Parametric Concept Design of Heavy Air Transport

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**Abstract.** In this paper, some issues of potential development of heavy air transport (HAT) civilian freight-carrying aircraft are talked about. Disadvantages of the air transport that are operated now are discussed. The comparison of the flight capacity of proposed dedicated cargo aircraft, having 120 tonnes payload, with existing converted freighter aircrafts Boeing 747-200 F and An 124 (Ruslan) is made. The broader set of values of payload and that of flight range is considered in order to achieve the better outcomes in the parametric research. Three criteria are used to evaluate the assessment of flight performance and economical features including the weight efficiency, fuel efficiency and the transportation cost.

**Keywords:** Transport aircraft, Freighter, Fuel efficiency, Weight efficiency, Cargo transportation

# INTRODUCTION

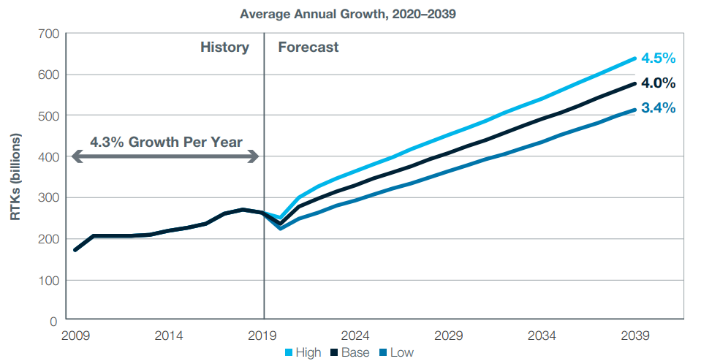
The percentage of cargo being transported by airplane is increasing gradually within the past ten years in the globe. At present, cumulative range of air transportation stands at more than 250 billion tonnes of the year (Figure 1). The percentage growth of cargo transportation during the last decade accelerated at the rate of 4.3 percent per annum on average [1].

Together with the current historic move to finding dedicated freighter aircraft to transport more than 50 percent of the entire air cargo globally despite the wide-body passenger aircrafts growing, the recent pandemic due to COVID-19 has proved that such a use of main-deck freighter aircraft is part of our continued cultural reliance on air-transport networks [1]. Even though the air cargo industry has been benefiting through the use of passenger widebody aircraft over the past decade this does not mean that the dedicated freighters will not continue to comprise at least half of all the air cargo traffic flown in the world.

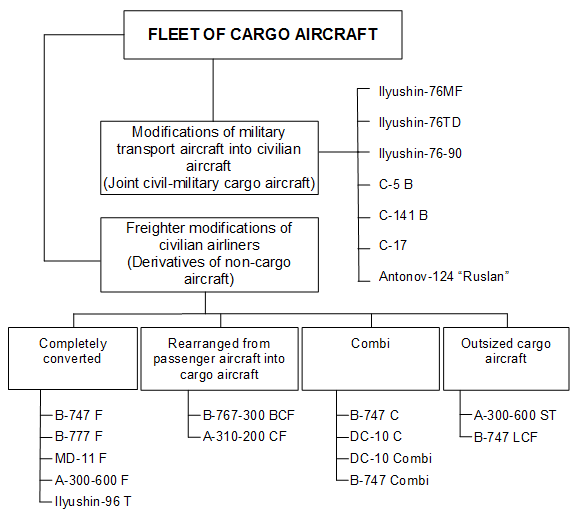
The key motivations in application of freighter in air fre King streams include; 1) most of the passenger belly capacity is not focused in the major exchanges of cargo trades; 2) shipper timing requirements are not served on most of the schedules on twin aisle passenger flight; 3) freight forwarders mostly would like to ship with palletized capacity which is not on the single aisle airplanes; 4) passenger bellies planes cannot ship hazardous materials or project cargo and finally; 5) payload-range concerns on the passenger aircraft may cut off on- fuselage [12].

