INTERMODAL INTEGRATION OF LARGE VOLUME AIR CARGO

Marin D. Guenov*
***Aerospace Engineering, Cranfield University, Cranfield, Bedford, MK43 0AL, UK**

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Abstract

Proposed is a novel air freight concept for intermodal container transport. The aim is to utilise the standardised (ISO) 20 and 40 foot containers currently in operation. Instead of a completely new, purpose built aircraft which would be too expensive, the baseline airframe considered is the planned Airbus freight configuration, A380-800F. Preliminary calculations show that an aircraft with the capacity and dimensions of A380 can carry up to six 40' or up to fourteen 20' containers as well as combinations of these, depending on load density. Considered are the necessary aircraft modifications, the cost and weigh implications, and also the efficiency of the concept. The conclusion is that such a modification may reduce the payload of the aircraft by about 6%, but the time savings can be very significant. Furthermore, the seamless integration of ISO 20' and 40' containers has the potential to radically change the air cargo business as it could become an integral part of the global manufacturing supply chain. This would extend the traditional air cargo market from perishables, clothing, high value and fragile items to components and even intermediate materials, given economies of scale.

1 Introduction

Cargo handling, including the associated paperwork is widely recognised as a bottleneck which limits the productivity of air shipping. For example, the current mean delivery time of 6.3 days has not changed much for quarter of a century as far as international freight is concerned. Over 25 years ago a NASA study [8] identified that the performance at the node of connection between two or more transportation modes is an important determinant of the degree of possible network optimisation. The same study predicted that "achievement of a viable large-volume air cargo will depend on the following:

a) Use of large containers that can be filled by shippers, surface carriers, or forwarders at off-airport sites.
b) Complete compatibility with surface freight systems to allow efficient ground interface and connecting surface for onward freight movements.
c) Cargo aircraft designed specifically for freight service and uncompromised by passenger considerations."

It appears now that these conclusions were ahead of its time. The focus of air freight has remained predominantly on low volume, high value items which could be combined with the passenger traffic.

The motivation behind this paper is to show that the business and technology drivers have changed and have become sufficiently strong to justify the return to issues a)-c) above. The objective is to introduce an enabling integration concept which utilises ISO 20' and 40' containers. The concept, named ICON, is shown in Fig. 1 and is based on a large wide body aircraft such as the forthcoming freight configuration of Airbus A380F.

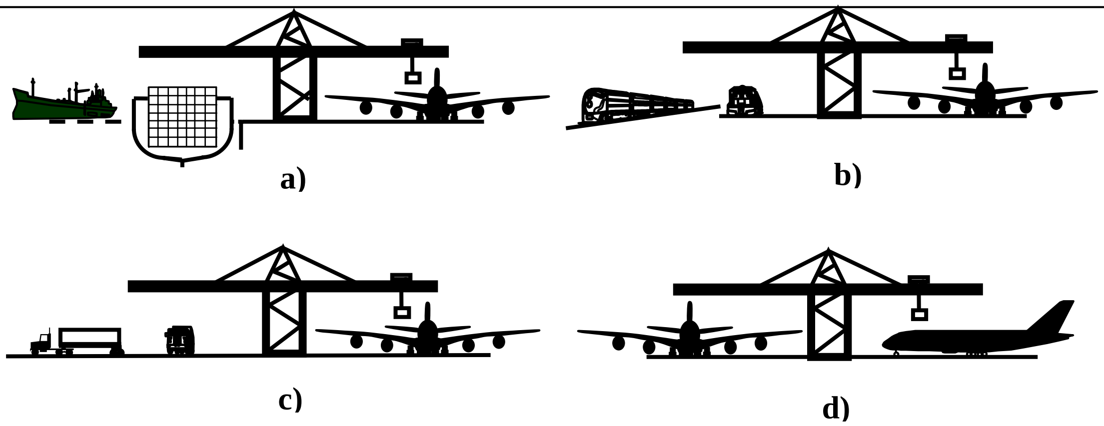

Fig.1. ICON: An integrated concept for air cargo: a) marine to air; b) rail to air; c) road to air; d) air to air.

