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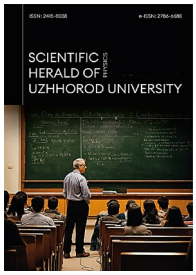


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# Introduction of fire-resistant containers into airfreight

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## Abstract

**Relevance.** Currently, the standardization at the international level has reached a high stage in the aviation industry. The high requirements for standardization of airfreight refer to the safety and punctuality of air travel.

**Purpose.** The purpose of this study was to modernize and improve the technology of consolidation of dangerous goods into fire-resistant unit load device containers, which will reduce the risk of fire spread, and enable the crew to make a landing in the event of an incident.

**Methodology.** The basis of the methodological approach in this study is a combination of system analysis of the main areas of the introduction of fire-resistant containers in modern air transport, with an analytical investigation

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of the main areas of modernization of fire-resistant containers intended for the transportation of dangerous goods, which in the future will contribute to a significant reduction in the risks of fires during air transportation and other emergencies that may cause forced landings of air transport.

**Results.** It was determined that the use of fire-resistant containers reduces fuel costs and environmental improvements by minimizing carbon dioxide emissions into the atmosphere.

**Conclusions.** Thus, the developers of modern refractory materials used in the manufacture of air cargo containers have broad prospects. In addition, the use of such containers will improve working conditions due to their environmental friendliness.

**Keywords:** logistics; transportation; safety standards; aviation; aircraft.

## Introduction

Airfreight is an important part of the cargo transportation industry. The importance of airfreight for the entire sphere of business activity is evidenced by the statistics of the International Air Transport Association (IATA), according to which the air cargo represents more than 35% of global trade by value, taking part in international trade [1]. IATA establishes not only the rules for the air cargo transportation and relations between participants in the air cargo chain, such as the shipper, the agent for airfreight, the agent for ground handling of cargo, carriers, consignees of air transportation, but also strict requirements for the qualification of airfreight agents in the process of transporting goods by air, accompanying documentation [2-5].

Teijin Aramid [6] and MACRO Industries [7] have entered into cooperation agreements in the joint development, manufacturing, and commercialization of more durable and fire-resistant containers for airfreight. The ultra-strong and lightweight Twaron fiber will be used to create new types of Unit Load Devices (ULDs) – MACRO-Lite ULD, which meet the high safety standards in aviation. Teijin Aramid is a subsidiary of Teijin Group and a world leader in aramids [6]. Its aramid products Twaron®, Sulfron®, Teijinconex®, Technora® and Ultra High Molecular Weight Polyethylene Endumax® show their value, where strength, sustainability, safety, heat resistance, or low weight is needed. The company's products are used in a wide variety of areas, including automotive, ballistic protection, marine vessels, civil engineering, protective clothing, ropes, fiber optic cables, oil and gas production. These high-performance materials are manufactured in factories in the Netherlands and Japan [8].

Teijin is a technology-driven global group offering advanced solutions in the areas of sustainable transportation, information and electronics, safety and protection, environment and energy, and healthcare. Its main fields of operation are high-performance fibers such as aramid, carbon fibers and composites, healthcare, films, resin and plastic processing, polyester fibers, sale of fiber products, and information technology (IT) [9-13]. The group includes about 150 companies and approximately 16,000 employees in more than 20 countries around the world. In the fiscal year ended March 31, 2015, the group's total sales amounted to 6.6 billion USD and total assets amounted to 6.9 billion USD [8]. The agreement with MACRO Industries represents Teijin Aramid's goal to collaborate with partners and participate in a global ecosystem where people work with Twaron.

MACRO Industries [7] is a private technology company that engages in research and development with a focus on materials and construction. The word "MACRO" in the name reflects the character of the people at the head of the company: their experience, loyalty, versatility, and practicality. The MACRO implementation team is a highly qualified and motivated group that continues to bring the latest technical solutions to life. MACRO is committed to the continuous implementation of its global ideas and goals for the development, improvement, and application of traditional and revolutionary technologies in transport, materials, residential environment, and defense industries. MACRO Industries is certified according to ISO 9001:2008 to AS9100 Rev C [14] and manufactures special products for the composite, aerospace, and defense industries, including cargo aviation and rail transportation at its sites in Kansas and Alabama [15; 16].