The forecasts point out that the present direction in which the leading airplane manufacturers Boeing and Airbus Industry are moving to is to be not less than 4.1 percent in the following 20 years. Figure 1 demonstrates that in the subsequent 20 years, the air cargo traffic in the world potentially can grow at least by a factor of two [1].

Currently, more than 50 percent of Freighter conversion of long-haul passenger airplanes are carrying out the freight transport section of the industry, with a volume of just below 2000 in the number. The latter operates half on the market of conventional passenger flights in cargoes. Majority of the aircrafts are not initially designed as freighter and this makes them to be designed as passenger jet airliners and then converted to freighter aircraft by the arrangement and deletion of equipments within the aircraft in the passenger cabin (Figure 2, 3). Over 1000 aircrafts are converted fully to cargo carriage traffic, these aircrafts include such wide-bodied aircrafts as: Airbus A300F, Airbus A330F, Boeing 747F, MD-11F, Il-96T.



**FIGURE 1.** World Air Cargo Traffic [1]



**FIGURE 2.** Fleet of cargo aircrafts

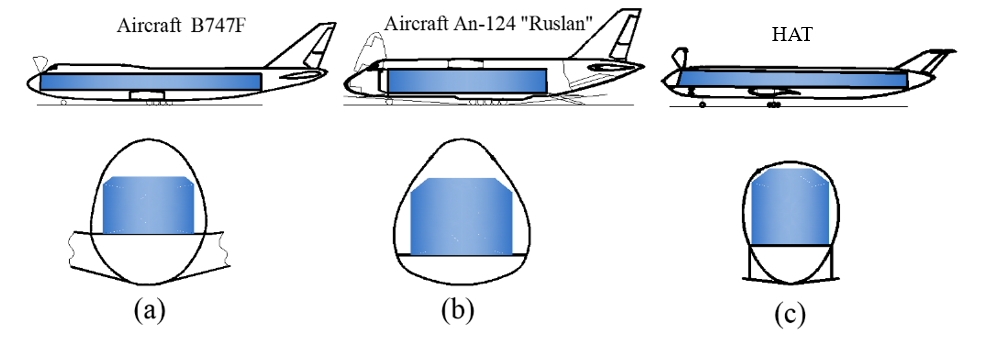
Generally, cargo alterations of aircraft all remain at the same take-off weight and geometrics, so the flight performance with these cargo aircraft is the same as the standard passenger aircrafts. Alternatively, however, the cargo holds of the cargo plane, in this instance, takes the form of being exceedingly disproportionately large in size even with respect to the weight that it is able to carry.

Such way, the maximum payload of the Boeing 747-400F is 112 *t* and the volume of cargo compartment is 1002 *m*3. That is to say, the volume that can be used to transport 1 *t* of freight is 8.9 *m*3. According to the data analysis of the statistical reports, the transportation capacity of 1 *t* of freight is less than 6 *m*3.

**Table 1.** Evaluation of performance of different HAT

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Characteristics | Parameter | Boeing 747-400F | Antonov 124-100 | HAT |
| Maximum take of gross weight, *t* | *W*TOW | 397 | 405 | 374 |
| Maximum payload, *t* | *W*payload | 112 | 120 | 120 |
| Volume of fuselage, *m*3 | *V*fus ext | 1996 | 2597 | 1072 |
| Cargo compartment capacity (volume), *m*3 | *V*cargoc | 1002 | 1027 | 720 |
| Usefulness coefficient of fuselage’s volume, % | *k*Vu | 50 | 39 | 67 |
| Weight of fuselage (design estimation), *t* | *W*fus | 36.1 | 50.8 | 24.2 |
| Fuselage drag, *t* | *D*fus | 10.01 | 12.2 | 6.3 |
| Fuel consumption [R=6000 *km*]*, t* | *W*fuel | 81 | 108 | 68 |
| Fuel efficiency, *gram*/(*t* × *km*) | *q*fuel | 120 | 150 | 95 |
| Weight efficiency (useful takeoff load ratio), % | *W*payload/*W*TOW | 28 | 26 | 32 |