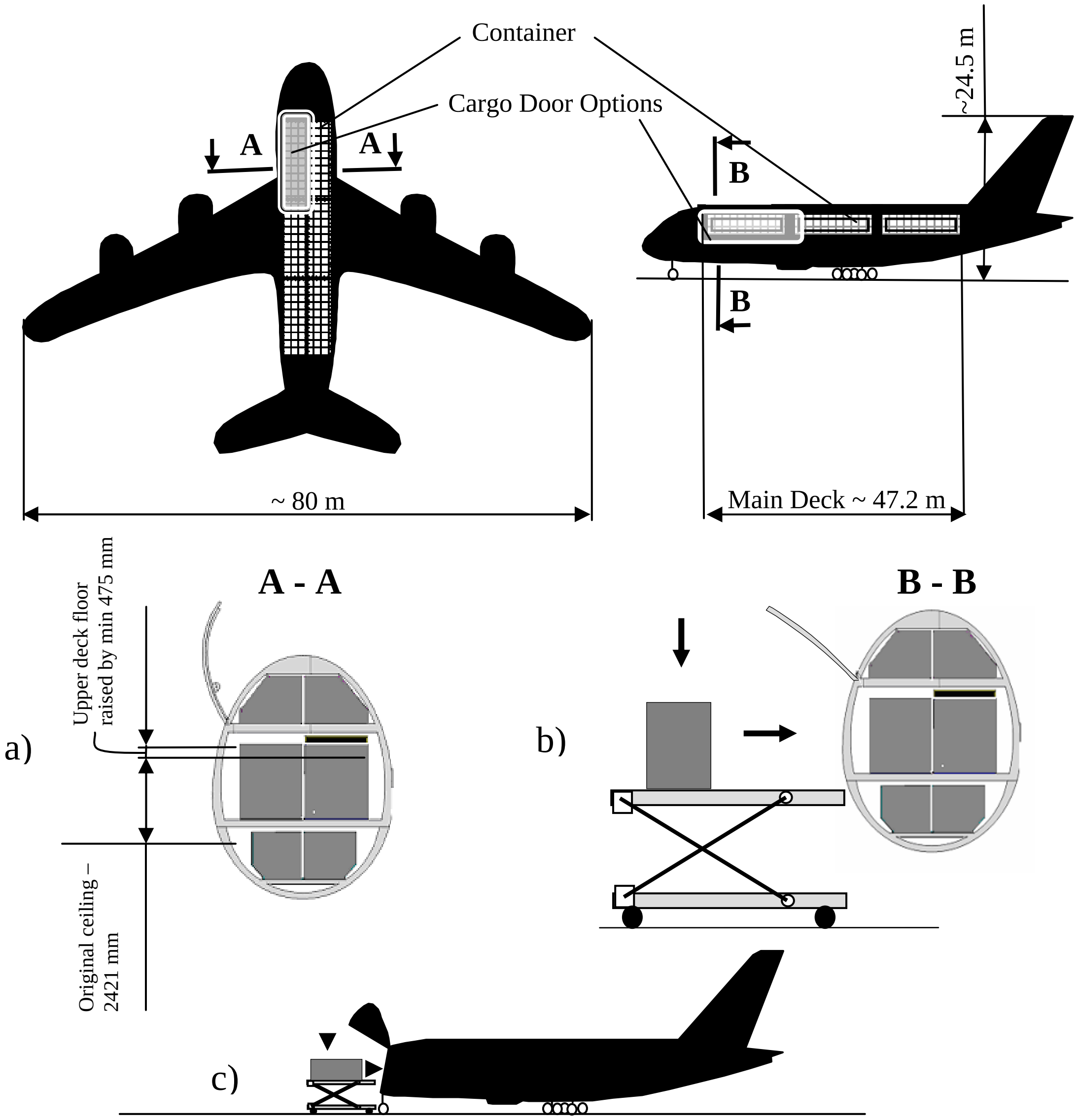

Fig.2. Large cut-outs for loading and unloading of 20’ and 40’ containers: a) cargo door located on top of fuselage; b) side cargo door; c) nose loading.

