Conceptual Design of a Global Fast Package Delivery System

by

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in Partial Fulfillment of the Requirements for the Degree of
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ABSTRACT

An analysis of the express package delivery market was performed to determine the potential for a Fast Package Delivery vehicle. Two express package markets were identified and addressed. These markets are 1) Scheduled Service and 2) Chartered On-Demand Service. The key design requirements needed to capture both markets are high speed and reliable systems. However, the design's sensitivity to speed is dependant upon the market.

For the scheduled service market, a cargo version of the proposed High Speed Civil Transport satisfies the design constraints. The vehicle would operate using existing express delivery infrastructure and provide eighteen hour service to the Far East. The vehicle would carry 6000 pounds of payload per node per day. Market forecasts show that the operator could charge between \$11 - \$15 per pound for their services.

A Mach 6 ramjet vehicle was chosen for the on-demand service. The vehicle would be able to operate from airports located at strategic business regions and provide four hour door-to-door service from Los Angeles to Tokyo. The vehicle has a maximum payload of 200 pounds at 9000 miles (Los Angeles to Singapore) and would address the time critical needs of the manufacturing, business, and medical communities. Market forecasts show that the operator could charge between \$200 - \$1000 per pound for the on-demand service

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Chapter 1, Introduction

> "Before man reaches the moon, mail will be delivered within hours from New York to California, Britain, India or Australia by guided missiles."
>
> Postal Officer, June 8, 1959

Figure 1-1, Missile Mail
Source: U.S. Postal Service Web Site

The need for the faster delivery of goods is nothing new. Nearly, forty years ago, the United States Postal Service attempted to use a guided missile to deliver mail. On June 8, 1959, the submarine U.S.S. Barbero fired a guided missile, carrying three thousand letters, at the Naval Auxiliary Air Station in Mayport, Florida [1] (See Figure 1-1). After witnessing the incident, a postal officer made the statement above. This is probably the first attempt at Fast Package Delivery (FPD).

Fast Package Delivery is the delivery of time critical packages, over intercontinental distances, in shorter time periods than previously available. Depending upon the nature of the package, the door-to-door delivery time may be as little as four hours [2,3]. A Fast Package Delivery System (FPDS) in the purest sense, would provide transit service for items such as perishable goods, time-sensitive business documents, and just-in-time supplies within an allotted four hour time span. However, not all express packages require delivery within four hours. Alternative solutions that reduce the delivery time of existing package networks could also be viable solutions.

Revenues for global package delivery reached nearly 35 billion dollars in 1996. By 2016, the global express market is expected to grow to over 250 billion dollars [2] (See Figure 1-2). It is from this highly competitive and growing market that the concept of FPD has emerged.

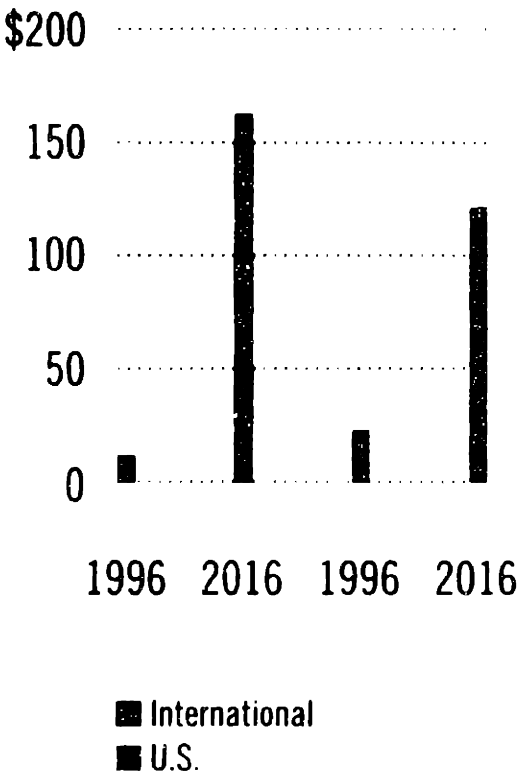


Figure 1-2, Global Express Market (In Billions)
Source: FedEx 1997 Annual Report

Chapter 2, Background

2.1 Previous Studies on Fast Package Delivery

In 1994, several aerospace corporations, under NASA funding, met to address the issue of FPD. The results of this study were published in the Commercial Space Transportation Study (CSTS). Since then, several companies have pursued FPD further including: Boeing [4] and Pioneer Rocketplane [5]. FPD is also part of NASA's Future-X strategy for space transportation technology development.

2.1.1 Likely Attributes for a Fast Package Delivery System

The Aerospace Corporation compiled a list of possible requirements, in addition to those obtained from the CSTS, for the Rapid Access Mission which includes FPD [6].

Table 2.1.1-1, Likely Fast Package Delivery System Requirements

Source: Aerospace Corporation, Future Spacelift Requirements Study

- Operational in 2000-2020
- Launch rate of 100-500/year
- Small payload fairing size
- Safe abort capability
- Reusable
- Suborbital (85% of orbital energy)
- Turnaround time in hours
- Possibly manned (for airport landing)
- Airport-like launch facilities
- Stricter environmental standards due to higher flight rates
- Current nominal g's and vibration levels
- 100x better reliability than current systems
- 3-10x cost reduction

2.1.2 Fast Package Delivery as a First Step Towards CST

Those who believe space technologies are the solution to FPD needs, see it as a means to stimulate investment in commercial space transportation. The CSTS suggests using FPD as a bridging mission for commercial space transportation development. FPD would allow investors, operators and authorities to learn and gain confidence in routine space transportation. Lower development risks, less expensive payloads (compared with satellites), and evolutionary technology implementation will give the industry some latitude to learn how to manufacture a commercial space vehicle [3].

2.2 Existing Express Package Delivery Services

In order to understand the needs of a FPDS, one must understand the operations and limitations of the current delivery networks. Express package delivery can essentially be broken into two categories: 1) scheduled service and 2) chartered on-demand service.

Scheduled service is easier to understand since almost everyone is familiar with the current express delivery systems. Scheduled service is the overnight delivery of packages on a daily basis. There are currently several providers of overnight express delivery which include: Federal Express, United Parcel Service (UPS), DHL and several others.

On-demand providers work on a smaller scale than the scheduled service providers. On-demand express delivery deals with the transportation of high priority, time sensitive materials. Providers generally deliver single packages with delivery times on the order of four hours [2,7]. Most often, the delivery requires the chartering of a private jet.

Scheduled and on-demand services represent the two extreme ends of the express package market. Scheduled service providers tend to operate fewer flights with large package volumes while on-demand service providers operate on a customer-by-customer basis offering multiple direct flights (See Figure 2.2-1).