The purpose of this study is to analyses upgraded ULD fire-resistant containers for the transport of dangerous goods, which should reduce the risk of in-flight fires and provide the possibility of an aircraft emergency landing in the event of an incident.

## Materials and Methods

The study was preceded by the creation of a qualitative theoretical base, which includes the findings of a number of research papers devoted to the investigation of problematic issues related to the design features of modern fire-resistant containers used in airfreight. To create the most objective and qualitative picture of research, and to facilitate the perception of the information provided, all the developments of researchers from other countries have been translated into English. This research was carried out in several key stages. At the first stage, a theoretical basis was set, including the results of studies of the key design features of fire-resistant containers (MACRO-Lite ULD), currently used in air cargo. Based on the information received, a systematic analysis of the main areas of the introduction of fire-resistant containers in modern air transport was carried out, the basis for which was the identification of the main features of their design, which are of key importance in terms of the practical

application of these containers for the air transportation of dangerous goods.

At the next stage, an analytical study of the key areas of modernization of fire-resistant containers intended for the transportation of dangerous goods was conducted, which in the long term will contribute to a significant reduction in the risks of in-flight fires, and other emergencies that may cause forced landings of air transport during the transportation of these containers. A graphical representation of the extent to which the design features of fire-resistant containers affect the safety of airfreight traffic is given, and modern design materials which are used in the manufacture of this type of container and must ensure their high strength and performance characteristics are described.

In addition, the main technical characteristics of the highly functional chemical fiber and the leading para-aramid product of the company Teijin Aramid – Twaron are presented, and the main aspects of the practical application of fire-resistant containers MACRO-Lite are described. Real images of the upgraded MACRO-Lite ULD containers are presented, which have shown good results in practical use in airfreight, as an alternative to modern polycarbonate structures and the typical aluminum ULD containers. In addition, this stage included a comparative analysis of the results obtained with the results and conclusions of researchers who conducted independent studies on the prospects for the introduction of fire-resistant containers in modern air transport, which generally contributes to the refinement of the results of this study. At the final stage of this study, conclusions were formulated based on the findings, reflecting the real prospects for the introduction of fire-resistant containers in airfreight today.

## Results and Discussion

### Container freight in modern aviation transport

Air container freight is not only the most modern but also the most cost-effective way of transporting cargo. Freight containers in air transport are actively used both on domestic and international airlines. A modern airfreight container is brought to certain standards, which provides transport of bulk goods by air, while simultaneously acting as a container, the final place of storage of the transported cargo and a transport unit of multiple-use equipment. According to the provisions of the ISO 830:1999 [17] standard, a freight container that may be used in air traffic is to be understood as a container:

- of a permanent character and accordingly strong enough to be suitable for repeated use;
- specially designed to facilitate the carriage of goods by one or more modes of transport, without intermediate reloading;
- fitted with devices permitting its ready handling, particularly its transfer from one mode of transport to another;
- so designed as to be easy to fill and empty;
- having an internal volume of 1 m3 or more.

The presented definition of a freight container implies that it can be used as a removable part of a modern aircraft, whereby the freight container must be adapted to the mechanized process of loading and unloading from the aircraft into another type of vehicle and vice versa. The dimensions of modern freight containers and their capacity are fully adapted to the load-carrying capacities and dimensions of the vehicles used today, while the strength and design must fully guarantee the integrity of the cargo during air transportation for a predetermined period of service. Operation of airfreight containers is possible in the temperature range from -60 to +70°C. All existing types of freight containers are standardized by gross weight, overall dimensions, connecting dimensions, as well as by the design features of devices for mounting them on rolling stock of railway and road vehicles, and for the gripping devices of loading and unloading machines. This feature allows for multimodal transport using various means of transport to realize the “door-to-door” principle known in logistics, while the time and cost implications of this principle are reduced to a minimum.