In the following section the business drivers for air cargo integration are outlined. An Engineering Perspective of ICON is presented in Section 3. Analysis of the potential efficiency (time savings) of ICON is presented in Section 4. Section 5 briefly discusses issues which are outside the scope of this paper, such as cargo hubs and ground infrastructure, but are nevertheless, important for the viability of the concept. Finally conclusions are drawn.

2 Business Drivers

Competitive advantage in the modern economy is associated not least with the effectiveness and the efficiency of the globally integrated supply chains. This is particularly true for the speed driven high-tech industries where high-value products and components need to be rapidly delivered by air to and from areas where new high-tech manufacturing processes are combined with low labour costs and high product standards. A recent empirical study by Kasadra et al [7] found that air cargo is instrumental to business competitiveness and economic development. Policy variables such as liberalisation, quality of customs and corruption were found to play significant roles, both directly and indirectly. The same report quotes successful case studies including companies such as Dell, Phillips and FedEx. The first two were able to optimise their supply chains and sourcing operations in Malaysia and Thailand, respectively, which was directly beneficial to the local economies. FedEx established its Asia hub in Subic Bay in 1995 and since then the area has attracted two hindered international companies. Foreign direct investment in the area rose from USD355 million in 1993 to USD 2.4 billion in 2002. Similar economic impacts were quoted for the UPS main U.S. hub in Louisville, Kentucky.

Despite this evidence, the cargo business model has proven resistant to change, especially the cargo divisions of the scheduled carriers which tend to be operated more as a by-product of the passenger focused operations. This business model seems to be justified by the fact that currently air cargo accounts approximately for 40 percent of the value of world trade, while in terms of weight and volume the percentages are below two [10]. There are signs, however, that the air cargo business is undergoing a structural change. This is evident in the increased share of the large Integrators in agile logistics. The Unisys report [10] speculates that the air cargo business of the future may borrow elements of the Low Cost Carriers (LCC) model in the passenger market. The LCC's success was based mainly on the simplified and transparent processes, high aircraft utilisation and low cost airports. Likewise the new business model for cargo services may not necessarily use the traditional gateway airport airports. Secondary airports with either no or few night operation restrictions can become hubs and could deliver cheaper and quicker ground handling times [10]. The large airframe manufacturers also seem to be optimistic. The medium and long term forecasts of Airbus [1] and Boeing [3] generally agree that the world air cargo traffic will expand with approximately 6% for the next two decades, tripling over current traffic level. The strongest average annual growth is predicted for the Asian cargo markets. It is expected that the trend of larger freighters replacing smaller cargo aircraft will continue during the next 20 years. Medium, wide-body and large cargo aircraft will lead fleet additions, growing from an overall share of 44% to 60% as traffic continues to build on long haul, international trade lanes [3]. Due to the different growth rates of passenger and freight traffic, the volume available for freight on a given route is bound to become insufficient. This adds to the fundamental appeal of dedicated freighters in terms of routes, schedule seasonality and service, which cannot be matched by passenger aircraft under-floor areas.

One of the advantages of large freighters such as A380F is that these can not only provide the volumetric payload necessary, but also stimulate traffic by lowering the cost per tonne threshold bellow which other modes are more economical. Considering the above figures and forecasts, it is reasonable to assume that the proposed air cargo integration (Fig. 1) of the 20' and 40' containers could contribute to a further economic growth.

3 The Airframe

Due to lack of existing airframes of appropriate size, the analysis in this section is based on the planned A380-843/863F freight version (Fig. 2) which henceforth will be referred to as A380F or A380-800F for brevity. It is assumed that the A380F will be modified in order to accommodate 20’ and 40’ ISO containers without affecting the external fuselage dimensions and shape. The aim of the conceptual study performed on this modification was to give answers to the following questions:

a) How many 20’ and 40’ ISO containers could be accommodated in the fuselage?
b) What internal modifications and structural reinforcements needed to be made?
c) What would be the effect of the reinforcements in terms of additional weight?
d) What would be the approximate cost of the conversion of the original A380-800F airframe?