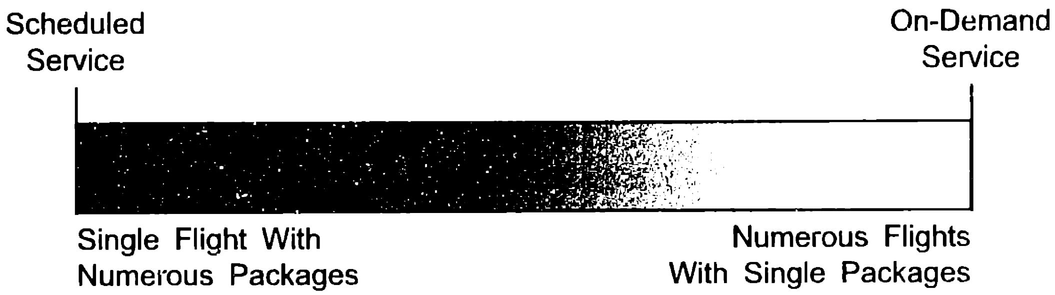


Figure 2.2-1, Express Market Spectrum

2.2.1 Existing Scheduled Service

Scheduled service providers are essentially selling an "overnight" delivery service. They delay package pick-up until the end of the business day, allowing the customer to work the entire day, and still provide overnight delivery. During international express routes, however, the scheduled service providers are no longer able to guarantee overnight delivery. Current express package delivery to South East Asia requires approximately three days.

Scheduled service providers operate on a hub and spoke system. They operate from international cargo hubs which serve several cities within a region. Examples of major international hubs are: Memphis, Tennessee and the Philippines. All international packages from cities such as Boston, New York, and Atlanta are first flown to Memphis where they are sorted according to international destination. Packages are then flown to an international hub in the region of the final destination. A package headed for Singapore would be flown to the hub located in the Philippines. At the Philippines, packages are sorted according to final destination and then loaded onto aircraft. The aircraft then fly to the final destination (Singapore) where the packages are sorted and then placed on trucks for delivery (see Figure 2.2.1-1).

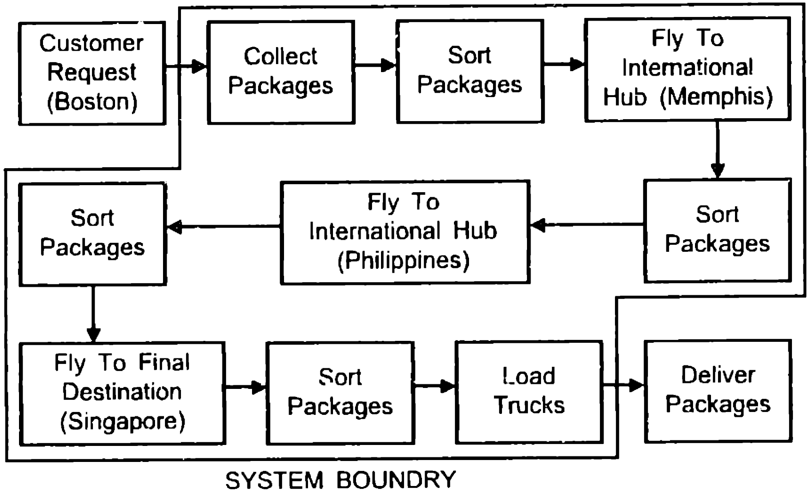
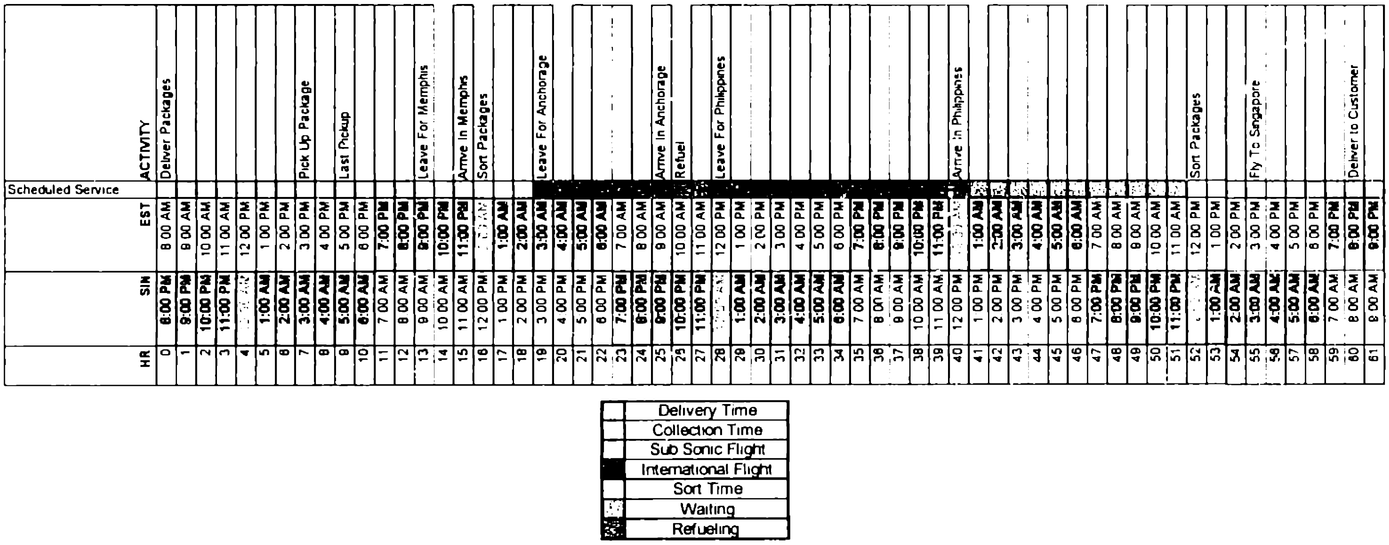


Figure 2.2.1-1, Scheduled Service Functional Flow Diagram

The three day delivery time is only partially due to the increased flight distances. Built into the process is a period in which the package must wait. The waiting period is primarily due to the sorting steps which are generally performed at midnight local time. This allows time for all international express packages to arrive before sorting begins. During the remainder of the day, the sorting facilities are processing other domestic two and three day packages. Figure 2.2.1-2, outlines the international express delivery process in a timeline format.



HR	ACTIVITY	EST	SIN
0	Deliver Packages	8:00 AM	8:00 PM
1		9:00 AM	9:00 PM
2		10:00 AM	10:00 PM
3		11:00 AM	11:00 PM
4		12:00 PM	12:00 AM
5		1:00 PM	1:00 AM
6		2:00 PM	2:00 AM
7	Pick Up Package	3:00 PM	3:00 AM
8		4:00 PM	4:00 AM
9	Last Pickup	5:00 PM	5:00 AM
10		6:00 PM	6:00 AM
11		7:00 PM	7:00 AM
12		8:00 PM	8:00 AM
13	Leave For Memphis	9:00 PM	9:00 AM
14		10:00 PM	10:00 AM
15	Arrive In Memphis	11:00 PM	11:00 AM
16	Sort Packages	12:00 AM	12:00 PM
17		1:00 AM	1:00 PM
18		2:00 AM	2:00 PM
19	Leave For Anchorage	3:00 AM	3:00 PM
20		4:00 AM	4:00 PM
21		5:00 AM	5:00 PM
22		6:00 AM	6:00 PM
23		7:00 AM	7:00 PM
24		8:00 AM	8:00 PM
25	Arrive In Anchorage	9:00 AM	9:00 PM
26	Refuel	10:00 AM	10:00 PM
27		11:00 AM	11:00 PM
28	Leave For Philippines	12:00 PM	12:00 AM
29		1:00 PM	1:00 AM
30		2:00 PM	2:00 AM
31		3:00 PM	3:00 AM
32		4:00 PM	4:00 AM
33		5:00 PM	5:00 AM
34		6:00 PM	6:00 AM
35		7:00 PM	7:00 AM
36		8:00 PM	8:00 AM
37		9:00 PM	9:00 AM
38		10:00 PM	10:00 AM
39		11:00 PM	11:00 AM
40	Arrive In Philippines	12:00 AM	12:00 PM
41		1:00 AM	1:00 PM
42		2:00 AM	2:00 PM
43		3:00 AM	3:00 PM
44		4:00 AM	4:00 PM
45		5:00 AM	5:00 PM
46		6:00 AM	6:00 PM
47		7:00 AM	7:00 PM
48		8:00 AM	8:00 PM
49		9:00 AM	9:00 PM
50		10:00 AM	10:00 PM
51		11:00 AM	11:00 PM
52	Sort Packages	12:00 PM	12:00 AM
53		1:00 PM	1:00 AM
54		2:00 PM	2:00 AM
55	Fly To Singapore	3:00 PM	3:00 AM
56		4:00 PM	4:00 AM
57		5:00 PM	5:00 AM
58		6:00 PM	6:00 AM
59		7:00 PM	7:00 AM
60	Deliver to Customer	8:00 PM	8:00 AM
61		9:00 PM	9:00 AM

