attachment, the experimenter must anticipate the maximum ballast weight to be carried by the gondola and should be aware that factors such as increasing float altitude or flight time and floating through sunsets will increase ballast weight. Ballast requirements are based on the gross weight of the system: balloon, rigging, gondola, and ballast. More ballast is required for an evening or night ascent than a morning or daytime ascent. Increasing the float altitude requires a larger, heavier balloon and increased ballast for all phases of the flight. Extended turnaround flights may easily require in excess of 1000 pounds of ballast.

ATTACHMENT TECHNIQUES

The CSBF gondola certification criteria require that all internal components remain contained (not necessarily intact) throughout flight and impact. However, to insure that delicate equipment is not extensively damaged upon impact, the designer may want to consider some sort of individual shock absorption system to protect internal components.

WELDS

Most experimenters weld at least a portion of the gondola. However, welding should be used cautiously. As the proposed use of a material approaches the material's strength rating, the quality of a weld becomes more critical. In addition, heat-treated or work-hardened metals are weakened by welding. For instance, the strength rating of a material such as 6061 T6 aluminum is reduced from 32,000-psi to 12,000-psi by welding. This effect may reduce strength below design requirements.

Welds are usually difficult to evaluate for design analysis; therefore, the CSBF recommends bolting critical members of the suspension system and gondola framework. The preferred attachment technique is a bolted gusset plate (Figure 6 on following page). An advantage of bolting is that damaged members can be easily replaced without cutting and re-welding the structure. For internal structures designed to support equipment, the CSBF suggests the use of supports clamped to the gondola members. This technique also allows the internal arrangement of equipment to be reconfigured without reconstructing the entire gondola frame.

Figure 6 Bolted gusset plate

SUSPENSION SYSTEMS

A typical gondola suspension system includes a suspension point which attaches the gondola to the CSBF flight train. The suspension point is, in turn, attached to the gondola by an arrangement of support members.

The gondola is usually suspended from the flight train by an eyebolt or pear-ring at the top of the gondola suspension system. The CSBF usually places a clevis in this eye to attach the gondola to the load train.

Gondola suspension points can be configured in a variety of ways. The photo in Figure 7 shows a suspension system in which the payload is suspended from a triangular plate with clevises attached to the two upper corners. The clevises were then suspended from the launch pin.

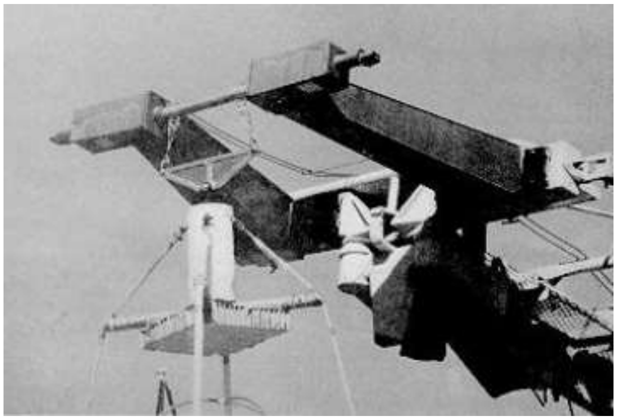


Figure 7 Gondola suspension system

The suspension members may be one of two types: flexible or rigid.

FLEXIBLE SUSPENSION SYSTEMS

A flexible suspension system is usually made up of cables, or less commonly, nylon webbing. A common design error is to use a flexible member but to restrict its movements at the attachment point with the gondola frame. At termination, the parachute recoils toward the payload causing the suspension system to go slack. If the member twists, it is possible that when the falling payload is jolted when the parachute opens, the attachment device will be damaged by abnormal loading.

A properly designed flexible suspension system should permit the flexible member to rotate fully around the attachment point without binding. Also, each flexible member should be capable of supporting the entire payload in the event one or more members fail.

The CSBF recommends using aircraft cable for flexible suspension systems rather than stainless steel. Stainless steel cables offer no particular advantages for balloon flight and are more expensive to replace.

As noted above, a flexible suspension system will recoil into the payload at flight termination. Any rotator or swivel and even the launch fitting may impact the top of the gondola. Provisions should be made to protect delicate instruments that may be damaged by such an impact.

RIGID SUSPENSION SYSTEMS

Rigid suspension systems are usually subjected to more stress conditions than flexible systems. The designer must pay close attention to the size and material of the suspension components, since the structure must account for any bending and compressive reactive loads not seen in flexible systems.

Most problems encountered in the design of rigid suspension systems stem from the difficulty of analyzing bending loads in a fixed beam. It is possible to design a strong, adjustable suspension system that induces no bending loads at either end of the main members.

One successful solution to this design problem places ball joints between the rigid member and the attachment points at each end (Figure 8 and Figure 9 on the following page). This type of member reduces bending loads by rotating at the joints.

Figure 8 Upper portion of rigid suspension system

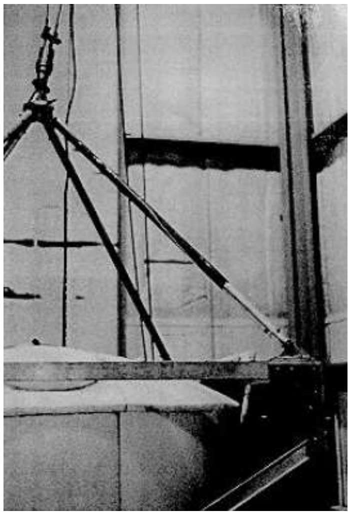


Figure 9 Entire rigid suspension system

THERMAL CONTROLS

The thermal flight environment presents a very complex design problem. Internal temperature is affected by insulation, outside surface color, the gondola's size, pressurization, heat produced by electronics, and braces which enhance heat transfer into and out of the gondola. Studies by Carlson et al (1, 2) examined the influence of these factors on the gondola, and a computer program for modeling a gondola's thermal properties was developed from this information (3). This computerized thermal modeling service is available to users through the CSBF.

Depending on the degree of thermal stability required for the payload to function properly, it may be necessary to manipulate the gondola's temperature through passive and/or active thermal control.

PASSIVE

Passive controls such as painted surfaces and insulation adequately protect most control-type electronics that are designed for the balloon flight environment. Because the thermal behavior of a surface painted with a color of known absorptivity/emissivity is more predictable than that of a bare metal surface, the gondola surface is often painted to control temperature.

Insulation will typically maintain the internal temperature of electronics boxes within a range of −50°C to +60°C. (See Appendix G on page 50 for thermal properties of paint and insulation.)

ACTIVE

When passive controls are inadequate, power equipment may require pressurization and, in extreme cases, may require active cooling. The most common active control device used on gondolas is the radiator (Figure 10).

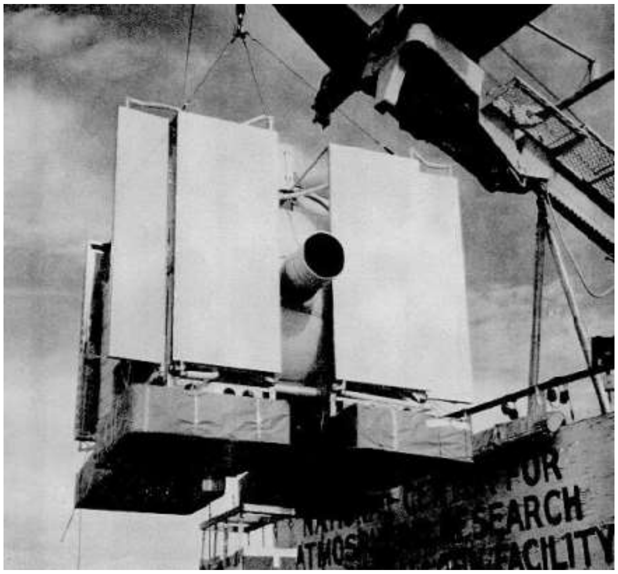


Figure 10 Radiator panels

Three types of radiator panels have been used successfully:

- Passive heat transfer
- Electrical resistance
- Fluid-filled

Several fluids have been used in gondola radiators with varying success. Ethylene glycol/water mixtures freeze at high altitudes; however, fluorocarbon fluids developed as electronics coolants have been used successfully. A series of fluorocarbon fluids called Fluorinert Electronics Liquids are available through 3M Commercial Chemicals Division. See the Fluorinert information publications available from 3M (St Paul, Minnesota) for the properties of these fluids.

The CSBF highly recommends that all electronics be thermally and vacuum checked to determine the limits of operation. A range of −50°C to +60°C up to 150,000 feet is sufficient in most cases. An environmental chamber is available at CSBF in Palestine. However, it must be reserved with the LDB Lead to avoid long delays when several scientific groups are preparing for flight. For maximum support, the use of the environmental chamber should be scheduled during the off-season (usually from November through February and from mid-June through mid-August).

GONDOLA DESIGN REQUIREMENTS FOR CERTIFICATION

This section outlines requirements that must be met as part of the certification process.

DIMENSIONS

Gondola structures must be contained within certain area and volume envelopes for integration tests, launch and operational purposes, and recovery operations.

The gondola must be limited to the envelope dimensions shown in Figure 11 to be accommodated by either of the Antarctic payload buildings. This will enable such procedures as rolling out of the building, weighing, and transferring to the launch vehicle.

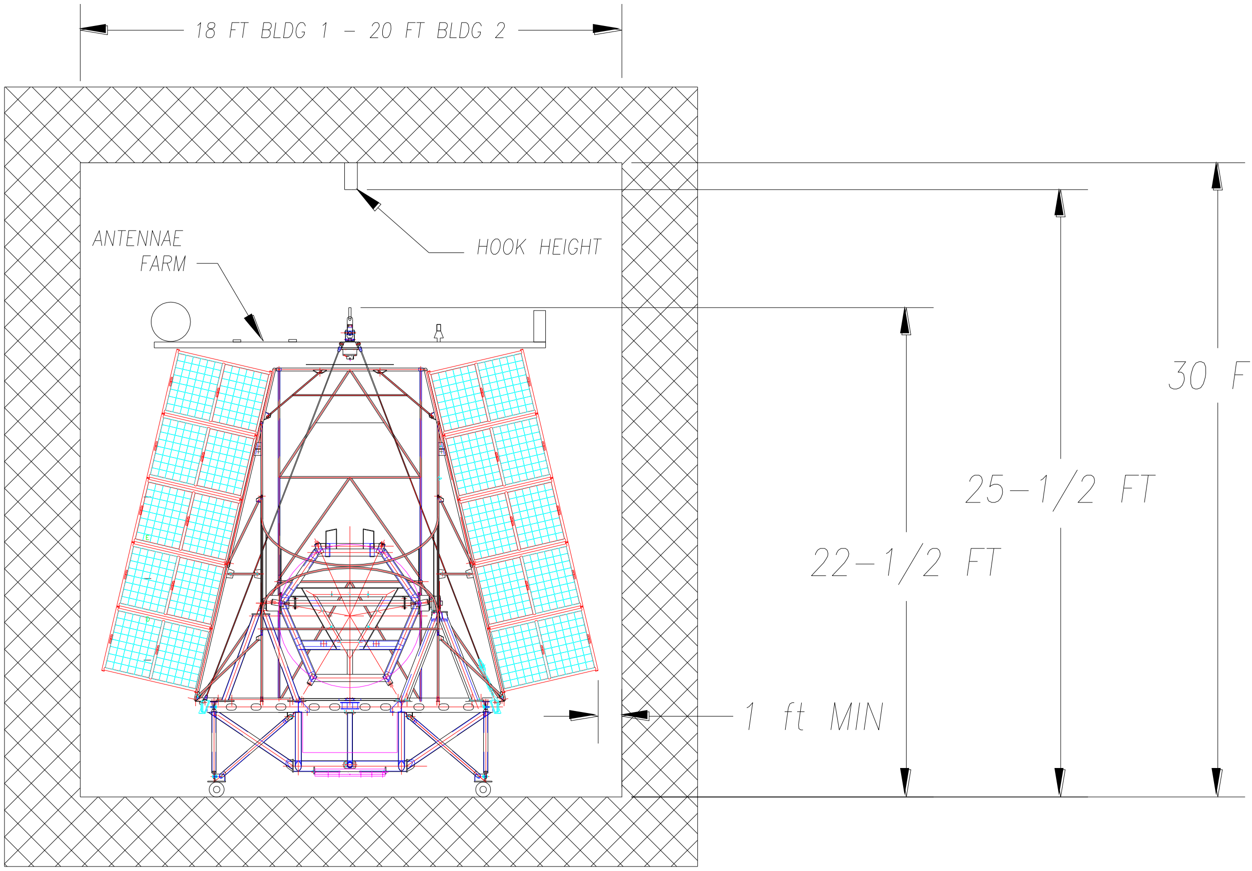


Figure 11 Gondola dimension requirements

WHEELS OR WHEELED CART

The gondola structure must be equipped with appropriately sized wheels enabling it to be moved on a horizontal plane without hanging it by the suspension system. Wheels must be correctly rated for the gondola weight and flooring type

CAUTION

The flooring of the payload buildings in Antarctica is wood with elements beneath the panels to heat the flooring. Improperly rated wheels could damage the floor and possibly the heating system.

At a remote launch site, a hoist may or may not be available for lifting and moving the gondola. In this situation the structure could be supported by a wheeled cart or cradle, which would allow work below and around the payload. Ideally, the cart/cradle would be tall enough to allow mounting of solar panels, crush pads, and ballast hoppers without lifting the structure.

NOTE

If opting for a cart/cradle system, hoist hook heights must be considered. The structure must still fit inside the dimension envelope shown in Figure 11 on page 18 while resting on the cart.

FOOTPRINT

Mandatory safety requirements state that the gondola must be supported by jack stands installed underneath during any lifts and whenever work is to be done below or around the suspended structure. A flat footprint on the gondola is preferred to place the jack stands at a minimum of three locations.

WIND RESISTANCE

When payloads are suspended on the launch vehicle during compatibility tests, they are typically exposed to the elements for considerable amounts of time (over 8 hours). Externally mounted equipment such as antenna mounts and solar panels must be able to sustain surface crosswinds of up to 16 knots during testing.

ANTENNAE

Over-the-horizon (OTH) antennae must be the highest point on the gondola structure, and must be supported in such a way to ensure minimal vibration.

