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FUTURE CONCEPTS FOR AIR CARGO DELIVERY

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ABSTRACT

Air cargo delivery is a vital part of today's air transportation industry and is also an area of aviation whose future continues to evolve and develop. While taking a brief look back in to the history of air cargo delivery, this paper will examine current methods of air cargo delivery and also discuss potential concepts for the future of air cargo delivery and the markets to which they might be applied.

BACKGROUND

It is appropriate to look back to the birth of air cargo with the first use of aerial mail transportation as far back as 1870 when in that year letters were carried out of Paris by free balloons, cast adrift in the winds. The first of such flights were made on September 23, 1870, and carried 500 pounds of mail. This service offered 2 to 3 flights per week. A total of 65 flights were made carrying over two billion letters. In 1911, demonstrations of airplane mail services were made in India, England and the United States. The first airmail service in the United States was conducted at the aviation meeting at Nassau Boulevard, Long Island, N.Y., during the week of September 23rd, 1911. Earle L. Ovington, with his "Queen" monoplane, was duly appointed an air mail carrier and covered a set route between the temporary post office established at the flying field and the post office at Mineola, N.Y., dropping the mail pouches at the latter point for the postmaster to pick up. A total of 32,415 post cards, 3,993 letters and 1,062 circulars were carried.

Figure 1 JN-4H "*Jenny*"

The beginning of the civil cargo aircraft started during the year 1918 when Congress appropriated $100,000 to the Post Office Department for the development of an experimental airmail service. With these funds, the Post Office Department was able to purchase, maintain and operate what was called in those days "aeroplanes". The development and use of large military bombing planes during World War I demonstrated that these "aeroplanes" could be used for fast commercial and mail transportation. The first aircraft used for airmail was the Curtis JN-4H "*Jenny*" with a payload of 200 pounds bulk at 75 mph and a ceiling of 6500 ft.

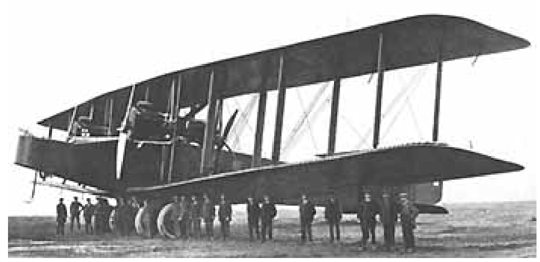

Figure 2 Handley Page V/1500

In November of 1919, American Railway Express Company inaugurated the first full scale endeavor of an air express services in the United States. The airplane selected by the express company was the Handley Page V/1500, which had an approximate payload of 7,500 pounds and a wingspan of 126 feet.

Figure 3 Douglas DC-4

The next significant development in air cargo delivery came during the Word War II timeframe with the development of the Douglas DC-3 and DC-4 aircraft. The Douglas DC-4, a passenger aircraft developed prior to WWII, was converted to a cargo aircraft and had the military designation C-54 *"Skymaster"* in 1942. The U.S. Navy used the aircraft to provide rapid air delivery of critical equipment, spare parts, and specialist personnel to naval activities and fleet forces worldwide. The C-54 had a split Main Cargo Door located aft of the wing.

Similar aircraft of this same type included aircraft such as the Curtis C-46 Commando, the Lockheed Constellation L-649 and the Douglas C-74 Globemaster which had a payload capacity of 48,000 pounds. In 1943, American Airlines began operating the first transcontinental all-cargo services with DC-3 air-freighters. American Airlines was the first airline to offer a service of this type. In June of 1946 American Airlines was the first airline to provide scheduled service with a four-engine DC-4 air-freighter. Also, American Airlines used both DC-6A air-freighters (beginning in 1953) and DC-7 combi aircraft (an aircraft that carries both cargo and passengers on the main deck), to continue to set records for carrying cargo. Slick Airways operated DC-4, DC-6 (first pure freighters), Curtis C-46, CL-44D4-6 (Canadair) and L-1049 Super Constellation as cargo aircraft.

The CL-44D4-6, used by Slick Airways, was a unique aircraft in that the entire tail sections would swing open allowing for the loading of long oil pipes. Eventually Slick Airways and Flying Tigers Line became one airline which, in turn, eventually was merged with Federal Express Corporation in 1989.

Figure 4 Lockheed L-1049 *"Super Constellation"*

Figure 5 Canadair CL-44D4-6

The Douglas DC-7 was the last of the Douglas propeller-powered transports. Introduced in May 1953, it entered service with American Airlines in November 1953. It was the first commercial transport able to fly nonstop westbound across the United States against the prevailing winds. The DC-7 like the DC-6 had a main cargo door aft of the wing on the left side of the aircraft and forward of the wing on the left side as well.