3.1 Weight Analysis

The analysis of the publicly available data on *A380* [2] showed that the length and width of the available space on the main deck of the fuselage allows for the accommodation of up to fourteen 20’ containers or a combination of up to six 40’ and two 20’ containers. Since the height of these containers varies between 8’6” (2591mm) and 9’6” (2896mm), the ceiling of the main deck (i.e. the upper deck floor) needs to be raised up by at least 475 mm in order to accommodate all container sizes (see Fig. 2-a) . This solution still allows for the upper and lower decks to be loaded with the original 96x125inch pallets in the upper deck, and LD-3 containers in the lower deck. However, taking into consideration the aircraft’s maximum payload of 150 tonnes and rated mass (full) of up to 32000 kg and 24000 kg, for the 40’ and 20’ containers, respectively, it becomes clear that the loading density and the reinforcement of the floor become a major consideration.

According to the available data on A380F, the maximum weight allowable on the main deck is 126.28t; the length of the deck being 47.2 m. Thus the maximum distributed (running) load is calculated to be 26.3 KN/m. This figure, in turn, is used to calculate the maximum load density when 20’ and 40’ containers are situated on the main deck side by side. The combinations and the calculated loadings and densities are presented in Table 1. The combinations include: two 40’ containers (this combination is shown in Fig. 2), two 20’ containers and one 40’ container, and two 20’ containers. As it can be seen from Table 1, the container loading and the density are relatively low, but are not unusual for air freight, considering that 5,000 cm^3 equals one kg for low density cargo [5].

Two loading configurations are considered for the stress calculations (including the large cut outs), given the available 150t payload of A380F:

Combination	**Container Type**	**Tare Mass per container [kg]**	**Rating (full) per container [kg]**	**Container Loading [%]**	**Load Density [kg/m3]**
2x40’	40' x 8'6"	3,800	30,480	46.9	185.1
2x20’	20' x 8'6"	2,275	24,000	26.8	176.6
1x40’ and	40' x 8'6"	3,800	30,480	34.6	136.6
2x20’	20' x 8'6"	2,275	24,000	34.6	227.8

Table 1 Container loading and load densities.

Note: Containers made from composite materials can be almost half the weight of the steel ones and are not considered in these worse case scenarios.

a) ICON-A. In this configuration the 40’ and 20’ containers are loaded to the limits presented in Table 1, so that the allowable distributed loads on main deck floor are not exceeded. In this case, 114 tones of payload are carried in the big ISO containers. The remaining 36 tones have to be shared between the pallets and LD containers on the upper and lower decks, respectively. With this configuration, the floor does not need to be reinforced.
b) ICON-B. In this configuration the 40’ and 20’ containers are loaded at their rating weight. Hence, the floor of the main deck needs to be reinforced. The possibility to share the 150 tones payload between the 40’ and 20’ containers is taken into account. In this configuration, the aircraft carries only big containers on the main deck, but is still able to adopt the ICON-A configuration.

The worst case scenario of two fully loaded 20’ containers situated side-by-side was considered for the calculation of the distributed loads on the floor of the main deck of ICON-B. This load is subjected to the acceleration induced by the emergency landing condition specified in JAR 25 (*Joint Aviation Requirement 25 – Large Aeroplanes, Change 15,* Joint Aviation Authority, October 2000). For the purposes of this analysis, the case of 6g downward acceleration was considered. The structural analysis was carried out between frames 21 and 95 of the fuselage, which are the boundaries of the main deck. Two reinforcement cases were considered. The first option was to introduce vertical beams under the main deck while the second option was to increase the size of the transverse I-beams of the main deck. The structural analysis showed that the vertical beam design is lighter (the additional weight is 1,050 kg against 1,575 kg for the I-beam enlargement). However, the vertical beam design does not allow for containers to be stored on the lower deck. Only half sized pallets can be loaded, which limits the ability of the ICON-B aircraft to carry a wide range of containers. Furthermore, the manufacturing, engineering and tooling costs are expected to be larger for the vertical beam configuration since it would require more changes to the original design of the A380-800F structure. Additional design and structural analysis was carried out to estimate the weight of the changes required for both configurations. These included: four longitudinal I-beams to carry the loads from the rollers and the restraints on the main deck, the introduction of a large cut-out (which requires reinforcement) for the large cargo door, and the door itself, including the opening mechanism. Two options were considered for the large cargo door, top (Fig. 2-a), and side door (Fig. 2-b). The summary of the weight estimates is presented in Table 2. The additional weight is calculated as percentage of the Operating Weight Empty (OWE) of the A380-800F which is 252 tones.