Line-of-sight (LOS) antennae must be the lowest point on the structure (including CSBF equipment).

NOTE

BOTH requirements must be satisfied within the appropriate envelope (Figure 11) for launch and building maneuverability.

SUSPENSION SYSTEMS

The following design criteria should be used in planning gondola structures and suspension. Gondolas must be designed so that all load-carrying structural members, joints, connectors, decks, and suspension systems are capable of withstanding the conditions listed below without ultimate structural failure.

1. A load 10 times the weight of the payload applied vertically at the suspension point.
2. For multiple-cable suspension systems, each cable must have an ultimate strength greater than five times the weight of the payload divided by the sine of the angle that the cable makes with horizontal (should be >30 degrees) in a normal flight configuration. Cable terminations, cable attachments, and gondola structural members must be capable of withstanding the load described above. Some exceptions to this criterion may be allowed for gondolas with more than four suspension points at the discretion of the CSBF certifying engineer.
3. A load five times the weight of the payload applied at the suspension point and 45 degrees to the vertical. This load factor must be accounted for in the direction perpendicular to the gondola's short side, perpendicular to the gondola's long side, and in the direction of the major rigid support members at the top of the gondola structure. If flexible cable suspension systems are used, they must be able to withstand uneven loading caused by cable buckling.
4. A side acceleration of 5-g applied to all components and equipment attached to and/or onboard the gondola structure or any portion of the flight system below the balloon.
5. The effects of stress concentration factors must be considered in the analyses of all critical mechanical structures and assemblies. The ultimate strength of the element should be de-rated proportionately to the applicable stress concentration factor. The stress concentration factors shall be based upon the specific load case and standard mechanical engineering design practices. A specific example of a structural element in which stress concentrations are to be considered is the shaft and housing of a swivel or rotator assembly.

   If a particular element does not pass when de-rated by the full effects of the stress concentration factor, the stress analyst must demonstrate that other factors such as material ductility offset the effects of stress concentrations. For instance, a tensile/pull test of an assembly can be used to demonstrate that it has an ultimate strength greater that the above criteria will allow. The CSBF recommends that proof tests be conducted by the science group as a standard practice to ensure that their hardware has adequate strength.
6. The ductility of all materials used for critical mechanical elements shall be considered in the analysis of the gondola structure. Specifically, the CSBF does not encourage the use of materials that are determined to be

brittle or that are not recommended for use in shock loading applications. Close examination of all materials that have a percent elongation less than or equal to 10% at an ambient temperature of -60°C shall be made to determine if the material is to be considered brittle.

If a material is determined to be brittle, the certification criteria listed in paragraphs 1, 3 and 4 above must be multiplied by a factor of 1.5. That is, the particular element that is fabricated using a brittle material must be able to sustain a 15-g vertical load, a 7.5-g load at 45 degrees, and a 7.5-g horizontal load without failure.

The gondola design also must ensure that all scientific equipment, CSBF equipment, and ballast remain contained when subjected to the loads described above and that the gondola is capable of supporting the weight of CSBF equipment. The CSBF Engineering Department should be contacted during the design stage for information on equipment and ballast weight for the flight.

SIP PROTECTION

CSBF telemetry support includes providing a Support Instrumentation Package (SIP) for both conventional (mini-SIP) and LDB flights. This component is usually located at the bottom of the structure and is exposed to high impact loads during landing. The gondola designer must consider implementing a protective structure around the SIP in order to increase its survivability. Ideally, the protective structure would be included as part of the original structure and must provide for easy access, installation, and removal of the SIP.

DESIGN SPECIFICATIONS AND ANALYSIS GUIDELINES

ASSUMPTIONS

The following assumptions are made by the CSBF certifying engineer in reviewing gondola design analyses:

- The suspension point is defined as the point where the scientist-furnished gondola suspension equipment interfaces with the CSBF-furnished flight system hardware.
- The payload weight includes the gondola structure, all scientific equipment and components, and all CSBF equipment (including ballast) affixed to the structure below the gondola suspension point.
- For analysis purposes, the base of the gondola may be assumed to be rigidly fixed (i.e., in a static condition). Other boundary conditions may be used upon prior approval of the CSBF.

The final stage of gondola certification is a visual inspection by a CSBF engineer. The gondola is checked for adequate suspension and crush pad cushioning. In addition, the certifying engineer checks all welds and verifies that the construction matches the description submitted by the user.

DRAWINGS AND STRESS ANALYSES

The scientist must provide design specifications and a stress analysis of the gondola to the CSBF at least 60 days prior to the anticipated flight date.

- Drawings showing the relative locations and dimensions of all structural and load-bearing gondola members. Materials identification shall be included in all drawings.
- At least one complete assembly drawing.
- Working drawings and specifications for all purchased and fabricated mechanical components and assemblies that are part of the flight train (e.g., rotators, swivels, turnbuckles, clevises, rings, and universal joints).
- A stress analysis of all major structural members, including decks and ballast attachment points. Identify the components, equipment, and weights comprising the loads.
- A statement certifying that the aforementioned requirements have been met. This statement must be signed by the principal investigator and the engineer responsible for the gondola structure.

The documentation for a certified gondola design is filed by the CSBF Engineering Department, and gondolas need not be re-analyzed for subsequent flights unless design changes are made. However, CSBF engineers visually re-inspect the assembled gondola before each flight, and the principal investigator is required to sign a Science Gondola Modification Certification Form verifying that the previously certified design was not changed.

PRESSURE VESSEL FLIGHT CERTIFICATION

CSBF mechanical engineers routinely evaluate the design and fabrication of payload gondolas for safety prior to' flight. This evaluation leads to an internal certification of the gondola that becomes a permanent part of the flight record. The evaluation and certification of payload pressure vessels previously was performed by the Balloon Program Office (BPO). BPO mechanical engineers would evaluate documentation supplied by individual science groups that provided data on pressure vessel design, material specifications, fabrication, flight history, and, testing history. The BPO evaluation would result in a memorandum certification retained in BPO flight history files.

A recent catastrophic failure of a payload pressure vessel has served to emphasize the flight safety evaluation of pressure vessels, as well as highlighting the requirement to evaluate the payload as a total entity for flight safety purposes. As a part of the corrective action initiative, the pressure vessel certification responsibility has devolved to CSBF. The following paragraphs will discuss the implementation the certification procedures that will be employed by CSBF.

Pressure vessel certification will be performed in addition to the current gondola certification process. Existing gondola certification procedures are neither modified nor superseded.

Payload pressure vessel certification will be performed by CSBF Mechanical Engineering. Responsible personnel will be assigned to evaluate individual payloads as required.

Individual science group Principal Investigators (PIs) will continue to be responsible for the design, fabrication and testing of all pressure vessels associated with their payloads. Test programs must be performed to the extent necessary to demonstrate that the pressure vessel(s) will not present an unacceptable risk to personnel or property as a consequence of ground or flight operations.

As a part of the annual Candidate Flight Program formulation process, individual science group Principal Investigators will be request to supply the information listed below as a part of their flight application.

- Design pressure analysis showing maximum design pressure(s).
- Normal operating pressure for ground and flight operations.
- Overview of material and construction specifications.
- Pressure test dates, methodology, and results.
- Past flight history of the pressure vessels.

The certifying mechanical engineer will review the flight application for the presence and adequacy of the preceding documentation requirements.

The Operations Department Head or applicable Campaign Manager will coordinate obtaining any missing or inadequate information from the applicable Principal Investigator.

Based on the information supplied, the certifying mechanical engineer will determine whether or not the operation of the payload pressure vessel will present an unacceptable ground or flight safety risk. The emphasis of the process will be on determining the possibility of significant structural failures. Determining minor failure modes that could result only in possible science degradations are not within the purview of this process.

If the certifying mechanical engineer determines that the payload pressure vessel(s) does not present unacceptable safety risks, the engineer will draft and forward to the Operations Department Head a memorandum of certification stating approval for flight operations. The memorandum will be made a permanent part of the flight record retained by CSBF

PAYLOAD SAFETY PROCESS

GENERAL

This section outlines the Columbia Scientific Balloon Facility's (CSBF) process of certifying and documenting that a balloon payload complies with applicable safety requirements during integration and launch. It addresses the tasks, responsibilities, submittals, safety reviews/meetings, and schedules associated with the process. The philosophy of the CSBF payload safety process is that the CSBF scientific user is responsible for insuring that the payload complies with CSBF policy. CSBF is responsible for checking, monitoring, and documenting compliance.

From a safety standpoint, payloads flown by NASA's Balloon Program pose reduced risks in comparison to other NASA Expendable Launch Vehicles. Hazards associated with balloon payloads fall into a somewhat limited and generic set of safety considerations. Standard safety hazards in ballooning can be categorized as follows.

- Radioactive Sources
- Lasers
- Chemical Hazards
- Pressure Vessels
- High Voltage

Contained Pyrotechnics

Safety compliance requirements for the above hazards are addressed in the NASA Balloon Program Ground Safety Plan. Identified safety hazards that fall outside these areas are handled through separate safety plans and reviews. The following sections describe the process. Table 1 is an abbreviated depiction of the CSBF Payload Safety Process.

Table 1 Payload safety process

TASK	SAFETY TASK DESCRIPTION	RESPONSIBILITY	REFERENCE PARAGRAPH	SCHEDULE
Initiate Project and Document Safety Assessment				
1	Identify safety hazards falling within *CSBF Ground Safety Plan*	CSBF Operations Manager	2.1	3-9 Months before payload ships to launch site
2	Identify safety hazards falling outside of standard *CSBF Ground Safety Plan*	CSBF Operations Manager	2.2	3-9 Months before payload ships to launch site
3	User prepared special safety plan for hazards not covered in *CSBF Ground Safety Plan*	Principle Investigator	2.3.1	1 Month before payload ships to launch site
Conduct Safety Reviews				
1	Review standard and special payload safety issues and plans	CSBF Site Manager/Operations Manager	3.1	Beginning three months before payload ships to launch site
2	Resolve open safety concerns, action items and discrepancies	CSBF Operations Manager	3.2	As assigned
Finalize and Approve Safety Assessments and Plans				
1	Prepare final Balloon System Prelaunch Safety Package	CSBF Operations Manager / Campaign Manager	4.1	Immediately following arrival at launch site
Periodic Compliance Checks				
1	Verify that procedures / plans are being followed.	CSBF Operations Manager / Campaign Manager	5.1	Periodic from payload arrival at launch site through launch
Prelaunch Review				
1	Review applicable routine and special safety issues and plans with flight line personnel	CSBF Flight Director	6.1	< 72 hours before launch
2	Recovery Plan	CSBF Flight Director	6.2	< 72 hours before launch

INITIATE PROJECT AND DOCUMENT SAFETY ASSESSMENT

CSBF GROUND SAFETY PLAN

HAZARDS FALLING WITHIN CSBF GROUND SAFETY PLAN

The CSBF Flight Application Form is sent out to prospective users in July of each year. The form includes a safety section covering hazards normally associated with balloon payloads. The CSBF Ground Safety Plan is available on the CSBF website so the prospective user can identify safety issues and determine whether the payload complies with CSBF policy.

HAZARDS FALLING OUTSIDE CSBF GROUND SAFETY PLAN

The Flight Application also contains questions about safety hazards not covered in the Ground Safety Plan whereby special cases are identified and flagged. The Flight Application requests that the user forward all home institution safety documentation to CSBF. Most balloon payloads originate at NASA centers or universities. Users are usually required to undergo rigorous safety processes at their home institutions while building up their instrumentation. This documentation is used by CSBF as a further check of compliance with safety requirements.

USER VERIFICATION OF COMPLIANCE WITH CSBF GROUND SAFETY PLAN

The principle investigator is required to submit signed documentation indicating that the payload complies with CSBF safety standards delineated in the CSBF Ground Safety Plan. This form is sent to CSBF prior to shipment of the payload to the launch site.

USER-PREPARED SPECIAL SAFETY PLANS

When the user identifies a safety issue falling outside those covered in the CSBF Ground Safety Plan (i.e. superconducting magnet, toxic gas, etc), a separate safety plan must be prepared by the user and submitted to CSBF for review. The CSBF Safety Officer is responsible for review of these plans for compliance with established industry safety standards.

CONDUCT SAFETY REVIEWS

Program Review Meetings are held monthly at CSBF to discuss support of upcoming campaigns and operations. Flight Applications and project files are reviewed in some detail. Safety related status, concerns, and issues are discussed. Action items on safety compliance are documented and tracked.

Response and close of safety related action items for each upcoming operation are discussed at the monthly Program Review Meetings. Closing of action items are the responsibility of the Operations Manager or the assigned Campaign Manager. Emphasis is placed on insuring that applicable safety documentation is at CSBF prior to shipping the instrumentation to the launch site.

FINALIZE AND APPROVE SAFETY ASSESSMENT PLANS

Immediately following the scientist’s arrival at the launch site, a Flight Requirements Meeting is held. The Flight Application Form is reviewed for compliance with standard and special safety issues prior to beginning of payload integration. The signed Payload Safety Compliance form, special safety plans for non-standard hazards, and user institution safety documentation is reviewed, discussed, and assembled into the Balloon System Prelaunch Safety Package (BSPSP). Unresolved issues, if any, are referred to the CSBF Safety Officer. The completed BSPSP package serves as a formal approval of the project from a safety standpoint.

PERIODIC COMPLIANCE CHECKS

The CSBF Operations Manager or Campaign Manager is responsible for periodic inspection of integration areas for compliance with routine and special safety procedures and plans. These inspections will typically take place on at least a bi-weekly basis.

PRELAUNCH REVIEW

FLIGHT READINESS REVIEW

Flight Readiness Review meetings are held once the science payload is flight ready and no sooner than 72 hours prior to a scheduled launch. Standard flight line payload safety procedures and special safety plans, if any, are reviewed with appropriate personnel. Checklists are used to insure safety compliance. These meetings are rescheduled every 72 hours should a launch delay occur.

RECOVERY PLAN

A completed form indicating step-by-step instructions for safe payload handling during recovery operations is submitted by the principle investigator at the Flight Readiness Review meeting. This form is reviewed and approved by the Flight Director.