The U.S. civilian cargo jet era began with the introduction of the Boeing B707-321C model in 1963 with a Main Deck Cargo Door. Pan Am airlines was the first airline to operate the Boeing 707-321C jet freighter. Jets were already flying for passenger carriers since 1952 when the first De Havilland Comet 1 was delivered to British Overseas Airways Corporation (BOAC) and when the first commercial Boeing 707-121 was delivered to Pan Am in October 26, 1958.

Figure 6 Douglas DC-8

The DC-8 was the first Douglas jet-powered transport. It entered service simultaneously with United Airlines and Delta Air Lines on September 18, 1959 as a passenger aircraft. Later, in 1963, Douglas incorporated a freighter configuration to the family of DC-8's for cargo operations. During the same year Boeing rolled out the first B727-100. One of the variants included a convertible passenger-cargo model with a Quick Change (QC) option as the B727. Boeing gave the B737 the same upper lobe fuselage as the B707 and B727, so the same upper-deck cargo pallets could be used for all three jets. Commonality between the B707, B727 and B737 fuselage was vital. In February 1969 the first flight of the B747-100 was accomplished which created the first double deck aircraft for passenger and cargo service.

Figure 7 Douglas MD-11

Over the past thirty years a variety of other aircraft have been developed and have been produced in a freighter configuration which include the DC10, MD11, B767, A300 and A310 to list a few.

CURRENT AIR CARGO DELIVERY

Since the Wright Flyer was designed and first flown in 1903, aircraft have evolved. However, the uses of aircraft have pretty much remained the same. Aircraft have typically either transported passengers or freight. Today's modern aircraft remain much the same and are tending to follow the historical trend of bigger is better.

The freight industry continues to project growth in the worldwide freighter fleet. Even though the industry in currently experiencing a decline in traffic similar to, but not as severe as, the passenger market, the industry's resilience is projected to prevail and the freighter fleet is estimated to double within the next 20 years and that is taking into account the retirement of older aircraft such as the DC8, DC9, B727 and A300F's.

The air freight market growth is expected to continue strongly, reflecting the integral role air freight plays in the global economic growth. History has shown a doubling of the jet freighter fleet every 10 years in order to meet growth. With the significant replacement of many of the older narrow-body freighters with wide-body aircraft, the majority of the worldwide freighter fleet growth will consist of wide-body freighters.

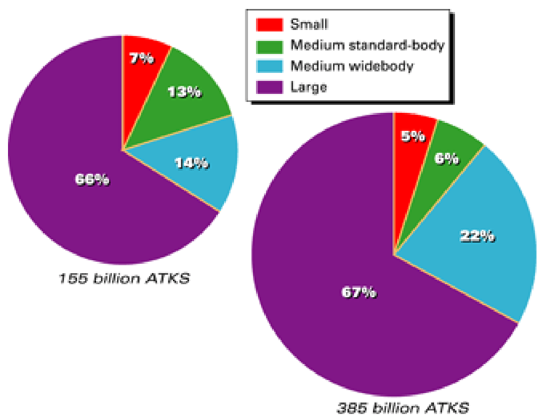

Figure 8 Wide-body World Capacity Percentages

Currently, the combined wide-body segments comprise nearly 40 percent of the world's total freighter units.

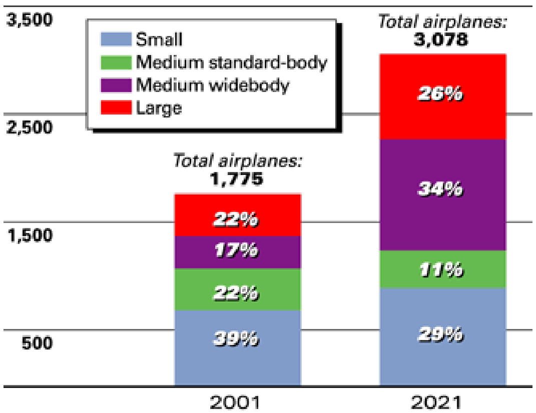

Figure 9 Wide-Body World Freight Capacity

Within the next 20 years, that percentage of wide-body aircraft is estimated to grow to 60 percent and will consume approximately 90 percent of the capacity.