This implies that the ratio of the capacity of cargo compartment to the carrying volume required to carry a certain amount of load is 30% more than what is required. In addition, taking into account volume of external contour of fuselage (which is equal to 1996 *m*3) accounts for two times more than the cargo compartment. So real required loading capacity of 112 *t* of cargo on B747F is 672 *m*3 only. The volume fraction of the outer profile of fuselage is less than 34% [4, 5]. The cargo store of the Ilyushin-96 T airplane can contain over 34 cargo pallets R6 and R2 inside the cargo compartment that can reach over 230 *t* of the weight. But, this airplane has a less carrying capacity of up to 92 t. With these illustrations, we realize that there are very huge reservoirs that provide an auger to the transportation of air cargoes efficiency through the development of the heavy air transportation (HAT) aircraft [6].



**FIGURE 3.** The cargo compartments of various transport aircrafts: Converted (a),   
modification of military into civilian (b) and HAT (c)

On the contrary, passenger networks are much more widespread, and many of the destinations that can be part of them do not have too much cargo demand. This disparity in distribution of passengers and cargo has been a determining factor that led such a radically different load factor within the belly space and the freighters which was approximately 30 and 75 percent respectively, during the past one decade. Moreover, passenger planes will be filled to their maximum range and ban on passenger flights is placed in big cargo airports. To such positional reasons, the freighters are more likely to carry more than half of the trade in air in the world in the next 2 decades [1].

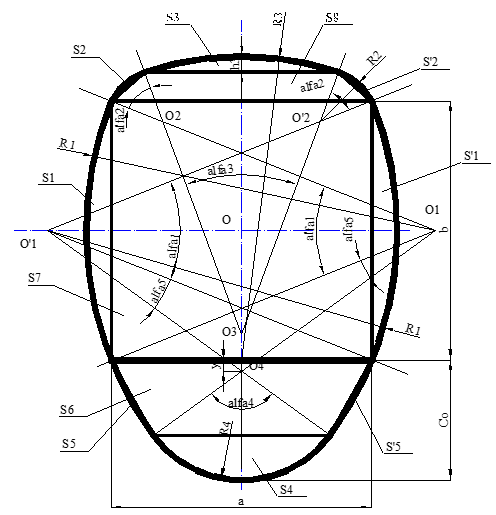
In terms of any transport, an airplane is not an exception, the primary goal of the design striving to raise the percentage of the payload substance in a total weight balance. Any type of machine should accomplish as much beneficial work as it can when it is a transitional object of the smallest degree. Minimization of structural mass of transport vehicle is the primary principle of design of transport vehicle.

A number of studies have already been conducted relative to the flying-wing (FW) [2, 3], however, most of them present demerits in terms of stability as well as the actual projection into reality when contrasted with that of the conventional configurations. In this paper, the evaluation of the flight performance and economic characteristics estimation of the proposed dedicated freighter aircraft has been provided. It covers a broad spectrum of payload and flight range values to obtain more research results using parametric research.

The following is the organization of other parts of this paper. In the next section the performance of existing cargo airplanes and pure freighters is compared in terms of flights and economics. Parametric study of the cargo planes and the new idea of aircraft designing are discussed in the below sections. This is continued by a conclusion that talks about the end.

