THE CHALLENGES OF TRANSPORTING SPECIAL LOADS IN MILITARY AND CIVIL AIRCRAFT

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ABSTRACT

Military and civil air logistic missions may require the transportation of special cargo, that is, items that cannot be restrained to military or civil pallets per the according specification and that were not conceived to support aircraft vibration and load factors associated with different flight phases. Odd-sized loads are a common example of special cargo that require alternative restriction methods for a safe transportation. The objective of this work is to present different aspects and requirements to be considered for the restraining and transportation of special loads in military and civil air logistic missions, supporting the decision-making to transport it based on the benefits and the risks of the operation, illustrated by incident examples associated with poor special cargo conditioning inside the aircraft.

Keywords: Cargo Restraint, Airfreight Requirements, Incidents, Decision Making Criteria.

1. INTRODUCTION

Air freight is generally defined as any cargo transport operation in an aircraft that is not mail or that is not associated with a passenger's ticket (excluding items shipped under the cover of an airway bill) (Hui et al., 2004).

Air freight operations are carried out consistently both on civil and military aviation. Military airfreight operation has some variation from country to country, but share operation similarities. For example, in Brazil it consists of two different types of mission: strategical airlift and tactical airlift. The first one is associated with long-distance flights for transporting supplies and equipment (such as vehicles) between theaters of operation, which can be exemplified by airlift operations between military bases and humanitarian aid missions. The second one is associated with the transportation of supplies and equipment inside a theater of operation, requiring take off and landing from non-prepared or semi-prepared runways on occasion (Antunes et al., 2018).

Civil airfreight, performed either using the lower decks of passenger aircraft or through dedicated freighters, represents approximately 35% of world trade shipments by value, and is a key asset for the import and export of goods in a global market, meaning in general that countries with better air cargo connectivity also participate in more trade operations in value terms (Shepherd et al., 2016). Its importance was reaffirmed during the global COVID-19 pandemics, where the reduction in available passenger aircraft resulted in the air cargo capacity not being sufficient to accommodate cargo shipments once demand began to rebound, resulting in an accelerated passenger aircraft conversion to freighters (IATA, 2021b), exemplified in Brazil by ANAC's (Agência Nacional de Aviação Civil) resolutions number 600 and 639, allowing airlines to carry cargo in the cabin on an exceptional and temporary basis from December 2020 to July 2022 (ANAC, 2020, 2021). This scenario culminated in an estimated worldwide load factor of 53.9% for air freight in 2020, the highest value registered by IATA (International Air Transport Association) since 1990 (IATA, 2021b).

The majority of civil airfreight operations on wide-body aircraft are performed using ULDs (Unit Load Device) for restraining/containing the transported goods. ULDs may be defined as equipment used to load freight, such as standardized containers and pallets (Lu & Chen, 2011). On unusual circumstances, transported items in airfreight operation are called special cargo, that is, cargo that requires special handling and securing/restraining procedures but meeting limitations specified in the aircraft manuals and approved by the type certificate (TC/STC) (FAA, 2022), not being fully compatible with standard ULDs.

For military airfreight operation, loads considered special for civilian flights such as vehicles and smaller aircraft are routinely transported between bases. Military special loads are any cargo that may require special handling methods, contains hazardous material, operates during flight, or interfaces with aircraft non-cargo systems (Department of Defense, 2021). The term ULD is not normally associated with military pallets, such as the standard 463L pallet, which are largely used for transporting cargo in general, including special loads.

Safe restraint is fundamental for special loads, as they are commonly odd-sized and/or heavy; their movement inside the aircraft cargo compartment/cabin may result in catastrophic scenarios due to center of gravity (CG) shift. Load shift represents approximately 11% of accidents associated with cargo transport (Baxter & Wild, 2021).

The objective of this work is to present a general overview of special cargo freight operation, including different aspects and requirements to be considered for the restraining and transportation of special loads in military and civil air logistic missions, providing means to support the decision-making to transport them based on the benefits and the risks of the operation.

2. GENERAL REQUIREMENTS AND GOOD PRACTICES FOR THE AIRFREIGHT OF GOODS

2.1. Military Airfreight

While military freight operations are not regulated by civilian authorities and therefore could have operational doctrines varying significantly between countries, it is usually observed that they share similarities worldwide as operational doctrines incorporate aspects from aircraft manuals.