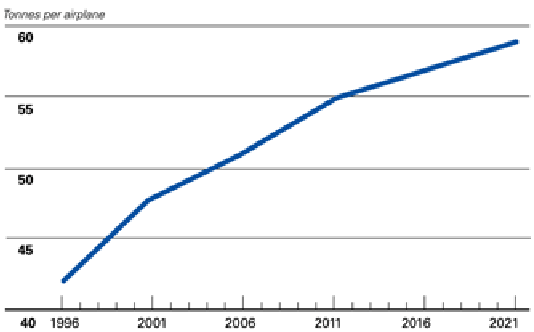

Figure 10 Average Freighter Capacity Trend

In addition, over the past 5 years, average freighter payload has increased about 14 percent. Over the next 20 years, the average payload is projected to grow 23 percent, due to the fleet replacement trends mentioned earlier.

FUTURE AIR CARGO DELIVERY

With freighter aircraft trends moving towards the larger wide-body aircraft in significant numbers, where is this newly found capacity going to be used? With the domestic market already well defined and with no new opportunities available, expansion in the worldwide freight market is where the majority of the growth is expected to take place.

Currently, customers are faced with only two options for their intercontinental freight shipments, air freight which is fast, reliable and costly or ocean freight which is slow, unreliable but inexpensive.

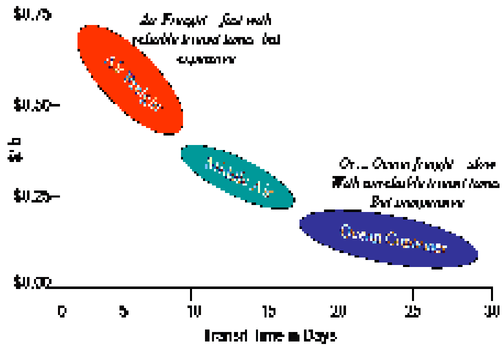

Figure 11 Middle Air Freight Market

While air freight is the mode of choice for moving high value freight, the vast majority of international tonnage travel is by sea. A possible future unmet market need is for freight service that is faster than ocean shipping and less expensive than shipping by air freight. This "Middle Air Freight" market could prove to be the next freight frontier in that there is perceived to exist an enormous potential.

Currently the U.S. export market is approximately 1.8 MM metric tons of which 62 percent is transported by sea and the current U.S. import market is approximately 2.7 MM metric tones of which 69 percent is transported by sea. What can be concluded is that if just a small percentage (5-10 percent) of the sea traffic were to utilize a middle air freight service, the revenue potential could be very significant.

FUTURE CONCEPTS

It would seem that one of the key aspects of being able to capitalize on a potential middle air freight market would be to have a transportation system that has a very large volume capability. Traditionally, freighter aircraft were, and are for the most part, designed to transport people first and freight second. Passenger aircraft have certain requirements such as high speed, high altitude, pressurized environment, windows, exits, emergency equipment, etc, which all contribute additional costs to the design, manufacture and operation of that aircraft. Most freight (export and import) is light, which tends to drive the current aircraft utilization to being volume limited thereby not taking advantage of the aircraft's full payload carrying potential.

Blended-Wing-Body (BWB)

The BWB (Blended Wing Body) is a new concept in aircraft design which offers great potential while substantially reducing both manufacturing and acquisition costs while improving aircraft performance and flexibility for both passenger and cargo missions. When compared with conventional configurations, the BWB has been found to be superior in all key areas. The advantages arise from a combination of aerodynamic and structural improvements which reduce the total wetted area of the airplane and lower the weight at the same time that they improve the lift-to-drag ratio. The result may prove to be a paradigm shift in the way airplanes of the future are designed.

Figure 12 Boeing Blended-Wing-Body Aircraft

The BWB program began in 1993 as a small NASA funded study to examine the potential of alternate configurations for subsonic transports. This study began with a refined sizing of the initial BWB configuration where minimum takeoff gross weight (TOGW) was set as the figure-of-merit. Primary constraints included an 11,000-foot takeoff field length, 150-knot approach speed, low-speed trimmed Clmax of 1.7, and a cruise Mach number of .85. Initial cruise altitude (ICA) was allowed to vary to obtain minimum TOGW, but with the requirement that the ICA be at least 35,000 feet.

This yielded a trapezoidal wing with an aspect ratio of 10 with a corresponding span of 280 feet and an area of 7840 square feet. The resulting trapezoidal wing loading was on the order of 100 lb/ft^2 - substantially lower that the 150 lbs/ft^2 typical of modern subsonic transports.

The explanation being that a significant portion of the trapezoidal wing is in effect hidden by the center-body, and therefore the cost of trapezoidal wing area on airplane drag is reduced. This in turn allowed the airplane to be optimized with a larger trapezoidal area to increase span with a relatively low cost on weight.