**DEDICATED FREIGHTER AIRCRAFT SCHEMES**

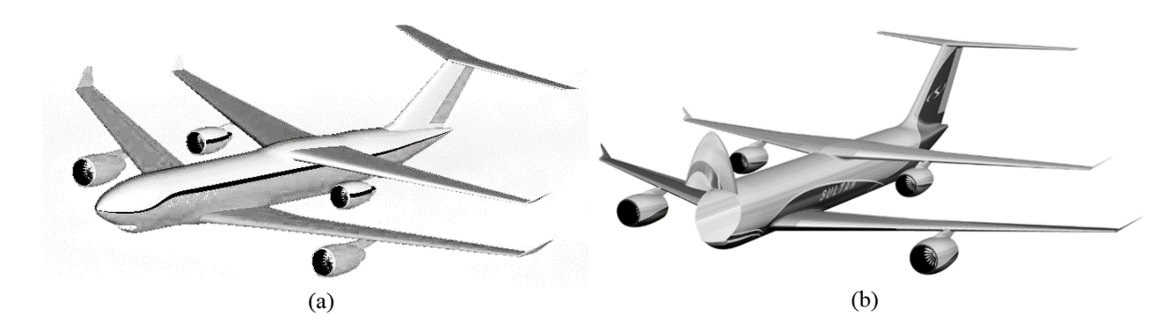
With regard to the relation coefficient of freight density 6 *m*3/*t*, the volume of cargo compartment is defined equal to 720 *m*3 [7]. Fuselage cross section (Figure 4) is produced through several arc curves and drawn in the form that allows maximizing the application of all space between the containers, taking into consideration the empty space.



**FIGURE 4.** HAT fuselage cross section **FIGURE 5.** Multiple axle bogies in landing gear

The nose segment located on the cabin has the cargo compartment main door with the opening of the compartment on the upper side of the same (Figure 6). Structurally, cargo compartment is set in a manner that the conventionally set-up construction lacks cutouts in sideways orientation of the fuselage. It has a dual purpose floor to cargo compartment. It carries loads of the payload and also, maintains the longitudinal stress of the bending moment, that is, distributed along the fuselage. Landing gear onto which the legs are referred is constituted by a few bogies each of which comprises of axles (Figure 5).

The wing center section is assembled with the upper panel connected to the fuselage structure of the cargo compartment to the floor design of that section on the union of the fuselage and the wing. This is why the upper wing section located in the center wing group is under both longitudinal and lateral stress, on the one hand, because of the stress of the bending moments of the wing section and, on the other hand, the hollows on the fuselage [7, 8, 10].



**FIGURE 6.** HAT’s tandem wing configuration: (a) flight mode (b) nose loading mode

Some design calculations have been done based on density related technical characteristics in order to outline the characteristic performance of the airplane. Some characteristics of the airplane performance of proposed HAT are compared to those of (Table 1) B 747-400F and An 124-100 Ruslan. To begin with, we can see that there is a great percentage of the capacity of the cargo compartment relating to the outer size of the fuselage (67%). In that regard, the electronic computations of estimated mass are two times lighter than fuselage of An 124-100 and 1.5 times lighter than the fuselage of B 747-400F because the size of the fuselage cross section is much smaller.

It can estimate the force produced by the fuselage aerodynamic drag in cruise condition as HAT = 6.2 *t*,   
B 747-400F = 10 *t* and An 124-100 = 12 *t*. By this means, HAT fuselage drag is 1.5 or 2 times less than the prototypes that are made. The 32 percent (useful takeoff load ratio Wpayload/*W*TOW) rather high weight efficiency, combined with very high aerodynamic quality is one of the key reasons why the HAT is considerably better in fuel efficiency.

Most of the time, the volume of the fuselage cargo compartment necessary is defined by volumetric density *µ* of the cargo

As an example to design a special container carrier aircraft’s volumetric density *µ* is 4.2 *m*3/t, containing cargo with granular freight 2 *m*3/*t* and a tanker that will carry liquids 1.2 *m*3/*t.* Consequently, freighters most devoted to it is shrunken geometrical size and through this, it is possible to have a greater weight efficiency and fuel efficiency.

The tow expensive variables that are present in acquisition of the transport aircraft performance are:

Payload tonne-kilometer (PTK) is the measure of 1 tonne of cargo travelled 1 kilometre.

Revenue tonne-kilometer (RTK): 1 t revenue freight transported 1 km. 1 ton of revenue freight tonne-kilometres is revenue passenger weight, or the revenue goods weight per kilometre, most commonly referred to instead of freight tonne-kilometre, but it quantifies the entirety of revenue.