Main steps for load preparation/transportation observed on operational doctrines are exemplified on AFI 24-605 Volume 2 Section C (Department of Defense, 2020) and may be summarized as follows:

- Clear and precise identification of the transported loads;
- Check the airworthiness of pallets through visual inspection;
- Check the airworthiness of tiedown equipment (TDE) such as nets, straps or chains used to secure the loads through visual inspection;
- Guarantee the correct cargo restraint by:
  - Calculating the correct amount of TDEs to be used considered the load weigh and aircraft load factors;
  - Not using a mix of TDEs from dissimilar material (metallic chains and webbing straps);
  - Knowing and respecting the rated loads of TDEs;
  - Attaching TDEs to cargo only at points that can withstand the respective TDE load;
  - Making cargo restraint and TDE disposition symmetrical;
- Weight and measure loads;
- Load the cargo inside the aircraft following the aircraft loading and weight & balance manuals.

These instructions show that cargo preparation/transportation are treated similarly to aircraft equipment, with associated airworthiness concerns, so that cargo movement is restrained for the entire flight envelope of the aircraft. As it is not reasonable for aircraft manufactures to access the virtually endless cargo restraint scenarios and possibilities, loadmasters and load riggers are key agents for guaranteeing safety of operation.

2.2. Civil Airfreight

Unlike the military operations scenario, civil airfreight does not have operational doctrines issued by a government authority prescribing adequate steps for load preparation and transportation.

In an effort to provide general guidelines for cargo aircraft operators and reduce safety-associated issues, the US Federal Aviation Administration (FAA) has issued guidelines for preparing, loading and restraining cargo on freighters. AC 120-85B (FAA, 2022), SAFO 13005 (FAA, 2013a) and SAFO 13008 (FAA, 2013b) detail the same key aspects observed in military operational doctrines, while emphasizing the importance of training regularly all personnel involved with weight and balance, cargo loading system (CLS) operators and cargo buildup/loading/unloading responsible, who perform similar tasks as military loadmasters and load riggers in guaranteeing the safety of operation of civil airfreight. AC 120-85B also defines the role of special cargo analysis function (SCAF), who assumes the responsibility of creating and applying procedures for the identification, acceptance, and carriage of special cargo considering for example the characteristics detailed on Section 3.

The aircraft industry also have important contributions in reducing dependency on operators' informal knowledge, improvisation and intuition, supporting more robust and organized efforts. IATA's ULD Regulations and SAE standards/recommended practices for ULDs are examples of relevant industry documentation associated with civil airfreight.

3. SPECIAL LOADS DEFINITION

The need to transport special loads is a reality for both military and civil operators, with similar definitions of what special loads are.

For Department of Defense (2021), a special load, also known as an air transportability problem item, is any system/equipment that in its shipping configuration may exceed standard size, weight, have fragile or hazardous characteristics, lack of adequate means for handling and restraint, or may require special support equipment. A cargo is considered a potential problem item when its design requirement includes transportability in such aircraft and the item exceeds any one of the aircraft general condition (cargo envelope, maximum weight, weight distribution, floor loading limits, etc). For US military operations, special loads require Air Transportability Test Loading Agency (ATTLA) evaluation and it may result in an internal air transport certification (Department of Defense, 2020).

In civil operations, IATA (2021a) defines special cargo as goods that may require specific procedures including packaging, labelling, documentation and handling through the transport chain. These specific procedures may be due to the cargo nature, weight, dimensions and/or value. FAA (2022) complements this definition by stating that the cargo and procedures should meet limitations specified in the aircraft manuals and TC/STC. While the general definition of special cargo by both entities is similar, IATA considers characteristics other than geometrical and weight for classifying a load as special cargo, such as dangerous goods and live animals; FAA, however, consider these items to be cargo requiring special handling procedures, but not special cargo. This paper focuses on the FAA special load definition as the basis for discussion.

4. THE CHALLENGES OF SPECIAL LOADS AIRFREIGHT

Knowledge of procedures and good practises: The process for a safe and secure loading/restraint of special loads start by having a solid base on the general process of cargo loading and preparation, so that loadmasters and SCAFs can differentiate standard loads from special loads. Based on the aircraft manuals and their previous knowledge, loadmasters/SCAFs will generate a procedure for preparing and restraining a specific special load.

This procedure will remain informal knowledge unless properly registered in the appropriate documentation as lessons learned. It is important that airfreight operators keep a systemic register of lessons learned, so that procedures are matured (instead of being reinvented) in case of recurring special loads freight, reducing safety concerns.

Cargo attachment points for restraint: It is common for special cargo not to have proper attachment points for straps and chains, making it difficult for loadmasters/SCAFs to elaborate a tiedown layout for its restraint. Existing attachment points with unknown resistance are equally problematic, and could fail mid-flight if tiedown loads surpass their capacity, resulting in cargo movement and CG shift. Resistance of an attachment point should not be inferred without proper data to support it.

