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CONTAINERIZED AIR FREIGHT SYSTEM POWERED BY CRYOGENIC FUEL

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Abstract

This paper reviews conceptual study results of the heavy air freight system for transoceanic containerized cargo transportation.

Problems of the modern maritime container transportation and their negative influence on ecology are designated. Concept of the air freight system on cryogenic fuel is proposed. Discussed transport system represents an alternative to maritime container delivery with higher speed and reduced ecological impact. Main competitive advantages over traditional air freight will be greater payload weight and cheaper transportation. Three different subsonic fixed wing air vehicles for proposed transport system are investigated.

The results of the research obtained in this paper could be used as a starting point for detailed studies of the heavy air freight system on cryogenic fuel. Realization of such transport system will provide new logistics opportunities for world economy growth.

1 Introduction

Nowadays the long-range delivery of 90% of all goods around the world is performed by the maritime transport. The maritime cargo transportation network links large seaports around the world [1]. Significant part of cargo deliveries are carried out by container ships.

Maritime container deliveries are cheap, but they possess substantial drawbacks:

- Long duration of the cargo transportation due to low speed of the container ships (average speed 24-25 knots (44-46 km/h), further growth is limited by increase of fuel consumption in a geometric progression);
- Dependency on weather conditions;
- Relatively low security of the cargo due to possibility of the container loss in bad weather conditions en route;
- Huge level of emissions (emissions of 1 large containership are equal to 50 million cars [2]);
- Pollution of coastal waters.

Combination of these drawbacks leads to deceleration of the global supply chains and environmental pollution by harmful emissions and lost cargoes.

Therefore, there are prerequisites for the development of a new transport vehicle that will allow rapid transportation of the containerized cargo with less environmental impact in comparison with the maritime delivery of cargoes.

2 Concept of Heavy Air Freight System

The task of development the above-described transport vehicle can be solved by design of a special air freight system that includes ultra-heavy aircrafts with cryogenic fuel and ground facilities for insuring their effective operation.

Basic principles of the Heavy Air Freight System (HAFS) concept are as follows:

- Cargo transportation in standard 20…40-feet containers;
- Ultra heavy aircraft, optimized for container transportation;
- Specialized airports for the HAFS aircrafts should be constructed (they should be placed on the seashores);
- Application of the cryogenic fuel (liquefied natural gas (LNG), liquid/slush hydrogen

(LH_2/SlH_2)) with reduced environmental impact;
- Special airworthiness requirements for HAFS aircrafts.

The target payload of the HAFS aircraft will be 100 20-feet containers (twenty-foot equivalent units, TEU) or 1200 metric tons. It is advisable to consider the option with smaller payload – 500 metric tons (≈50 TEU), which will reduce the aircraft size for operations from existing airfields. This circumstance enables realization of the aircraft project in a shorter term and reduces cost of an infrastructure construction on the initial stage of HAFS.

It is known, that use of the cryogenic fuel requires the development of the new operational infrastructure with high safety level of fueling procedures [3, 4, 5]. Initial-stage fuel for the HAFS will be the LNG with already existed world infrastructure of production, storage and transportation. It is important, that the requirements for LNG storage and transportation are more “soft” than for LH_2 due to its higher boiling temperature [6]. The transition to liquid hydrogen will happen in the case of hydrogen technology get mature. This transition will be carried out by replacing the fuel system of the HAFS aircraft without affecting the airframe.

3 Aircraft of HAFS

Based on the HAFS concept, it is possible to formulate constrains that determine aircraft layout decisions:

- Mechanized cargo loading/unloading operations;
- Non-pressurized cargo holds;
- Spanwise load distribution;
- Large volume cryogenic fuel tanks with thermal insulation;
- Fuel tanks are not integrated into aircraft structure due to necessity of maintenance and replacement.

There were 2 concepts of the HAFS aircraft investigated – a ground effect vehicle (GEV) and a fixed wing aircraft.

Design of the HAFS aircraft in the GEV concept enables significant reduction of the overall aircraft size in comparison with classic aircraft for the same payload. The ground effect flight allows to use the low aspect ratio wing (AR=3÷4) with the high lift-to-drag ratio (L/D=25÷30). Instead of the existing hydro-GEVs, ground effect vehicles of the HAFS will operates from the airfields as it was proposed in the Boeing Pelican ULTRA project [7]. The “lifting body” aerodynamic scheme (example: V.Burnelli UB-14) can be successfully applied in the GEV layout – a large center wing will accommodate the cargo holds and provide a high lift in the ground effect flight.