Parametric researches have been done to estimate the technical and economic aspects of HAT. The parametric study of this, has the payload weight 100 t to 250 t and the calculated flight ranges curves (R) 6000 km to 12000 km. Two technical requirements are to be considered:

1. Weight efficiency (Wpayload/WTOW)

2. The fuel efficiency qfuel = (Wfuel/FTK), the gas consumption in *grams* of the transport infrastructure to the load per 1 *ton* weight and 1 kilometer of movement.

Their economic criterion is a single economic criterion that is transportation cost A, which is made up of Cost of flight hour, Payload and Average speed:

where ε is the payload factor, considering the partial loading of the aircraft on an average as per year, the average loading factor ε = 0.6~0.8.

**PARAMETRIC RESEARCH**

We have taken note of three kinds of HAT in the parametric research we have presented.

**1. Universal Aircraft (UA).**This airplane offers payload per unit of *µ* = 6 [*m*3/*t*] in the cargo compartment.

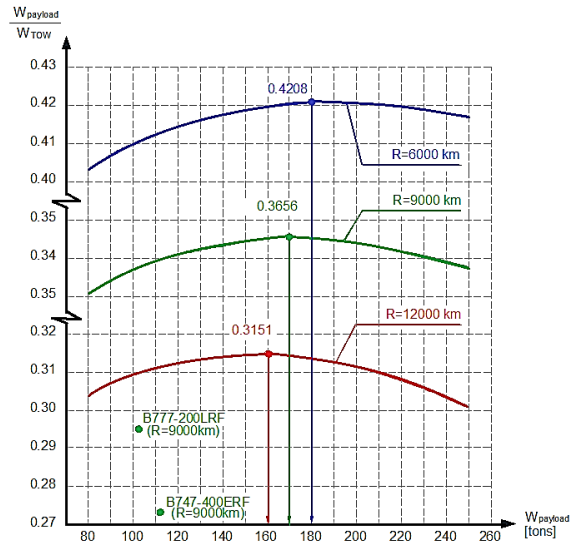
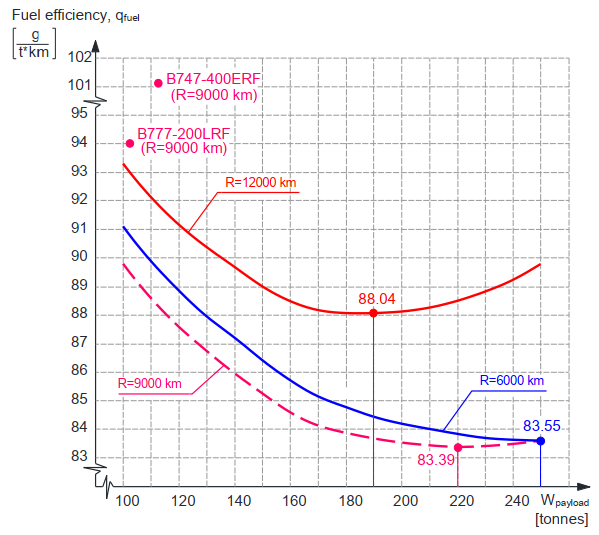
**2. Granular Transporter (GT).** The storage capacity of this aircraft allows payloads with density factor *µ* = 2 [*m*3/*t*].

**3. Tanker for Liquids (TL).**This airplane has a cargo space that is equipped with tanks to carry liquids whose payload capacity with density factor is *µ* = 1.2 [*m*3/*t*].

The findings of the parametric research of UA can be found below. Figure 7 demonstrates that weight efficiency depends on payload of the UA designed with payload maximum ranges of 6000, 9000 and 12000 km. As may be noticed, these relations possess optimum in the weight efficiency.