Creation of the original BWB was motivated by a search for an airplane configuration that could offer improved efficiency over the classic tube and wing. Takeoff weight and fuel burn were the primary figures of merit, and the BWB concept has shown substantial reductions in these two performance parameters. However, the BWB configuration offers some unique opportunities that were neither envisioned nor planned during it original creation in 1993.

The BWB is simply a big wing with an integrated fuselage and no empennage, save the winglets/verticals. There are no complex wing-fuselage and fuselage-empennage joints of highly loaded structures at 90 degrees to one another, and there are no fillets. All trailing-edge control surfaces are simple-hinged with no track motion, and there are no spoilers. This manifests a substantial reduction (on the order of 30-percent) in the number of parts when compared to a conventional tube and wing configuration. A similar reduction in manufacturing recurring cost is implied.

The Blended Wing Body (BWB) airplane concept represents a potential revolution in subsonic transport efficiency for large airplanes. The BWB advantage results from a main cabin that extends span-wise providing structural and aerodynamic overlap with the wing. This reduces the total wetted area of the airplane and allows for a long wingspan. A deep and stiff center-body provides for a very efficient structural wingspan.

The projected resulting improvements are:

Fuel Burn	27% Lower
Takeoff Weight	15% Lower
Operating Empty Weight	12% Lower
Total Thrust	27% Lower
Lift/Drag	20% Lower
DOC	15% Lower

Because of the inherent efficiencies of the BWB configuration, this aircraft concept is a very interesting candidate for a middle-market air-freighter. Using the BWB 800 passenger configuration as a starting point and modifying the configuration to maximize the freight carrying capability while also tailoring some of the performance characteristics to the middle air-freight mission, a very interesting aircraft emerges.

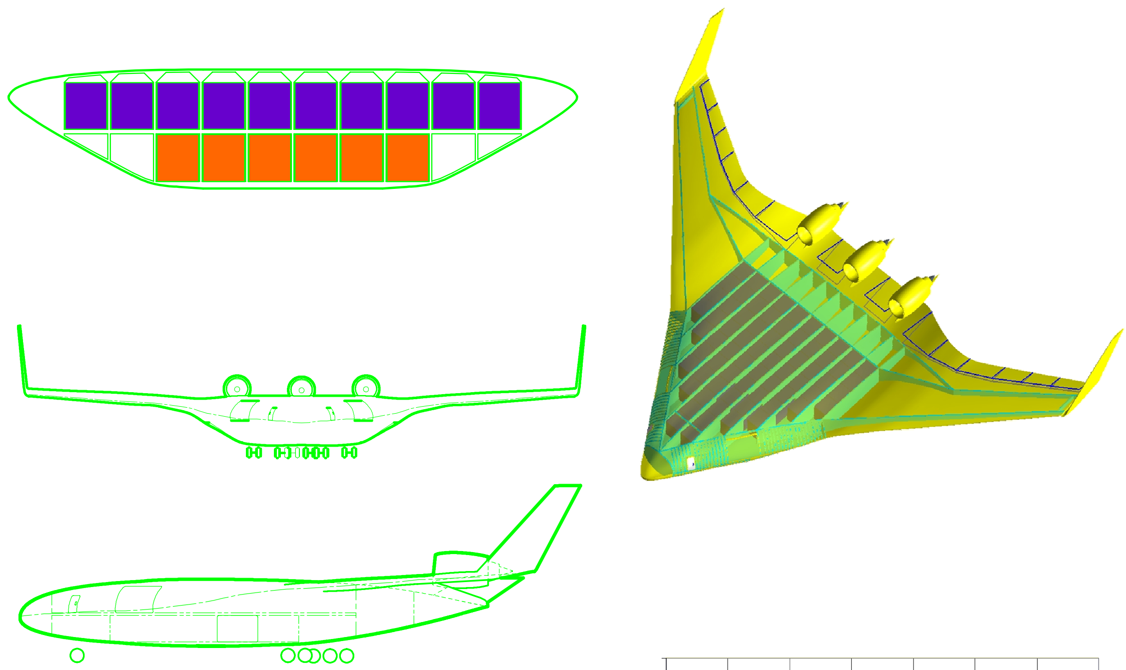

Figure 13 Boeing BWB Three View and Isometric

The resulting criteria for this new air-freighter includes a full double-deck with a 1,350,000 lb Maximum Gross Take-Off Weight (MGTOW), which also happens to match that projected by Airbus for the A380F, a maximum gross payload of approximately 525,000 lbs at a range of approximately 5000 nautical miles and having a payload volume of approximately 51,000 cubic feet. Also, the BWB would have a cruise speed of .85 Mach at an initial cruise altitude of 31,000 ft while maintaining a cabin pressure altitude of 12,000 ft and being powered by three 90,000 lb-class thrust engines. All this while remaining within the 80 meter box required to operate out of current modern day airports.

