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2020: Future Vision for Global Air Cargo

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Abstract

This paper describes a study conducted as a part of the National Aeronautics and Space Administration (NASA) Scenario-Based Strategic Planning process. During this process, Global Air Cargo was identified as one of several potential high-payoff vehicle classes for the year 2020. Within this vehicle class, a goal was established to provide a ten-fold reduction in the cost per ton-mile for air cargo shipments. In order to assess the issues associated with achieving this goal, a detailed systems analysis was conducted for this class of vehicle.

The current air cargo industry was examined to determine potential design requirements including range (by virtue of airport-to-airport distance pairings), operating field length requirements (determined from a statistical analysis of current airport infrastructure), and specific design features (e.g. inter-modal container carriage, joint civil/military use). Several air cargo configuration concepts were developed and examined as a part of this study. These included several exclusively all-cargo concepts sized for six range payload combinations, and two passenger configurations modified for freighter use. Performance for each configuration was compared to the baseline (existing) aircraft. Technology sensitivity analysis was conducted using the lowest payload, shortest range and highest payload, longest range concepts. For each range-payload combination, the best concept was selected for economic analysis and compared to current fleet aircraft.

The results indicate that a 75% reduction in the cost per ton-mile for cargo transportation (relative to DC-10-30F) is potentially achievable. In addition, a payload increase of 3x (over C-5B maximum) with a concurrent range improvement of 2.5x (relative to a C-5B) is also potentially achievable even within the current airport infrastructure limitations.

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Introduction

In 1996, the NASA Office of Aeronautics embarked upon a Scenario-Based Strategic Planning process. This process identified possible future world scenarios and potential aerospace vehicle types and technologies which might be valuable in the year 2020. This initial phase is described in Maintaining U.S. Leadership in Aeronautics, Scenario Base Strategic Planning for NASAs Aeronautics Enterprise.[1]

Subsequent to this initial phase, seven categories, or classes, of aircraft were identified as having potential high impact in these future scenarios. Goals were established for each vehicle category which quantified levels of improvements over existing aircraft for particular measures of merit. In order to assess the potential to achieve these goals and the technology advances required, the Systems Analysis Branches of the NASA Langley, Lewis, and Ames Research Centers were tasked to jointly conduct detailed systems studies for each of the vehicle categories. Within each category, the objective of these studies was to identify whether the particular measures of merit were appropriate and whether the goals established for each were reasonable.

Approach

In order to assess the potential to achieve the stated goals for the Global Air Cargo segment, a detailed systems analysis was conducted. The current air cargo industry was examined to determine potential design requirements including range (by virtue of airport-to-airport distance pairings), operating field length requirements (determined from a statistical analysis of current airport infrastructure), and specific design features (e.g. inter-modal container carriage, joint civil/military use). A list of cross-cutting technologies and their potential impacts/benefits in the 2020 timeframe was developed to be able to examine a then year vehicle capability. Several air cargo configuration concepts were developed and examined as a part of this study. These included several exclusively all-cargo concepts sized for six range-payload combinations, and two passenger configurations modified for freighter use. Each configuration was compared to the C-5B for performance and the DC-10-30F for cost. Technology sensitivity analyses were conducted using the lowest payload, shortest range and highest payload, longest range concepts to determine the impact of each of the specific technologies to the viability of the concepts. For each range-payload combination, the best concept was selected for economics analysis and compared to current fleet aircraft.

Concept Development

Air Cargo shipments today fall into two broad categories: integrated distribution shipments (a la Fed-Ex) and point-to-point shipments. With the integrated shipments, cargo is collected at various points and sent to one or more redistribution centers. Under this scenario, collection points are usually major metropolitan areas. However, expansion to non-major airports is key to growth opportunities. Additionally, point-to-point cargo shipments, such as bulk mail, constitute a high percentage of freight shipped. Therefore, the ability to transit between large numbers of available airfields is a positive attribute for future cargo aircraft. A data base of worldwide airfields[2] was used to analyze civilian, military, and joint-use airfields. In order to evaluate the range requirements for a future airlifter, airfield to airfield distances were computed for the airfields in the data base. A distribution of these distances can be found in Figure 1. As can be seen, the distances tend to fall into intra-continental range (those under approximately 3500nmi) and intercontinental range. Approximately 95% of the worldwide airfield-airfield parings can be serviced by an aircraft with an 8500nmi range. This range was considered a reasonable target inter-continental range.

