SAE Aerospace
An SAE International Group

AEROSPACE RECOMMENDED PRACTICE

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Air Cargo Unit Load Devices - Center of Gravity Control Methods

FOREWORD

In this document, the minimum essential criteria are identified by the use of the key word “shall”. Other recommended criteria are identified by the key word “should” and while not mandatory, are considered to be of primary importance in providing safely built-up air cargo Unit Load Devices.

TABLE OF CONTENTS

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1. SCOPE:

This SAE Aerospace Recommended Practice (ARP) provides the industry agreed methods to keep the center of gravity (C.G.) location of loaded air cargo Unit Load Devices (ULDs) within the maximum horizontal and vertical limits allowed by their airworthiness approval.

1.1 Purpose:

The purpose of this document is to define the methods to be used as a function of the type of cargo in order not to exceed the maximum allowable center of gravity limits defined for each unit load device (ULD) configuration in AS36100 or, for older unit types, NAS 3610 standards, so as to ensure:

a. the ULD base and aircraft conveyance system maximum allowable area loads will not be exceeded, and

b. the ULD and aircraft cargo restraint system will not be overloaded in the event of in-flight accelerations.

1.2 Field of Application:

1.2.1 This document applies to all types of unit load devices for use on board civil transport aircraft, airworthiness approved under TSO C90 in accordance with performance requirements and testing parameters of either AS36100 or NAS 3610 standards.

1.2.2 This document shall also apply to any non airworthiness approved unit load devices, such as "non certified containers" as defined in AS1677C, of the same sizes, the utilization of which is controlled by the aircraft type's Weight and Balance Manual provisions.

1.2.3 This document applies to either air cargo containers or air cargo pallets to be restrained by the aircraft's cargo restraint system. It does not apply to non unitized cargo, loaded in bulk or on a "floating" pallet not restrained in the aircraft's system (however, in either case, maximum allowable area load on the aircraft floor must be checked and complied with).

2. REFERENCES:

2.1 Applicable Documents:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 U.S. Government Publications: Available from U.S. Government Printing Office, Mail Stop SSOP, Washington DC 20402-9325.

14 CFR Part 21 - Certification Procedures for Products and Parts, Subpart O - TSO Authorizations

Technical Standard Order TSO C90 - Cargo Pallets, Nets and Containers

14 CFR Part 25 - Airworthiness Standards : Transport Category Airplanes

FAA Advisory Circular 120-59 - Air Carriers internal evaluation program

2.1.2 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale PA 15096-0001.

AS1677C	Requirements for Noncertified LD2, LD4 and LD8 Cargo/Baggage Containers
ARP5486	Air Cargo Pallets - Utilization Guidelines
ARP5595	Air Cargo Restraint Straps - Utilization Guidelines
ARP5596	Cargo Shoring Guidelines
AS36100	Air Cargo Unit Load Devices - Performance Requirements and Test Parameters
AS36101	Air Cargo Unit Load Devices - Load Distribution Model

2.1.3 AIA Publications: Available from Aerospace Industries Association of America Inc., 1250 Eye Street NW, Washington DC 20006.

NAS 3610	Cargo Unit Load Devices - Specification for - (Revision 10)

NOTE: Also see additional document references, non applicable or not necessarily so, pertaining to ULD C.G. location control, shown in Annex A (informative), Bibliography, hereafter.

2.2 Definitions:

C.G.: Overall center of gravity of a loaded air cargo Unit Load Device (ULD).

CONTAINER (AIR CARGO -): A rigid structure which interfaces directly with the aircraft cargo handling and restraint system and alone performs all the functions of a unit load device.

NET (AIR CARGO PALLET -): A webbing or rope net for restraining load onto an air cargo pallet.

PALLET (AIR CARGO -): A unit load device consisting of a flat platform with flat undersurface of standard dimensions, on which goods are assembled and secured by a net before being loaded as a unit onto the aircraft, and which interfaces directly with the aircraft handling and restraint system.