By taking advantage of the performance of such an aircraft, while significantly reducing the direct operating costs allows the operator to offer a very real middle air-freight alternative to either the high cost of pure air-freight or the very slow sea freight modes of transport. The fact that the BWB-MF (Middle Freighter) has nearly a 62 percent payload advantage coupled with a 15 percent decrease in direct operating costs when compared to other aircraft currently being

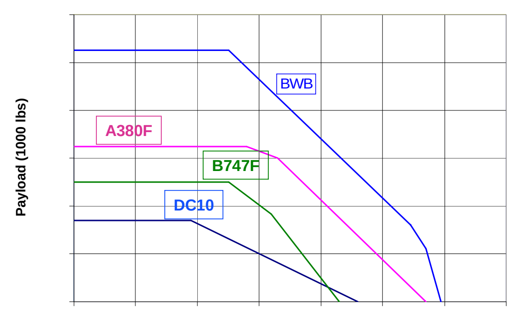

Figure 14 Payload/Range Comparison

developed, should make anyone in the freight industry sit up and take notice.

Hybrid Ultra Large Aircraft

A technology improvement in freight transportation that has been studied and that has shown some potential is Hybrid Ultra Large Aircraft (HULA) using Lighter than Air (LTA) technology.

Conventional aircraft freighters, while effectively solving the problem of speed, use enormous amounts of fuel at a time when the need to conserve fuel is pressing. Moreover, goods transported by conventional aircraft almost always have to be transferred to another mode of transportation before they can arrive at their final destination.

There is a mode of transportation, however, that if allowed to be developed, may be able to solve the problem of speed (as compared to conventional ocean shipping) and capacity, in that the vehicle can be designed to carry upwards of 2,000,000 pounds of payload. In addition, LTA and ULA Hybrids offer excellent fuel economy, as compared to conventional aircraft combined with significant flexibility in that freight can be loaded and off-loaded in undeveloped areas that offer very little infrastructure.

The use of dirigibles to transport enormous freight loads is not new, nor a concept just off the drawing board, still in need of extensive field testing. An inherent advantage of the hybrid aircraft over conventional aircraft is that through the use of a buoyant aerostatic lift (conventional aircraft use powered aerodynamic lift), the fuel cost of getting and keeping the hybrid aircraft aloft is a fraction of conventional aircraft.

One of the ULA Hybrids currently under development is the AeroCat, by AeroVehicles, Inc., which combines the advantages of aerodynamic lift derived from the lifting-body hull shape and the efficiencies of lighter-than-air buoyancy resulting from the helium filled envelope.

The fabric used to construct the hull is laminated with an internal catenary system supporting the payload module. The aerodynamic shape of the hull, an elliptical cross-section allied to a cambered longitudinal shape, provides up to 40 percent of the aircraft's lift. Multiple ballonets located fore and aft in each of the outer hulls provide pressure control.

"Ultra Large" means just that. These airships are very large, as 3.5 million cubic feet of helium are required to lift every 100 tons. The 500 ton cargo hybrid aircraft is over 800 feet long, 350 feet wide, and 180 feet tall, larger than a typical sports stadium.