The GEV concept has a number of drawbacks: the aerodynamic efficiency depends on sea waves, the need to avoid collisions with ships due to continuous cruise flight on extremely low altitude over sea (flight up to 3000 m altitude in case of emergency).

Advantage of the fixed wing aircraft concept is a high altitude flight (6-7 km) and higher speed. But such aircraft needs the high aspect ratio wing for the acceptable cruise lift-to-drag ratio and in combination with large required wing area it leads to the large wingspan.

Comparison of the HAFS aircraft variants is shown in figure 1.

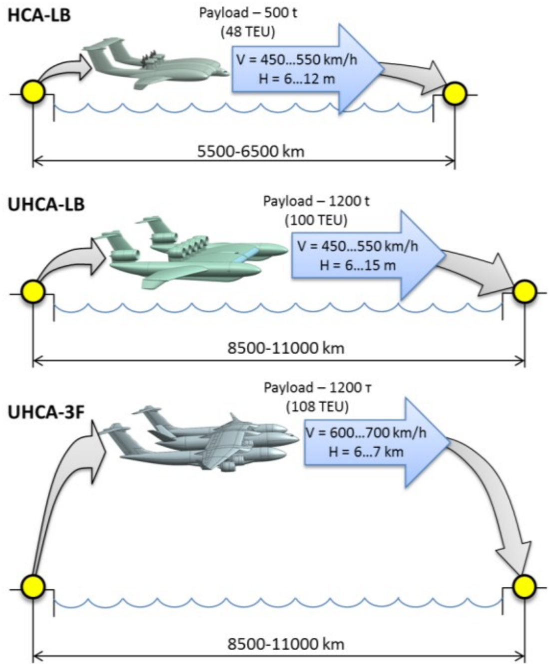

Fig. 1. Flight profiles of the HAFS aircraft variants

Within the GEV concept 2 variants of HAFS aircraft with payload 500 and 1200 t are designed.

The variant with 500 t payload (Fig. 2), named Heavy Cargo Aircraft with Lifting Body (HCA-LB), is aimed for transportation up to 48 TEU at the distance 6000 km with speed 450-550 km/h. Size of the center wing is selected due to accommodation of the cargo holds and the fuel tank for LNG. The «Payload-Range» diagram for the HCA-LB in comparison with the modern cargo aircraft is shown in figure 3. Estimation of the flight range was carried out using well-known engineering methods [8, 9].

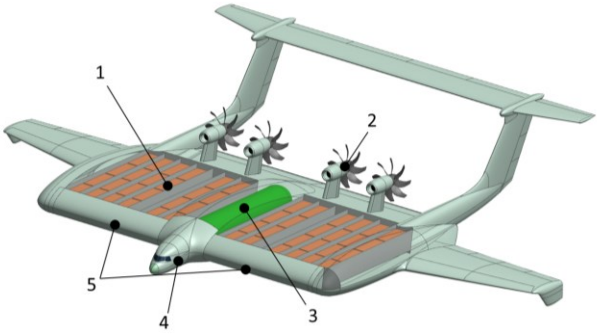

Fig. 2. Layout of the HCA-LB
(1 – cargo holds for 48 containers; 2 – engines with takeoff thrust 50-55 tf each; 3 – fuel tank with thermal insulation; 4 – crew cockpit; 5 – nose cargo doors)

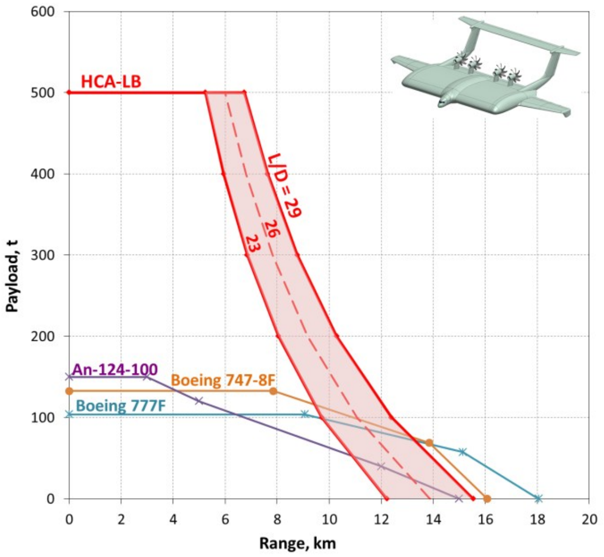

Fig. 3. «Payload-Range» diagram for the HCA-LB with different L/D in comparison with the modern cargo aircraft

The propulsion system of the HCA-LB consists of 4 engines and should provide takeoff thrust 50-55 tf each. This thrust level is now achieved in turbofans, but those engines are not optimal for low altitude cruise flight. There is a necessity to design special LNG-propelled engines for the HCA-LB with reduced specific fuel consumption in low altitude flight with average speed 500 km/h.