Should extraordinary safety measures be necessary during recovery, a formal plan is written, reviewed, and discussed with recovery personnel.

DOCUMENTATION

Table 2 lists documentation generated during the Payload Safety Process, who is responsible for generating it, and required signatures on the accompanying documentation. At the conclusion of each flight, all payload safety documentation will be archived in the flight folder.

Table 2 Payload safety process documentation

DOCUMENT	RESPONSIBLE PARTY	REQUIRED SIGNATURES
Flight Application	Principal Investigator	Principal Investigator
Special safety plans	Principal Investigator	Principal Investigator
User institution safety documentation	Principal Investigator	User Institutional Safety Office Representative
Verification of Safety Compliance form	Principal Investigator	Principal Investigator / CSBF Operations Manager
Program review meeting action item and closure	CSBF Operations Manager	CSBF Operations Manager
Balloon System Prelaunch Safety Package	CSBF Campaign Manager	CSBF Campaign Manager
Preflight Readiness meeting checklist	CSBF Flight Director	CSBF Flight Director
CSBF Recovery form	Principal Investigator	Principal Investigator / CSBF Operations Manager

ADDITIONAL DOCUMENTATION

For additional information, please refer to any of the following documents available on the CSBF Web site at http://www.csbf.nasa.gov/docs.html.

- *Balloon Flight Application Procedures User Handbook* (OF-600-10-H)
- *Cargo Door Dimensions for Antarctica Recovery Aircraft*
- *Ground Safety Plan* (OF-610-00-P)
- *Hold Harmless Form* (OF-601-00-F)
- *Waiver of Claims Form* (OF-602-00-F)

LDB FLIGHTS

Location: http://www.csbf.nasa.gov/ldbdocs.html

- *LDB Balloon Flight Support Application* (OF-300-11-F)
- *LDB Science Enclosures*

CONVENTIONAL FLIGHTS

Location: http://www.csbf.nasa.gov/convdocs.html

- *Conventional Balloon Flight Support Application* (OF-300-10-F)
- *CIP Interface User Handbook* (EC-200-90-H)
- *CIP Dimensions* (EC-150-20-02-DM)
- *G62 Batteries* (EC-500-20-D)

CONTACTS

SERVICES

Table 3 lists CSBF and the Balloon Program office contacts for services.

Table 3 Contact list for CSBF and Balloon Program Office

SERVICE	CONTACT	
	CSBF	BPO
COST ESTIMATES, FUND TRANSFERS		DAVID D. GREGORY
FIRST-TIME CONVENTIONAL AND LDB FLIGHT NOTIFICATION	DWAYNE ORR	DAVID D. GREGORY*
FLIGHT SUPPORT APPLICATIONS – CONVENTIONAL	MONA BREEDING, DWAYNE ORR	
FLIGHT SUPPORT APPLICATIONS – LDB	MONA BREEDING, BRYAN STILWELL	
FLIGHT SUPPORT DOCUMENTATION	MONA BREEDING	
GASES, CRYOGENS	CSBF CRYOGEN (PURCHASING)	
GONDOLA DESIGN CERTIFICATION	HUGO FRANCO	
NEW GONDOLA DESIGN NOTIFICATION	HUGO FRANCO	DAVID D. GREGORY*
NON-NASA SPONSORED FUNDING		DAVID D. GREGORY
POST-FLIGHT ASSESSMENTS AND FORMS	MONA BREEDING	
PRESSURE VESSEL CERTIFICATION	HUGO FRANCO	
RADIOACTIVE MATERIAL DOCUMENTATION REQUIREMENTS	ERICH KLEIN	
RADIOACTIVE MATERIALS	ERICH KLEIN	
REQUIREMENTS OR SCHEDULES	DWAYNE ORR	
USER-PURCHASED BALLOONS	JIM ROTTER	
USER SERVICES, QUESTIONS	DWAYNE ORR	
WAIVER OF CLAIMS / HOLD HARMLESS FORMS	MONA BREEDING	

* *Contact in addition to CSBF*

ADDRESSES

Table 4 lists contact information for CSBF and the Balloon Program office.

Table 4 Address list for CSBF and Balloon Program Office

ADDRESS	NAME	PHONE	FAX	E-MAIL
COLUMBIA SCIENTIFIC BALLOON FACILITY 1510 EAST FM ROAD 3224 PALESTINE, TEXAS 75803 P.O. BOX 319 PALESTINE, TEXAS 75802-0319	MONA BREEDING	903-723-8086	903-723-8056	mona.breeding@csbf.nasa.gov
	CRYOGEN PURCHASING		866-441-7849, 903-723-8054	cryogens@csbf.nasa.gov
	HUGO FRANCO	903-723-8091	903-723-8056	hugo.franco@csbf.nasa.gov
	ERICH KLEIN	903-723-8052	903-723-8056	erich.klein@csbf.nasa.gov
	JIM ROTTER	903-723-8030	903-723-8056	jim.rotter@csbf.nasa.gov
	DWAYNE ORR	903-723-8063	903-723-8056	dwayne.orr@csbf.nasa.gov
	BRYAN STILWELL	903-723-8097	903-731-8510	bryan.stilwell@csbf.nasa.gov
NASA/GODDARD SPACE FLIGHT CENTER WALLOPS FLIGHT FACILITY BALLOON PROGRAM OFFICE WALLOPS ISLAND, VIRGINIA 23337	DAVID D. GREGORY	757-824-1453	757-824-2149	david.d.gregory@nasa.gov

APPENDIX A – AIRCRAFT CABLE

Table 5 Construction and physical properties of Type I, carbon steel and corrosion-resistant steel wire

NOMINAL DIAMETER OF WIRE ROPE (IN)	TOLERANCE ON DIAMETER (PLUS ONLY)	ALLOWABLE INCREASE OF DIAMETER AT CUT END	CONSTRUCTION	MINIMUM BREAKING STRENGTH OF COMPOSITION A* (LB)	MINIMUM BREAKING STRENGTH OF COMPOSITION B** (LB)	APPROXIMATE WEIGHT PER 100 FEET (LB)
1/32	.006	.006	3 x 7	110	110	0.16
3/64	.008	.008	7 x 7	270	270	0.42
1/16	.010	.009	7 x 7	480	480	0.75
1/16	.010	.009	7 x 19	480	480	0.75
1/32	.012	.010	7 x 7	920	920	1.60
3/32	.012	.010	7 x 19	1,000	920	1.74
1/8	.014	.011	7 x 19	2,000	1,760	2.90
5/32	.016	.017	7 x 19	2,800	2,400	4.50
3/16	.018	.019	7 x 19	4,200	3,700	6.50
7/32	.018	.020	7 x 19	5,600	5,000	8.60
1/4	.018	.021	7 x 19	7,000	6,400	11.00
9/32	.020	.023	7 x 19	8,000	7,800	13.90
5/16	.022	.024	7 x 19	9,000	9,000	17.30
3/8	.026	.027	7 x 19	14,400	12,000	24.30

* Carbon steel
** Stainless steel

From MIL-W-83420C Spec Wire Rope

APPENDIX B – NICOPRESS® SLEEVES

For more than 30 years Nicopress® sleeves have been used with aircraft control cable, wire rope, and fiber rope. Nicopress® oval sleeves are used to eye-splice, and Nicopress® stop sleeves are used to terminate cable and rope.

Many types of Nicopress® tools are available for convenient and proper compression of sleeves both in the field and in the shop. They include:

- Bench tools
- Hand tools
- Manual hydraulic tools
- Power hydraulic tools

Packaged with each tool are detailed instruction sheets showing proper tool operation and adjustment along with gauges for checking sleeve compression. Nicopress® will furnish the necessary die groove dimensions required to fabricate special dies for customers wishing to use their own power press equipment.

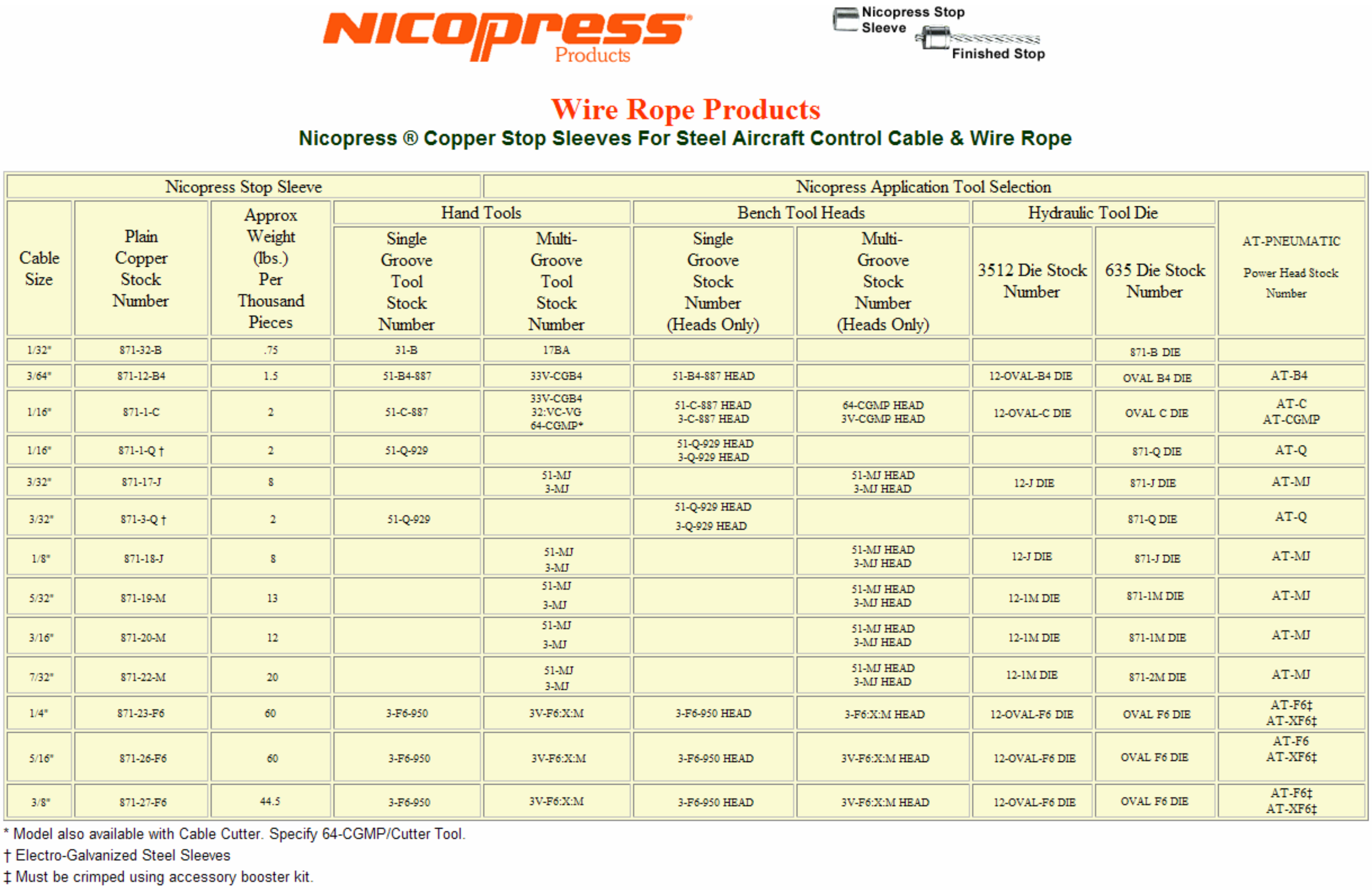
Pull tests have shown that copper and plated copper Nicopress® oval sleeves will hold military specification-grade aircraft control cable in tension until it breaks when the cable is made to military specifications.

Table 6 Mil specs for Nicopress® oval sleeves

SPECIFICATION	DATE	CONSTRUCTION
MIL-W-83420	9/7/73	3 x 7 7 x 7 7 x 19
MIL-W-1511A-4	2/20/64	6 x 19 IWRC
MIL-W-5424B	1/10/72	6 x 19 IWRC

Other types and grades of cable exist and may be used with Nicopress® sleeves. To establish the exact holding power of a Nicopress® sleeve when used with other types of cable, pull testing prior to use is recommended to ensure the proper selection of materials, the correct pressing procedure, and an adequate margin of safety for the intended use.

Nicopress® sleeves are available in other materials such as aluminum and stainless steel.