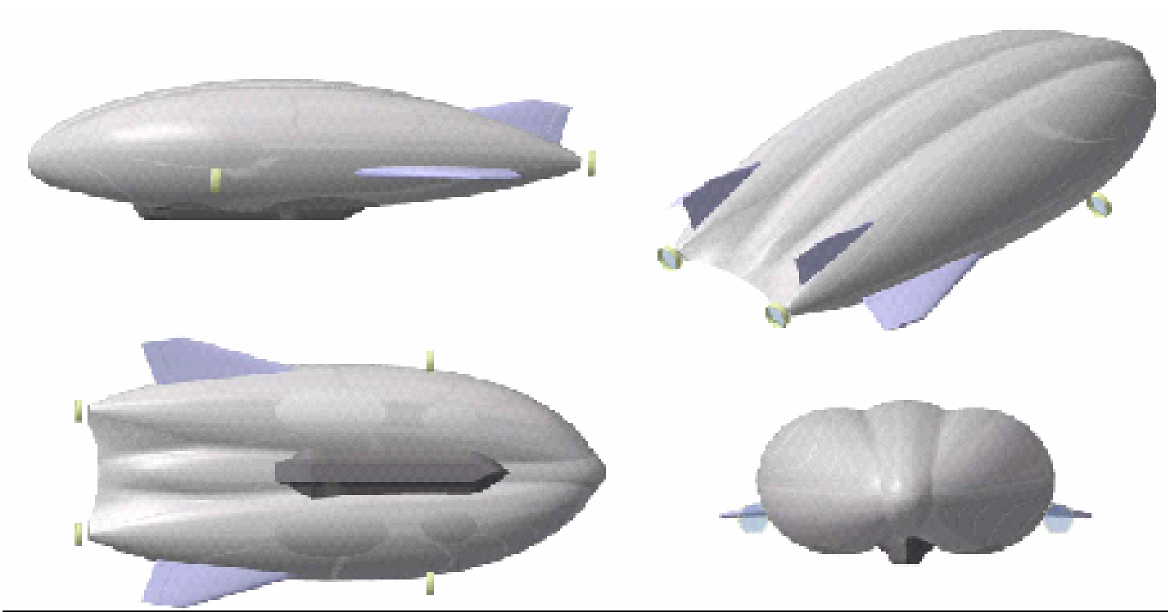

Figure 15 AeroVehicles, Inc *"AeroCat"*

The ULA Hybrid uses a non-rigid shape that provides 60 percent of its lift using buoyant aerostatic lift while the remaining 40 percent of lift is generated using powered aerodynamic lift while in motion.

Hybrid aircraft travel at a slower speed than conventional aircraft because much of their efficiency is derived from the 'free lift' of the buoyant gas, and higher speeds drive down that efficiency. Hybrid aircraft, however, are still many times faster than ocean going ships (90 knots vs. 20 knots). Adding to ground speed, the hybrid aircraft also use weather and winds aloft to their advantage in a manner similar to a sailing ship on the ocean.

The large size and the total mass of the vehicle also creates high inertia and good stability, easing loading and unloading of cargo. The AeroCat for example lands either on water and taxis over the shore or lands on a large flat area to load and unload.

Current conventional aircraft have specifically designed universal loading devices (ULD's) that the freight is loaded into prior to being loaded on to aircraft. These ULD's are specialized and designed for weight optimization and aircraft contours.

resulting from the relatively wide spaced air cushion landing system. By reversing the air cushion fans on landing, the aircraft is able to create suction between the ground and itself, thus remaining stationary aiding in loading and unloading. This attribute eliminates the requirement for large ground crews, elaborate tie-down systems, external mooring masts and other large support equipment.

HULA vehicles are no more vulnerable than any other high value transportation asset while their failure modes are much more benign, i.e., an buoyant vehicle tends to settle to the ground rather than smash into it like an aircraft if it suffers some catastrophe while in flight. The inert helium gas is under low pressure, about the

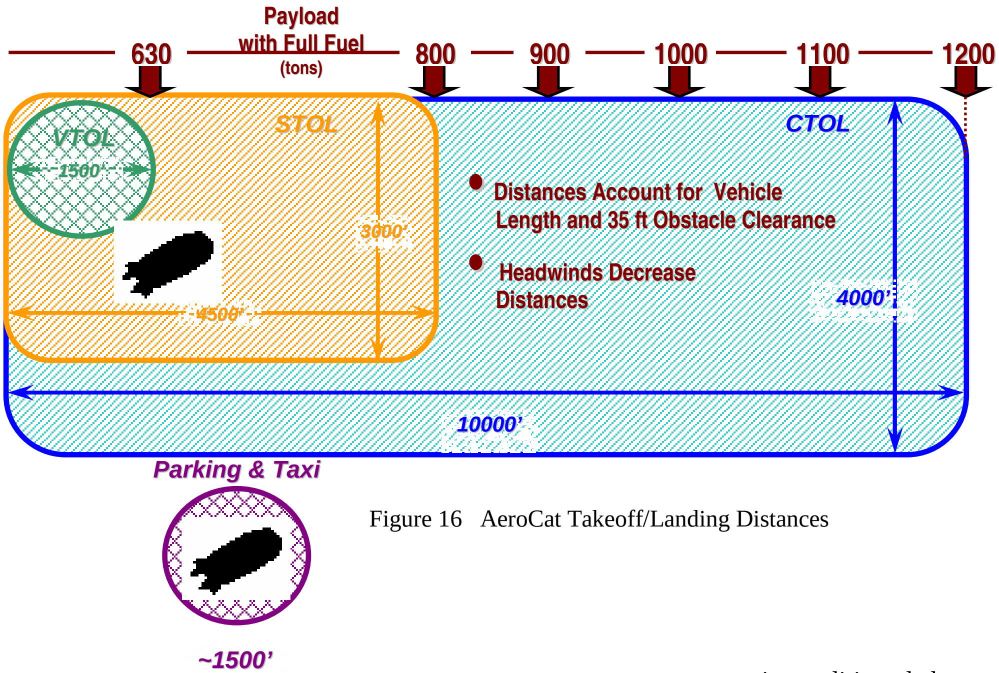

Figure 16 AeroCat Takeoff/Landing Distances

An advantage the AeroCat, and other HULA's have is that the vast majority of freight can be transported using current standard ISO intermodal containers thereby further simplifying loading and unloading. No longer will freight have to be trans-loaded from aircraft ULD's to over the road transports.