Similarly, other operating characteristics were also established. Again using the airfield data base, a distribution of runway lengths was generated. Figure 2. shows a distribution where approximately half the available runways are 8000ft. or longer. Since the current C-5B airlifter was designed for a nominal 8000ft. operating field length, this was selected as the target takeoff and landing field length. Previous studies have indicated that payload capacity has a strong impact on the operating economics. Since it was not known a-priori what payload might be nec-

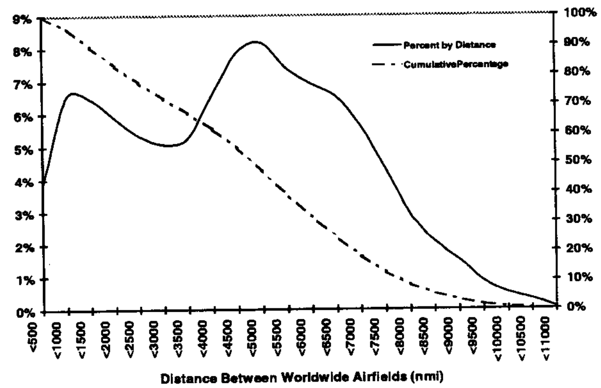

Figure 1. Range distribution between airfields

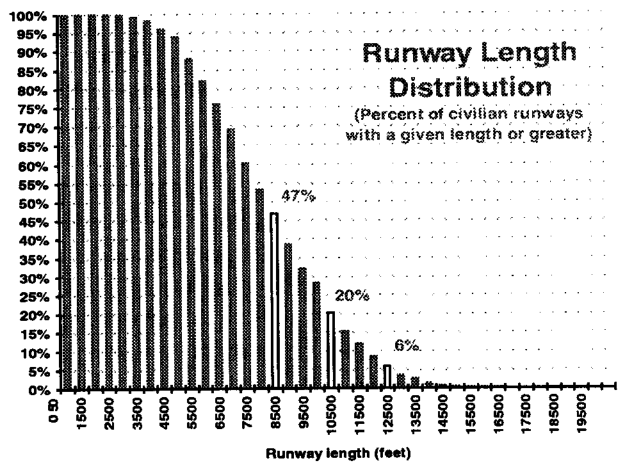

Figure 2. Runway lengths

essary to achieve the stated economic goal, nor was it known what a practical maximum payload might be in 2020, three payload categories were selected: 250,000lbs., 500,000lbs., and 750,000lbs. Since inter-modality was identified as a potentially key feature, this payload roughly corresponded to the carriage of 10, 20, and 30 TEUs (8x8x20 ISO container). However, payload bay sizes were also configured on the basis of 96"x96" commercial pallets and outsized military cargo such as the MH-47E (189 wide) helicopter, the RTCC (14 tall) crane, and the M1A2 (30 long) main battle tank. While military cargo carriage, and the cargo floor strength required for it, are thought of as penalties, the payload densities for containerized cargo tend to be much higher than for palletized cargo. Therefore, the cargo floor strength for a militarized version would not impose a penalty since it would be needed for commercial operations.

Nine all-cargo configuration types were considered in the concept formulation phase of the study. These included a conventional wing-body-tail concept, a blended wing-body or BWB, a twin fuselage concept, joined wing, delta wing, and inboard wing concepts, a pod-hauler concept, a spanloader, and a seaplane. Figure 3. provides a visual representation of the configurations evaluated. In addition, two "converted" passenger configurations were analyzed. An attempt was made to use each of the configuration types to develop a sized concept for each of the six payload-range combinations. An initial geometry model was developed for each configuration type and input into the FLight OPtimization System (FLOPS)[9] for analysis. A common set of technologies was used to describe each then-year (2020 technology level) aircraft model. Each configuration was then sized to the mission range-payload requirement along with the operating field length limit of 8000ft.