RESTRAINT SYSTEM: Equipment for supporting and restraining unit load devices in an aircraft against the ground/flight loads. It usually consists of such items as rollers, side guides and locks for securing unit load devices to the aircraft structure. It does not include unit load devices, barrier nets and tie-down straps.

UNIT LOAD DEVICE (ULD): A device for grouping, transferring and restraining cargo for transit. It may consist of a pallet with a net or it may be a container.

3. OBJECTIVES:

3.1 Airworthiness approval of each type and size of unit load device includes maximum load center of gravity (C.G.) eccentricity (offset) allowances at unit maximum gross weight, that are part of its testing and approval (see AS36100 or previous NAS 3610, as applicable, ultimate load criteria).

3.2 C.G. Location (Plan-View):

3.2.1 The ULD's overall center of gravity (C.G.) shall be within the maximum plan-view limits specified at maximum gross weight by the unit's approval AS36100 or NAS 3610 configuration.

NOTE: The unit's approval AS36100 or NAS 3610 configuration is engraved or permanently marked on the base edge rail (e.g., "NAS 3610 - 2A6P" for configuration 2A6 pallet), at a location selected to remain readable.

3.2.2 Allowable plan-view C.G. eccentricity is expressed and measured in percentage (%) of the ULD's base length or width from the geometric center of the base. At unit maximum gross weight, it shall not exceed ±10% thereof, measured from the base geometric center, for most ULD types and sizes. It shall not exceed ±5% longitudinally and ±10% laterally for sizes G (96 x 238.5 in) and R (96 x 196 in) units.

3.2.3 AS36101, ULD load distribution model, defines the reference load distribution model on ULD bases to be used to assess the overall C.G. plan-view location, by comparison to the reference case: non stiff maximum gross weight cargo of an homogeneous density occupying a reduced area of the base surface.

3.2.4 When the actual ULD gross weight is lower than maximum, linear trade-off may be operationally used for increased C.G. eccentricity limits in proportion of the lower gross weight, as per AS36101 Figure 2. Actual maximum allowable C.G. plan-view limits in operation are therefore a function of the unit's actual gross weight.

3.3 C.G. Location (Height):

3.3.1 The ULD's overall center of gravity (C.G.) shall be lower than the maximum height limit specified at maximum gross weight by the unit's approval AS36100 or NAS 3610 configuration, or the aircraft's Weight and Balance Manual, whichever is lowest (e.g., many size A or M units may, when carried on aircraft main deck, exhibit up to 1.22 m (48 in) C.G. height. Yet, if carried on the lower deck, they shall in most cases be limited to 0.91 m (36 in) height only).

NOTE: The unit's approval AS36100 or NAS 3610 configuration is engraved or permanently marked on the base edge rail (e.g., "NAS 3610 - 2A6P" for configuration 2A6 pallet), at a location selected to remain readable.

3.3.2 If there is uncertainty about the maximum C.G. height to be used for the unit on hand, a maximum of half the unit contour's measured maximum height may in most cases be used, when the contour height does not exceed 2.44 m (8 ft).

3.3.3 For a load lower than the ULD position's maximum gross weight, higher CG heights may be considered, subject to the provisions of the aircraft's Weight and Balance Manual: linear extrapolation of maximum allowable C.G. height versus ULD position maximum gross weight may generally be applied, if required.

3.4 Application Objectives:

Regardless of the maximum allowable limits, whenever building up a container or pallet prior to loading into an aircraft all steps should be taken, insofar as feasible due to the nature, shape and densities of cargo to be loaded, to provide a loaded ULD C.G. location as close as possible from its geometric center. When the nature or shape of cargo makes this impossible in practice, the objective should be to limit C.G. offset to one direction only, either longitudinal or lateral, not exceeding the maximum allowable offset in that direction. Only as a last resort, when dictated without alternative by the nature or shape of cargo, should both longitudinal and lateral maximum C.G. offsets be simultaneously used. It is also recommended, whenever possible, to avoid simultaneously using maximum horizontal and vertical C.G. limits.