Container freight in modern air transport is subject to strict control of all levels of compliance with specific safety parameters of container freight operation, among which compliance with fire safety requirements is a prerequisite for deciding whether a container may be used in air transportation. Such a condition is achieved through the use of special structural materials in the manufacture of freight containers which offer a high level of fire resistance under external influences. At the same time, the sustainability of the material used in the manufacture of containers and its ability to withstand a large number of loading and unloading cycles without mechanical damage is also of particular importance. These factors are of fundamental importance in terms of container freight safety, as well as reducing the risk of emergencies occurring during air flights caused by spontaneous ignition of the container material, which would necessitate an emergency landing of the aircraft and, in general, adversely affect the overall safety of container freight by air.

### Design features of MACRO-Lite ULD fire-resistant containers

Currently, the standardization at the international level has reached a high stage in the aviation industry. The high requirements for standardization of airfreight refer to the safety and punctuality of air travel [1; 18]. Regulation of cargo air transport is also subject to equipment used for loading and cargo (ULD), documentation required for transportation (Air Way Bill), electronic standards for information exchange between stakeholders in the transportation process (Figure 1).

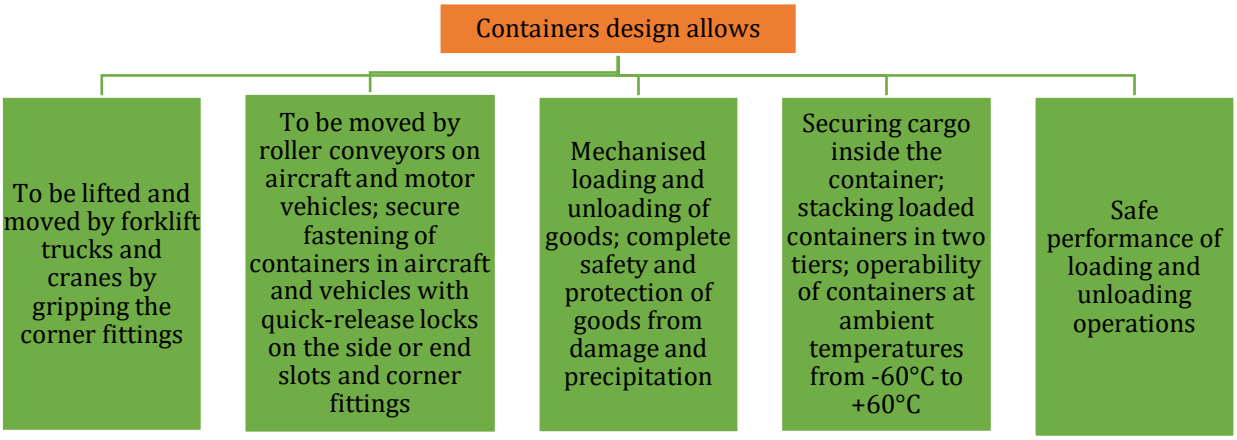


**Figure 1.** Container construction

**Source:** compiled by the authors

After a series of lengthy negotiations between Teijin Aramid and MACRO Industries, an agreement was reached on long-term cooperation in the direction of joint development, manufacturing, and commercialization of fire-resistant high-strength containers intended for their use in airfreight operations. The ultra-lightweight Twaron fiber, which has increased strength indicators, will find wide practical application in creating new types of ULD, which must meet today's high safety standards in aviation. The agreement reached with MACRO Industries is a clear reflection of Teijin Aramid's desire to achieve mutual understanding and cooperate with partners in the context of the implementation of a global ecosystem with the active use of Twaron in all areas of activity at the present stage. The MACRO-Lite ULD containers are designed using the next generation reinforced composite materials and, as recent tests have shown, making the containers fire-resistant for over 4 hours [19-21]. The MACRO-Lite material is ideal for replacing aluminum panels in existing air containers and allows fleet operators to easily upgrade their ULDs. Upgrading external surfaces with MACRO-Lite skins also reduces the cost and frequency of repairs. The MACRO-Lite ULD has all the benefits of a high-performance composite material but behaves like sheet metal making it more durable and cutting the costs for servicing and maintenance [22; 23]. It is estimated that there are about 900000 aluminum ULDs in circulation globally that can be replaced with MACRO-Lite metal panels [24-26].