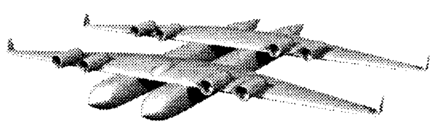

Figure 3a. Twin Fuselage

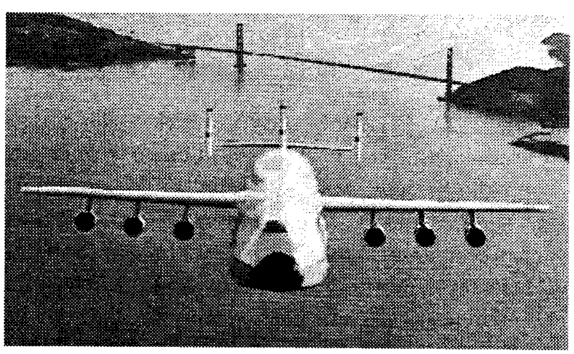

Figure 3b. Conventional Wing-Body

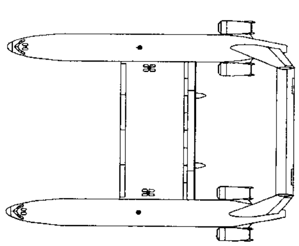

Figure 3c. Inboard Wing

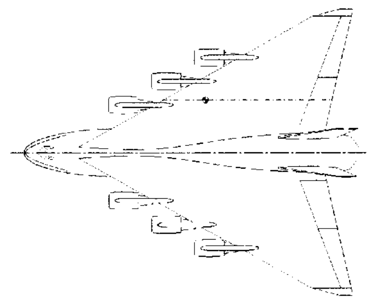

Figure 3d. Delta Wing

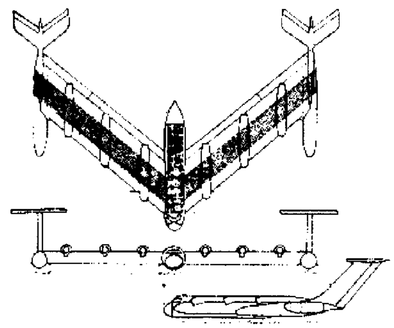

Figure 3e. Spanloader

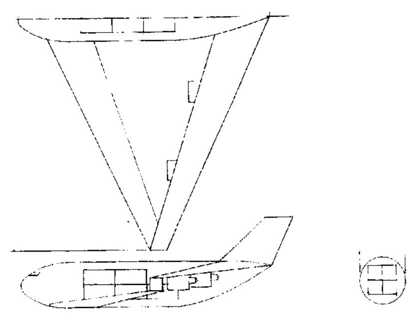

Figure 3f. Joined Wing

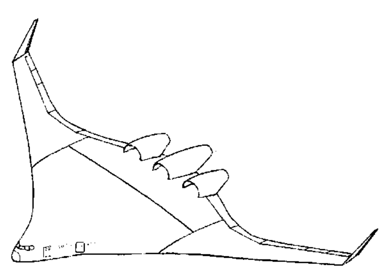

Figure 3g. Blended Wing-Body

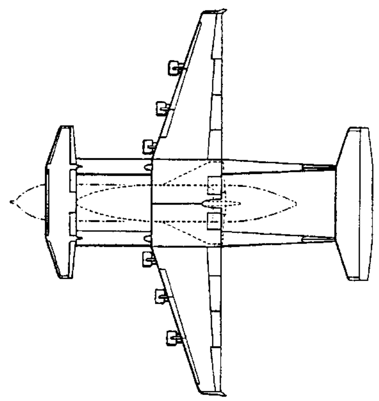

Figure 3h. Pod Hauler

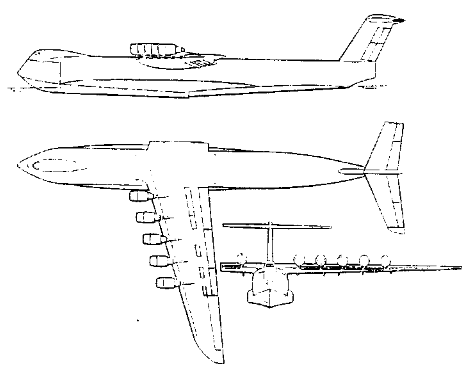

Figure 3i. Seaplane

Each of the configurations studied had particular strengths and weaknesses. The conventional wing-body-tail configuration would entail the least change from existing design practices. However, if the largest payloads are a necessary design requirement (or the technology progressions assumed fail to materialize) the conventional design rapidly degrades to an infeasible configuration. Even with the technology assumptions, the manufacture of a fuselage barrel section almost 40 feet across may be infeasible. The twin fuselage offers the potential advantage of using the center section wings to implement an overhead crane automated load/unload system. However, load balance could become a significant issue. Additionally, the largest of the twin fuselage configurations implements a tandem wing arrangement with uncertain aerodynamic properties. The blended-wing configuration also has significant uncertainties in that it uses a highly non-circular pressure vessel. Also of issue is the ability to load and unload large cargo containers quickly from this configuration. The spanloader configuration has significant advantages in high payload applications but the implementation of the landing gear system is highly problematic. One proposed option was to limit the total span to that which would land normally on existing runways and rotate the craft 90° for taxi. The inboard wing configurations were span limited to 70 for taxiway considerations. This made the vehicle impractical for all but the lowest payloads. The pod hauler, although having the ability to reconfigure the type and size of the payload bay, still must have a significant fuselage structural arrangement to attach both the pod and the landing gear. This drove the structural weight fraction significantly higher than other configurations. The joined wing configuration analysis indicated similar results to previous studies in that the improved aerodynamics of the joined wing were not sufficiently large enough to overcome the increased structural weight of the wing. The delta wing configuration showed a slightly different trend in that the improved structural weight was insufficient to overcome the degraded aerodynamics. The seaplane had two distinct advantages: (1) virtually unlimited operating sites and (2) significantly lower weight and size (since the configuration was not being driven by a fixed takeoff distance constraint). The infrastructure necessary to support seaplane cargo operations worldwide would have to be regenerated since they were all but abandoned in the early sixties. Detailed sizing and performance information is contained in the next section. A FAR Part-36 noise analysis was not performed for any of these configurations and may be a significant issue.