The volume of the HCA-LB fuel tank is chosen to provide 6000 km range with a maximum payload (with the LNG fuel), the aircraft size constrains for operations from the airports with ICAO code 4F was taken into account. Due to these constraints the aircraft does not have enough space for the adequate volume fuel tank for the liquid hydrogen.

The variant with 1200 t payload, named Ultra Heavy Cargo Aircraft with Lifting Body (UHCA-LB), is shown on figure 4. This aircraft intended for transportation up to 100 TEU at distance up to 11000 km with speed 450-550 km/h. The «Payload-Range» diagram for UHCA-LB is shown in figure 5.

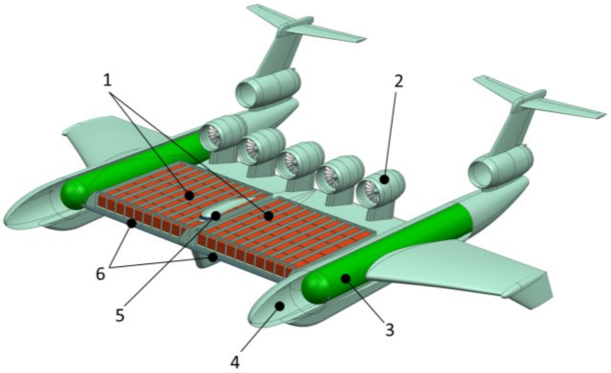

Fig. 4. Layout of the UHCA-LB
(1 – cargo holds for 100 containers; 2 – engines with takeoff thrust 80-106 tf each; 3 – fuel tank with thermal insulation; 4 – demountable nose fairings for fuel tank maintenance and replacement; 5 – crew cockpit; 6 – nose cargo doors)

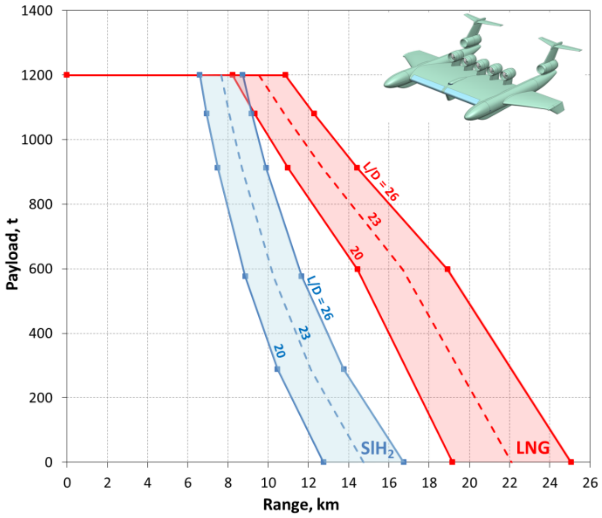

Fig. 5. «Payload-Range» diagram for the UHCA-LB with different L/D

Main differences of the UHCA-LB layout in comparison with the 48 TEU variant – larger center wing for 100 TEU cargo holds and two side fuselages for removable fuel tanks.

Propulsion system of the UHCA-LB consists of 7 engines and should provide takeoff thrust 80-106 tf each (depends on fuel type – LNG/LH$_2$) to achieve thrust-to-weight ratio 0.2.

Within fixed wing aircraft concept there is designed a variant of the HAFS aircraft with 1200 t payload, named Ultra Heavy Cargo Aircraft with Three Fuselages (UHCA-3F, fig. 6). This aircraft intended for transportation up to 108 TEU at distance up to 11000 km with speed 600-700 km/h. The cruise altitude is up to 7000 m. The «Payload-Range» diagram for the UHCA-3F is shown in figure 7.

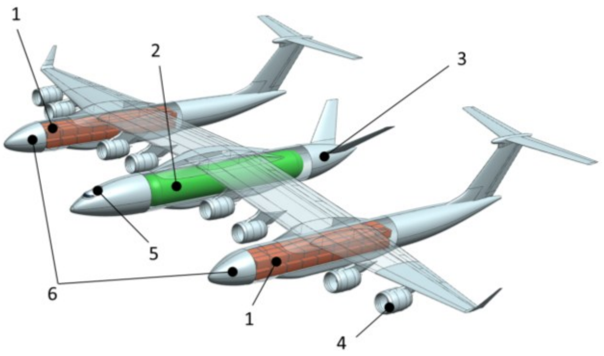

Fig. 6. Layout of the UHCA-3F (1 – cargo holds in side fuselages for 54 containers each; 2 – fuel tank with thermal insulation; 3 – demountable tail fairing for fuel tank maintenance and replacement; 4 – engines with takeoff thrust 76-100 tf each; 5 – crew cockpit; 6 – nose cargo doors)