As an example, the maximum weight efficiency, which is designed to have a range of 6000 km is 0.42, when loaded with 180 t of payload. This is to mean that their performance of UA will be at maximum efficiency (at payload 180 t) based on weight criteria. The amount of take-off weight that the aircraft in this case is calculated to be 427.8 tons. In the instance of the UA that is to be specifically designed to fly a distance of 9000km the peak weight-efficiency of 0.37 valuation will read like the aircraft flies with maximum payload 170 t, take off weight of 465 t. The payload weight of 160 t together with the weight efficiency 0.32 and the take-off weight 507.7 t are the best features of the UA that has been specially developed to work in the range of 12000 km. Its UA outcomes demonstrate that, as the optimum aircraft are to be used against payloads linked to increasing span, optimum got shifted to the left hand along, viz., airplane optimum payloads will lower. In the case of range increase to 12000 km as compared to 6000 km, the weight efficiency is cut down by around 10 %.

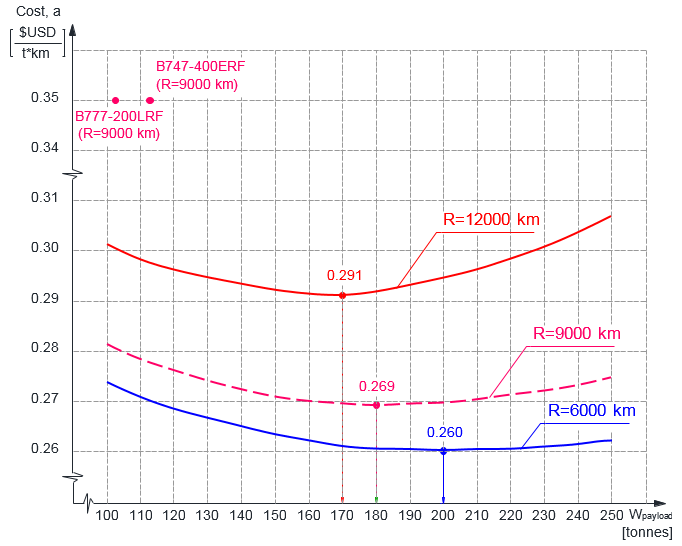
In overall terms, it can be concluded by saying the optimum UA that carries maximum weight efficiently ought to be of a special design that carries a payload of 160 to 180 tonnes. Figure 8 indicates how the fuel efficiency (*q*fuel) is dependent on payload *W*payload of the UAs having ranges 6000, 9000 and 12000 km. The plane that will be having 12000 km will have the maximum payload of 200 t that will have the range of 9000 km and this one will have the maximum payload of 220 t and one which has got 6000 km will have the maximum payload of 250 t.

**FIGURE 7.** Dependency of weight efficiency **FIGURE 8.** Dependency of fuel efficiency on

*Wε* = *f* (*W*payload, *R*) on payload for UA payload qfuel = *f* (*W*payload, *R*) for UA

In this way, the value of maximum payload has a negative impact on fuel economy. The greater the estimated distance, the more the airplane must be designed to, recognize it is less in terms of payload so as to perform well. The dependence is analyzed, and it indicates the following features. First of all, it appears that the shorter the calculations of the range, the airplane will burn less fuel.



**FIGURE 9.** Cost of transportation has a dependency on the payloads. A = f (*W*payload, *R*) for UA

Nevertheless, the results indicate in practice the fuel efficiency of UA designed to fly 9000km flight range is higher than UA designed to fly 6000km flight range as shown in Figure 9.

On the basis of this finding main features of more efficient aircrafts are:

• payload = 200 t, take off weight = 475.8 t, and projected flight range = 6000 km.

• The payload = 180 t, take-off weight = 492 t and an estimated flight range = 9000 km.

• having a payload = 170 t, take off weight = 540 t and estimated flight range = 12000 km.