Concept	**Option**	**Additional Weight (kg)**	**% of A380-800F OWE**
ICON- A			
Main deck distributed load-	Top Door	7,600	3.02%
max 114t	Side Door	6,777	2.69%
ICON- B			
Main deck distributed load-	Top Door	9,175	3.64%
max 150t	Side Door	8,352	3.31%

Table2. Additional weight-summary of weight estimation

The ICON aircraft’s OWE is between 2.7 and 3.7 percent heavier than the original A380-800F, which corresponds to a weight between 6.8 and 9.2 tones. As a result, the maximum payload which an ICON aircraft can carry is reduced from 150t to 141t, which represents 6 percent approximately.
It can be seen from Table 2 that the side door solution is superior in terms of weigh (almost 1t lighter). This is due mainly to the lower stresses on the side of the fuselage which in turn determine the reinforcement needed for the large cut-out. However, considering the whole intermodal (ICON) concept, both options have

advantages and disadvantages. For example the top door design would not require scissor lifts for the loading and unloading of the large containers. This eliminates one expensive piece of equipment, the associate operating costs, and also one extra load transfer operation. On the other hand, the top door design would require a crane with a larger span (outreach), unless the aircraft approaches the crane frontally, as shown on right hand side of Fig. 1-d. One additional advantage of this schema is that it would eliminate the need for either a toll dock crane or a crane with a retractable boom on both sides to clear the high tail fin (24m) of A380. This approach is also suitable for nose loading (Fig. 2-c) which is not discussed in this paper. The top door design may be considered a less safe option due to the possibility of dropping or swinging the container, which can cause damage to the airframe.

3.2 Cost Analysis

It is recognised that due to the lack of detailed data, the cost analysis can be used only to approximately indicate the cost of transforming the existing A380F into the ICON configuration. The A380F airframe is chosen since its specifications appear closest to the requirements of the ICON concept.

A RAND Corporation cost model, "DAPCA IV", was used [9]. It is applicable at conceptual design stage and is appropriate for the level of detail in this study. The model estimates the hours required for research, development, test and evaluation (RDT&E) performed by the engineering, tooling, manufacturing, and quality control teams, respectively. These are multiplied by the appropriate hourly rates to yield costs. Development, support, flight-test, and manufacturing material costs are directly estimated by the model.

The main input variables to DAPCA IV are shown in Table 3. The model uses also hourly ('wrap') rates for engineering, tooling, quality control and manufacturing (not shown in the table). At this level of fidelity, weight is the only differentiating variable. That is why the empty weight of ICON is equal to the empty weight of A380-800F plus the maximum weight of the structural changes from Table 2. (In reality the payload will be reduced to keep the aircraft determining parameters, e.g., engines, range, ceiling, takeoff and landing distance, etc., unchanged.)

Parameter	ICON	A380-800F
Empty Weight (kg)	261,200	252,000
Maximum Velocity (km/hr)	945	945
Number of aircrafts to be produced in 5 years	62	62
Number of flight test aircraft	3	3

Table 3 DAPCA Cost Model Input Parameters.

It is assumed that a total of 62 aircraft will be produced in 5 years. This assumption is based on the 20 year forecast by Boeing and Airbus of approximately 250 new large freighters (see section 2 above). The model also assumes that the number of flight test aircraft will be between two and six. The engine costs are not considered since they will be the same in both cases.