Wire Rope Products

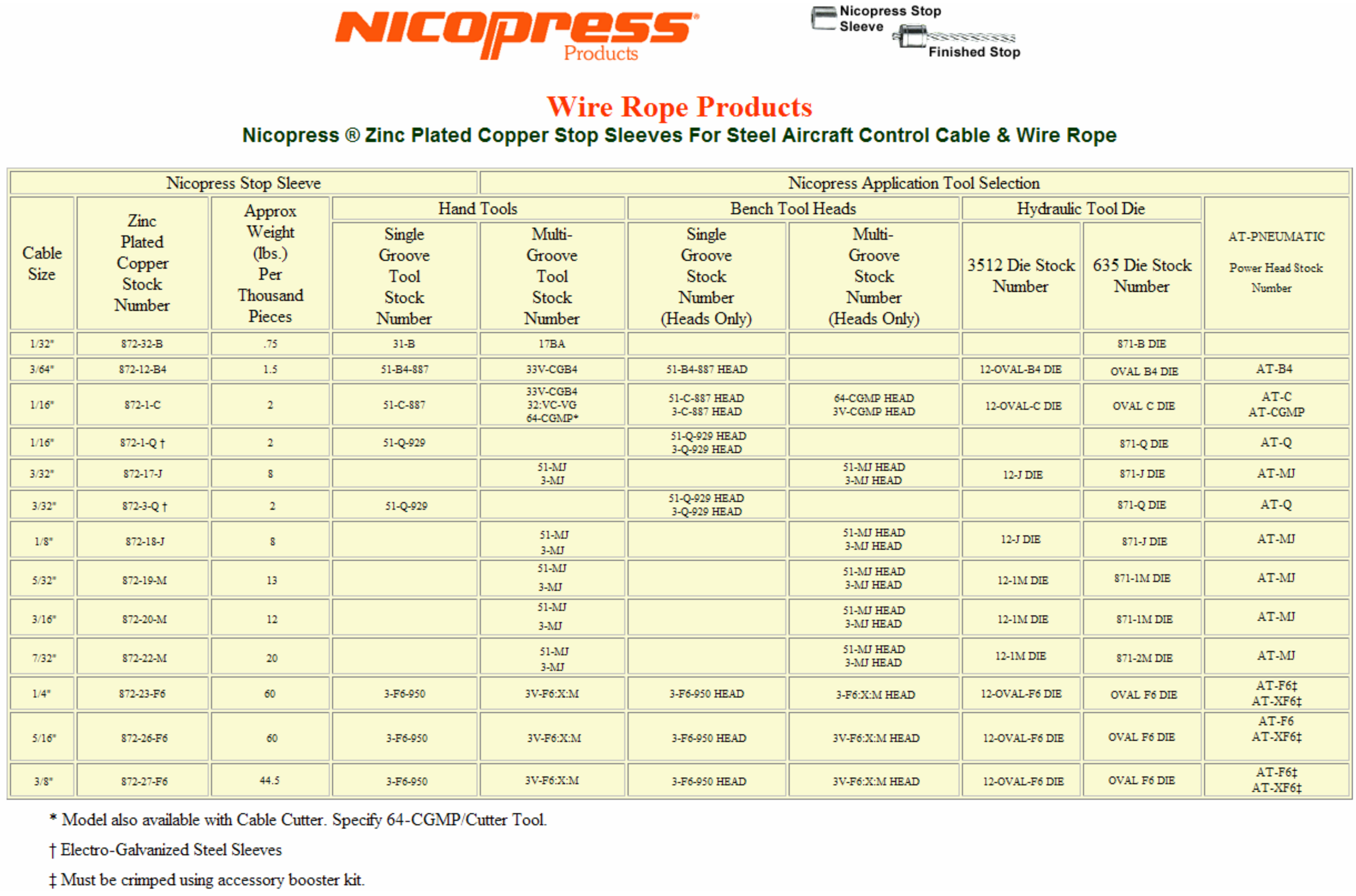
Nicopress ® Copper Stop Sleeves For Steel Aircraft Control Cable & Wire Rope

Nicopress Stop Sleeve			Nicopress Application Tool Selection						
			Hand Tools		Bench Tool Heads		Hydraulic Tool Die		
Cable Size	Plain Copper Stock Number	Approx Weight (lbs.) Per Thousand Pieces	Single Groove Tool Stock Number	Multi-Groove Tool Stock Number	Single Groove Stock Number (Heads Only)	Multi-Groove Stock Number (Heads Only)	3512 Die Stock Number	635 Die Stock Number	AT-PNEUMATIC Power Head Stock Number
1/32"	871-32-B	.75	31-B	17BA				871-B DIE	
3/64"	871-12-B4	1.5	51-B4-887	33V-CGB4	51-B4-887 HEAD		12-OVAL-B4 DIE	OVAL B4 DIE	AT-B4
1/16"	871-1-C	2	51-C-887	33V-CGB4 32:VC-VG 64-CGMP*	51-C-887 HEAD 3-C-887 HEAD	64-CGMP HEAD 3V-CGMP HEAD	12-OVAL-C DIE	OVAL C DIE	AT-C AT-CGMP
1/16"	871-1-Q †	2	51-Q-929		51-Q-929 HEAD 3-Q-929 HEAD			871-Q DIE	AT-Q
3/32"	871-17-J	8		51-MJ 3-MJ		51-MJ HEAD 3-MJ HEAD	12-J DIE	871-J DIE	AT-MJ
3/32"	871-3-Q †	2	51-Q-929		51-Q-929 HEAD 3-Q-929 HEAD			871-Q DIE	AT-Q
1/8"	871-18-J	8		51-MJ 3-MJ		51-MJ HEAD 3-MJ HEAD	12-J DIE	871-J DIE	AT-MJ
5/32"	871-19-M	13		51-MJ 3-MJ		51-MJ HEAD 3-MJ HEAD	12-1M DIE	871-1M DIE	AT-MJ
3/16"	871-20-M	12		51-MJ 3-MJ		51-MJ HEAD 3-MJ HEAD	12-1M DIE	871-1M DIE	AT-MJ
7/32"	871-22-M	20		51-MJ 3-MJ		51-MJ HEAD 3-MJ HEAD	12-1M DIE	871-2M DIE	AT-MJ
1/4"	871-23-F6	60	3-F6-950	3V-F6:X:M	3-F6-950 HEAD	3-F6:X:M HEAD	12-OVAL-F6 DIE	OVAL F6 DIE	AT-F6‡ AT-XF6‡
5/16"	871-26-F6	60	3-F6-950	3V-F6:X:M	3-F6-950 HEAD	3V-F6:X:M HEAD	12-OVAL-F6 DIE	OVAL F6 DIE	AT-F6 AT-XF6‡
3/8"	871-27-F6	44.5	3-F6-950	3V-F6:X:M	3-F6-950 HEAD	3V-F6:X:M HEAD	12-OVAL-F6 DIE	OVAL F6 DIE	AT-F6‡ AT-XF6‡

* Model also available with Cable Cutter. Specify 64-CGMP/Cutter Tool.

† Electro-Galvanized Steel Sleeves

‡ Must be crimped using accessory booster kit.



Wire Rope Products

Nicopress ® Zinc Plated Copper Stop Sleeves For Steel Aircraft Control Cable & Wire Rope

Nicopress Stop Sleeve			Nicopress Application Tool Selection						
Cable Size	Zinc Plated Copper Stock Number	Approx Weight (lbs.) Per Thousand Pieces	Hand Tools		Bench Tool Heads		Hydraulic Tool Die		AT-PNEUMATIC Power Head Stock Number
			Single Groove Tool Stock Number	Multi-Groove Tool Stock Number	Single Groove Stock Number (Heads Only)	Multi-Groove Stock Number (Heads Only)	3512 Die Stock Number	635 Die Stock Number	
1/32"	872-32-B	.75	31-B	17BA				871-B DIE	
3/64"	872-12-B4	1.5	51-B4-887	33V-CGB4	51-B4-887 HEAD		12-OVAL-B4 DIE	OVAL B4 DIE	AT-B4
1/16"	872-1-C	2	51-C-887	33V-CGB4 32:VC-VG 64-CGMP*	51-C-887 HEAD 3-C-887 HEAD	64-CGMP HEAD 3V-CGMP HEAD	12-OVAL-C DIE	OVAL C DIE	AT-C AT-CGMP
1/16"	872-1-Q †	2	51-Q-929		51-Q-929 HEAD 3-Q-929 HEAD			871-Q DIE	AT-Q
3/32"	872-17-J	8		51-MJ 3-MJ		51-MJ HEAD 3-MJ HEAD	12-J DIE	871-J DIE	AT-MJ
3/32"	872-3-Q †	2	51-Q-929		51-Q-929 HEAD 3-Q-929 HEAD			871-Q DIE	AT-Q
1/8"	872-18-J	8		51-MJ 3-MJ		51-MJ HEAD 3-MJ HEAD	12-J DIE	871-J DIE	AT-MJ
5/32"	872-19-M	13		51-MJ 3-MJ		51-MJ HEAD 3-MJ HEAD	12-1M DIE	871-1M DIE	AT-MJ
3/16"	872-20-M	12		51-MJ 3-MJ		51-MJ HEAD 3-MJ HEAD	12-1M DIE	871-1M DIE	AT-MJ
7/32"	872-22-M	20		51-MJ 3-MJ		51-MJ HEAD 3-MJ HEAD	12-1M DIE	871-2M DIE	AT-MJ
1/4"	872-23-F6	60	3-F6-950	3V-F6:X:M	3-F6-950 HEAD	3-F6:X:M HEAD	12-OVAL-F6 DIE	OVAL F6 DIE	AT-F6‡ AT-XF6‡
5/16"	872-26-F6	60	3-F6-950	3V-F6:X:M	3-F6-950 HEAD	3V-F6:X:M HEAD	12-OVAL-F6 DIE	OVAL F6 DIE	AT-F6 AT-XF6‡
3/8"	872-27-F6	44.5	3-F6-950	3V-F6:X:M	3-F6-950 HEAD	3V-F6:X:M HEAD	12-OVAL-F6 DIE	OVAL F6 DIE	AT-F6‡ AT-XF6‡

* Model also available with Cable Cutter. Specify 64-CGMP/Cutter Tool.

† Electro-Galvanized Steel Sleeves

‡ Must be crimped using accessory booster kit.

APPENDIX C - BOLTS

Table 7 Steel aircraft bolts – strength requirements

SIZE	ULTIMATE TENSILE STRENGTH (LB)[1]		DOUBLE SHEER STRENGTH (LB)[2]
	Eyebolts	Fine Thread[3] Hexagon Head	All Bolts
No. 6	–	–	2,120
No. 8	–	–	3,000
No. 1	1,150	2,210	4,250
1/4	2,450	4,080	7,360
5/16	3,910 (AN44)	6,500	11,500
5/16[4]	5,290 (AN45)	6,500	11,500
3/8	7,015	10,100	16,560
7/16	9,200	13,600	22,500
1/2	14,375	18,500	29,400
9/16	10,125	23,600	37,400
5/8	–	30,100	46,000
3/4	–	44,000	66,300
7/8	–	60,000	90,100
1	–	80,700	117,800
1-1/8	–	101,800	147,500
1/14	–	130,200	182,100

---

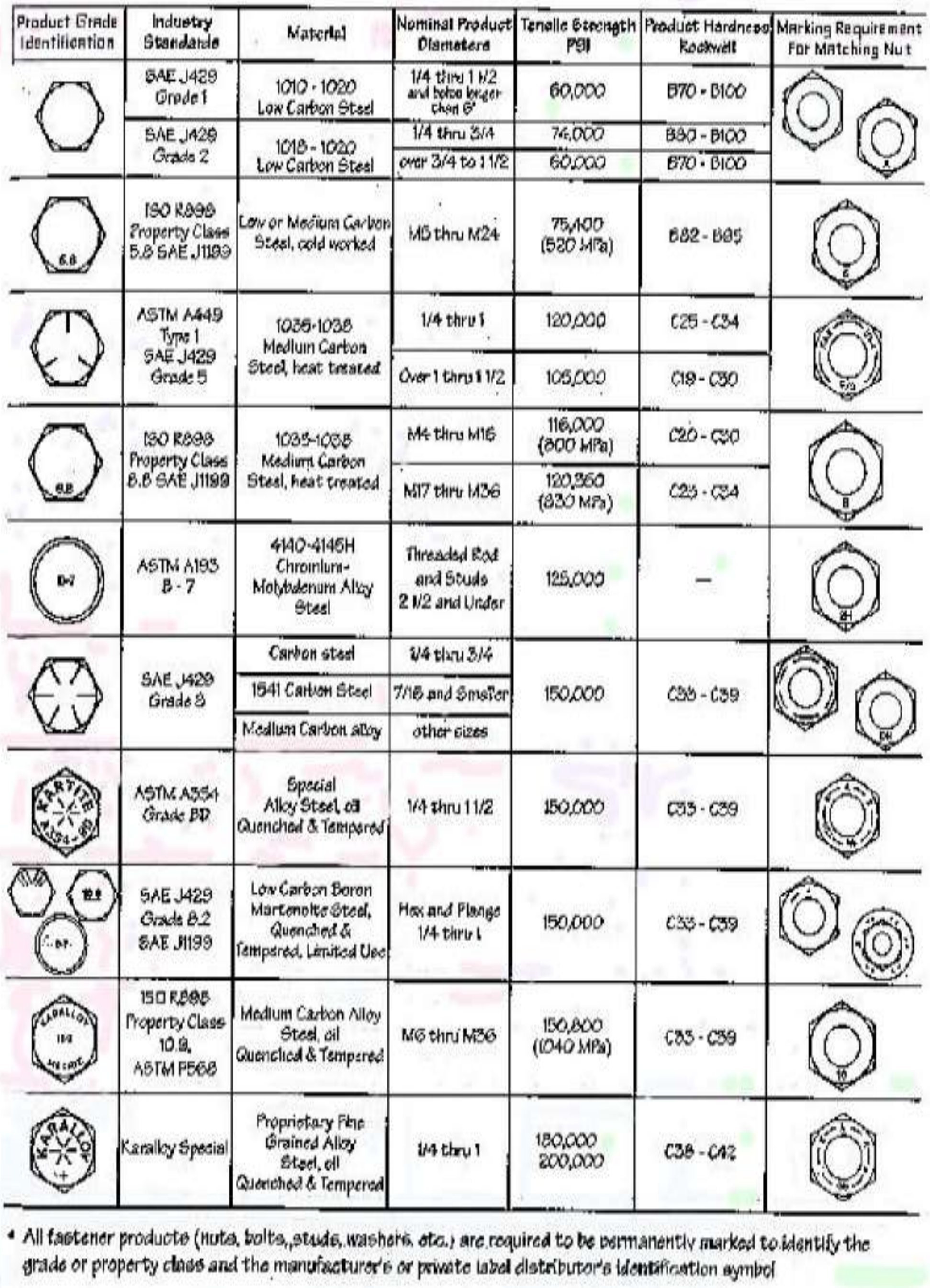
[1] The values shown for the ultimate tensile strength are for minimum values and are based on 125,000 psi for non-corrosion-resistant and corrosion-resistant steel. The strength values shown for the eyebolts are based on the strength of the eye. The root area of the thread is the basis of calculation for the tensile strength of hexagon head bolts. Clevis bolts shall have tensile strengths equal to one-half of the requirements for hexagon-head bolts when used with AN320 or MS21083 nuts. Clevis bolts are intended primarily for use in shear applications.

[2] Ultimate shear strengths are computed on the basis of 60 percent of the ultimate tensile strengths.

[3] Class of thread is as specified on the applicable standard drawing.

[4] Different from size 5/16 above in the design of the eye section.