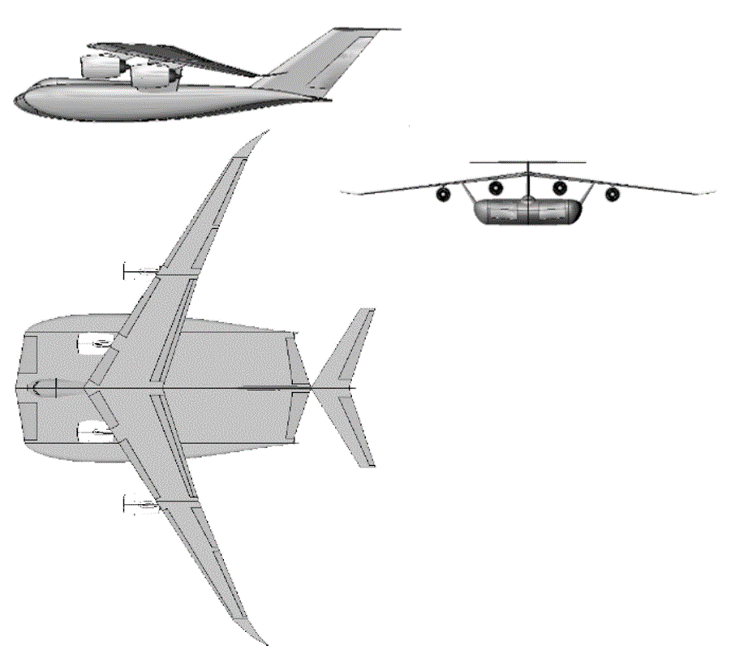
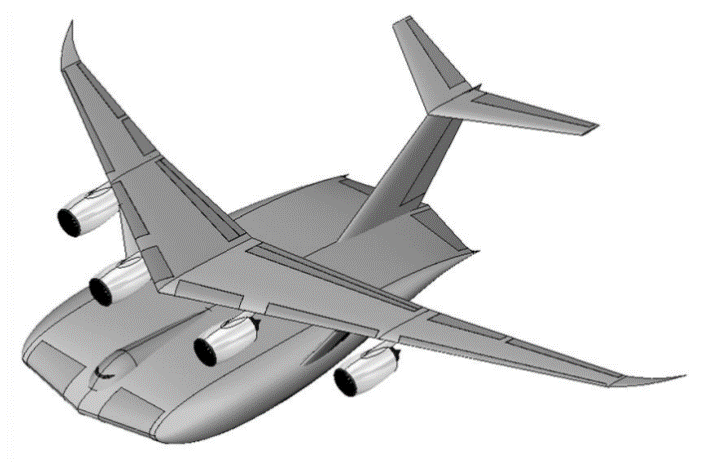
The interpretation of these findings is that the maximum values of the payloads are reduced as the estimated flight range is increased. Other than this, even at transportation increasing in the estimated range of 6000 to 12000 km and the cost of transportation 0.26 to 0.291 (USD) i.e. increases by an approximate 12% only. The comparable findings were achieved in GT and TL projects during parametric analysis.

**AIRCRAFT SCHEMES (IN THE FUTURE)**

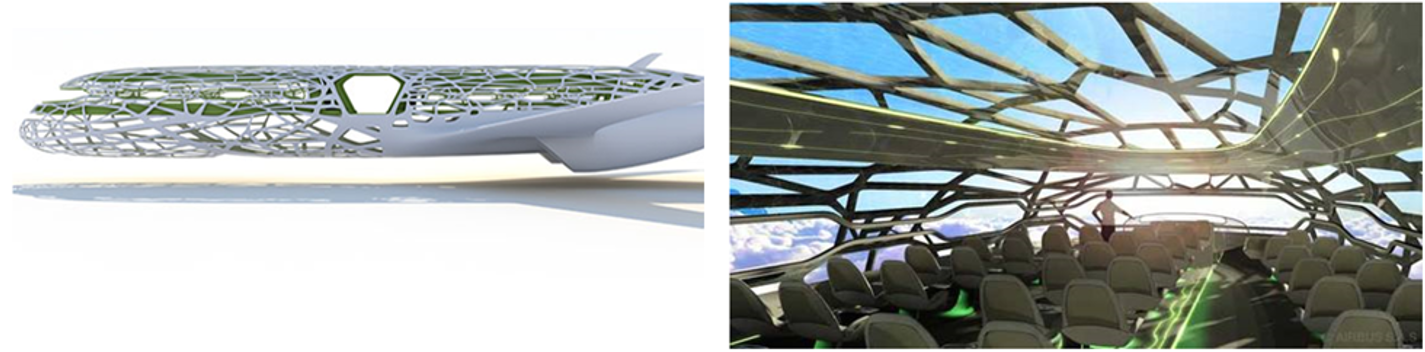
It is perceived that new standards will be established in the civil aviation sector by the new planes in the next two to three decades. Aviation community is attempting to make future aircraft greener, in that, they will produce less harmful emissions, and will be quiet and less expensive. Figures 10-11 describe some of the newest designs of the aircrafts of the future. Figure 10: Lifting body configuration of big freight aircraft is shown on the basis of an early assessment of the mechanics and structures.