Performance Analysis

Initially, a C-5B configuration model was developed and analyzed using FLOPS in order to calibrate the aerodynamics, and systems and equipment weight predictions.[3,4,5] Following this, a template configuration was developed which contained the model changes due to the 2020 technology impacts. Each individual configuration was then created by adjusting the geometry and other parameters in the template to the unique features of the configuration under study. The gross takeoff weights for the sized configurations are shown in Table 1. In some cases, the range-payload combination was found to be infeasible. For example, the inboard wing configuration could not produce a viable configuration beyond the 250,000lb payload level. This was due to the nature of the aerodynamics of this concept. While the inboard wing does show a significant improvement over a conventional wing of similar geometry, the limit on the total vehicle span to 70ft. (taxiway width limit) imposed a high induced drag penalty which could not be overcome. For the configurations studied, it was felt that even with the use of an Air-Cushion Landing System (ACLS), the existing airport runways could not support a vehicle weighing more than 2 million pounds. Without an ACLS, most of the runways being considered would not support much over 1 million pounds. The configurations were allowed to cruise at optimum altitude and Mach number for best fuel economy. This resulted in cruise speeds between M=0.775 and M=0.82. It was assumed that for the 8500nmi missions, an on-board relief crew would be necessary.

Configuration	250klb 3500nmi.	500klb ------	750klb 3500nmi	250klb. 8500nmi	500klb -------	750klb 8500nmi
Conv. WBT	513	972	1440	656	1332	2109
BWB	596	1025	1350	760	1224	1776
Joined Wing	1060	1620	2140	1360	2270	3070
Twin Fuse	541	982	1422	685	1223	1802
TF w/InbdWing	766	xxxxxxx	xxxxxxx	xxxxxxx	xxxxxxx	xxxxxxx
Pod Hauler	942	1429	2153	1166	2036	2970
Spanloader	xxxxxxxx	xxxxxxx	1342	xxxxxxx	xxxxxxx	1829
Seaplane	xxxxxxxx	xxxxxxx	xxxxxxx	825	1306	1812
Combi800				827		
Combi-Supersonic	629*	(*96,500lb payload, 6500nmi)				

Table 1. Gross takeoff weights for the sized configurations, klb.

The converted passenger configurations are models from other vehicle classes being studied. Passengers and accommodations for them were removed and replaced with cargo. The Combi-800 aircraft represents an 800 passenger vehicle configured to carry 250,000lbs. of cargo 8500nmi. Note that this vehicle does not meet the 8000ft. operating field length requirement. The Combi-Supersonic configuration represents an attempt to satisfy the stated goal of a Trans-Pacific overnight capability of 100,000lbs. A converted 300 passenger (mixed class) vehicle sized for Mach 2.4/6500nmi can carry approximately 96,500lbs. of cargo.

Within each range-payload combination, the lowest gross takeoff weight vehicle was chosen for further analysis. Table 2. provides a summary of the salient characteristics of the selected configurations. Note that the span for all configurations was limited to 300 feet (with folding tips, 250ft. without).