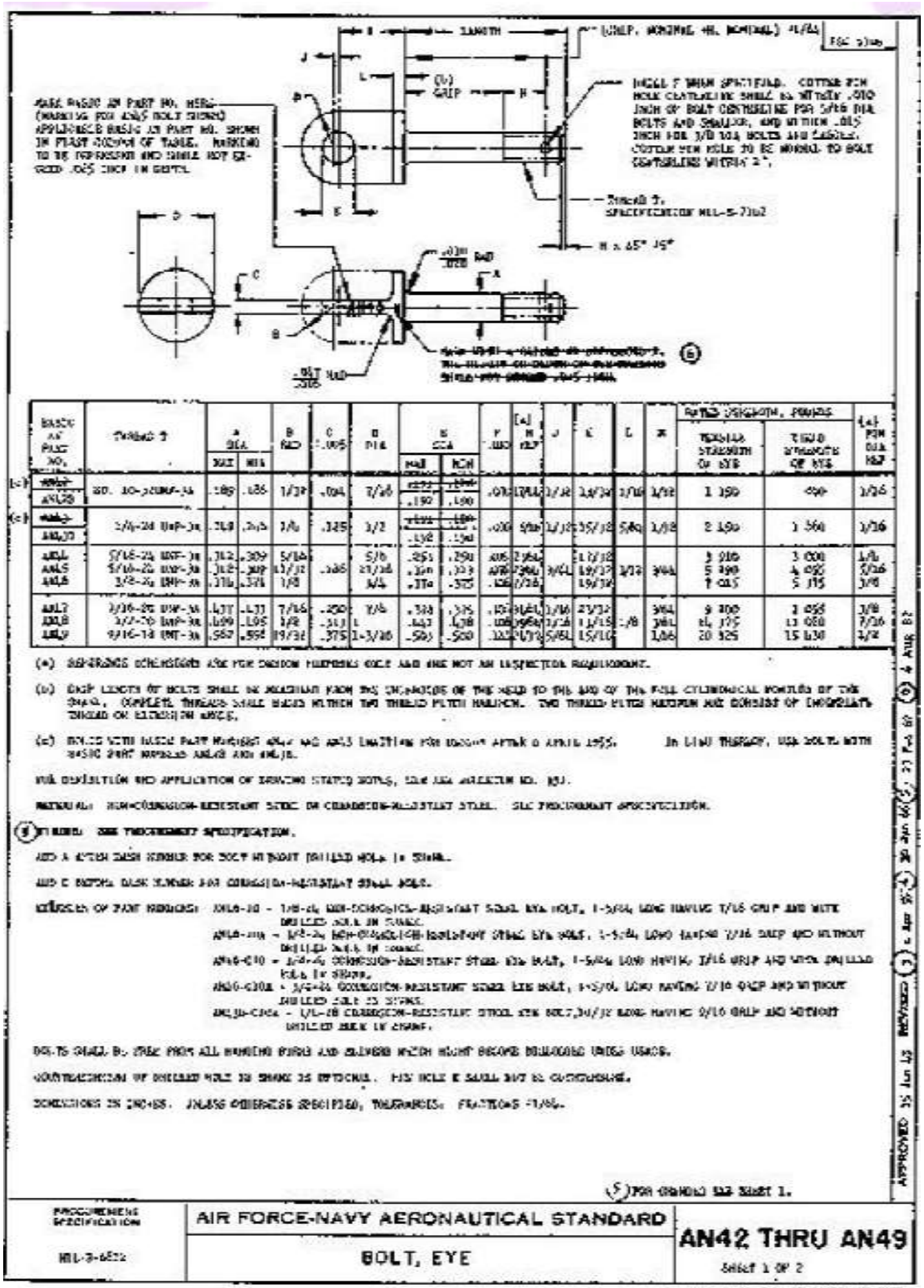
Table 8 Standard guide for fastener selection and product marking requirements



Product Grade Identification	Industry Standards	Material	Nominal Product Diameters	Tensile Strength PSI	Product Hardness Rockwell	Marking Requirement For Matching Nut
	SAE J429 Grade 1	1010 - 1020 Low Carbon Steel	1/4 thru 1 1/2 and bolts longer than 6"	60,000	B70 - B100	
	SAE J429 Grade 2	1018 - 1020 Low Carbon Steel	1/4 thru 3/4	74,000	B80 - B100	
			over 3/4 to 1 1/2	60,000	B70 - B100	
	ISO R898 Property Class 5.8 SAE J1199	Low or Medium Carbon Steel, cold worked	M5 thru M24	75,400 (520 MPa)	B82 - B95	
	ASTM A449 Type 1 SAE J429 Grade 5	1035-1038 Medium Carbon Steel, heat treated	1/4 thru 1	120,000	C25 - C34	
			Over 1 thru 1 1/2	105,000	C19 - C30	
	ISO R898 Property Class 8.8 SAE J1199	1035-1038 Medium Carbon Steel, heat treated	M4 thru M16	116,000 (800 MPa)	C20 - C30	
			M17 thru M36	120,350 (830 MPa)	C23 - C34	
	ASTM A193 B - 7	4140-4145H Chromium-Molybdenum Alloy Steel	Threaded Rod and Studs 2 1/2 and Under	125,000	–	
	SAE J429 Grade 8	Carbon steel	1/4 thru 3/4	150,000	C33 - C39	
		1541 Carbon Steel	7/16 and Smaller			
		Medium Carbon alloy	other sizes			
	ASTM A354 Grade BD	Special Alloy Steel, oil Quenched & Tempered	1/4 thru 1 1/2	150,000	C33 - C39	
	SAE J429 Grade 8.2 SAE J1199	Low Carbon Boron Martensite Steel, Quenched & Tempered, Limited Use	Hex and Flange 1/4 thru 1	150,000	C33 - C39	
	ISO R898 Property Class 10.9, ASTM F568	Medium Carbon Alloy Steel, oil Quenched & Tempered	M6 thru M36	150,800 (1040 MPa)	C33 - C39	
	Karalloy Special	Proprietary Fine Grained Alloy Steel, oil Quenched & Tempered	1/4 thru 1	180,000 200,000	C38 - C42	

- All fastener products (nuts, bolts, studs, washers, etc.) are required to be permanently marked to identify the grade or property class and the manufacturer's or private label distributor's identification symbol

Table 9 Air Force-Navy Aeronautical Standard for bolt, eye (1)



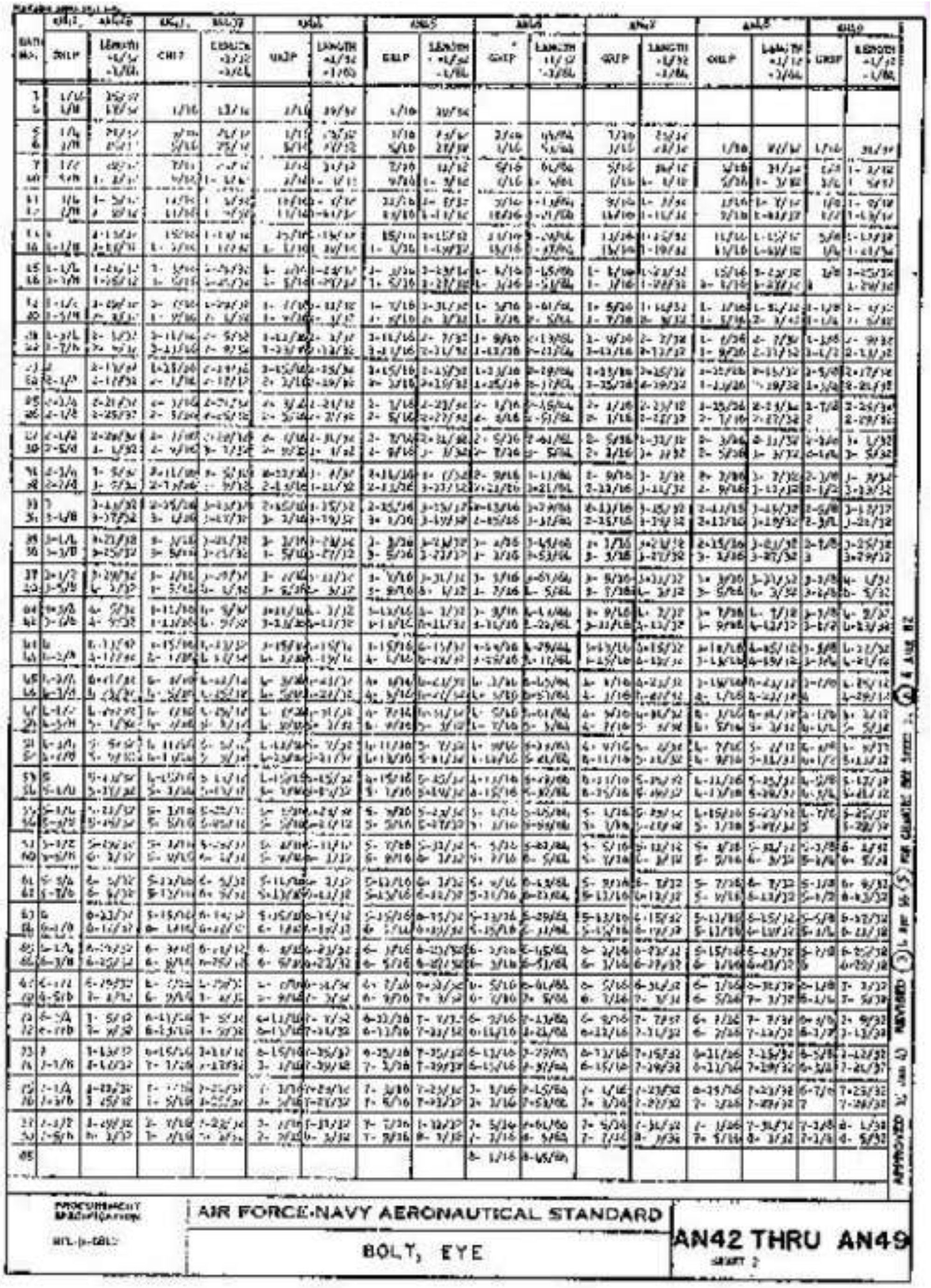
AIR FORCE-NAVY AERONAUTICAL STANDARD

BOLT, EYE

AN42 THRU AN49

SHEET 1 OF 2

Table 10 Air Force-Navy Aeronautical Standard for bolt, eye (2)