Since DAPCA IV is applicable to new aircraft only, two sets of estimates were performed: one for the ICON concept and another one for the A380-800F. These estimates were used to obtain the difference between the RDT&E and flyaway costs of the ICON and the A380-800F configurations. DAPCA IV produced a value of $931 million in 1999 US dollar value. This figure, or more accurately, the constituent wrap rates, should be escalated with the appropriate cost indexes. This was not done, however, since the DAPCA model appears to produce rather conservative estimates. This conclusion was reached when a control estimate was performed on the A380-800F and compared to the publicly available figure for the development cost of the A380 programme, which EADS [4] estimated at U.S. $10.7 billion. This estimate

covers both R&D expenses and tooling for various versions of the A380, but does not include certain infrastructure elements or general and administrative expenses. The DAPCA IV model produced and estimate which is almost three times higher. Thus assuming that the purchase cost of ICON will be the same as

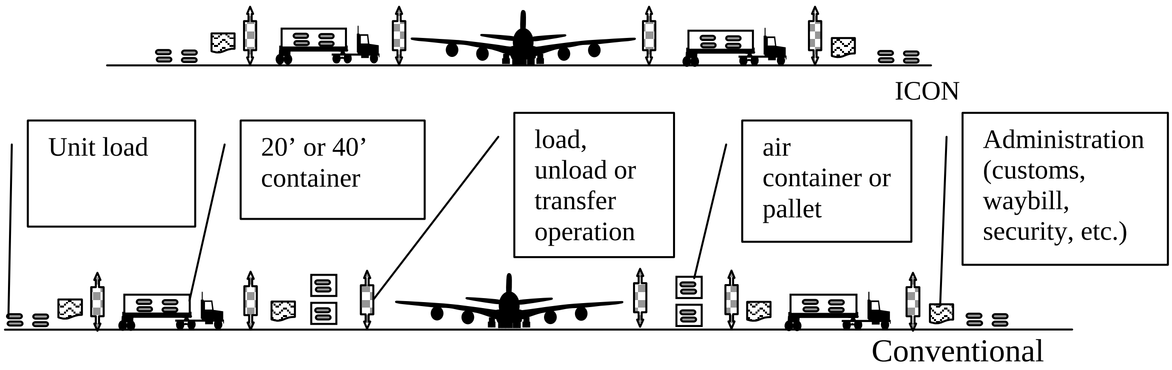

Fig. 3. Schematic representation of loading, unloading and transfer operations.

that of A380F (approximately $230million), the break even point to recover the conversion RDT&E costs will be reached with the sale of up to 30 ICON aircraft. This figure is only indicative, but is sufficiently accurate to show that the ICON concept is not prohibitively expensive, given the long term freight forecasts for large wide body aircraft.

4. Efficiency of ICON

Nose, tail, or side loading and unloading of air cargo, which is based on the existing pallets and air containers would require at least one additional *load-transport-unload* cycle in order to reach the other transport modes (and vice versa). In practice such a cycle would require ‘trucking’ the containers from the railroad depot or from the seaport to the airport, unloading them, rearranging the cargo into air containers and then loading the containers on the aircraft. Furthermore, time for “paperwork’ will be required at the points where the cargo is transferred to the next agent in the logistics chain. This can be significantly reduced or even avoided altogether when sealed containers are used.

In support of this argument a comparison between the efficiency of ICON and the conventional method (Fig. 3) is performed under the following conservative assumptions:

a) loading, unloading and transfer times are equal
b) only one size unit load, one size ISO container (20’ or 40’) and one size air container (pallet) is used
c) the 20’ or 40’ container is already mounted on the truck
d) administration is a compound task representing ‘paperwork’ and is averaged along the transport (logistics) chain
e) there is no intermediate storage
f) surface transport takes the same time for both options

The cycle time for ICON (Fig. 3) is:

$$T^I = zt_l + zt_a + t^I_l + t^I_l + zt_l + zt_a =$$
$$T^I = 2zt_l + 2zt_a + 2t^I_l \qquad (1)$$

where:
z is the number of unit loads (e.g. boxes or pallets) in a 20’ or 40’ ISO container,
t_l is the average time for loading or unloading of one unit load into or from an ISO (20’ or 40’) container,
t_a is the average administration time (e.g. paperwork, inspection, customs, security, etc.),
t^I_l is the average time for loading or unloading one 20’ (or one 40’) ISO container on (from) the aircraft.