Figure 2.2.1-2, Scheduled Service Timeline

By organizing the time allotments into percentages of the total delivery time, several observations may be made (See Figure 2.2.1-3). First, The three largest pieces are flight time, collection time, and wait time. The collection time cannot be changed since this would require pick-up times during normal working hours which in turn would prevent companies from working the entire day before pick-up. This leaves only flight time and wait time. By using a faster vehicle the flight time could be reduced. However, the arrival time of the vehicle must be coordinated with the next international sorting time. The vehicle must arrive at the international hub before midnight local time. In order to minimize waiting time, the vehicle should arrive as close to midnight as possible. In Chapter 6, the scheduled service process will be optimized for a new fast package vehicle.

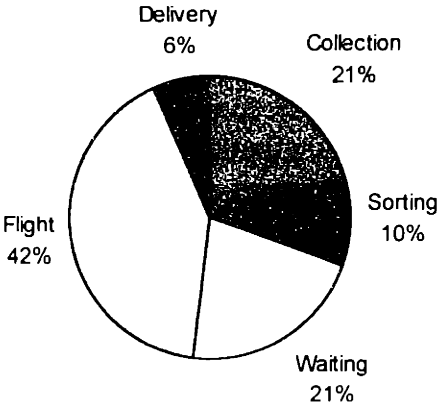


Figure 2.2.1-3, Time Allocations

It should be noted that most scheduled service providers do offer a faster express service for a premium. Delivery personal wait for the specified package at each phase and route the package such that it leaves on the next flight out. This service does allow overnight delivery to limited international destinations. Generally these destinations are the major hubs in Europe through which express packages are normally routed.

2.2.2 Existing On-Demand Service

On-demand service providers work on a customer-by-customer basis. Due to the nature of some items, the monetary value of the package is insignificant when compared to the potential loss due to product failure. On-demand service providers work with such time critical components as manufacturing line components, transplant organs, and time sensitive documents. The potential losses are so great that it becomes economically acceptable to dedicate an entire aircraft to the delivery of a solitary package.

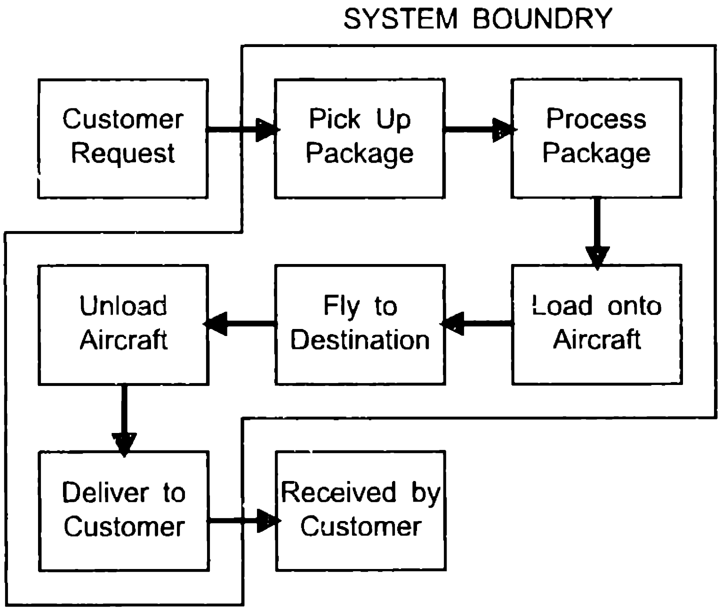


Figure 2.2.2-1, On-Demand Functional Flow

In today's market, just-in-time needs require a four hour door-to-door delivery time. In major manufacturing companies, such as Intel, the loss due to a disruption in a production line can cost as much as $200,000 an hour [7]. With businesses operating increasingly on a global scale, suppliers are required to respond to customer needs on a world wide basis. This requires vast amounts of warehouses situated within four hours of major customers.

Figure 2.2.2-1 characterizes existing on-demand activities. As mentioned earlier, each customer's package is handled on an individual basis. The driving factor is minimizing warehouse costs while still meeting just-in-time needs. A faster vehicle would not result in a quicker response time than four hours. Instead a faster vehicle would allow for fewer warehouses with greater separation distances then with a slower vehicle.

In the on-demand case, speed is the driving factor. Sorting is nonexistent since the number of packages is essentially one, and waiting periods are eliminated because the package is not coordinated with others.

Chapter 3, Design Constraints

3.1 Market Assessment

Over the next twenty years, the international express market is expected to grow from 5.6 percent to 40 percent of the total international cargo market [2] (See Figure 3.1-1). The CSTS, using Federal Express as a benchmark, cited a $16 billion annual express market, of which one-quarter was international, resulting in a $4 billion annual international express market [3]. The global air freight market is predicted to grow at seven percent per year through the year 2010. Figure 3.1-2 depicts the annual FPD market in pounds , for both a 5 percent and a 10 percent market growth per year, and assuming a FPDS could capture either 3% or 5% of the total express market [3].