PROCUREMENT SPECIFICATION

AIR FORCE-NAVY AERONAUTICAL STANDARD

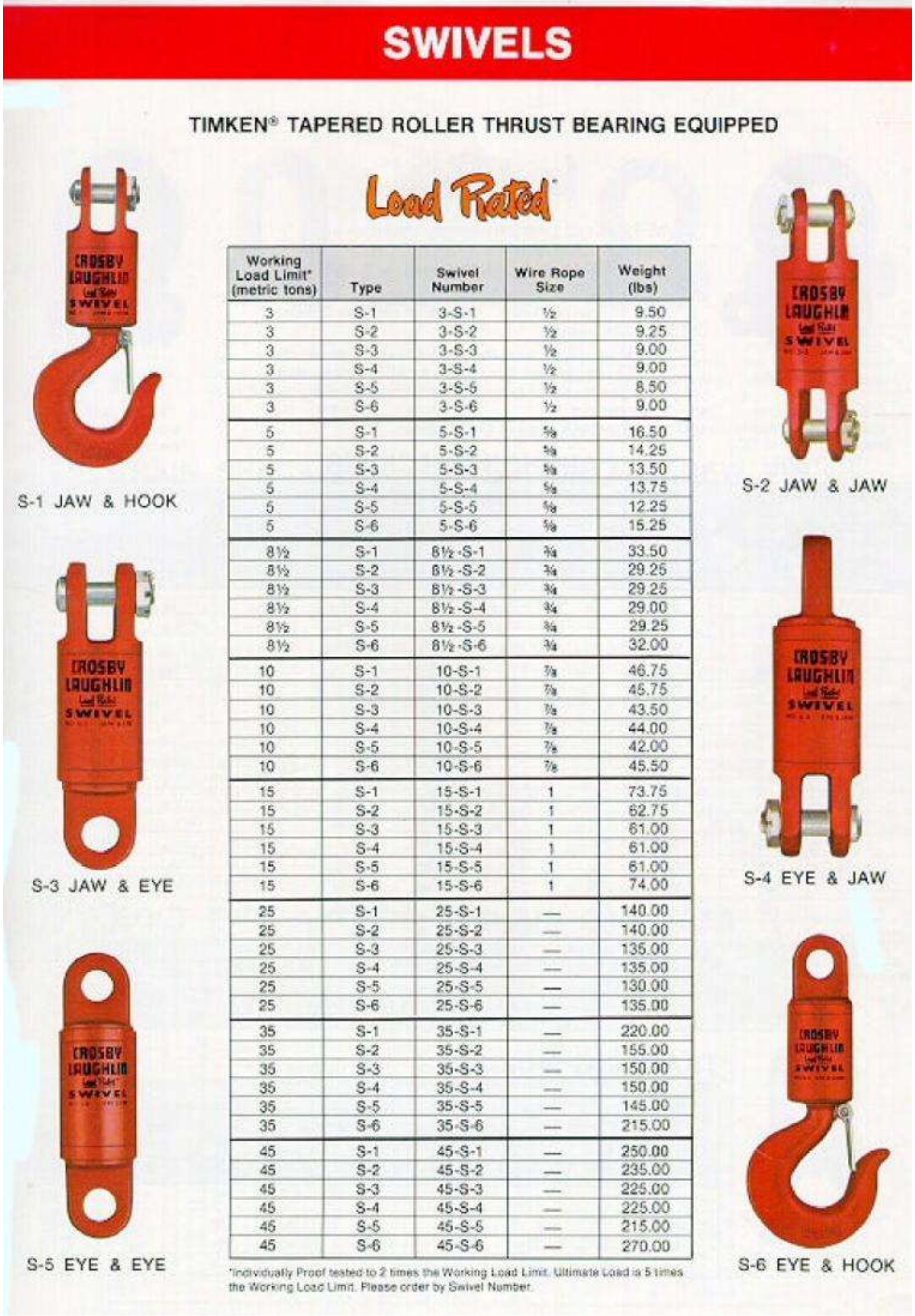
BOLT, EYE

AN42 THRU AN49

SHEET 2

APPENDIX D - SWIVELS

Table 11 Swivels



SWIVELS

TIMKEN® TAPERED ROLLER THRUST BEARING EQUIPPED

Load Rated®

Working Load Limit* (metric tons)	Type	Swivel Number	Wire Rope Size	Weight (lbs)
3	S-1	3-S-1	½	9.50
3	S-2	3-S-2	½	9.25
3	S-3	3-S-3	½	9.00
3	S-4	3-S-4	½	9.00
3	S-5	3-S-5	½	8.50
3	S-6	3-S-6	½	9.00
5	S-1	5-S-1	⅝	16.50
5	S-2	5-S-2	⅝	14.25
5	S-3	5-S-3	⅝	13.50
5	S-4	5-S-4	⅝	13.75
5	S-5	5-S-5	⅝	12.25
5	S-6	5-S-6	⅝	15.25
8½	S-1	8½-S-1	¾	33.50
8½	S-2	8½-S-2	¾	29.25
8½	S-3	8½-S-3	¾	29.25
8½	S-4	8½-S-4	¾	29.00
8½	S-5	8½-S-5	¾	29.25
8½	S-6	8½-S-6	¾	32.00
10	S-1	10-S-1	⅞	46.75
10	S-2	10-S-2	⅞	45.75
10	S-3	10-S-3	⅞	43.50
10	S-4	10-S-4	⅞	44.00
10	S-5	10-S-5	⅞	42.00
10	S-6	10-S-6	⅞	45.50
15	S-1	15-S-1	1	73.75
15	S-2	15-S-2	1	62.75
15	S-3	15-S-3	1	61.00
15	S-4	15-S-4	1	61.00
15	S-5	15-S-5	1	61.00
15	S-6	15-S-6	1	74.00
25	S-1	25-S-1	—	140.00
25	S-2	25-S-2	—	140.00
25	S-3	25-S-3	—	135.00
25	S-4	25-S-4	—	135.00
25	S-5	25-S-5	—	130.00
25	S-6	25-S-6	—	135.00
35	S-1	35-S-1	—	220.00
35	S-2	35-S-2	—	155.00
35	S-3	35-S-3	—	150.00
35	S-4	35-S-4	—	150.00
35	S-5	35-S-5	—	145.00
35	S-6	35-S-6	—	215.00
45	S-1	45-S-1	—	250.00
45	S-2	45-S-2	—	235.00
45	S-3	45-S-3	—	225.00
45	S-4	45-S-4	—	225.00
45	S-5	45-S-5	—	215.00
45	S-6	45-S-6	—	270.00

*Individually Proof tested to 2 times the Working Load Limit. Ultimate Load is 5 times the Working Load Limit. Please order by Swivel Number.

S-1 JAW & HOOK

S-2 JAW & JAW

S-3 JAW & EYE

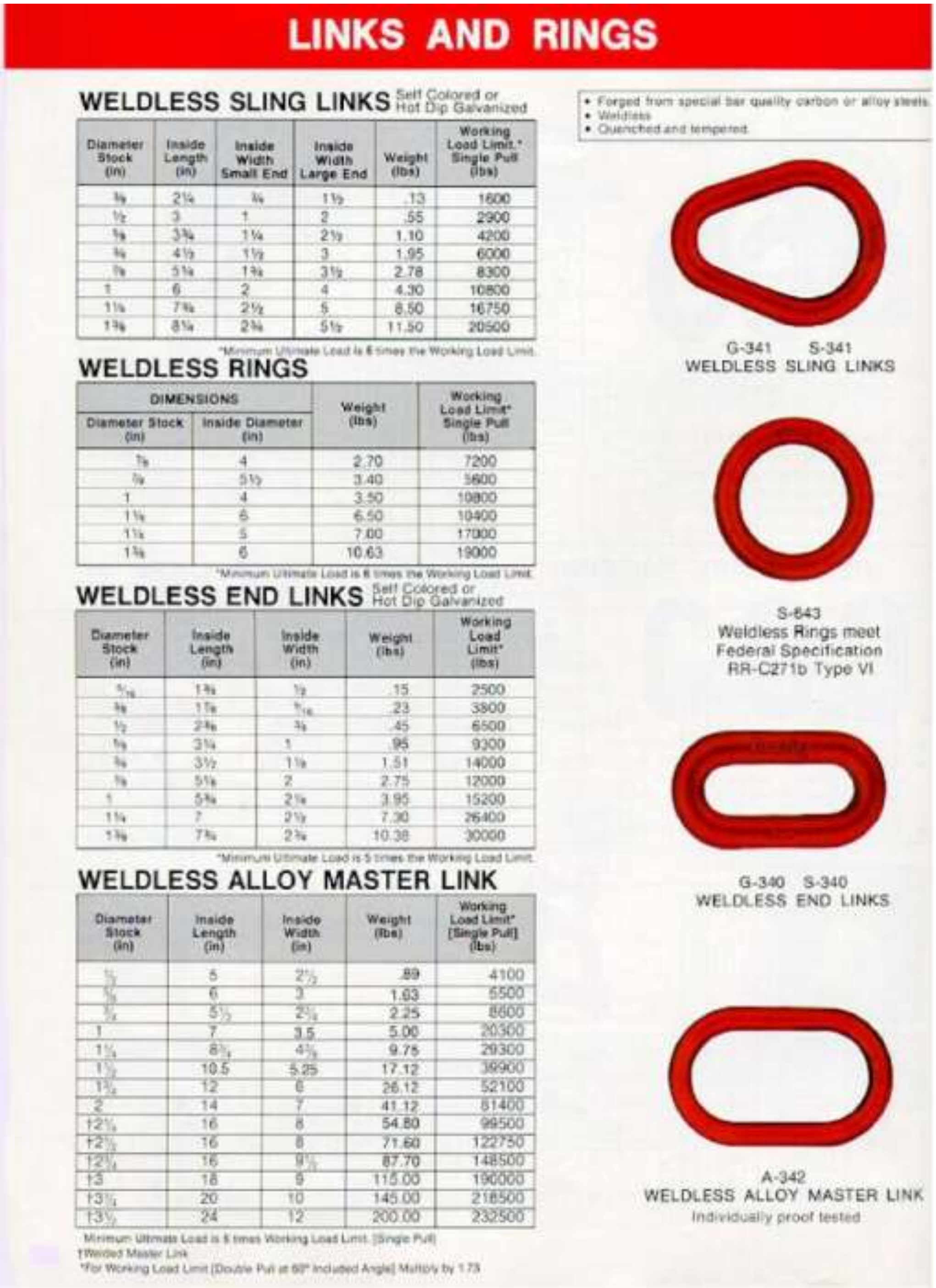
S-4 EYE & JAW

S-5 EYE & EYE

S-6 EYE & HOOK

APPENDIX E – LINKS, RINGS, AND SHACKLES

Table 12 Links and Rings



LINKS AND RINGS

WELDLESS SLING LINKS Self Colored or Hot Dip Galvanized

Diameter Stock (in)	Inside Length (in)	Inside Width Small End	Inside Width Large End	Weight (lbs)	Working Load Limit.* Single Pull (lbs)
3/8	2¼	¾	1½	.13	1600
½	3	1	2	.55	2900
5/8	3¾	1¼	2½	1.10	4200
¾	4½	1½	3	1.95	6000
7/8	5¼	1¾	3½	2.78	8300
1	6	2	4	4.30	10800
1¼	7½	2½	5	8.50	16750
1⅜	8¼	2¾	5½	11.50	20500

*Minimum Ultimate Load is 6 times the Working Load Limit.

WELDLESS RINGS

DIMENSIONS		Weight (lbs)	Working Load Limit* Single Pull (lbs)
Diameter Stock (in)	Inside Diameter (in)		
7/8	4	2.70	7200
7/8	5½	3.40	5600
1	4	3.50	10800
1⅛	6	6.50	10400
1¼	5	7.00	17000
1⅜	6	10.63	19000

*Minimum Ultimate Load is 6 times the Working Load Limit.

WELDLESS END LINKS Self Colored or Hot Dip Galvanized

Diameter Stock (in)	Inside Length (in)	Inside Width (in)	Weight (lbs)	Working Load Limit* (lbs)
5/16	1⅜	½	.15	2500
⅜	1⅞	9/16	.23	3800
½	2⅜	¾	.45	6500
⅝	3¼	1	.95	9300
¾	3½	1⅛	1.51	14000
⅞	5⅛	2	2.75	12000
1	5¾	2⅛	3.95	15200
1¼	7	2½	7.30	26400
1⅜	7¾	2¾	10.38	30000

*Minimum Ultimate Load is 5 times the Working Load Limit.

WELDLESS ALLOY MASTER LINK

Diameter Stock (in)	Inside Length (in)	Inside Width (in)	Weight (lbs)	Working Load Limit* [Single Pull] (lbs)
½	5	2½	.89	4100
⅝	6	3	1.63	5500
¾	5½	2¾	2.25	8600
1	7	3.5	5.00	20300
1¼	8¾	4⅜	9.75	29300
1½	10.5	5.25	17.12	39900
1¾	12	6	26.12	52100
2	14	7	41.12	81400
†2¼	16	8	54.80	99500
†2½	16	8	71.60	122750
†2¾	16	9½	87.70	148500
†3	18	9	115.00	190000
†3¼	20	10	145.00	218500
†3½	24	12	200.00	232500

Minimum Ultimate Load is 5 times Working Load Limit [Single Pull]
†Welded Master Link
*For Working Load Limit [Double Pull at 60° Included Angle] Multiply by 1.73

- Forged from special bar quality carbon or alloy steels.
- Weldless
- Quenched and tempered.

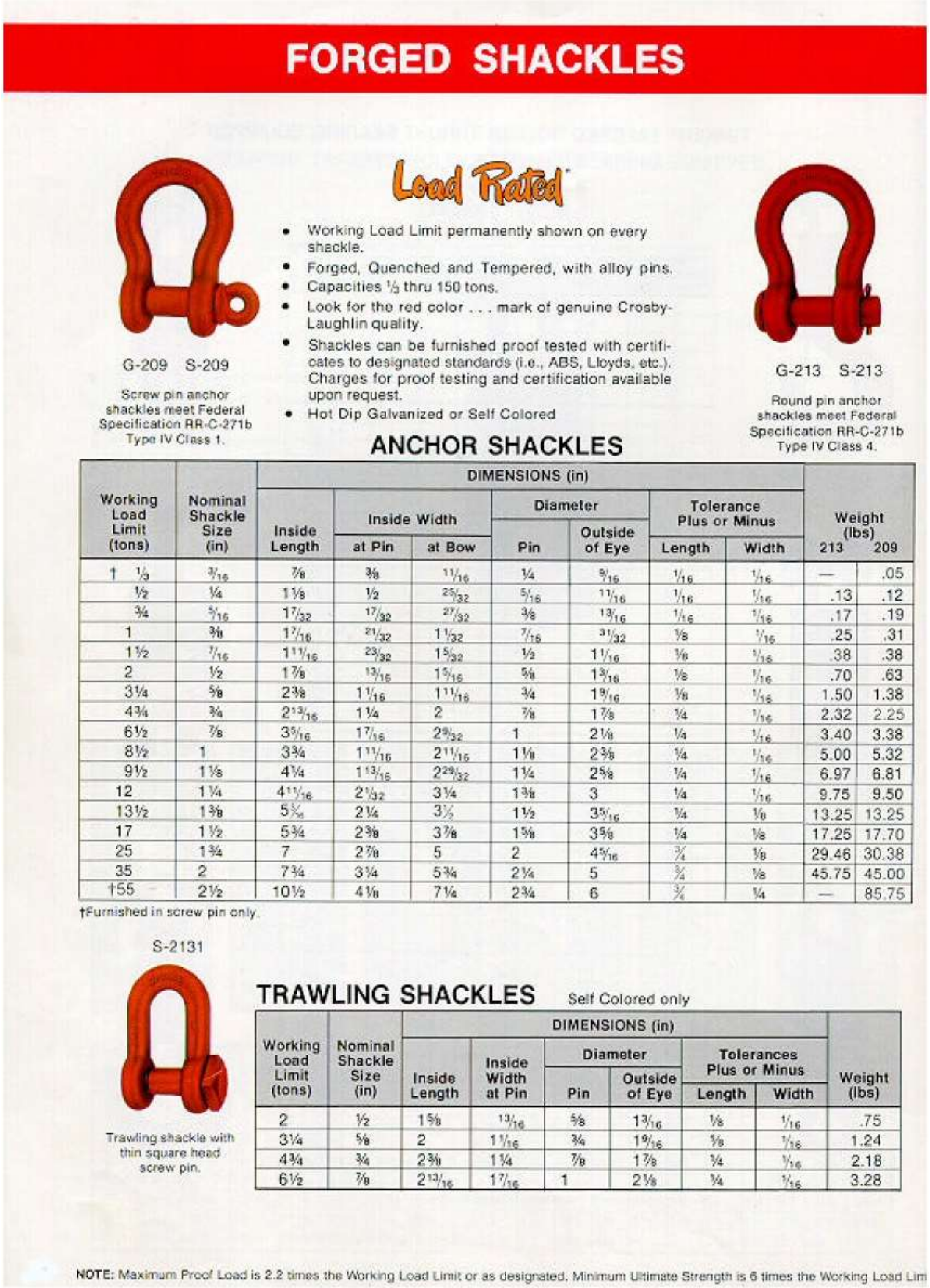
G-341 S-341
WELDLESS SLING LINKS

S-643
Weldless Rings meet Federal Specification RR-C271b Type VI

G-340 S-340
WELDLESS END LINKS

A-342
WELDLESS ALLOY MASTER LINK
Individually proof tested

Table 13 Forged shackles



FORGED SHACKLES

Load Rated

- Working Load Limit permanently shown on every shackle.
- Forged, Quenched and Tempered, with alloy pins.
- Capacities ⅓ thru 150 tons.
- Look for the red color . . . mark of genuine Crosby-Laughlin quality.
- Shackles can be furnished proof tested with certificates to designated standards (i.e., ABS, Lloyds, etc.). Charges for proof testing and certification available upon request.
- Hot Dip Galvanized or Self Colored

G-209 S-209

Screw pin anchor shackles meet Federal Specification RR-C-271b Type IV Class 1.

G-213 S-213

Round pin anchor shackles meet Federal Specification RR-C-271b Type IV Class 4.

