Fuel and Emission Savings from the use of Lightweight Composite Unit Load Devices

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Abstract: This paper aims to explore the benefits and feasibility of lightweight composite Unit Load Devices (ULDs) as an alternative to conventional aluminum and steel ULDs. The advantages of such ULDs are quantitatively highlighted through determination of potential fuel, cost, and emission savings from the reduced weight of the device. Case studies are performed upon Boeing 777-300ER and 737-800 aircraft through replacement of LD3 and LD7 devices. Analysis indicates that maximum theoretical cost and emission savings of AUD 183,828 and 24.62 tonnes per aircraft, per year can be achieved. The analysis indicates that the potential higher upfront purchasing cost of lightweight ULDs can be quickly offset by the weight savings of said devices.

Keywords: Unit Load Device, Fuel and Emissions, Sustainability, Aviation

Nomenclature

ULD	: Unit Load Device
IATA	: International Air Transport Association
FAA	: Federal Aviation Authority
TSO	: Technical Standard Orders
CFRP	: Carbon Fibre Reinforced Polymer
AUD	: Australian Dollar
ROI	: Return on Investment

1. Introduction

Over the last 60 years, the aviation industry has decreased the cost of a flight per person by 70 % (International Energy Agency, 2020). To achieve this, countless improvements in design and operation were required across the industry. One key contributor to these advancements are improvements in material science, enabling aircraft designers to decrease weight with a corresponding increase in efficiency. An increasing trend of conventional aluminium and steel structures being replaced by composites materials in the aviation industry can be observed. Composite materials are able to outperform metals in many applications, being stronger, stiffer, and lighter Huang (2000). Currently, a noticeable trend from manufacturers such as AEROTUF and Nordisk is utilising composites to design lightweight Unit Load Devices (ULDs). These new ULDs, despite having a larger upfront initial purchasing cost, quickly offset the additional requirements in operation with their significantly decreased weight, resulting in decreased fuel consumption and emission production. This work forms a preliminary analysis of the potential monetary, fuel, and emission savings that result from the implementation of lightweight composite ULDs. Case studies are performed upon Boeing 777-300ER and 737-800 aircraft, representative of widebody and narrowbody aircraft, respectively.

2. Background

ULDs are storage devices, often in the shape of boxes or pallets, that are designed as a modular and standardised container for air cargo transport. A variety of ULDs exist to transport various means of cargo that range from simple strapped containers for mail transport through to thermally controlled containers for the transport of sensitive medical equipment. ULDs are typically rectangular in design with minor modifications made to their structure to allow them to nest and tesselate within cargo regions of the aircraft fuselage, as shown in Fig. 1. To facilitate the generalised nature of ULDs, each ULD conforms to a design designation and is given a model number. As ULDs are often closely integrated with the structure of the aircraft, they require certification in accordance with IATA and FAA Technical Standard Orders (TSOs). In this analysis, the nominal properties of type LD3 and LD7 devices have been used for the analysis of the widebody and narrowbody aircraft, respectively.

ULDs are typically composed of a simple monocoque design consisting of an aluminium or steel frame, aluminium base, and aluminium sheet cladding. Devices may likewise be equipped with doors for ease of access that are of triple strap, soft, and, hard designs. All serve a similar purpose and are typically composed of high tensile nylon webbing or aluminium sheets.

Fig. 1. LD3 containers loaded into an Airbus A300 (Wikipedia, NA).

The tare mass of a conventional aluminium ULD varies slightly between manufacturers but with nominal values of 82 kg and 210 kg for LD3, and LD7 devices, respectively. Variability in the mass of the containers, which are standardised upon their geometry, is typically due to the choice of alloy employed in construction with 7000 or 2000 series aluminium being the most common. Thinner wall thicknesses are employed for the cladding and frame to reduce the weight whilst the base of the structure is over-engineered to accommodate for the variability in cargo (William, 2016)

Several manufacturers are exploring the potential use of lightweight composite materials for the reduction of ULD mass. Of these, AEROTUF (2021)have marketed their AeroBox design. The AeroBox is based upon the AKE LD3 type with a tare mass of 59 kg. Composed of composite honeycomb sandwich panels, the design is approved for use under TSOC90 standards by the FAA and EASA (US Department of Transportation, 2011). The AeroBox, whilst significantly lighter than its conventional aluminium counterpart, is touted as offering "… maximum durability…" indicating safety factors commensurate with ongoing and rigorous operation, indicative of even greater potential mass savings (AEROTUF, 2021). Nordisk Aviation Products (2021) have likewise marketed their Nordisk Ultralight AKE LD3 ULD composed of a 7000 series aluminium frame and unspecified composite shell with a tare mass of 49 kg.