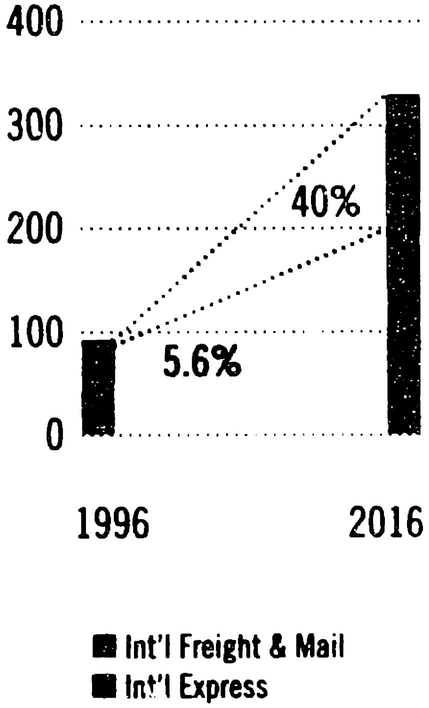


Figure 3.1-1, International Express Share of Total International Cargo Market (in Billions)
Source: Boeing World Air Cargo Forecast, 1997

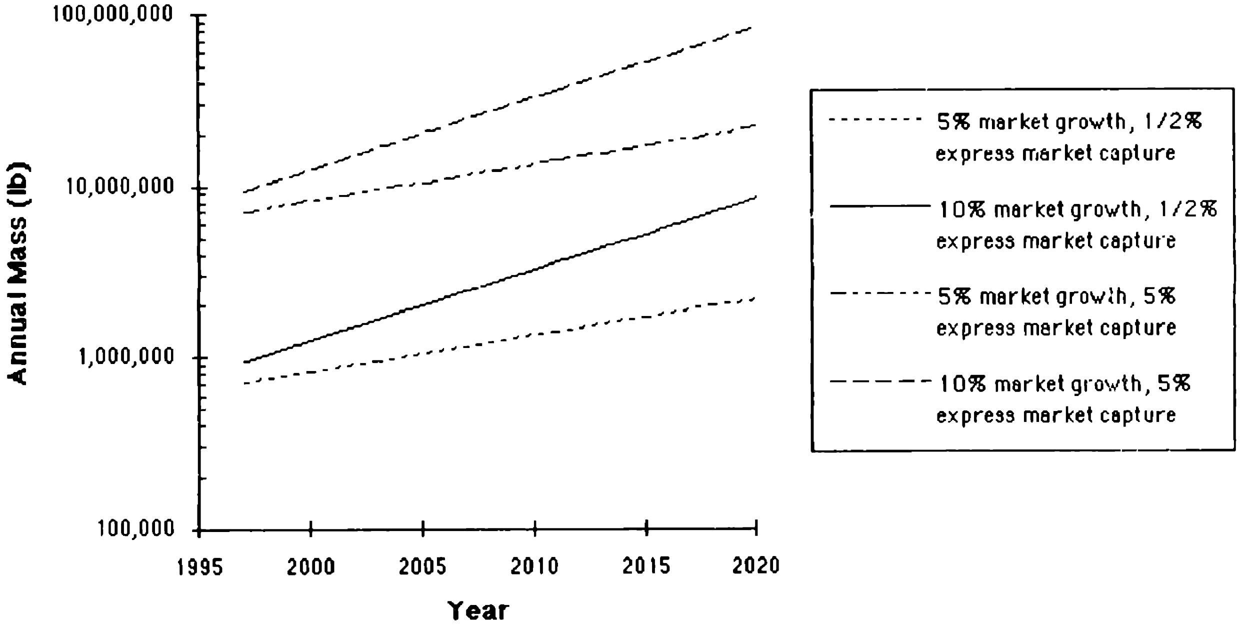


Figure 3.1-2, Estimate of Annual Express Package Delivery Mass
Source: NASA-Industry Commercial Space Transport Study

3.1.1 Scheduled Service Market

There are various methods of operating and introducing a scheduled service vehicle. Each method has its own advantages and disadvantages. It is assumed that these two cases would each use the existing collection, sorting, and distribution infrastructures.

Case 1, Limited scheduled service between major city pairs.

Limited scheduled service between major city pairs would allow the operator to establish operations while minimizing the vehicle fleet size and thereby initial operating costs. It would also allow express service providers the chance to learn how to operate the system before investing large amounts of resources. City pairs would be selected from among the top express package routes according to volume. However, the distance between major city pairs must also be large enough as to allow for an adequate time advantage over existing express services. Therefore, city pairs must be separated by at least 4,000 nautical miles and offer a significantly large enough market base as to allow for operations startup. Major city pairs with such qualifications appear in Figure 3.1.1-1 with an asterisk.

There is some concern that limited service may not provide an adequate customer base. Federal Express began business by servicing only a select number of key locations with small biz-jets. However, this proved inadequate, and it was not until they expanded their market penetration that their business grew. Thus, it seems that there is a critical number of city pairs required to insure a sufficient market [3].

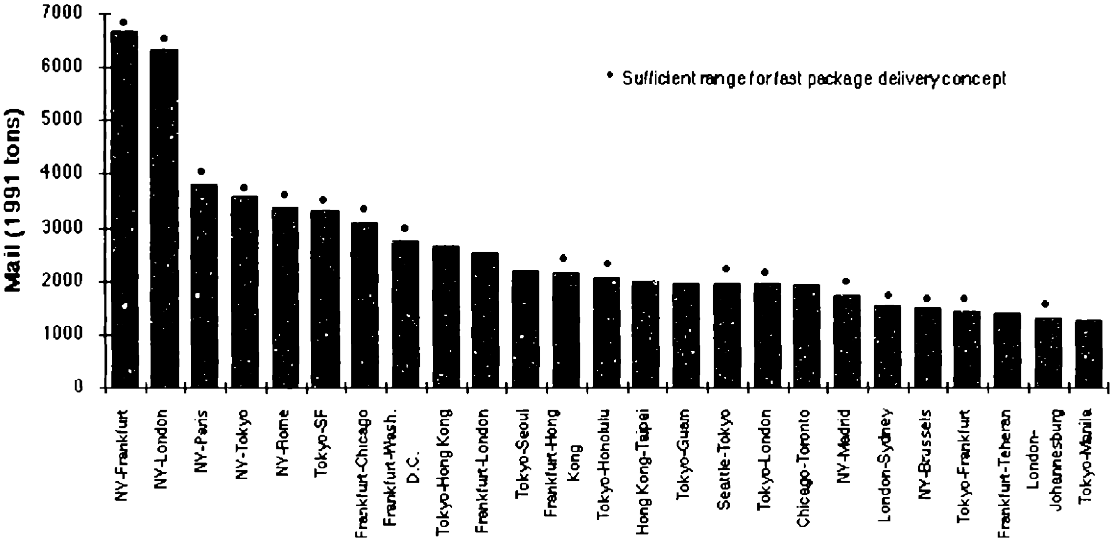


Figure 3.1.1-1, Top Air Freight City Pairs
Source: NASA-Industry Commercial Space Transportation Study

Case 2, Scheduled service between numerous city pairs.

By operating between numerous city pairs, the operator can maximize the market penetration and package volume. This, however, would require a significant amount of startup capital in order to purchase a large enough fleet size [3].

Market studies show that a scheduled service provider which could offer eighteen hour delivery to the Far East could charge between $11- $15 per pound. Next day delivery to the Far East is not possible due to time zones. This price is based of statistical trends for existing scheduled and on-demand services. For more detail into the market analysis for both scheduled and on-demand see reference 10.

3.1.2 On-Demand Market

Due to the nature of the on-demand business case, it is more difficult to predict then for scheduled service. Cargo volumes may vary greatly from day-to-day. Final destinations, to which packages must be delivered, will also change on a package by package basis. Currently, on-demand chartered services account for about 10 percent of the revenues generated by the express delivery market [3].