Clearance to aircraft structure: The transport of out-sized cargo can be challenging during the handling procedure. The cargo entrance, specially in civil freighters that have lateral doors requires skilled personnel to guarantee that the aircraft will not be damaged during loading and positioning procedures. The reduced clearance also requires special care during restraint, as a cargo movement due to loose lashing may cause damage during flight.

Floor load limits: Aircraft loading manual (weight and balance manual, for civil operation) should ideally have clearly stated cargo floor load limits (or restrictions) to avoid any floor structure damage during loading, take-off, flight and landing at the interface between cargo and floor. Special loads often pose a challenge for load derivation due to asymmetry of geometry or weight distribution. Proper weighting of the special load using a scale (or set of scales) in fundamental for understanding how loads migrate to the aircraft floor, allowing for proper shoring calculation if better load distribution is required to meet floor structural limits.

Proper restraint of cargo: Calculating the correct amount of TDEs for restraining a cargo based on its weight/aircraft load factors and proposing a symmetric TDE layout are the basic procedure for any load restrain. These steps however might not be sufficient for odd-sized special cargo, whose shape may cause difficulties to rest the load in a stable equilibrium on the aircraft floor/over a pallet. Rotations associated with poor load equilibrium may induce slack to lashings or chains, rendering load restrain less effective (or ineffective in worst cases). Load stabilization through shoring (if cleared by the aircraft loading manual) is usually an effective way to secure unstable loads, but on cases of excessively unstable loads or luxury items, custom cradles (that can support aircraft load factors) may be required for transporting the special load.

Safe of flight for special cargo: When transporting special loads, it is important to guarantee its integrity during flight, considering the associated load factors. Manufacturers/proprietaries of special items on occasion claim that a special load is proven for transportation based on previous transport experience on different modals such as road, rail and maritime transport.

This is not sufficient evidence for equipment safe of flight as load factors differ significantly between transport modes. Table 1 provides a general comparison for load factors in air, road, rail and sea transport, evidencing that aircraft ultimate load factors overwhelm the other modes of transport.

For military (MIL) transport, if people are in front of cargo, 9G forward restraint is recommended, based on 14 CFR 25.561 (FAA, 2002)/RBAC 25 (ANAC, 2022b) emergency load factors.

For civil application, 9G forward restraint is normally fulfilled by a barrier net or a barrier wall inside the cargo compartment to contain the movement of loads (or part of loads broken apart during an emergency landing) towards the aircraft cockpit, as civil freighters do not transport supernumeraries and cargo in the cabin except for the cases listed under 14 CFR 121.583 (FAA, 2007)/RBAC 121 (ANAC, 2022a); this is a key difference between civil and military freight transport operations.

Table 1 Comparison between air (SAE International, 2020; Department of Defense, 2021), road, rail and sea transport load factors (IMO et al., 2014)

Load Factor	Air		Road	Rail	Sea
	Civil*	MIL			
Forward	1.5G	3G	0.8G	0.5G	0.4G
After	1.5G	1.5G	0.5G	0.5G	0.4G
Up	2.5G	2G			
Down	5G	4.5G	1G	1G	1G
Lateral	1.5G	1.5G	0.5G	0.5G	0.8G

*Estimated based on A-size ULD 15,000 lb maximum weight and ultimate load criteria.

5. EXAMPLES OF OCCURRENCES RELATED TO SPECIAL LOADS POOR CONDITIONING/RESTRAINT

5.1. Soviet Navy's Tupolev Tu-104A Accident

Type of Operation: Military
Year: 1981
Deviation on: Knowledge of procedures and good practises, Proper restraint of cargo

A high profile flight from Pushkin Airport (ULLP, Russia) to Khabarovsk-Novy Airport (KHV/UHHH, Russia) transporting 44 passengers including 16 admirals and generals of the soviet navy crashed eight seconds after taking-off from the runway. Accident investigation pointed that one of the key points leading to the aircraft crash was CG variation due to cargo movement and passengers not respecting seating assignments (Bureau of Aircraft Accidents Archives, 2021; Ertsov & Fetisov, 2010).

Witnesses have stated that 500 kg paper rolls were loaded in the aircraft cargo compartment with an unknown restraint setup. Paper rolls (loaded at the last minute, according to witnesses) would have rolled to the rear part of the aircraft (Shigin et al., 2008), making aircraft CG exceed aft allowable limit by 4.7% of the MAC (mean aerodynamic chord) (Ertsov & Fetisov, 2010), pitching the aircraft up to a point of no recovery. The aircraft loaded with paper rolls is loosely illustrated in Figure 1, with possible paper roll positions.