ANCHOR SHACKLES

Working Load Limit (tons)	Nominal Shackle Size (in)	DIMENSIONS (in)							Weight (lbs)	
		Inside Length	Inside Width		Diameter		Tolerance Plus or Minus			
			at Pin	at Bow	Pin	Outside of Eye	Length	Width	213	209
† ⅓	3/16	⅞	⅜	11/16	¼	9/16	1/16	1/16	—	.05
½	¼	1⅛	½	25/32	5/16	11/16	1/16	1/16	.13	.12
¾	5/16	17/32	17/32	27/32	⅜	13/16	1/16	1/16	.17	.19
1	⅜	1 7/16	21/32	1 1/32	7/16	31/32	⅛	1/16	.25	.31
1½	7/16	1 11/16	23/32	1 5/32	½	1 1/16	⅛	1/16	.38	.38
2	½	1⅞	13/16	1 5/16	⅝	1 3/16	⅛	1/16	.70	.63
3¼	⅝	2⅜	1 1/16	1 11/16	¾	1 9/16	⅛	1/16	1.50	1.38
4¾	¾	2 13/16	1¼	2	⅞	1⅞	¼	1/16	2.32	2.25
6½	⅞	3 5/16	1 7/16	2 9/32	1	2⅛	¼	1/16	3.40	3.38
8½	1	3¾	1 11/16	2 11/16	1⅛	2⅜	¼	1/16	5.00	5.32
9½	1⅛	4¼	1 13/16	2 29/32	1¼	2⅝	¼	1/16	6.97	6.81
12	1¼	4 11/16	2 1/32	3¼	1⅜	3	¼	1/16	9.75	9.50
13½	1⅜	5¼	2¼	3½	1½	3 5/16	¼	⅛	13.25	13.25
17	1½	5¾	2⅜	3⅞	1⅝	3⅝	¼	⅛	17.25	17.70
25	1¾	7	2⅞	5	2	4 5/16	¾	⅛	29.46	30.38
35	2	7¾	3¼	5¾	2¼	5	¾	⅛	45.75	45.00
†55	2½	10½	4⅛	7¼	2¾	6	¾	¼	—	85.75

†Furnished in screw pin only.

S-2131

Trawling shackle with thin square head screw pin.

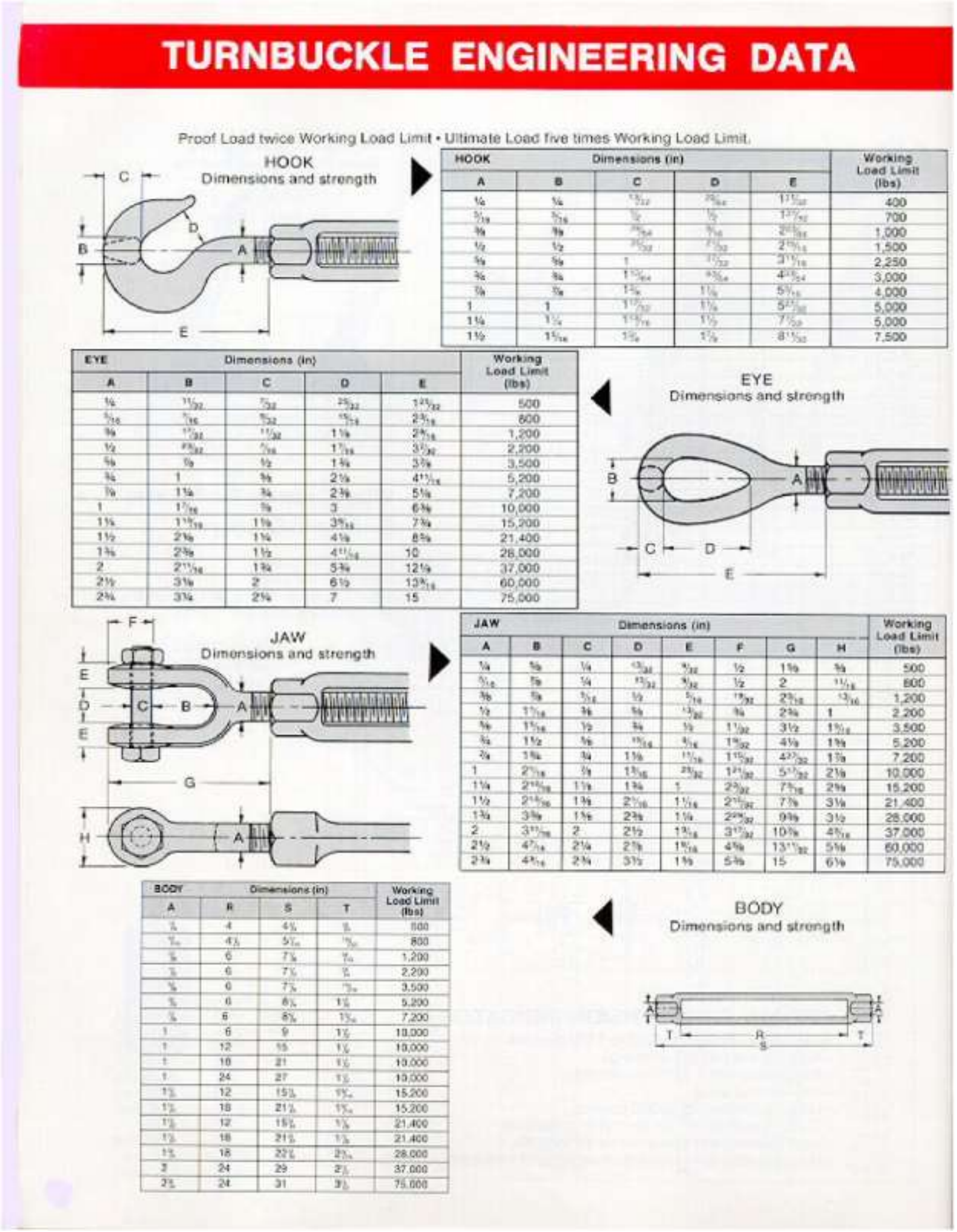
TRAWLING SHACKLES

Self Colored only

Working Load Limit (tons)	Nominal Shackle Size (in)	DIMENSIONS (in)						Weight (lbs)
		Inside Length	Inside Width at Pin	Diameter		Tolerances Plus or Minus		
				Pin	Outside of Eye	Length	Width	
2	½	1⅝	13/16	⅝	1 3/16	⅛	1/16	.75
3¼	⅝	2	1 1/16	¾	1 9/16	⅛	1/16	1.24
4¾	¾	2⅜	1¼	⅞	1⅞	¼	1/16	2.18
6½	⅞	2 13/16	1 7/16	1	2⅛	¼	1/16	3.28

NOTE: Maximum Proof Load is 2.2 times the Working Load Limit or as designated. Minimum Ultimate Strength is 6 times the Working Load Lim

Table 14 Turnbuckles



TURNBUCKLE ENGINEERING DATA

Proof Load twice Working Load Limit • Ultimate Load five times Working Load Limit.

HOOK
Dimensions and strength

HOOK	Dimensions (in)				Working Load Limit (lbs)
A	B	C	D	E	
1/4	1/4	13/32	25/64	1 17/32	400
5/16	5/16	1/2	1/2	1 27/32	700
3/8	3/8	35/64	9/16	2 25/64	1,000
1/2	1/2	25/32	21/32	2 15/16	1,500
5/8	5/8	1	27/32	3 11/16	2,250
3/4	3/4	1 11/64	63/64	4 25/64	3,000
7/8	7/8	1 3/8	1 1/8	5 5/16	4,000
1	1	1 17/32	1 1/4	5 27/32	5,000
1 1/4	1 1/4	1 15/16	1 1/2	7 7/32	5,000
1 1/2	1 5/16	1 5/8	1 7/8	8 11/32	7,500

EYE	Dimensions (in)				Working Load Limit (lbs)
A	B	C	D	E	
1/4	11/32	7/32	25/32	1 23/32	500
5/16	7/16	9/32	15/16	2 3/16	800
3/8	17/32	11/32	1 1/8	2 9/16	1,200
1/2	23/32	7/16	1 7/16	3 7/32	2,200
5/8	7/8	1/2	1 3/4	3 7/8	3,500
3/4	1	5/8	2 1/8	4 11/16	5,200
7/8	1 1/4	3/4	2 3/8	5 1/8	7,200
1	1 7/16	7/8	3	6 3/8	10,000
1 1/4	1 15/16	1 1/8	3 9/16	7 3/8	15,200
1 1/2	2 1/8	1 1/4	4 1/8	8 5/8	21,400
1 3/4	2 3/8	1 1/2	4 11/16	10	28,000
2	2 11/16	1 3/4	5 3/4	12 1/8	37,000
2 1/2	3 1/8	2	6 1/2	13 9/16	60,000
2 3/4	3 1/4	2 1/4	7	15	75,000

EYE
Dimensions and strength

JAW
Dimensions and strength

JAW	Dimensions (in)							Working Load Limit (lbs)
A	B	C	D	E	F	G	H	
1/4	5/8	1/4	13/32	9/32	1/2	1 5/8	5/8	500
5/16	7/8	1/4	13/32	9/32	1/2	2	11/16	800
3/8	7/8	5/16	1/2	5/16	19/32	2 3/16	13/16	1,200
1/2	1 1/16	3/8	5/8	13/32	3/4	2 3/4	1	2,200
5/8	1 5/16	1/2	3/4	1/2	1 1/32	3 1/2	1 5/16	3,500
3/4	1 1/2	5/8	15/16	5/8	1 9/32	4 1/8	1 5/8	5,200
7/8	1 3/4	3/4	1 1/8	11/16	1 15/32	4 27/32	1 7/8	7,200
1	2 1/16	7/8	1 3/16	25/32	1 21/32	5 17/32	2 1/8	10,000
1 1/4	2 15/16	1 1/8	1 3/4	1	2 3/32	7 5/16	2 5/8	15,200
1 1/2	2 15/16	1 3/8	2 1/16	1 1/16	2 15/32	7 7/8	3 1/8	21,400
1 3/4	3 3/8	1 5/8	2 3/8	1 1/4	2 29/32	9 3/8	3 1/2	28,000
2	3 11/16	2	2 1/2	1 5/16	3 17/32	10 5/8	4 5/16	37,000
2 1/2	4 7/16	2 1/4	2 7/8	1 9/16	4 3/8	13 11/32	5 1/8	60,000
2 3/4	4 5/16	2 3/4	3 1/2	1 3/8	5 3/8	15	6 1/8	75,000

BODY	Dimensions (in)			Working Load Limit (lbs)
A	R	S	T	
1/4	4	4 1/2	1/4	500
5/16	4 1/2	5 1/16	9/32	800
3/8	6	7 1/8	9/16	1,200
1/2	6	7 1/2	3/4	2,200
5/8	6	7 7/8	15/16	3,500
3/4	6	8 1/4	1 1/8	5,200
7/8	6	8 5/8	1 5/16	7,200
1	6	9	1 1/2	10,000
1	12	15	1 1/2	10,000
1	18	21	1 1/2	10,000
1	24	27	1 1/2	10,000
1 1/4	12	15 1/2	1 3/4	15,200
1 1/4	18	21 1/2	1 3/4	15,200
1 1/2	12	15 1/2	1 3/4	21,400
1 1/2	18	21 1/2	1 3/4	21,400
1 3/4	18	22 1/2	2 1/16	28,000
2	24	29	2 1/2	37,000
2 1/2	24	31	3 1/2	75,000

BODY
Dimensions and strength

APPENDIX F – U-JOINTS

Alloy steel u-joints as advertised in Boston Gear Mechanical Product catalog are recommended.

Table 15 U-joint specifications

BOSTON CATALOG NUMBER	MAXIMUM RECOMMENDED PAYLOAD (LB)
J 150	1,100
J 175	1,300
J 200	1,800
J 250	2,400
J 300	3,000

APPENDIX G – PAINT AND INSULATION

Table 16 Insulation data

Name	α	Σ	Density (lb/ft^2)	Conductivity (Btu[in/ft^2] hr °F)	Specific Heat
Ethafoam	0.655	0.78	2.2	0.35	0.5
Dark blue foam	0.442	0.725	1.8	0.23	0.5
Light blue foam	0.61	0.836	2.1	0.185	0.27

Table 17 Thermal surface samples

Sample No.	Description	Sherwin Williams Identity	α	Σ	A/Σ
1	Tracom Black	A61350	0.928	0.92	1.01
2	Waifer Grey	A6A37	0.663	0.908	0.73
3	Old Tavern Brown	A6N53	0.905	0.915	0.99
4	Plantation Brown	A6N56	0.83	0.718	0.90
5	Fairfax Brown	A6N81	0.86	0.918	0.94
6	Cape Hatteras Blue	A6L52	0.778	0.913	0.87
7	Peace Yellow	A6Y61	0.269	0.897	0.30
8	Admiral Gold	A6U69	0.495	0.903	0.55
9	Sandpiper	A6A58	0.536	0.903	0.59
10	Sundance Yellow	A6Y68	0.33	0.908	0.36
11	King Yellow	A6Y56	0.365	0.901	0.40
12	Harvest Gold	A6Y63	0.51	0.909	0.56
13	Leatherstocking Green	A6N51	0.815	0.915	0.8
14	Buchs County Gold	A6G55	0.89	0.916	0.88
15	Ardmore Green	A6G124	0.873	0.916	0.95
16	Sage Green	A6G99	0.605	0.907	0.66
17	Colony Green	A6G54	0.779	0.915	0.85
18	Provincial Gold	A6Y55	0.709	0.913	0.78
19	Woodland Olive	A6G125	0.78	0.913	0.85
20	Super White	A6W40	0.236	0.895	0.29
21	White Tape		0.375	0.917	0.41
22	Light Blue Foam		0.61	0.836	0.73
23	Dark Blue Foam		0.442	0.725	0.61
24	Ethafoam		0.655	0.78	0.84

The CSBF uses Sherwin Williams white appliance paint #1400878 on most metal surfaces. This epoxy base spray enamel adheres well to metal without extensive surface preparation.