An on-demand service will provide delivery services for two key areas. The first area is commodities for which immediate delivery justifies a premium. These commodities include: just-in-time delivery of critical parts to overseas assembly lines and manufacturing facilities, urgent and original documents, and precious metals [3]. Figure 3.1.2-1, shows the past and predicted growth of just-in-time and quick response market [2]. The second area is commodities which require fast delivery due to their perishable nature. These commodities include: fresh delicacies from overseas, biological specimens which must avoid deterioration, and vital organs to patients in critical need of transplants [3].

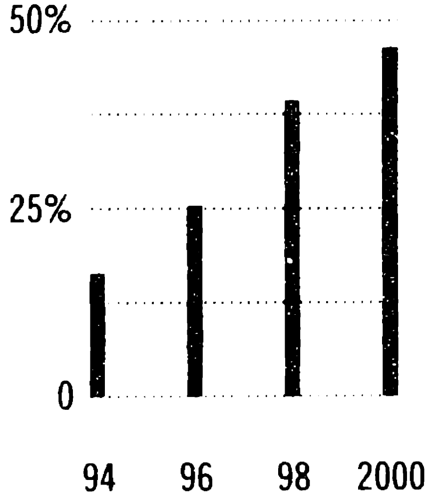


Figure 3.1.2-1, Percent of Product Shipped Just In Time/Quick Response
Source: Ohio State University Survey of Career Patterns in Logistics, 1996

Just as there are several methods of starting and operating a scheduled service vehicle there are various methods of operating an on-demand vehicle [3].

Case1, Chartered operations between major city pairs.

Chartered operations between major city pairs would minimize the vehicle fleet size. It would also reduce the number of endpoint stations which may need specialized equipment to address the FPDS's needs. Once again, there may be several problems due to a lack of package volume between major city pairs.

Case 2, Chartered operations between major embarkments and many destinations.

Chartered operations between major embarkment points and many destinations will allow the operator to capture a larger market at the expense of a large fleet size. It would also require numerous endpoint stations to address the FPDS's needs.

The remaining question is, what would potential customers be willing to pay? The cargo industry claims that a product can bear between three and six percent of its value for transportation [3]. Figure 3.1.2-2 shows the relationship between package cost and the transportation cost for various commodities. According to the CSTS, customers would be willing to spend between $200 and $1,000 per pound for priority packages [3,4,10]. Some items, such as transplant organs, would require a flat delivery fee since the package weight is negligible. For this type of package, market forecast predict a flat fee of $80,000 per flight [10].

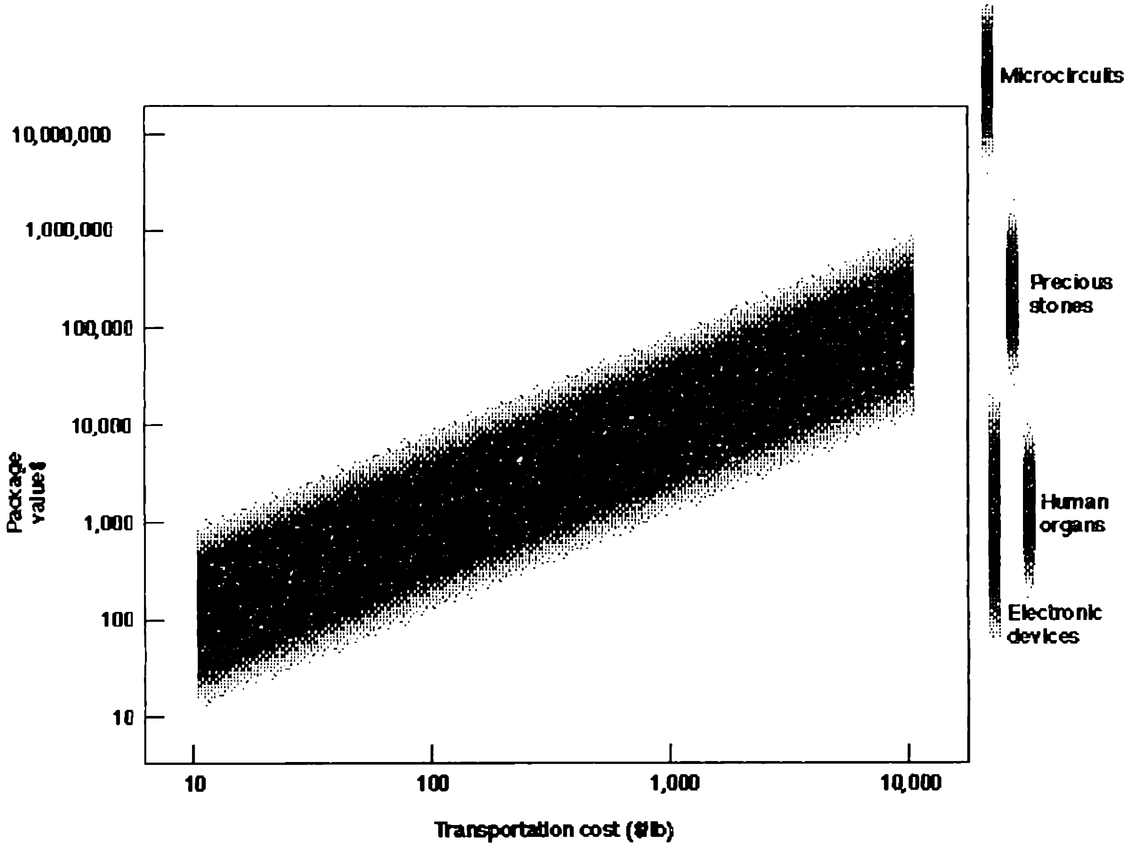


Figure 3.1.2-2, Transportation Costs VS Package Value
Source: Commercial Space Transportation Study

3.2, Policy and Regulatory Issues

> "Automobiles were banned in the streets of many cities: Boston, Chicago, and Bar Harbor, to name a few. In Massachusetts, an act to require that all cars be equipped with a bell which would ring with each wheel revolution was voted down, as was one for shooting off roman candles to warn of the vehicle's approach. . . In 1907, Glencoe, Illinois built humps in the streets to discourage speeding. Three years earlier, they had stretched a steel cable across the road to stop the "devil wagons." Most of this was antagonism rather than an attempt to accomplish constructive regulations."
>
> Automotive Information Systems Inc, 1997 [14]

The quote above illustrates how new technologies often have difficulty being accepted into everyday life. This section will outline current regulatory issues regarding systems proposed for Fast Package Delivery. However, it should be noted that no "constructive regulations" have been created as to date. As the number of commercial launch vehicles increases, regulatory agencies will be forced to address the issue. Many of the issues center around the integration of existing air traffic with commercial launch traffic.

3.2.1, Commercial Launch Regulations

In 1984, under the Commercial Space Launch Act, the Department of Transportation (DoT) was charged with the oversight of commercial space launches. The DoT's two main goals are: 1) To protect the public health and safety, safety of property, and national security and foreign policy interests of the United States. 2) To encourage, facilitate, and promote commercial space launches [6].

In April of 1988, the DoT published the Commercial Space Transportation Licensing Regulations which outlines the launch license approval process. In order to receive a license the operator must obtain the following three approvals.

1. Safety Approval - Verify that the launch vehicle will not pose any safety threats to the general public.

2. Political Approval - The launch must not violate any current U.S. foreign policies.

3. Payload Approval - The operator must prove that the payload poses no threat to either the United State's interests or to the health of its constituents.