Configuration	Conventional WBT1	Conventional WBT2	Span Loader	Conventional WBT3	Twin Fuselage	Blended Wing-Body
Payload, lbs.	250k	500k	750k	250k	500k	750k
Range, nmi	3500	3500	3500	8500	6500	6500
TOGW, lbs.	513,000	972,000	1,342,000	656,000	1,223,000	1,776,000
Wing Area, sq. ft.	5700	11400	17300	7000	11100	14600
No. of Engines	4	4	4	4	6	4
Thrust per Engine, lbs.	37,300	60,500	109,800	47,700	69,300	109,000
Mission Fuel, lb.	76,500	149,900	266,700	179,900	340,300	427,900
OWE, lbs.	186,800	322,000	325,000	225,700	406,400	476300

Table 2. Characteristics of selected configurations.

Technology Impact and Sensitivity Analysis

Each of the configurations developed used the same basic available technology set. This set was derived by using current and projected technology developments and incorporating their expected benefits at the individual technology level. The technology set for 2020 was taken as a whole and used in the design and analysis for each of the vehicle classes in the Scenario Based Planning studies. Assessing the impact of individual technologies was done in reverse in that the 2020 configurations were sized first and individual technologies removed singularly to determine the impact thereof. For convenience, only two configurations were chosen for this analysis, the short range, small payload (3500nmi, 250k) conventional and the twin fuselage, large payload (8500nmi, 750k) configuration. In addition, an attempt was made to develop the same configurations using exclusively current technology for comparitive purposes. The size and weight of the "current technology" vehicle for the large configuration is somewhat speculative since design closure was extremely difficult to achieve even discounting the ability to use existing infrastructure. Although the Air Cushion Landing System technology item does not indicate an extremely high payoff in weight reduction, it can be considered mandatory to be able to use most of the existing 8000ft. runways with vehicles over 1 million pounds. A summary chart showing technology impacts of the technologies investigated for the two configurations is shown in Figure 4.

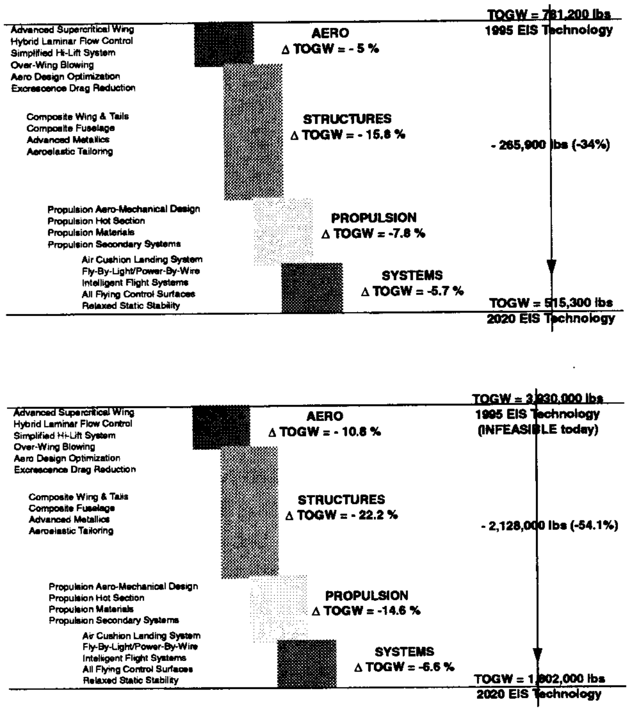

Figure 4. Technology impact assessment, small and large configurations

Cost, Economics and Market Potential

The stated goal of the Global Air Cargo sub-segment was to reduce the cost of air cargo by an order of magnitude. The best configurations for each of the range-payload combinations studied were used to compute a cost-per-available-ton-mile. The Tailored Cost Model (TCM) was used to compute the costs for the study.[6] The DC-10-30F was used as representative of current fleet aircraft for comparison purposes using the same cost model (validated against existing industry cost data). A production run of 600 aircraft was used for consistency in computing the cost figures for all configurations. Table 3 indicates the results of the cost comparison. While none of the configurations achieved the goal of 90% reduction, a 70% reduction may be achievable. Additionally, as was found in previous studies, larger payloads yield lower costs.