4. TYPES OF CARGO:

4.1 In order to meet the above objectives, when any piece or stack of cargo occupies only part of the pallet's or container base surface, it shall be loaded centered and not in a corner (see 5.1 hereafter).

4.2 In addition, the AS36101 reference load distribution model is based on non stiff cargo of an homogeneous density: in all other cases, different situations exist which require different unit build up methods in order to automatically guarantee the applicable C.G. limits will be met. Accordingly, it is necessary to identify the type of cargo concerned prior to building up the ULD, as follows:

4.3 Cargo Densities:

4.3.1 Cargo density (measured for each piece or package) is an essential element to be at least roughly determined for controlling the overall C.G. location of the ULD. It considerably varies depending on the nature of cargo carried, e.g.:

4.3.2 Low Density (below 80 kg/m^3/5 lb/ft^3): Common examples are flowers, baby chicken in boxes, or foam materials.

4.3.3 Medium Density (120 to 200 kg/m^3/8 to 12 lb/ft^3): Most general cargo, baggage and mail. "Express cargo" and parcel mail usually are on the low side of this range.

4.3.4 High Density (over 320 kg/m^3/20 lb/ft^3): Common examples are liquids, mechanical parts, or printed material.

NOTE: Density, however, closely depends on contents conditioning: e.g., letter mail when bulk packed in bags has a much lower density than the same mail packed tight in boxes, etc.

4.4 Cargo Mix:

4.4.1 In presence of a variety of natures of cargo, there will be different densities and the resulting overall C.G. location will closely depend on the relative locations of these onto the ULD base.

4.4.2 Homogeneous Cargo: When cargo, whatever it is, for a given ULD entirely consists (whole unit load) in the same commodity with the same conditioning (identical packages), there is per definition no risk of exceeding the maximum allowable C.G. limits, providing the general principle in 4.1 above is complied with.

4.4.3 Random Cargo: Is defined as cargo consisting of a large number of small (average less than 1 m/3 ft largest dimension) and lightweight (individual piece weight not exceeding 50 kg/110 lb) load items all different from each other, with very similar (not varying more than ±20%) densities, so that they can statistically be considered to average over a given volume. Common examples are: baggage, most express cargo, parcel mail.

NOTE: Assurance of randomness requires constant checking by trained staff. For instance, within a batch of passenger baggage that can be considered random may happen one crate or item exceeding one of the set criteria (dimension, piece weight, density).

4.4.4 Non Homogeneous Cargo: Is defined as a case when a given ULD is to be loaded with a mix of two or more commodities/package types of significantly different densities (belonging to different categories as defined in 4.3.2, 4.3.3 and 4.3.4 above).

4.4.5 Large Cargo: Is defined, for the purpose of this document, as heavy (over a minimum of 150 kg/330 lb per piece) and large enough pieces that their individual influence on ULD C.G. and base area load needs to be determined. A single such piece may be set onto the ULD base.

NOTE: For large cargo, piece stiffness may have to be taken into account for area load check and shoring. But it does not affect C.G. eccentricity.

5. CENTER OF GRAVITY CONTROL METHODS:

5.1 General:

Regardless of the type of cargo, in order to meet the objectives in Section 3 above, when any piece or stack of cargo occupies only part of the pallet's or container base surface, it shall be loaded centered in relation with the base and not in a corner. When only a partial load is planned or may result from the build up process, cargo stacking shall start in the pallet's or container base center area rather than at an edge.

5.2 Additional ULD build up methods for each of the different types of cargo identified in 4.4 above were developed and experience proven to automatically guarantee the C.G. limits will be met in each case:

5.3 Homogeneous Cargo:

See 4.4.2.

5.3.1 The general rule in 5.1 above shall be complied with, and

5.3.2 The height of the packages stack shall be kept constant (horizontal top level) throughout the ULD's surface. Where the number of packages does not allow it, the partial upper tier shall comply with 5.1.