Although, the Commercial Space Transportation Licensing Regulations outlines the needed approvals, it neglects to specify the standards by which the above approvals must be met. Instead, operator's licenses are granted on a case-by-case basis.

3.2.2 Special Use Airspace

Currently, Special Use Airspace's (SUA) are used to maintain a separation between air traffic and space vehicles. The SUA is generally activated three hours prior to launch and remain in effect for several hours after launch. The SUA restricts access to only aircraft involved in launch or recovery operations. All other air traffic is diverted around the SUA. However, due to the size of the SUA it can adversely affect the air traffic flow. For example, the Kennedy Space Center SUA covers approximately 900 square miles [15] (See Figure 3.2.2-1).

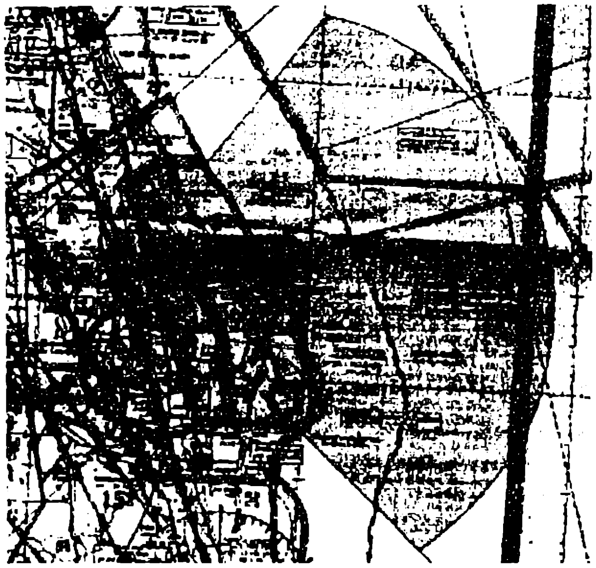


Figure 3.2.2-1, Kennedy Space Center SUA (Dark Tinted Region)

Source: Integration of Reusable Launch Vehicles into Air Traffic Management

The size of the SUA is restricted to the probability of less than 1 in 10 million that the vehicle will cross over to ordinary airspace. The potential impact points of released stores or a malfunctioned vehicle are continuously monitored. If the projected impact point crosses the SUA boundary, the vehicle must be destroyed [15].

There are several ideas on how to integrate the increased RLV traffic into the existing system. These range from RLV-aircraft self separation methods based on current aircraft separation technology to mission specific SUA's. Preliminary recommendations suggest that the use of SUA's will continue as the RLV traffic increases. SUA's are seen as simple to activate while providing the greatest amount of safety to the public. Some RLV's such as Pioneer Rocketplane's Pathfinder operate similarly to aircraft during various points of its mission. These vehicles are likely to operate in more mixed modes of operation, possibly obeying traditional air traffic regulations during take-off and landing, but requiring a SUA during space operations.

3.2.3 Private Launch Sites

Commercial launches are currently performed out of Vandenberg Air Force Base and Cape Canaveral Air Station. Commercial operators are allowed to build there own launch facilities as long as they are approved by the Department of Transportation. However, commercially operated launch facilities would most likely meet strict zoning laws as well as stiff opposition from lobbyist groups.

3.2.4 Reentry Issues

Reentry is not covered under any current legislation. The House of Representatives has recently passed H.R. 1275 the Civilian Space Authorization Act (CSAA) which will grant the DoT the authority to regulate space vehicle reentry. At the time of this writing, the CSAA was awaiting Senate action.

Reentry issues include the overflight of populated areas. Legislation would consist of allowable flight paths dependent upon safety and reliability of the system as well as shock wave propagation and environmental concerns. There are some international concerns regarding launch vehicle reentry. Most reentry trajectories would overfly foreign countries and international regulations must be developed which define the boundary between air and space and the right to sovereignty. Foreign policy could also dictate reentry trajectories depending upon the United State's relationship with the overflown country.

3.2.5 Damage to Personnel Property

Current legislation holds the vehicle operator liable for all damages incurred by people or property on the ground due to the operation of a launch system. Launch vehicle operators are required to purchase insurance to cover collateral damage prior to launch. However, existing insurance regulations neglect certain aspects of RLV operations. First, the launch vehicle itself does not have to be insured. Second, issues concerning damage induced to existing space items by a launch system have not been addressed. Third, international agreements must be reached concerning the salvage rights of "dead" systems and space junk [6].

3.2.6 Airport Restrictions

Any system which plans to use existing airports must be able to integrate with the existing air traffic network. This includes the establishment of standard descent trajectories, the ability for the system to loiter in a holding pattern, and be capable of moving under its own power once on the ground. The vehicle must be able to see and be seen by other air traffic and ground controllers.

Considerations concerning manned and unmanned aircraft are currently made depending on the weight of the vehicle. Vehicles, such as Predator, are allowed to operate through remote piloting. Larger vehicles are restricted to piloted flight in which the pilot must be physically on-board. The exact size limit for unmanned flight is not standardized.

The reliability of unmanned systems is primarily a perception issue. Unmanned vehicles are perceived to be less reliable. The issue with unmanned vehicles will begin to resolve itself as more unmanned air vehicles enter operation and the public's perception of autonomous flight changes.

3.2.7 Future Requirements

It is clear that the DoT will need to develop new regulations to insure the safety of the general public with the commencement of RLV operations. These regulations will have to address high launch rates, aircraft-like operations, aircraft-like reliabilities, reusability, and safe abort capabilities. Most likely future licensing will reflect current aircraft / operator / airport licensing.

Chapter 4, Existing Systems and Competitors

Several of the X-Prize contenders, such as Pioneer Rocketplane, have stated that they intend to operate fast package derivatives of their vehicles. In Boeing's study, they proposed several concepts for the fast package market [4]. The fast package mission requires approximately eighty-five percent of the energy required for low earth orbit insertion. It is these reusable launch vehicles (RLV's) which could be direct competitors for the fast package market.

There is a flaw in many of these competitor's vehicles. The error lies in their market analysis. Scheduled and on-demand services differ in market size and cost per pound, but many of the competitors have confused the two. Market predictions forecast large amounts of scheduled service payload; however, the market price per pound to deliver such payloads should be roughly ten percent of current rates ($11-$15). Market forecasts for on-demand service are tougher to predict, but should remain roughly the same percentage, about 10%, of express delivery packages as today about. The price, however, to deliver such packages is substantially higher ranging from $200 - $1000 per pound. The error, which the previous FPDS studies embraced, is the confusing of the two (See Figure 4-1). These studies predict the large volumes of express packages associated with scheduled service, yet couple them with the large price per pound associated with the on-demand market.