ULDs with MACRO-Lite panels can contain a fire with a peak temperature of 1200°F (648.9°C) for four hours, whereas aluminum containers could only do so for a few minutes (Figure 2). This extra time is critical to ensure the safe landing of the crew in the event of an in-flight fire. In addition, this improved fire resistance will allow cargo carriers to meet the likely safety restrictions on the transportation of lithium-ion batteries [19; 27].


**Figure 2.** ULD with MACRO-Lite panels

**Source:** compiled by the authors

MACRO-Lite addresses the air transportation industry's increasing concerns over fire hazards and stricter safety regulations for the transport of lithium-ion batteries. Since 1 January 2015, the International Civil Aviation Organisation (ICAO) [28] has banned airlines from transporting lithium-ion batteries as cargo in the belly hold of passenger aircraft, and many airlines no longer accept these batteries as cargo.

Lithium-ion batteries, transported as cargo or used by passengers to power their electronic devices, have been the cause of a number of onboard fires [29]. 5.5 billion USD worth of lithium-ion batteries are legally produced each year, and now they can only be transported by sea and overland, making these fire-resistant containers a game-changer for the airfreight industry. The new ULDs are made of MACRO-Lite panels stretched across an aluminum frame. MACRO-Lite is a fiber-reinforced plastic composite similar to that used in ballistic body armor. The units work by depriving a fire of oxygen. During the tests, they withstood temperatures of 1200 degrees for up to four hours.

**Special features of Teijin Aramid's Twaron fiber**

Twaron is a high-performance chemical fiber and the leading para-aramid product of Teijin Aramid. It features a unique combination of mechanical properties, chemical resistance, exceptional durability and thermal stability [30-32]. Twaron's aramid fibers are highly recognized in many industries for the benefits they offer in a very wide range of specialty products. The company Teijin Aramid has more than 30 years of experience in aramid production. This speaks not only about the technical perfection of the company's products but also about the accumulated vast amount of knowledge and experience that can be used in the implementation of joint developments. The company has always worked closely with their customers and clients to ensure that the products meet the specific requirements of each application. Twaron's para-aramid fiber provides a wealth of benefits in the widest range of applications. The products are offered in various forms depending on the specific purpose: filament yarn, staple fiber, short-cut fiber, powder, pulp, fabrics and laminates.

Twaron demonstrates a unique combination of features that make them stand out from other synthetic fibers:

– high strength (excellent strength-weight properties);
– high modulus of elasticity;
– high dimensional stability;
– exceptional heat, cut and chemical resistance;
– no melting point (destruction starts only at 500°C);
– low flammability;
– no electrical conductivity.

These characteristics are the result of a 100% procrystalline structure with molecular chains preferentially oriented along the fiber axis. [33; 34]. Twaron is used in a wide range of applications with high material requirements: ballistic protection products; civil engineering products; composites; cut protection; elastomer reinforcement; engineering plastics; thermal protection products; friction products; optical fiber cables; reinforced thermoplastic pipes; ropes and cables; sealing materials; specialty technical paper; tyres.