Additionally, the AeroCat ULA Hybrid also has the flexibility to operate from virtually any reasonable flat surface land or water, snow or desert, due to the retractable hovercraft type landing system and the stability of a catamaran

same as an air-conditioned skyscraper, so the gas envelope is very damage tolerant to holes.
The AeroCat HULA is also environmentally sensitive in that it does not require large forested or protected areas to be altered or paved to provide landing or operating areas. Normal takeoffs and landings, at maximum gross weight and zero wind can be made within five aircraft lengths. Lower payloads or even slight headwinds shorten the distance considerably, even to less than on hull length.

This configuration would utilize four engines, two of which would be positioned forward on each side of the hull and two positioned on the stern points of the hull. All engines would have ducted propellers complete with directional vanes for vectored thrust on takeoff, landing, taxiing and ground operations. Depending on the final size of particular versions, the number and orientation of the engines can vary.

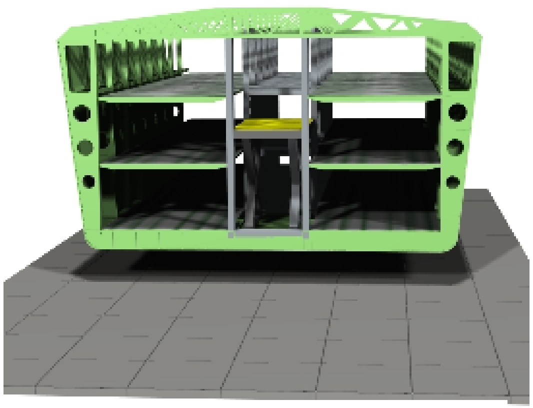

Figure 17 AeroCat Interior Concept

With payloads measured in hundreds of tons, and conservative cruising speeds of 80-100 knots at altitudes less than 10,000 feet using existing technology to meet air freight needs, HULA's deserve an in depth look. These unique air vehicles can be designed for immediate integration with current cargo shipping infrastructures. Built using existing aircraft manufacturing methods and technology and with the ability to take off and land from undeveloped areas carrying standard intermodel containers currently used with trucks, trains and ships, the HULA's have very interesting and significant potential.

Regardless of how big the first HULA may be, many think that this concept could usher in the biggest breakthrough in air-freight transport in the 21st century.

Ultra Large Transport Aircraft

A concept that, by some, is considered to be on the fringe of practicality is the idea of a large sea plane being used for moving large amounts of freight across either the Pacific or Atlantic oceans.

One such concept aircraft is the Pelican Ultra Large Transport Aircraft (ULTRA) currently under study by the Boeing Phantom Works. The Pelican is a low flying aircraft that basically flies in ground effect. By flying close to the water, the wing downwash angle and wing tip vortices are suppressed, resulting in a major drag reduction and outstanding cruise efficiency. A Wing in Ground Effect (WIG) provides extraordinary range and efficiency.

WIG vehicles offer a capability to fill the void between current conventional cargo aircraft and the slow moving ocean ships. WIG vehicles can offer the speed of a conventional aircraft while, at the same time, being able to transport very large payloads with a reduced fuel consumption.

Wing in Ground Effect (WIG) is the phenomenon described when a cushion of air is created under an aircraft's wings during landing. Just prior to touching down, an air cushion develops and, unless the pilot changes the shape of the wings, the air cushion remains trapped between the wings and the runway.

Ground effects increases lift and reduces air resistance, or drag. The primary reason for developing an aircraft to operate in ground effect is to obtain the highest possible lift to drag ratio so as to reduce the thrust requirements and subsequently, fuel costs.

WIG vehicles typically fly close to the surface, taking advantage of the reduced drag and increase lift. Although the term used is "Wing in Ground Effect", WIG vehicles typically only fly of bodies of water.

WIG vehicles could provide the size, weight, and volume of lift that is projected for the next 20 years. WIG vehicles are hybrid sea and air vehicles capable of very heavy lift over long ranges. It is believed to be technologically feasible to build vehicles that are at least three times larger and ten times heavier than the largest conventional aircraft.