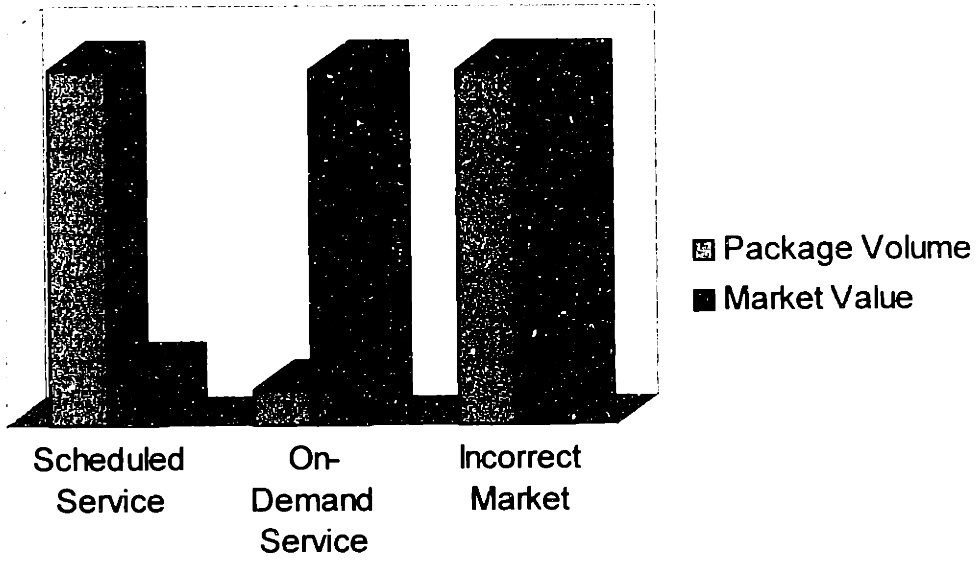


Figure 4-1, Express Delivery Markets

Problems occur from a skewed market. The vehicle is oversized for the mission. This in turn leads to loss of profits by operating below full cargo capacity, or leads to significantly long collection times such that the four hour door-to-door requirement of the on-demand service is not met. Either way the vehicle is not profitable.

4.1 Concorde

Assuming the market assessment outlined earlier is correct, then the simple question of, "Why is Concorde not currently used in a fast package role?" must be addressed. The Concorde, being faster than other commercial aircraft, already provides transatlantic flights to time-critical business personnel. It seems that express package delivery would be an easy extension of the Concorde's capabilities. British Airways, which currently operates Concordes between New York and London, is the seventh largest express freight deliverer in freight ton per kilometer and offers several freight services including: scheduled freight, express freight, dangerous goods, valuable cargo, funeral services, and diplomatic mail. Yet, British Airways uses 767's and 777's for shorthaul routes and 777's and 747-400's for global routes. They are opening a new World Cargocentre at London, Heathrow Airport in 1998 [18].

Since its conception, Concorde was intended to carry passengers. British Aerospace performed a small study to determine Concorde's potential market. They asked business travelers and tourists if they would fly Concorde. Ninety percent of the business travelers replied they would fly Concorde if it were the same price. Thirty percent of the North Atlantic and fifty percent of the Pacific tourists stated they would fly Concorde at the same price. As high as eighty-five percent of the business travelers poled stated that they would fly Concorde even up to a fifty percent price increase of normal subsonic flights. Concorde's market, from the start, was the time-restricted business class [8].

Figure 4.1-1, Concorde
Source: British Airways Homepage

Length: 203 ft 9 in
Wing Span: 83 ft 10 in
Cruise Velocity: Mach 2.02
Cruise Altitude: 60,000 ft
Range: 3870 miles
Payload: 100 Passengers and 1300 pounds loose cargo
Weight Take-Off: 408,000 pounds
Weight Empty: 173,000 Pounds

Concorde has very little room which can be devoted to cargo. There are two cargo bays within Concorde. Under the floor, there is 227 cubic feet devoted to cargo storage, and another 470 cubic feet in the rear of the fuselage, most of which is taken up by the passenger's luggage. In order to use standard LD cargo containers, the seats would need to be removed (See Figure 4.1-2).

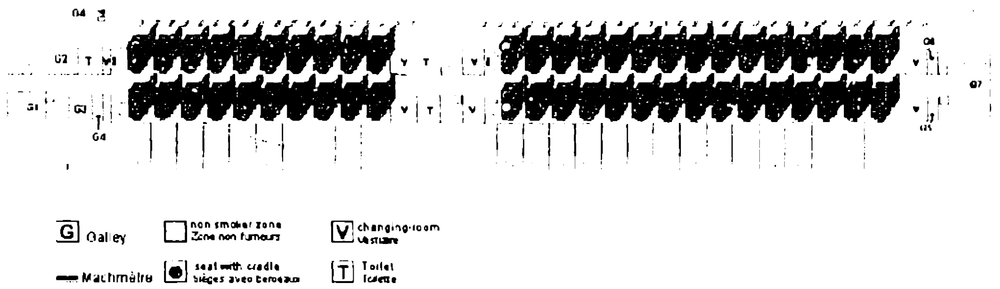


Figure 4.1-2, Concorde Interior View
Source: The Un-Official Concorde Homepage

There are still several other constraints which must be addressed. In order to load the containers, there must be at least seventy inch doors on each side of the fuselage. All of Concorde's doors are a mere thirty inches wide (See Figure 4.1-3). Hence, the exterior fuselage must be modified to allow for the insertion of cargo containers. Once inside, it is easily noticed that existing LD containers are not optimized for Concorde's fuselage cross section (See Figures 4.1-4 & 4.1-5). Concorde fuselage is very long and slender especially when compared to the typical wide bodied transports like the 747-400. The wide bodied aircraft are able to carry two LD-3 containers side-by-side within the cross section. The Concorde, however, would have difficulty fitting one. In order to optimize internal space, new cargo containers would need to be designed.

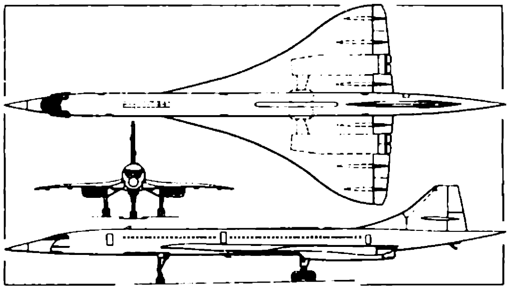


Figure 4.1-3, Concorde Three View
Source: Janes, All The Worlds Aircraft

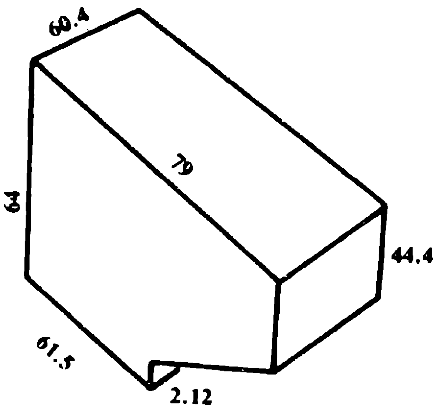


Figure 4.1-4, LD-3 Cargo Container
Source: Aircraft Design, a Conceptual Approach

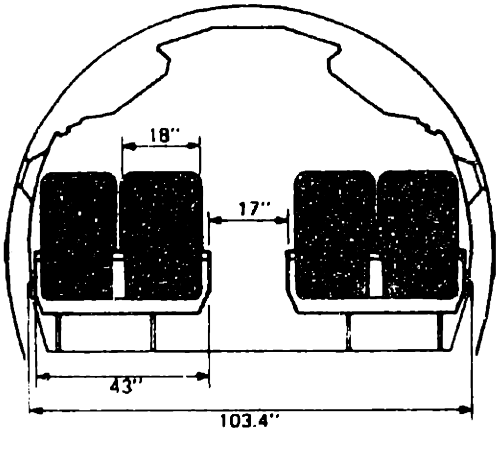


Figure 4.1-5, Concorde Cross Section
Source: Concorde, Clark & Gibson

The remaining stumbling block to using Concorde for FPD is related to constraints on its useful life. Concorde first flew in 1975, and most of the airframes are getting old; therefore, they are destined for retirement in 2005 after thirty years of service. This would leave very little time for an operator to make a profit after performing all the necessary modifications needed to make Concorde into a cargo transport. In addition, there are some plans to develop a Concorde successor called Alliance. Alliance is scheduled to enter service sometime around 2010 and will carry twice the payload to twice the range. Currently, there has been no mention of a cargo derivative.