**Application of MACRO-Lite fire-resistant containers**

The study of MACRO-Lite fire-resistant containers was launched to improve the safety of the United Parcel Service (UPS) company, specializing in express delivery and logistics (Figure 3). Along with the fire-resistant properties, the panels are a more durable and lightweight option than current polycarbonate designs Maintaining the UPS safety strategy, the new containers also resulted in fuel savings of over 1287040 liters and the avoidance of 3200 tons of $CO_2$ emissions. In addition, the new UPS containers proved to be more durable, resulting in a 69% reduction in container repair costs, which, in turn, had a positive effect on the economics of airfreight, using a revolutionary alternative to polycarbonate structures.


**Figure 3.** UPS Containers

**Source:** compiled by the authors

purchased these containers as part of its "Weight Watchers" program, also saved around 800000 kilograms of fuel and reduced $CO_2$ emissions to 2500 tons per year.

## Conclusions

Based on test results, airlines using the upgraded MACRO-Lite ULD containers have confirmed that the use of Twaron para-aramid fiber in these containers makes them significantly lighter and more durable than standard aluminum ULDs. Analysis showed that Teijin Aramid's extra strong and lightweight Twaron fiber is highly heat-resistant and 5 times stronger than steel of the same weight. It can be concluded that the use of these containers leads to a reduction in fuel costs and environmental improvements by minimizing carbon dioxide emissions into the atmosphere. The use of these containers will improve working conditions due to their sustainability. The results clearly show that the introduction of fire-resistant containers in air cargo has a tangible economic effect, which is reflected in reduced costs for fuel and maintenance, the latter being possible as a result of the increased resistance of cargo containers to external aggressive environments through the use of high-tech materials with high strength characteristics in their design.

This leads to broad prospects that open up to the developers of modern refractory materials used in the manufacture of aircraft cargo containers. Simultaneous compliance with the requirements of high strength of structural materials, along with the mandatory provision of their sustainability and fire resistance, are a prerequisite for the manufacture of cargo containers in compliance with the main parameters of their high quality, and the feasibility of their practical use as an alternative to aluminum. Further theoretical and practical developments in the search for efficient and high-tech material options for use in the manufacture of fire-resistant air freight containers will contribute to new, stronger, more resistant to external aggressive environments and cost-effective airfreight containers, which ultimately will be of fundamental importance for the safety and economics of airfreight.

## Acknowledgements

None.

## Conflict of Interest

None.

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# Впровадження вогнестійких контейнерів в авіаперевезеннях

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**Анотація**

**Актуальність.** Сьогодні стандартизація на міжнародному рівні досягла високого рівня в авіаційній галузі. Високі вимоги до стандартизації авіаперевезень стосуються безпеки та пунктуальності авіаперевезень.

**Мета.** Метою даного дослідження була модернізація та удосконалення технології консолідації небезпечних вантажів у вогнестійкі контейнери одиничного завантаження, що дозволить зменшити ризик розповсюдження пожежі, а також надасть можливість екіпажу здійснити посадку у разі виникнення інциденту.

**Методологія.** Основою методологічного підходу в даному дослідженні є поєднання системного аналізу основних напрямів впровадження вогнестійких контейнерів на сучасному авіаційному транспорті, з аналітичним дослідженням основних напрямів модернізації вогнестійких контейнерів, призначених для перевезення небезпечних вантажів, що в перспективі сприятиме суттєвому зниженню ризиків виникнення пожеж під час авіаційних перевезень та інших надзвичайних ситуацій, які можуть стати причиною вимушених посадок повітряного транспорту.

**Результати.** Визначено, що використання вогнестійких контейнерів сприяє зниженню витрат на паливо та покращенню екологічної ситуації за рахунок мінімізації викидів вуглекислого газу в атмосферу.

**Висновки.** Таким чином, перед розробниками сучасних вогнетривких матеріалів, що використовуються при виготовленні авіаційних вантажних контейнерів, відкриваються широкі перспективи. Крім того, використання таких контейнерів дозволить поліпшити умови праці завдяки їхній екологічності.

**Ключові слова:** логістика, перевезення, стандарти безпеки, авіація, літаки.