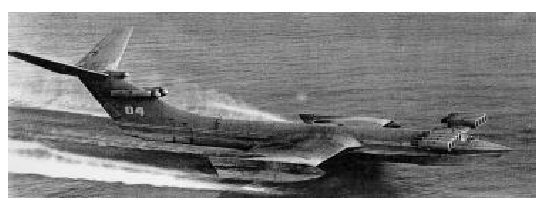

Figure 18 Russian KM *"Caspian Sea Monster"*

Developed initially by the Russians in the 1960's, the first WIG, named the "Caspian Sea Monster", was capable of lifting 540 tones and cruised at 310 miles per hour. This vehicle took off and landed on the sea and held a steady altitude of 10 feet above the surface. Current WIG technology has the capability of flying between 20 and 90 feet above the surface of the sea and can cruise at 400 knots. Higher altitudes are possible when necessary to transit small land masses or to avoid shipping or other obstacles, but these altitudes cause a significant decrease in fuel efficiency.

Dwarfing all previous flying giants is the Pelican which is a high capacity cargo planes concept currently being studies by the Boeing Phantom Works. The Pelican would stretch more than the length of a U.S. football field and have a wingspan of 500 feet and a wing area in excess of an acre. It would also have twice the external dimensions of the world's current largest aircraft, the Russian An225, and would be able to transport five times its payload, up to 1,400 tons of cargo.

Figure 19 Boeing Pelican Concept Aircraft

Designed primarily for long-range, transoceanic transport, the Pelican would fly as low as 20 feet above the sea, taking advantage "Wing in Ground Effect". Over land, it would fly at altitudes of 20,000 feet or higher. While operating from ordinary paved runways, the Pelican would use 38 fuselage-mounted landing gears with a total of 76 tires to distribute its weight. The lateral spacing of the landing gear would be approximately 45 feet with the landing gear row of tires being 180 feet in length. Due to the landing gear configuration of the aircraft it is presumed that it would demand a "fly off/fly on" maneuver using an auto pilot/auto land system. At lift off, and on landing, the deck angle would need to be maintained parallel to the runway to assure concurrent contact of all the gear similar to the B-52. A crosswind landing gear design would also be needed to align the gears with the runway, again similar to the B-52.

Eight 80,000 lb shaft-horsepower engines would be required to power the Pelican similar to the 60,000 lb shp GE LM-6000 marine engine. A new marine engine would need to be developed based on the GE90 core. The Pelican is configured with four engine pods with counter rotating propellers having four blades each. Each engine pod would contain two engines with a geared combiner gearbox with either/both of the engines being capable of driving both propellers. In low level ground effect cruise, one engine in each pod would be throttled to idle to improve specific range.

WIG vehicles seem to be capable of filling the niche between slow moving ships and fast but expensive airplanes. WIG vehicles have the potential of carrying a larger payload, using less fuel for the same size payload as compared to conventional freighter aircraft.

With a payload of 1.5 million pounds, the Pelican could fly 10,000 nautical miles over water and 6,500 nautical miles over land. Flying in ground effect demands the latest flight control technology. Reliable systems will provide precise, automatic altitude control and collision avoidance. Cruise altitude would be adjusted according to sea state, and if the seas get too rough, the Pelican would be capable of climbing to a higher altitude and continue the flight.

Although the Pelican concept shows a promising solution, it also has some significant challenges to overcome. Several areas of risk are present and would need to be overcome in order for this aircraft to come to fruition. These hurdles include: gearbox and propeller design, marine engine development, land gear design, flight control systems, bird strike potential and corrosion due to continuous operation over salt water.

SUMMARY AND CONCLUSIONS

Before the airplane even had begun to fly, there has been delivery of air-cargo. In its earliest beginnings it was the balloon and today it is large jet aircraft. But what is next? What is over the air-freight horizon? It seems that today's conventional aircraft has been, and is being, utilized in every conceivable way in order to get the job done and its profit margins can only sustain its applicability so far.

The intent of this paper has been to present possible alternatives to current air cargo delivery and how these alternatives might be applied to potential future markets.

There seem to be several prospective next-generation air-cargo vehicle possibilities on various drawing boards today all of which are technically feasible. Some, if not all, of these concepts are high risk, but the possible rewards are also high.

Tube and wing designs have been relatively unchanged for decades and the efficiencies of this design have been taken as far as it can go. What is needed is a leap to the next generation freighter.

That leap will require a change in the demands of the transport marketplace as much at it will require new engineering solutions. The potential of the middle air-freight market is readily apparent, now what is needed is the right solution to be able to properly develop it.

Acknowledgements

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