Very little academic literature has explored the use lightweight composite materials for ULD construction. William et al. (2016) explored the design of an ultra-lightweight LD3 ULD using Carbon Fibre Reinforced Polymer (CFRP) skinned, Nomex honeycomb sandwich panels. Analytical design was completed that indicated compliance with the TSO C90 standard (US Department of Transportation, 2011). The theoretically compliant ULD design possessed a mass of 20 kg, a 75 % reduction over a convention ULD. William et al. (2016) design, whilst exceptionally lightweight, was not engineered towards durability and hence represents a minimum theoretical limit upon the use of composite materials for ULD design.

Overall, the design of such a lightweight ULD device must balance mass reduction with durability and cost. High performance composite materials remain significantly more expensive than conventional metallic alloys, such as aluminium, and must hence be considered in the design. Overall, the greater interest in composite ULDs stems from the trend to increasingly implement composite materials in aircraft design. If the results of said implementation are a guide for the successfulness of composite ULDs then there is great promise for their application.

3. Methodology

The majority of lightweight composite ULD Research and Development (R&D) has targeted the LD3 type due to their common occurrence and use in larger widebody aircraft that are typically employed for long haul flights where the effects of mass savings would be most dominant. As such, little work has been completed towards the R&D of LD7s, and hence, little data exists regarding the potentially improved tare mass of such devices.

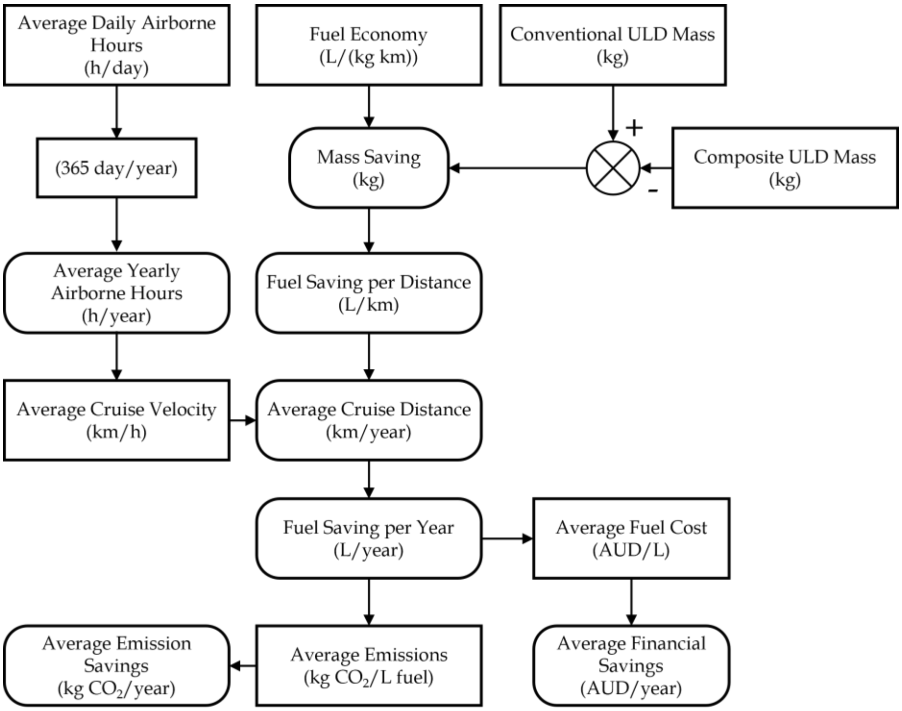

Fig. 2. The logic flow for determination of the financial and emissions savings.

As such, the estimated tare mass of a lightweight composite LD7 ULD has been extrapolated from existing LD3 data. This extrapolation estimates the tare mass of the LD7 as 109.25 kg.

The logical flow for the quantitative analysis is illustrated in Fig. 2. This preliminary approach has used data source from the Global Airline Industry Program to determine the average daily airborne hours (Massachussets Institute of Technology, NA). Cruise velocity for the 777-300ER and 737-800 were sourced from their airport planning manuals (Boeing, 2021). The large variability in flight paths has not been accounted for in this study. Moreover, climb, descent, and loiter have not been assessed and hence, any conclusions of the study must be adopted conservatively.