NOTES: - Other precautions are needed for stable "T" stacking and protection against shifting. See ARP5486.
- When a container presents an unsymmetrical contour, filling it up to a constant height will automatically result in C.G. offset towards the overhanging part. It becomes even more important that the top level be strictly horizontal, because with some contours this will border on maximum allowable C.G. eccentricity. In this case, if there is not enough cargo left to be able to evenly spread it across the top of the previously loaded layer, the upper level should be placed on the side opposite the overhang, rather than in the center.

5.4 Random Cargo:

See 4.4.3. If this definition is not met, see 5.5 or 5.6 hereafter, as appropriate.

5.4.1 The miscellaneous small packages shall be randomly distributed in bulk over the ULD (usually a container) base area surface, taking care not to concentrate a series of seemingly identical heavy items together at an end or in a corner.

5.4.2 Assurance of randomness requires constant checking by trained staff: any items that appear significantly different in size or weight shall be identified, and handled as either non homogeneous cargo (see 5.5) or large cargo (see 5.6), as appropriate.

5.4.3 The height of the packages stack shall be kept constant (horizontal top level), or made constant prior to ULD dispatch, throughout the ULD's surface.

NOTE: When a container presents an unsymmetrical contour, filling it up to a constant height will automatically result in C.G. offset towards the overhang. It is even more important that the top level be horizontal, because some contours will border on maximum allowable C.G. eccentricity. In this case, if there is not enough cargo left to be able to evenly spread it across the top of the previously loaded layer, the upper level should be placed on the side opposite the overhang, rather than in the center.

5.5 Non Homogeneous Cargo:

See 4.4.4.

5.5.1 The general rule in 5.1 above shall be complied with, and

5.5.2 In view of the different densities of the various commodities, care shall be taken when stacking to ensure symmetrical loading around the base's geometric center (see example in Figure 1).

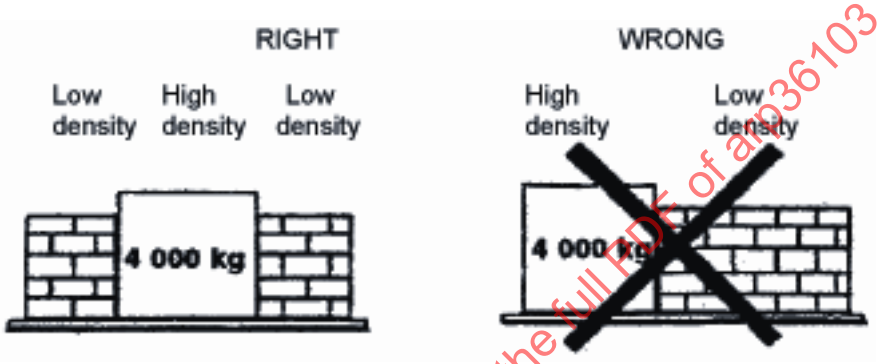

FIGURE 1 - Example of High and Low Density Mix: RIGHTWRONG

5.6 Large Cargo:

See 4.4.5.

5.6.1 When an individual large piece of cargo, of sufficient weight to significantly affect the C.G. location of the built up ULD, is to be loaded, it is necessary to know the location of its C.G., in the event of it being also offset in relation with the piece's geometric center. It should be marked on the item or crate by the shipper, using the ISO C.G. symbol:

Loading personnel should then orientate the piece so that its marked C.G. be correctly positioned on the ULD base to avoid C.G. offset.

5.6.2 If the piece's C.G. is unmarked and if its weight is a concern, it must be checked to estimate its C.G. location. A simple check method is to adjust forklift blades so that they are less than ½ the width of the piece. Lift the piece slightly off the ground, checking for tipping one way or the other. Adjust position of the forklift blades under the piece until the estimated C.G. is found. Mark the piece with the ISO C.G. symbol at the center point between the blades. During loading, orientate the piece so that its estimated C.G. be correctly positioned on the ULD base to avoid C.G. offset.