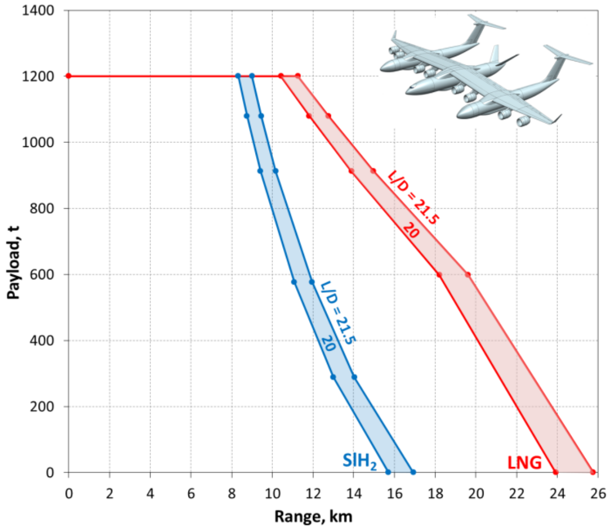

Fig. 7. «Payload-Range» diagram for the UHCA-3F with different L/D

In the three-fuselage layout of the UHCA-3F, cargo holds for 54 containers (total – 108 containers) are placed in the side fuselages, and removable tank for cryogenic fuel (LNG/LH$_2$) - in the central fuselage. Separation of cargo and fuel tank in different fuselages allow to distributing loads on wingspan and reduces wing weight.

The propulsion system of UHCA-3F consists of 8 engines and should provide takeoff thrust 76-100 tf each (depends on fuel – LNG/LH$_2$).

The flight performance and size comparison of HAFS aircraft variants are provided in table 1 and figure 8.

Table 1

Aircraft	HCA-LB	UHCA-LB		UHCA-3F	
Fuel	LNG	LNG	LH$_2$	LNG	LH$_2$
MTOW, t	1000	3625	2767	3700	2842
Payload, t	500	1200		1200	
V$_{CRUISE}$, km/h	450-550	450-550		600-700	
Range, 10^3×km	6	11	8.5	11	8.5
TO thrust, tf	4×50	7×106	7×80	8×100	8×76
Wing loading, kg/sq.m	370	635	485	685	526

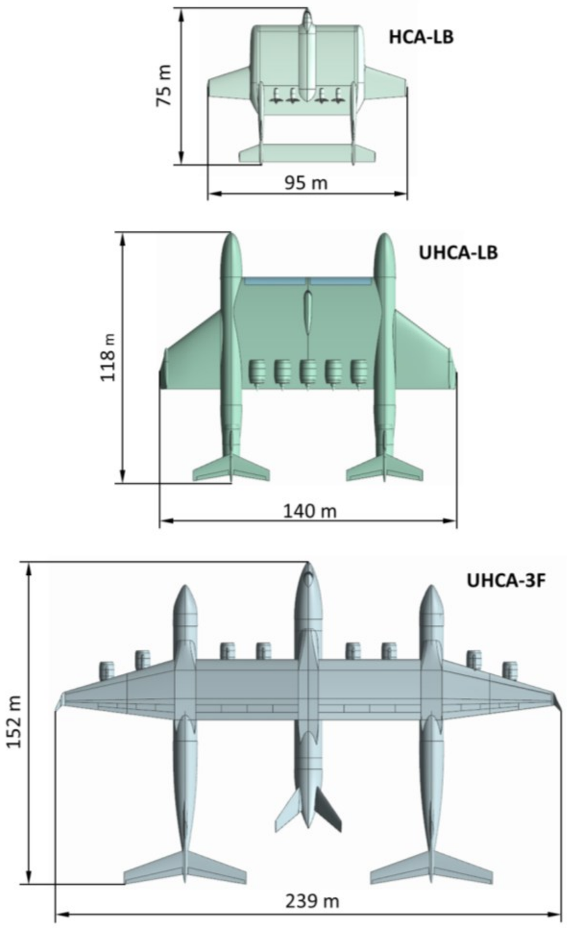

Fig. 8. Size comparison of the HAFS aircraft

4 Airport Infrastructure for HAFS

The HAFS airport (fig. 9) is a specially constructed airport, designed for the HAFS aircraft servicing. These airports should be placed on the sea/ocean coasts (probably artificial peninsulas).