Cylindrical loads such as paper rolls may be classified as special loads as rolls lack of adequate

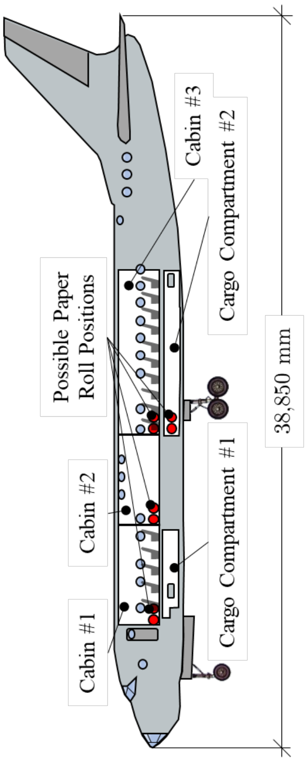

Figure 1 Tupolev Tu-104A - General Representation.

means for handling; and can be easily restrained on an unstable equilibrium when rigged, but move during take-off as a result of associated load factors and vibration. This accident exemplifies that poor restraint and cargo movement (which could have been noticed during load preparation and cargo compartment inspection prior to take-off) may result in loss of aircraft control.

5.2. National Air Cargo's Boeing 747-400 Accident

Type of Operation: Civil, transporting military payload
Year: 2013
Deviation on: Knowledge of procedures and good practises, Cargo attachment points for restraint, Proper restraint of cargo

A Boeing 747-400BCF (Boeing Converted Freighter) operated by National Air Cargo, Inc. crashed shortly after take-off from Bagram, Afghanistan. The aircraft was completely destroyed and all seven aircraft occupants were fatal victims.

The aircraft was transporting five mine-resistant ambush-protected (MRAP, two Cougar and three M-ATV) vehicles on pallets (Figure 2), considered special cargo as they could not be placed in ULDs or restrained in place using the the aircraft's cargo handling system. Instead, the cargo was restrained by straps attached to aircraft and by the cargo floor rollers, a condition named floating pallet (NTSB, 2015).

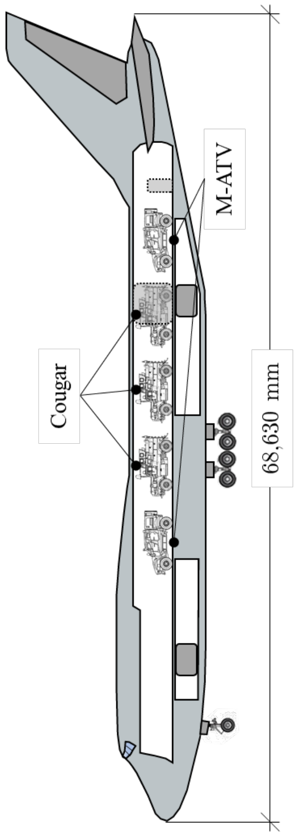

Figure 2 Boeing 747-400BCF - General Representation.

National Transportation Safety Board (NTSB) investigation shows that the likely accident cause was poor restraint of the cargo, which lead to at least one vehicle moving into the tail section of the airplane, damaging flight control components such that it was not possible for the flight crew to regain control of the airplane. Key issues observed for this airfreight operation was the operator's inadequate procedures for calculating the restraint of cargo, as well as the lack of knowledge on the allowable loads of both aircraft and cargo attachment points for TDEs, leading to undersized restraint of the vehicles that could not withstand the loads associated with take-off (NTSB, 2015).

NTSB investigation also identified a gap in terms of regulation, training and official documentation regarding special loads restraint and preparation, later discussed in FAA SAFO 13005, 13008 and AC 120-85B addressing important concerns observed during this investigation.

5.3. Everts Air Cargo's Douglas C-118A Liftmaster Accident

Type of Operation: Civil
Year: 2013
Deviation on: Proper restraint of cargo

The first officer of an Everts Air Cargo Douglas C-118A Liftmaster noticed an increase of stiffness in the airplane's elevator control movements. The aircraft was transporting a load of oversized, oil drilling tools to a oil production site. A cargo compartment inspection performed by the the flight engineer discovered that two 31-foot long oil drilling tools had shifted, damaging the aircraft's aft pressure bulkhead. Ground inspection showed that various frames, stringers and structural longerons received substantial damage as well. The aircraft crew reported that the likely accident cause was that at least one of the five straps securing the special load loosened during taxi/take-off, resulting in cargo movement. Movement was potentiated by the fact that the tools were covered in ice and snow (NTSB, 2014) .