5.6.3 A single heavy piece shall then be loaded with its C.G. approximately on the ULD base geometric center. In the event of two similar pieces, they shall be loaded with their individual C.G.s located approximately symmetrical in relation to the ULD base geometric center. Etc.

NOTE: If the cargo piece(s) do(es) not fully occupy the ULD base, there may also be a requirement for protection against possible shifting within the ULD. See ARP5486.

5.7 C.G. Height:

5.7.1 In the event of stacked homogeneous cargo or random cargo as defined, C.G. height will be half the stack's, hence automatically comply with the maximum allowable C.G. height limit.

5.7.2 In the event of stacked non homogeneous cargo, the heaviest/highest density packages shall be systematically loaded first and the lightest/lowest density ones last. In addition to reducing cargo crushing, this will automatically ensure that the overall C.G. height be lower than the limit.

5.7.3 In the event of large cargo being high and heavy enough to create concern as to C.G. height, its C.G. height should be identified from shipper's markings (see 5.6.1), calculated, or measured. If the piece's C.G. height is higher than maximum allowable per ULD approval configuration or aircraft Weight and Balance Manual requirements, whichever is less:

a. If a single piece reaches unit maximum gross weight, it is not acceptable upright. Consideration may be given to the possibility of carrying it in another position with a lower C.G.,

b. If it is below unit maximum gross weight, the possibility of applying a higher C.G. limit may be considered, subject to the provisions of the aircraft's Weight and Balance Manual (see 3.3.3). The unit's load may also be completed up to maximum gross weight with (preferably heavy) other cargo, as low as possible, around the large piece in order to bring down the overall C.G. height (a rough calculation may be required). Both methods may be simultaneously used.

NOTES: - Such a high C.G. single piece also constitutes a "tall" load with a risk of tipping to be prevented. Additional cargo around it is one of the means to prevent this risk (see ARP5486 and ARP5595).
- Such a load also presents a high likeliness of undue load concentration onto the base. See ARP5596 for applicable shoring requirements.

6. TRAINING REQUIREMENTS:

6.1 Operating Instructions:

6.1.1 The carrier shall establish and distribute to all affected employees, including sub-contractors and shippers where they are allowed to build up ULDs for loading aboard aircraft, ULD build-up operating instructions taking into account the requirements of ULD airworthiness approval, the approved Weight and Balance Manual(s) for the aircraft type(s) operated, and the recommendations of the present ARP.

6.1.2 The carrier shall take all necessary steps to ensure these operating instructions are understood and applied at each site by at least one suitably trained competent person (see 6.2 hereafter) or under his direct supervision, including the establishment and implementation of such procedure as can guarantee an aircraft will not be dispatched with cargo ULDs on board unless each ULD was inspected and found by such a competent person to effectively meet C.G. eccentricity requirements prior to release for loading aboard the aircraft.

6.1.3 The above requirements also apply whenever all or part of ULD build-up is sub-contracted, and should be included by the carrier in the corresponding handling contracts (see IATA AHM 810, Standard ground handling agreement).

6.2 Training and Qualification:

6.2.1 The carrier shall establish and implement recurrent training programs to ensure his ULD build-up operating instructions, including ULD C.G. control methods, are fully understood and practiced by a sufficient number of competent persons throughout his organization, his subcontractors', and any shippers allowed to directly prepare air cargo ULDs for loading aboard aircraft.

6.2.2 The basic contents of such training programs should include at least the contents of the present ARP as well as ARP5486, ARP5595 and the basic principles of ARP5596, and be taught using field training and practical demonstrations with actual cargo inasmuch as feasible.

6.2.3 It is recommended such training be individually recorded after a proficiency check was performed, both theoretical and practical (at actual ULD build-up). Such individuals may be deemed qualified to perform built-up ULDs inspection and release for loading aboard an aircraft (for training program contents and qualification recording procedure, see IATA AHM 692, Ramp handling and loading procedures, training and qualifications).