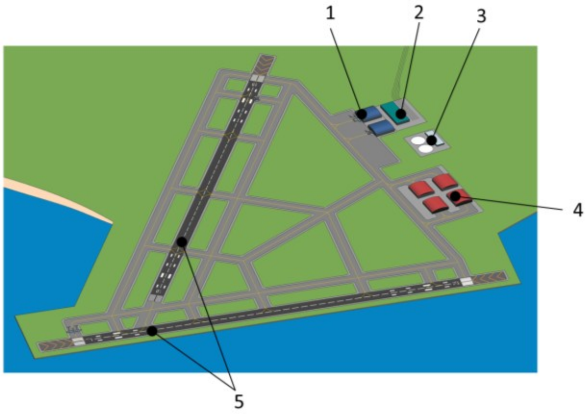

Fig. 9. Variant of the HAFS airport infrastructure
(1 – cargo terminals, 2 – automotive and railroad cargo paths, 3 – refueling complex, 4 – service hangars, 5 – runways)

The major requirement to airport is the minimum turnaround time of HAFS aircraft, special attention should be paid to the development of specialized cargo terminals that allow automated unloading / loading of containers and simultaneously fueling. In addition to communication with the seaport, cargo terminals must be provided with access roads and railways. HAFS airports will be able to take in other cargo aircraft. Due to the huge size of the runways, HAFS airports can be used as bases for air launch systems for spaceships.

Specialized operation infrastructure of HAFS airport should include:

- Cargo terminals;
- Maintenance facilities;
- In dependence of fuel type:
    - LNG fueling complex (supplied by LNG from production facilities and seaports);
    - LH2 fueling complex, based on the hydrogen production plant.

5 Conclusion

The concept of the heavy air transport system designed for transoceanic container transportations is developed. The proposed transport system will compete with marine container ships, differing in the high speed of cargo delivery in combination with improved environmental characteristics.

Super heavy aircrafts on LNG and liquid hydrogen are the heart of the HAFS. Three variants of HAFS aircraft – HCA-LB (48 TEU), UHCA-LB (100 TEU), UHCA-3F (108 TEU) are considered. HCA-LB and UHCA-LB are ground effect vehicles, while UHCA-3F is a three-fuselage fixed wing aircraft. These layouts are developed using the principle of load distribution along the wingspan, which makes it possible to reduce the total bending moments on the wing and, accordingly, to reduce the weight of its structure. Weight and size of the HCA-LB allow it to operate on existing airports with ICAO code 4F. UHCA-LB and UHCA-3F needs specialized airfields. A necessary condition for the effectiveness of HAFS as an element of the global transport network are the special cargo terminals that allow rapid, automated unloading / loading of containers to the aircraft, reducing turnaround time at the airport. The use of cryogenic fuel with improved environmental characteristics in comparison with aviation kerosene will require the design of a special fueling infrastructure that meets the safety requirements.

The obtained results can be used as a basis for further scientific and technical investigations of future transport aviation.

References

[1] Kaluza, P.; Kölzsch, A.; Gastner, M.T.; Blasius, B.: The complex network of global cargo ship movements. J. R. Soc. Interface (2010) 7, 1093-1103, doi: 10.1098/rsif.2009.0495. URL: https://rsif.royalsocietypublishing.org/content/7/48/1093/

[2] Vidal, J.: Health risks of shipping pollution have been ‘underestimated’, The Guardian, 9 April 2009. URL: http://www.theguardian.com/environment/2009/apr/09/shipping-pollution/

[3] Brewer, G.D.; Morris, R.E.: Study of LH2 Fueled Subsonic Passenger Transport Aircraft. Lockheed-California Company, NASA CR-144935, January 1976.

[4] Westenberger, A.: Liquid Hydrogen Fuelled Aircraft – System Analysis (CRYOPLANE), Final Technical Report, Airbus Deutchland GmbH, 2003.

[5] Pohl, H.W., Ed., Hydrogen and Other Alternative Fuels for Air and Ground Transportation. John Wiley & Sons, Germany, 1995.

[6] Alternative Jet Fuels. Chevron Corporation, 2006.

[7] Cole, W.: The Pelican: A bird for the long haul. 2002. URL: http://www.boeing.com/news/frontiers/archive/2002/september/i_pw.html

[8] Torenbeek, E.: Synthesis of Subsonic Airplane Design, Delft University Press, 1982.

[9] Nicolai, L.M.; Carichner, G.E.: Fundamentals of Aircraft and Airship Design: Volume I – Aircraft Design, AIAA Educational Series, Reston, USA, 2010.

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