In determining typical aircraft fuel economics, the payload-range curves for both case study aircraft have been extracted from their respective airport planning manuals (Boeing, 2021). These curves were extracted through digitization via discrete data point extraction. As these data points were extracted manually, it is noteworthy to consider human error that may have arisen from said process. The results of the digitization process are illustrated in Fig. 3 and Fig. 4.

A linear regression is fit to the digitized data from which the gradient of the line is taken as the estimated aircraft fuel efficiency. A zero-intercept gradient has been enforced. The resulting fuel efficiencies are estimated as 62.7 litres per kilogram per kilometre and 40.4 litres per kilogram per kilometre for the 737-800 and 777-300ER, respectively. Pearson's linear correlation coefficients of 0.9934 and 0.9915 for the 737-800 and 777-300ER, respectively, indicate that the digitized data are accurately represented by the linear fit.

Kerosene fuel costs have been obtained from the IndexMundi (2021) and as of May 2021 are 0.426 AUD per litre. Aviation fuel prices are prone to incredible variability and hence, use of a single value introduces large uncertainties and potential error. Moreover, as the cost of kerosene is estimated to double by 2030, any results obtained in this work are likely to underestimate the improved performance from the implementation of lightweight composite ULDs in future years (Federal Aviation Authority, 2021).

Finally, the estimated CO_2 production per litre of fuel has been taken from Department of Infrastructure and Regional Development (2017) at a value of 2.51 kg per litre.

4. Results and Discussion

The results of the analysis are compiled in Table 1 and Table 2 for the 737-800 (LD7) and 777-800ER (LD3), respectively. The analysis indicates that implementation of the LD7 ULD upon the 737-800 would result in savings of AUD 6857 per ULD per year, corresponding to an overall saving of AUD 68,570 per aircraft per year. Implementation likewise results in an emission reduction of 40,400 kg of CO_2 per ULD per year, corresponding to an overall saving of 404,000 kg of CO_2 per aircraft per year.

Analysis upon the 777-300ER was completed in considering the three different LD7 designs from Nordisk Aviation Products (2021), AEROTUF (2021), and William et al. (2016). The maximum theoretical limit obtained from the design of William et al. (2016) is a financial saving of AUD 183,300 per aircraft per year and emission reduction of 1,083,000 kg of CO_2 per aircraft per year.

These results are encouraging, especially when considering the manufacturing cost of such lightweight composite ULDs is approximately AUD 10,000. As such, the Return on Investment (RoI) of the composite ULD is typically less than four years. Furthermore, increasing fuel prices in coming years will accelerate the RoI and promote the implementation of such devices.

Moreover, in considering the increasingly strict emissions reduction standards for the aviation industry, the implementation of lightweight composite ULDs is aligned with the goal of improving the average aircraft fuel efficiency of aircraft by 40 – 50 % by 2050 (Ranasinghe et al., 2019).

Fig. 3. Payload-fuel efficiency of the Boeing 737-800.

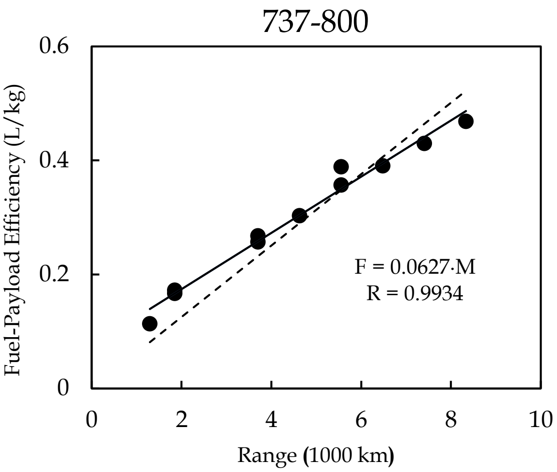

Fig. 4. Payload-fuel efficiency of the Boeing 777-300ER.

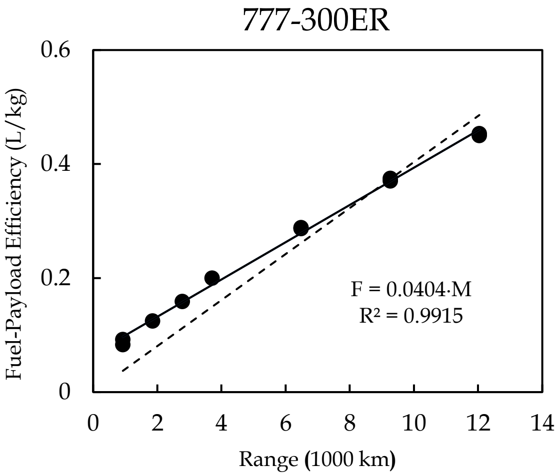

Table 1. Savings from LD7 ULD implementation upon the Boeing 737-800.