Vehicle	DC-10-30F	CWBT	CWBT	Spanloader	CWBT	Twin Body	BWB
Payload (lbs.)	(current)	250k	500k	750k	250k	500k	750k
Range (nml)		3500	3500	3500	8500	8500	8500
Cost (c/atsm)	12.3	5.34	4.27	3.87	5.64	4.8	3.6
Percent Reduction		56.6	65.3	68.5	54.2	61.3	70.7
Assumptions:	600 unit production, 12% ROI, 20 yr. finance period @ [illegible], CY [illegible]						

Table 3. Cost comparison results.

In determining the potential market for large, all-cargo aircraft, a number of factors were considered. Projections of air cargo growth were obtained from several sources. The demand projections shown in Figure 5. were computed using information about world economic and social conditions indicated in the Scenario Based Planning document. As can be seen, annualized air-cargo growth could potenially range from 9.2% in a world where econonmic activity is high and the United States maintains aerospace industry superiority to 3.7% where aerospace activity is severly constrained due to environmental regulations. The projections include currently projected air cargo growth with additional demand. This additional demand was computed using information from the Commodity Flow Survey[7] to determine possible conversion of cargo from other modes of transportation due to container carriage and large capacity.

Based solely on the total cargo demand (considering available existing aircraft in 2020) there is projected to be a total potential for 388 short-haul aircraft and 688 long-haul aircraft, respectively. This translates to a total sales potential (over a 15 year production period) for the short-haul transport of $33 billion and $55 billion for the long-haul transport, excluding any military dual-use purchases. This would indicate a sufficient, i.e. commercially viable, demand would exist to justify the development of both vehicle types.

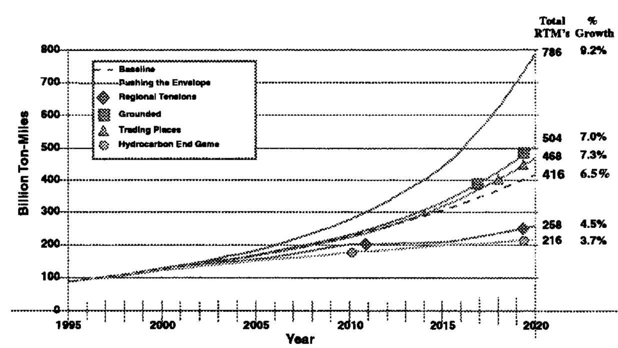

Figure 5. Air cargo demand projections

Conclusions

As part of the National Aeronautics and Space Administration (NASA) Scenario-Based Strategic Planning process, Global Air Cargo was identified as one of several potential high-payoff vehicle classes for the year 2020. Within this vehicle class, range/payload and cost goals were established to provide a ten-fold reduction in the cost per ton-mile for air cargo shipments. A study was conducted to determine the opportunities inherent in these goals, the potential to meet them, and the technologies and configurations required to do so.

The potential design requirements identified for future air cargo vehicles include: intra- and inter-continental range of 3500nmi and 8500nmi, respectively (by virtue of airport-to-airport distance pairings), payloads of 250klb, 500klb, and 750klb (10, 20, 30 TEU), operating field length of 8000ft. (determined from a statistical analysis of current airport infrastructure), and specific design features (e.g. inter-modal container carriage, joint civil/military use). Several air cargo configuration concepts were developed and examined as a part of this study which included conventional and unconventinal configurations. Performance for each configuration was compared to the baseline (existing) aircraft. In comparison to the C-5B cargo aircraft, 2020 unconventional cargo configurations have the potential to obtain a 2.5x improvement in range while carrying a 3x improvement in payload. Technology sensitivity analyses were conducted using the lowest payload, shortest range and highest payload, longest range concepts. Improvements in gross weight were 34% and 54%, respectively, for the two configurations examined (conventional wing-body-tail and large twin fuselage tandem wing). The study indicates that the twin fuselage, tandem wing configuration offered the most design flexibility and reasonably low weights for the range-payloads examined.

The results of the cost analyses indicate that a reduction in the cost per ton-mile for cargo transportation of 75% (relative to DC-10-30F) is potentially achievable. As was found in previous air cargo configuration studies,[8] the cost benefits increase with increasing payload. The study found large air-cargo vehicles to be potentially commercially viable. In addition, while the cost reduction predicted during this study did not meet the original goal of a 90% reduction, it nonetheless represents a revolutionary capability when compared to existing fleet aircraft.

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