The cycle time for the Conventional air container transport is:

$$T^C = zt_l + zt_a + zt_l + zt_a + t^r_l + t^r_l + t^C_l + t^C_l + zt_l + zt_a + zt_l + zt_a \qquad (2)$$

where:
t^C_l is the average time for loading (unloading) of a number of air containers on (from) the aircraft

which contain the total of z unit loads (i.e. the number of units in one 20' or 40' container),
t^{r}_{l} is the average time for loading (unloading) of z unit loads into (from) a number of air containers.
Let us assume that k (k >1, k = 2, 3, 4…) is the ratio between the number of elementary units (z) in one intermodal container and the number of elementary units in one air (LD) container. Then the number of air containers required to accommodate the z units will be z/k and Eq (2) can be rewritten:

$$T^C = 4zt_l + 4zt_a + 2\frac{z}{k}(t_l + t_l^I) \qquad (3)$$

The time saving in one complete intermodal transport operation with N large ISO containers is then obtained from Eq (1) and Eq (3):

$$\Delta T = (T^C - T^I)N =$$

$$\Delta T = 2z[\frac{k+1}{k}t_l + t_a + (\frac{1}{k} - \frac{1}{z})t_l^I]N \qquad (4)$$

Equation (4) is sufficiently accurate to show that the time saving can be very significant since it grows with the product of the number of unit loads (z) and the number of intermodal containers (N). The equation does not take into account time savings due to loading and unloading for temporary storage at (or near) airports, which is not unusual for conventional air cargo transport and can be significant.
An estimate was also performed on the cycle time, Nt^{I}_{l}, for loading/unloading of the ICON aircraft with a number of combinations of 20' and/or 40' containers (plus thirty six LD-3 containers loaded on the lower deck and fifteen pallets on the top deck). The aim was to check that the ICON turn-round time will be no higher than the A380-800F turn-round time of 120±20 min (depending on the layout of the three decks). The load transfer schema is depicted in Fig. 4. Again, a conservative estimate of the transfer cycle dimensions was derived from the half-span of A380-800F (40m, plus 10m clearance), the height of the fuselage (11m), assuming top cargo door, the vertical fuselage clearance (5m), and also the assumption that a container may be located in a ship's hull, below the water line. The crane is assumed stationary, but extra time is allowed for positioning it and also for the positioning of the equipment for loading/unloading of the air containers and pallets. The horizontal (travelling) and vertical (hoisting) velocities of the trolley were obtained from dock container crane specifications. The loading sequence of the 20' and/or 40' containers included times for raising/lowering the rollers of the internal roller conveyor of the aircraft, individual longitudinal and lateral transfer times (derived from the conveyor velocity specifications) for each container inside the fuselage, and also average time for locking/unlocking of the container. The worse case scenario was found when fourteen 20' containers were loaded and unloaded. This combination forms the critical path of the whole turn-round cycle and was estimated to be in the order of 80 minutes- still substantially faster than the conventional A380-800F turn-round time.
Currently the cost of air-freight can be up to several times higher compared to the cost of the other transport modes. However, in addition to the benefit of ensuring a several times faster delivery across the supply chain, the cost of the ICON concept will be compensated in part by additional benefits such as:
a) Improved frequency and reliability of delivery across the supply chain
b) Improved safety and lower insurance premiums
c) Reduction of inventory levels and therefore reduction of storage and warehousing costs.
d) Improved responsiveness to customer demand (including reduced time to market)

It should also be emphasised that the business drivers analysed in Section 2 above were based on existing air cargo technology. However, by integrating air cargo with the other transport modes, the ICON has the potential to make a significant impact on the global supply chain. The use of standard 20' and 40' could facilitate door-to-door, time-definite service for the global manufacturing supply chain thus extending the air cargo business to the transportation of components, equipment and even intermediate materials. In this respect ICON may also lead to a different business model, streamlining the complex chain of handlers in the shipment of air cargo, including, for example, factory warehouse, local trucking, long-haul trucking, customs broker, forwarder, airport warehouse, aircraft handler and air carrier. At present this interrupted handling can cause delays while the considerable accumulated cost is usually passed to the consumer [10].