Parameter	Unit	Value
Tare Mass	kg	123.9
Mass Saving	kg	86.10
ULDs per Aircraft	ULD/aircraft	10
Fuel Saving per Year	L/year	16,100
Average Financial Saving per ULD	AUD/(ULD year)	6,857
Average Emission Saving per ULD	kg CO_2/(ULD year)	40,400
Average Financial Saving per Aircraft	AUD/(aircraft year)	68,570
Average Emission Saving per Aircraft	kg CO_2/(aircraft year)	404,000

Table 2 Savings from ULD LD3 implementation upon the Boeing 777-300ER using Nordisk Aviation Products (2021), AEROTUF (2021), and William (2016).

Parameter	Unit	Nordisk	AEROTUF	William (2016)
Tare Mass	kg	49.00	59.00	20.00
Mass Saving	kg	34.00	24.00	63.00
ULDs per Aircraft	ULD/aircraft	44		
Fuel Saving per Year	L/year	5,293	3,736	9,807
Average Financial Saving per ULD	AUD/(ULD year)	2,255	1,592	4,178
Average Emission Saving per ULD	kg CO_2/(ULD year)	13,290	9,380	24,620
Average Financial Saving per Aircraft	AUD/(aircraft year)	99,210	70,030	183,800
Average Emission Saving per Aircraft	kg CO_2/(aircraft year)	584,500	412,600	1,083,000

5. Conclusion

This paper has conducted a preliminary quantitative analysis upon the implementation of lightweight composite ULDs. The use of such devices aims to reduce the mass of existing conventional ULDs through the application of advanced materials. Two case studies were conducted upon 777-300ER and 737-800 aircraft, representative of a widebody and narrowbody aircraft, respectively. The analysis conducted utilised nominal operational parameters for these aircraft and examined several commercial composite ULD designs. The results of the study indicated that implementation of such devices would have a large impact towards decreasing the fuel usage of aircraft, resulting in both financial and environmental emission reductions. Whilst a more detailed analysis is required, the preliminary work completed thus far highlights the strong potential in lightweight composite ULD implementation and that greater work should be completed in this field.

References

AEROTUF. 2021. Aerobox [Online]. Available: https://www.aerotuf.com/aerobox/> [Accessed 11 May 2021].

Boeing. 2021. Airport Compatibility - Airplane Characteristics for Airport Planning [Online]. Available: https://www.boeing.com/commercial/airports/plan_manuals.page [Accessed 7 April 2021].

Department of Infrastructure and Regional Development 2017. Managing the Carbon Footprint of Australian Aviation. Canberra: Department of Infrastructure and Regional Development.

Federal Aviation Authority 2021. Forecast uncertainties. Federal Aviation Authority.

Huang, S.-C. A. 2000. An Analysis of Air Passenger Average Trip Lengths and Fare Levels in US Domestic Markets. p.

IndexMundi. 2021. Jet Fuel - Monthly Price (Australian Dollar per Gallon) - Commodity Prices - Price Charts, Data, and News [Online]. IndexMundi. Available: https://www.indexmundi.com/commodities/?commodity=jet fuel&months=12&currency=aud [Accessed 11 May 2021].

International Energy Agency 2020. Aviation. Paris: International Energy Agency.

Massachussets Institute of Technology. NA. Airline Data Project [Online]. Available: http://web.mit.edu/airlinedata/www/Aircraft&Related.html [Accessed 15 May 2021].

Nordisk Aviation Products. 2021. Nordisk UltraLite® AKE [Online]. Available: http://www.nordisk-aviation.com/en/ld containers/nordisk-lite-family/nordisk-ultralite-ake/ [Accessed 4 May 2021].

Ranasinghe, K., Guan, K., Gardi, A. & Sabatini, R. 2019. Review of advanced low-emission technologies for sustainable aviation. Energy, 188, p. 115945.

US Department of Transportation 2011. Cargo Pallets, Nets and Containers (Unit Load Devices). IHS Markit.

Wikipedia. NA. Unit load device [Online]. Available: https://en.wikipedia.org/wiki/Unit_load_device [Accessed 30 October 2021].

William, G. W., Shoukry, S. N., Prucz, J. C. & William, M. M. 2016. Lightweight composite air cargo containers. SAE International Journal of Aerospace, 9, p. 185-189.

William, M. M. 2016. Design of Composite Sandwich Panels for Lightweight Applications in Air Cargo Containers, West Virginia University.