Although the issues in areas dealing with aerodynamics and flight mechanics could be solved with the help of the already developed methods and tools, one must say that there is a lot of work to be done in the area of structures. Even though different finite element models have been developed mass estimates of this kind of aircraft configuration still face the problem of a high amount of uncertainty and that further efforts should be made in the future [2].

The engineers of the Airbus company are perfecting the concept that can surely leave boldest fantasies of the science fiction behind. The Airbus project is pursuing the futuristic vision of a bionic airplane design (Figure 11). This structure will use the characteristics of a skeleton of the bird [9, 11].



**FIGURE 10.** The large future cargo aircraft scheme



**FIGURE 11.** The fuselage of bionic structure aircraft [9]

**CONCLUSION**

There are advantages and disadvantages of air transport that is in operation now that is discussed. The analysis of the need of HAT aircrafts. The performance that has been estimated by the flight and economic characteristics of proposed configuration of HAT are brought out. The parametric study findings indicate that there is reasonability to conduct further research and advancement of HAT. Based on the comparative study of HAT against three criteria, irrespective of the cargo payloads and route structures entered into the model nine, it is pointed out that HAT can be up to 7~10% more efficient in terms of weight load efficiency Wpayload/WTOW, 7~13% more efficient in terms of fuel efficiency and 20 percent economical in terms of transportation cost than the present day cargo modifications of both the passenger aircrafts of the type B 747-400 ERF and B 777-200 LRF.

**FUTURE SCOPE**

Air cargo transportation is likely to experience a dramatic improvement in the future due to technological innovation needs, efficiency needs in operation and sustainability objectives. Future freighter designs have indicated that there exists substantial reserves in structural and volumetric efficiency. Future studies must strive to work on the optimal cargo compartment size and it should be based on the Payload size. This could arise to the design of purpose-built heavy air transport aircraft with an increase in payload efficiency of 7-10%, fuel efficiency of 7-13% and 20% cut in transportation costs as compared to the existing freighter modifications.

More advanced designs like lifting-body or blended-wing designs should achieve better aerodynamics, and economy of weight structures. It may be possible to use these concepts to enable greater fractions of loads, with no compromising of stability during flight. Even though early research possibilities exist, more needs to be done to deal with design-oriented issues on both structural design and mass estimation on this unusual set-up.

Cargo aircraft of the future are expected to use newer materials like the composite material coupled with 3D-printed bionic structures by replicating nature designs like bird skeleton to obtain a high strength-to-weight ratio. The developments will allow thinner yet stronger airframes made of increased fuel economy and reduced emissions.

Green airlines and environment-related regulations will hasten the creation of aircraft that will be quiet, less-emitting, and operate on alternative or mixed-fuel propulsion systems. The use of sustainable aviation fuel (SAF) and hydrogen-based propulsion will be the vital research points in future.

Besides the already foreseen doubling in air cargo traffic in the world within 20 years, the future of this sphere envisages the incorporation of cargo-specific airports and intelligent logistic hubs. This will increase connectivity along major demand trade corridors and minimize the usage of passenger belly space to transport cargo.

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