APPENDIX H – EXAMPLE CRUSH PAD DESIGN

The following problem shows how crush pad requirements can be calculated for a given gondola. The first solution is a simplistic approach, which does not take into account all of the conditions affecting the gondola at landing. The second solution considers a more realistic set of impact conditions.

PROBLEM

Provide ground impact protection for a science payload weighing 3,000 pounds and allow a maximum stopping load of 10-g.

DEFINITION	DESCRIPTION
W	Weight
V	Velocity
Vi	Velocity immediately prior to impact
K.E.	Kinetic energy
S	Minimum allowable stopping distance
S’	Actual available stopping distance
	Total required payload/crush pad contact area
Tc	Total required minimum thickness of crush pad
Ti	Crush pad thickness increment
Tu	Usable crush pad thickness
Tt	Actual total thickness used
N	Integer number of crush pad thickness increments (Ti) to use
C.S.	Crush strength of crush pad
	10 lb/in^2 = 1440 lb/ft^2
G	Maximum allowable stopping acceleration
g	Acceleration due to gravity
	32.2 ft/sec/sec

GIVEN	DESCRIPTION
Vi	20 ft/sec
Ti	4 in
Tu	0.7 (70%)
C.S.	10 lb/in^2
G	10 g

Solution 1

K.E. = 1/2 x W/g x V^2
= 1/2 x 3,000 / 32.2 x 20^2
= 18,633 ft-lb

S = V^2/ (2 x g x G)
= 20^2 / (2 x 32.2 x 10)
= 0.62 ft = 7.5 in

Tc = S/Tu
= 7.5 / 0.7
= 10.7 in

Tt = N x Ti > Tc
= N x 4 > 10.7

N = 3

Tt = 12 in

S’ = Tt x Tu
= 12 x 0.7
= 8.4 in = 0.7 ft

K.E. = A x C.S. x S’
or A = K.E. / C.S. / S’
= 18,633 / 1,440 / 0.7
= 8.5 ft ft ^{2}

Based on the above calculations, a square crush pad arrangement 4.3 feet on each side and 12 inches (three layers) deep will provide the needed protection.

CAUTION

Solution 1 assumes that the payload will impact the ground in an upright orientation (no swinging). In most cases this is an unrealistic situation. It also assumes that the center 18.5 square feet of the gondola can support 30,000 pounds with no damage. This may or not be true.

SOLUTION 2

Solution 2 assumes, more realistically, that the gondola may not be upright at impact and, for this reason, the crush pad should be located at the corners rather than at the center of the gondola.

For this example, assume that a design analysis indicates that each corner can withstand 2.5 W without deformation. Therefore, if the gondola lands upright on all four corners, it can withstand 10 g; if it lands mainly on two corners, it can withstand 5 g; and if it lands mainly on one corner, it can withstand 2.5-g. (These assumptions may be different for an actual gondola.)

The kinetic energy will be the same no matter how many corners impact simultaneously.

K.E. = 1/2 x W/g x V^2
= 1/2 x 3,000 / 32.2 x 20^2
= 18,633 ft-lb

ALL CORNERS IMPACTING SIMULTANEOUSLY

For the case in which all corners impact simultaneously, a 10-g acceleration is allowable.

S = V^2/ (2 x g x G)
= 20^2 / (2 x 32.2 x 10)
= 0.62 ft = 7.5 in

Tc = S/Tu
= 7.5 / 0.7
= 10.7 in

Tt = N x Ti > Tc
= N x 4 > 10.7

N = 3

Tt = 12 in

S’ = Tt x Tu
= 12 x 0.7
= 8.4 in = 0.7 ft

K.E. = A x C.S. x S’
or A = K.E. / C.S. / S’
= 18,633 / 1,440 / 0.7
= 18.5 ft^2

Based on these calculations, a square crush pad arrangement on each corner, 3.1 feet on each side and 12 inches (three layers) deep, will provide the needed protection.

TWO CORNERS IMPACTING SIMULTANEOUSLY

For the case in which two corners impact simultaneously, a 5-g acceleration is allowable.

S = V^2/ (2 x g x G)
= 20^2 / (2 x 32.2 x 5)
= 1.24 ft = 14.9 in

Tc = S/Tu
= 14.9 / 0.7
= 21.36 in

Tt = N x Ti > Tc
= N x 4 > 21.3

N = 6

Tt = 24 in

S’ = Tt x Tu
= 24 x 0.7
= 16.8 in = 1.4 ft

K.E. = A x C.S. x S’
or A = K.E. / C.S. / S’
= 18,633 / 1,440 / 1.4
= 9.25 ft^2

Based on these calculations, a square crush pad arrangement on each corner, 2.2 feet on each side and 24 inches (six layers) deep, will provide the needed protection.

ONE CORNER IMPACTING INITIALLY

For the case in which one corner impacts initially, a 2.5-g acceleration is allowable.

S = V^2/ (2 x g x G)
= 20^2 / (2 x 32.2 x 2.5)
= 2.49 ft = 29.8 in

Tc = S/Tu
= 29.8 / 0.7
= 45.6 in

Tt = N x Ti > Tc
= N x 4 > 45.6

N = 12

Tt = 48 in

S' = Tt x Tu
= 48 x 0.7
= 33.6 in = 2.8 ft

K.E. = A x C.S. x S'
or A = K.E. / C.S. / S'
= 18,633 / 1,440 / 2.8
= 4.62 ft^2

Based on these calculations, a square crush pad arrangement on each corner, 2.2 feet on each side and 48 inches (12 layers) deep, will provide the needed protection.

CONCLUSION

An inverted pyramid configuration of three crush pad layers 3 feet on each side, followed by three layers 2.5 feet on each side, followed by three layers 2 feet on each side, with one pyramid on each corner, would protect this gondola under the given conditions. The upper corners of the gondola should also be protected from tip-over upon ground impact.

CAUTION

THE PRECEDING CALCULATIONS ONLY APPLY UNDER THE GIVEN CONDITIONS. THIS SOLUTION WILL NOT ADEQUATELY PROTECT ALL 3,000-POUND GONDOLAS.

APPENDIX I – LAUNCH VEHICLE CAPABILITIES

Table 18 CSBF Launch vehicle capabilities

LAUNCH VEHICLE	DISTANCE FROM PIN FITTING TO GROUND (FT)	GONDOLA HEIGHT SUSPENSION POINT TO GROUND (FT)	MAXIMUM GONDOLA WEIGHT (LB)
Tiny Tim	36.5	31	6,500
Crane	26.0	21	5,500
BST	22.0	17	3,000
Ascend II	16.5	12	2,400

Appendix J – Aircraft Recovery Options

Twin Otter

Loading

Maximum load including passengers: 2200 pounds

Maximum floor loading: 200 lb/ft^2

Range

One-way range without refueling: 720 nm

Operating radius, no loiter: 360 nm

Operating radius, terminations: 250 nm

Loiter time: 1.3 hours

Door Sizes

Two door sizes:

- 56-in wide x 50-in high
- 61-in wide x 50-in high

Door Limits

Door limits for the Twin Otter are shown in Figure 12.

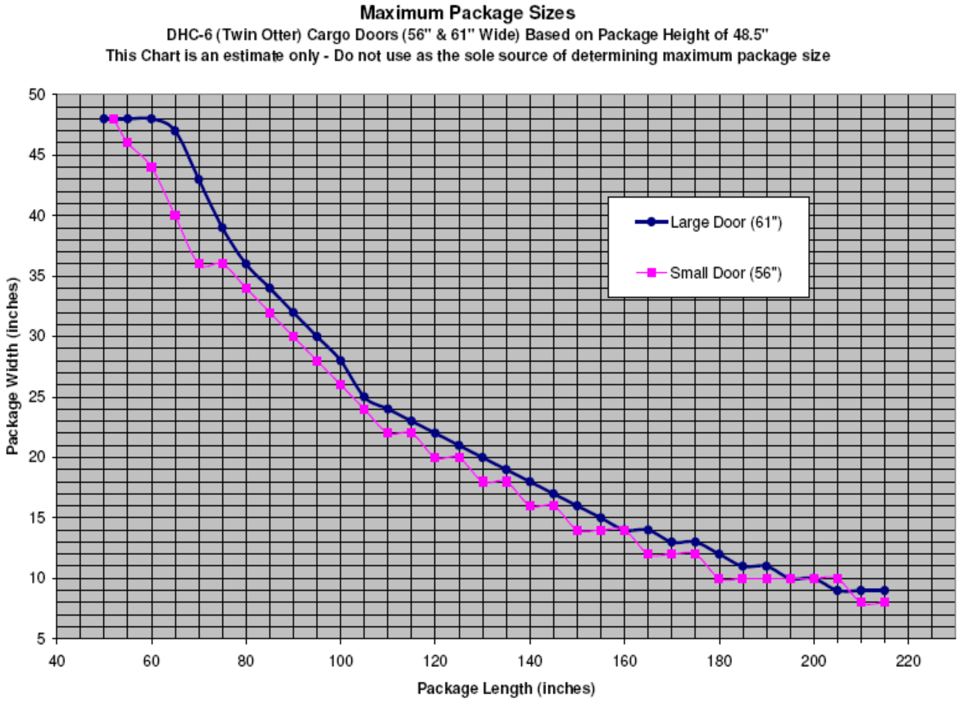


Figure 12 Twin Otter maximum package sizes

Bassler

Loading

Maximum load including passengers

- One-way load: 2900 pounds
- Round trip load: 2600 pounds

Maximum floor loading: 200 lb/ft^2

Range

Maximum range including passengers

- One-way range: 1000 nm
- Round trip range: 500 nm

Landing Requirements

A 3000-foot groomed ski way or minimal sastrugi formations

Door Size

Width:	84.5 inches
Height at forward end:	70.6 inches
Height at aft end:	55.7 inches
From the ground line:	56.5 inches

Figure 13 Bassler cargo door dimensions

Figure 14 Bassler cargo door photograph

Cabin Dimensions

Length:	38 feet
Width:	7 feet
Height	6 feet

Maximum Package Size Table

Width, Inches

Length, Inches	4	8	12	16	20	24	28	32	36	40	44	48	52	56
69	69	69	69	69	69	69	69	69	69	69	69	69	69	69
73	73	73	73	73	73	73	73	73	73	73	73	73	73	60
77	77	77	77	77	77	77	77	77	77	77	70	70	70	60
81	81	81	81	81	80	80	80	80	80	80	72	72	72	60
85	85	84	84	80	76	76	72	72	72	72	68	64	64	60
89	84	84	80	80	76	72	72	68	68	64	64	64	60	56
93	84	84	80	80	76	72	68	64	64	64	64	64	60	56
97	84	84	80	76	72	72	68	64	64	64	64	60	60	56
101	84	80	76	76	72	68	64	64	64	64	64	60	60	
105	80	80	76	76	72	68	64	64	64	64	60	60	60	
109	80	80	76	72	68	68	64	60	60	56	56	56	56	
113	76	76	76	72	68	64	60	60	60	56	56	56	52	
117	76	76	76	72	68	64	60	60	60	56	56	56		
121	76	76	72	68	64	60	60	60	60	56	56	52		
125	76	76	72	68	64	60	60	56	56	56	56	52		
129	76	76	72	68	64	60	60	56	56	56	56	52		
133	72	72	66	66	64	60	60	56	56	56	52	48		
137	72	72	68	64	64	60	60	56	56	56	52			
141	72	72	68	64	64	60	60	56	56	56	52			
145	72	72	68	64	64	60	60	56	56	52	52			
149	72	72	68	64	64	60	60	56	56	52	48			
153	72	72	68	64	64	60	60	56	56	52	48			
157	72	72	68	64	60	60	56	56	52	52	48			
161	72	72	68	64	60	60	56	56	52	48	44			
165	72	68	68	64	60	60	56	56	52	48				
169	72	68	68	64	60	60	56	56	52	48				
173	72	68	68	64	60	60	56	56	52	44				
177	72	68	68	64	60	60	56	56	52	40				
181	72	68	64	64	60	60	56	52	48					
185	72	68	64	64	60	60	56	52	48					
189	72	68	64	64	60	60	56	52	48					
193	68	68	64	64	60	60	56	52	44					
197	68	68	64	64	60	60	56	52	44					
201	68	68	64	64	60	60	56	48	36					
205	68	68	64	64	60	60	56	48						
209	68	68	64	64	60	60	56	48						
213	68	68	64	64	60	60	56	48						
217	68	68	64	60	60	56	56	48						
221	68	68	64	60	60	56	52	44						
225	68	68	64	60	60	56	52	44						
229	68	68	64	60	60	56	52	44						
233	68	68	64	60	60	56	52	40						
237	68	68	64	60	60	56	52	36						
241	68	64	64	60	60	56	48	36						
245	68	64	64	60	60	56	48	32						
249	68	64	64	60	60	56	48	32						
253	68	64	64	60	60	56	48							
257	68	64	64	60	56	52	44							
261	68	64	64	60	56	52	44							
265	68	64	64	60	56	52	44							
269	68	64	64	60	56	52	40							
273	68	64	64	60	56	52	40							
277	68	64	64	60	56	52	32							
281	68	64	64	60	52	52	28							
285	68	64	64	60	52	52	28							
289	68	64	64	60	52	48	28							
293	68	64	64	60	52	48								
297	68	64	64	60	52	48								
301	68	64	60	60	52	48								
305	68	64	60	60	52	48								
309	68	64	60	60	52	44								
313	68	64	60	60	52	40								
317	68	64	60	60	52	40								
321	68	64	60	60	52	40								
325	68	64	60	60	52	40								
329	68	64	60	56	52	36								
333	68	64	60	56	52	36								
337	68	64	60	56	52	32								
341	68	64	60	56	52	32								
345	68	64	60	56	52	32								
349	68	64	60	56	52	28								
353	64	64	60	56	48	28								
357	64	60	56	52	48	24								
362	48	44	40											
366-445	8													

Figure 15 Bassler maximum package sizes

RAMP

Figure 16 Bassler door ramp

HELICOPTER

ANTARCTICA

Maximum interior load

- Dimensions: 5 ft x 3 ft x 3 ft
- Weight: 1600 to 1800 pounds

Sling weight: 1800 pounds

Range from McMurdo

- Without fuel cache: 150 nm

(Cannot operate on High Antarctic Plateau (altitude)