5. Ground Infrastructure and Hub Location

Currently most large airports handle both freight and passengers [6]. Until recently there has been

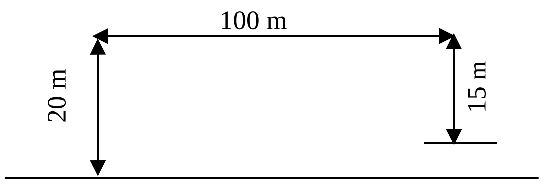

Fig.4. Transfer cycle - dimensions.

little incentive to invest in all-freight hubs. For example, about 80% of the UK air freight goes through the London airports. However, there is already a good indication that the demand for air cargo may push towards the spread of freight-focused airports. Wiebner [11] gives examples such as the airports of Liege, Columbia, S.C., and Wilmington, Ohio (owned and managed by Airborn Express) where it was found that express cargo operations are far greater than what the operators could hope for from passenger airlines.

When determining the location of potential hubs for the ICON concept the following generic requirements will apply:

a) Existence of a large industrial, commercial and consumer base to ensure return on investment.

b) The existence of a good surface transportation and telecommunication networks. (It should also be emphasised that currently the majority of international shipments move via boat.)

c) The hub location should be close to as many large industrial centres as possible, but far enough to ensure that there are no or little noise or night flight restrictions.

Given the above considerations it is reasonable to assume that the candidate locations will be distributed mainly in North America, Asia, Europe, and to a lesser extent in Australia (including Oceania) and perhaps the Middle East (e.g. Dubai). Detailed analysis on the number and potential locations of the hubs was beyond of the scope of this study. Taking USA only as an example, prospective candidates for conversion can be existing commercial or disused military airports in coastal areas such as those near Seattle, Jacksonville, FL, Los Angeles, or inland cities such as Dallas or Chicago.

The ground airport structure necessary to accommodate the ICON concept would require the installation of sea-port type container cranes. Depending on the location of the large cargo door (e.g. on the side or on top of the fuselage) or the approach of the aircraft (Fig. 1), these cranes may require little modification, or a more radical design. In any case the crane would represent a sizeable investment cost.

In addition to being able to facilitate takeoff and landing of aircraft the size of A380, the airport infrastructure has to include, if not already existing, the extension of the taxiway to the connection point between the transportation modes (i.e. the area where the cranes will be situated).

6. Conclusions

Proposed is novel air freight concept for intermodal container transport, named ICON. The aim of ICON is to utilise the standardised 20 and 40 foot containers currently in operation. Instead of a completely new, purpose built aircraft which would be too expensive, the baseline airframe considered is the planned Airbus freight configuration, A380-800F. Preliminary calculations show that an aircraft with the capacity and dimensions of A380 can carry up to six 40' or up to fourteen 20' containers as well as combinations of these, depending on load density. Two large cut-out options were considered to realise the cargo door – top and side of the fuselage, respectively. The necessary aircraft modifications were considered as well as the cost and weigh implications of the conversion. Conceptual design estimates indicate that the proposed modifications may lead to a reduction of the payload by about 6 percent. However, the time savings and cost benefits can be significant. The time savings due to the reduction of the loading, unloading and transfer operations grow with the product of the number of unit loads and the number of 20 or 40 foot containers. In addition to the time savings, the cost benefits of the concept will include reduced packaging, storage and warehousing costs. The economic impact of the concept can be even more significant considering that the integration of 20' and 40' containers has the potential to radically change the air cargo business model as it could become an integral part of the global manufacturing supply chains. This would extend the traditional air freight market from perishables, high value and fragile items to components and even capital equipment and intermediate materials, given economies of scale.

Conceptual cost estimating indicated that approximately up to 30 ICON aircraft will be needed to recover the modification of A380-800F. Additional investment regarding the airport ground infrastructure will include sea-port type container cranes and a possible extension of the taxiway. There is already a good indication that the demand for air cargo will push towards the spread of freight-focused airports, where the later stimulate local economic growth. The proposed ICON concept can only contribute to this trend.

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