This accident exemplifies the difficulties of restraining special loads when attachment points are not available on the cargo itself for connecting straps or chains. In conditions were TDEs are looped over equipment for restraining them inside the cargo compartment, unstable load equilibrium may result in loss of retention, as previously discussed on Section 4.

6. SUPPORTING DECISION MAKING FOR TRANSPORTING SPECIAL LOADS

Based on the challenges to transport special loads detailed on Section 4. as well as on the accidents associated with loose special cargo presented on Section 5., a checklist is proposed for initial assessment of a special load airfreight operation. The checklist is presented on Appendix A.

The proposed checklist goes over the general aspects of a safe transportation of a special load, while proposing corrective actions for simpler issues, or suggesting not to transport the evaluated load on cases where safety cannot be assured.

This checklist is meant to serve as a general guideline, therefore not being in any way exhaustive on all the possible scenarios and challenges a loadmaster/SCAF may find on airfreight operation. The aircraft operational manual is the most complete reference for instructions and guidelines, and should always be readily available for loadmasters.

7. CONCLUSION

As cargo is treated similarly to aircraft equipment, it is fundamental to guarantee its airworthiness through proper load preparation and restraint. Special loads pose additional challenge for loadmasters/SCAFs due to weight, geometry and/or lack of provisions for attaching proper restraint. It is important for freight companies and military forces to keep a well-registered and updated procedures documentation for special loads based on the rigging/loading solutions their loadmasters/SCAFs develop, allowing for repeatability and improvement of special loads handling processes.

Operators should avoid assuming premises or making educated guesses regarding general characteristics of the special load, as incidents/accidents could result in worst problems than the ones being solved with the freight operation.

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A GENERAL CHECKLIST FOR SPECIAL LOADS

Knowledge of procedures and good practices			
1.	Is the loadmaster trained in the general process of cargo preparation, loading and restraint?	□Yes	□No (A.1, A.2)
2.	Is the loadmaster trained in the process of cargo preparation, loading and restraint for special loads? Civil: knowledge of FAA SAFO 13005, 13008, AC 120-85B and company's training materials Military: according to the force's operational doctrine	□Yes	□No (A.1, A.2)
Note: It is suggested for the loadmaster to consult previous lessons learned associated with the transport of this type of special load prior to cargo preparation, loading and restraint, as well as registering any new lesson obtained from this operation.			
Safe of flight for special cargo			
3.	Has the special load been assessed by its manufacturer and/or supplier regarding its transportability by air considering the associated load factors? Load factors according to aircraft operational manual(s)	□Yes (skip 3.1)	□No (A.3)
3.1.	Does the special cargo inspection show any risk of components detaching with possibility of affecting weight and balance?	□Yes (A.0)	□No
Cargo attachment points for restraint, Proper restraint of cargo			
4.	Has the loadmaster assessed that force components from proposed TDEs meet the special load inertial forces for the associated load factors in all directions? Load factors according to aircraft operational manual(s)	□Yes	□No (A.4)
5.	Has the loadmaster assessed and approved the strength of the attachment points for TDEs at the aircraft for the proposed tiedown layout considering the associated load factors? Load factors according to aircraft operational manual(s)	□Yes	□No (A.4)
Between 6.1 and 6.2, choose the one that fits the special load rigging scenario inside the aircraft:			
6.1	Has the loadmaster assessed and approved the strength of the attachment points for TDEs at the special load for the proposed tiedown layout considering the associated load factors? Load factors according to aircraft operational manual(s); strength of payload hardpoints per manufacturer and/or supplier instructions	□Yes	□No (A.4)
6.2.	Can the special load be properly contained by standard TDEs (nets, straps, etc.) without the use of hardpoints at the cargo considering the associated load factors? Load factors according to aircraft operational manual(s)	□Yes	□No (A.0)
Clearance to aircraft structure			
7.	Does cargo clearance to aircraft structure respects the limits detailed on the aircraft operational manual?	□Yes	□No (A.0)
Floor load limits			
8.	Do the vertical inertial loads resulting from the payload weight and associated load factor meet floor load limits detailed on the aircraft operational manual? Load factors according to aircraft operational manual(s); For bulk loads, consider the use of shoring per operational manual(s) when necessary.	□Yes	□No (A.0)

Associated Actions:

A0. DO NOT TRANSPORT.

A1. Redo cargo preparation, loading and restraint with trained personnel.

A2. Freight company to review internal processes regarding preparation and availability of personnel.

A3. The freighter should not guarantee cargo proper functioning after delivery.

A4. Recalculate tiedown layout taking into consideration strength of the attachment points.