It seems reasonable to assume that Concorde is used by businesses to fly time-critical items in the suitcases of their employees. However, it is highly unlikely that Concorde will ever be utilized in a fast package delivery role.

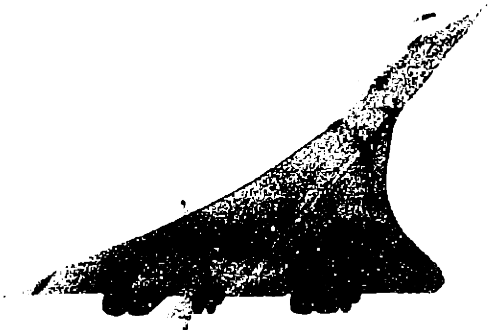


Figure 4.1-6, Concorde

Concorde

Operational: 1975 - 2005
Payload: 100 Passengers
Velocity: Mach 2.02
Range: 3750 Miles

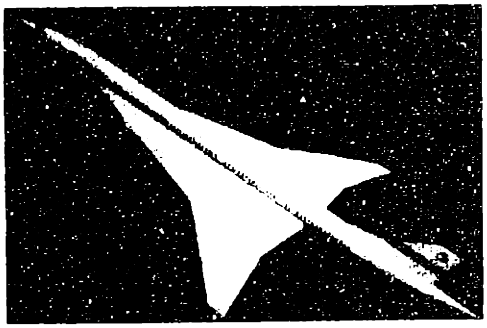


Figure 4.1-7, Alliance

Alliance

Operational 2010?
Payload: 200 Passengers
Velocity : Mach 2.02
Range 7450 Miles

4.2 Kistler Aerospace

The Kistler K-1 is a two stage reusable launch vehicle being designed to launch satellites weighing up to 10,000 pounds into low earth orbit (LEO) (See Figure 4.2-1). Both stages are fully reusable through the use of a parachute recovery system. Kistler is scheduled for operation in early 1999 with launches taking place at Nevada Test Site and Woomera Test Range in Australia. The program is expected to cost 500 million dollars for the first three vehicles and deliver satellites at $1,000 to $1,500 per pound. Kistler has not mentioned any intention to pursue the fast package market [9].

There are several reason why the K-1 would not be suitable for the fast package role. First, the turnaround time is too long, about two weeks, and thereby would require a large fleet size. Second, the cycle life of the vehicle is relatively low. Kistler has used mostly existing technology and there is some

Figure 4.2-1, Kistler K-1
Source: Kistler Homepage

concern over the reusability of the rocket engines. Initial estimates suggest a maximum of ten flights before the engines need to be replaced. Third, since the vehicle has two stages, it could pose logistical problems. It could prove to be difficult to maintain equal numbers of upper and lower stages at each end of the distribution route. Fourth, the K-1 is a rocket and it is highly unlikely that any airport or populated area would allow it to operate nearby. Kistler is performing flight tests at Woomera Test Range due to perceived safety concerns with the parachute recovery system. Last, the payload size must be very large in order to generate a profit. At the low end of the quoted price per pound, the K-1 would manage the upper limit of the on-demand market. The large payload size, however, would require the vehicle to operate in the scheduled service market at which these prices are extremely high.

4.3 Kelly Space and Technology

The Eclipse Astroliner is a fully reusable launch system designed by Kelly Space and Technology to deliver payloads up to 10,000 pounds into LEO (See Figure 4.3-1). The Eclipse is scheduled for service in mid-2001. Kelly Space and Technology is considering Atlantic City International Airport, New Jersey; Williams Gateway Airport, Meza, Arizona; California Spaceport , Vandenberg, California; and White Sands Missile Range, New Mexico as possible launch sites. The Eclipse Astroliner is towed behind an aircraft at take-off and performs a conventional landing allowing it to operate from airports. The program is expected to cost 140 million dollars and be able to deliver satellites at $2,000 per pound. Kelly Space and Technology has expressed some interest in the fast package market [9].

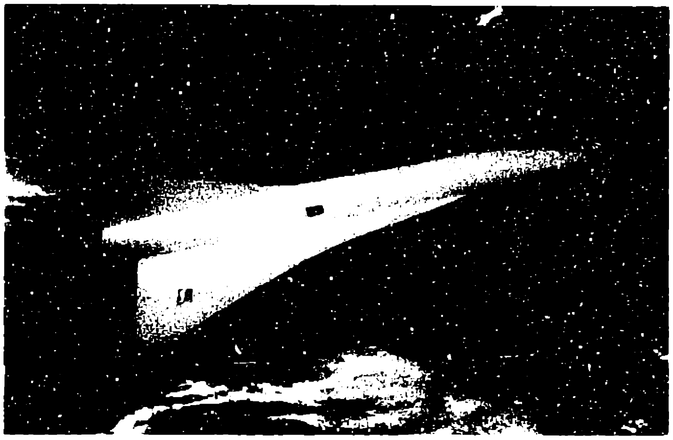


Figure 4.3-1, Kelly Space & Tech, Eclipse Astroliner
Source: Kelly Space and Technology Homepage

Although Kelly Space and Technology has expressed interest in the fast package market, it is very unlikely that the Eclipse Astroliner could compete successfully. The price per pound is double what market forecasts predict for the upper limit of the on-demand market. The payload size suits the scheduled service which drives the price per pound even lower. Skeptics wonder if it will even be profitable in the satellite insertion role due to its high costs. There are also some operational concerns. It is yet unproven whether an airport will allow a tethered take-off or unpowered landings.

4.4 Pioneer Rocketplane

Out of the vehicles addressed, Pioneer Rocketplane's Pathfinder is the most likely competitor. Zubrin has been an enthusiastic supporter of the fast package concept [5]. Pathfinder is a fully reusable launch system designed to carry 6,500 pounds of payload to LEO (See Figure 4.4-1). Pathfinder has a projected operation date of the later part of 2000. The program is expected to cost 100 million dollars and will be capable of delivering satellites at approximately $1,000 to $1,500 per pound. A graph of Pioneer's projected fast package payload versus range is shown in Figure 4.4-2. Pioneer is quoting delivery costs of $200 to $1000 per pound. Proposed launch sites have not been disclosed; however, it is likely that the Pathfinder will be able to operate out of existing airports. Pathfinder will use two Pratt & Whitney jet engines for take-off and landing and will refuel with hydrogen after take-off [5,9].

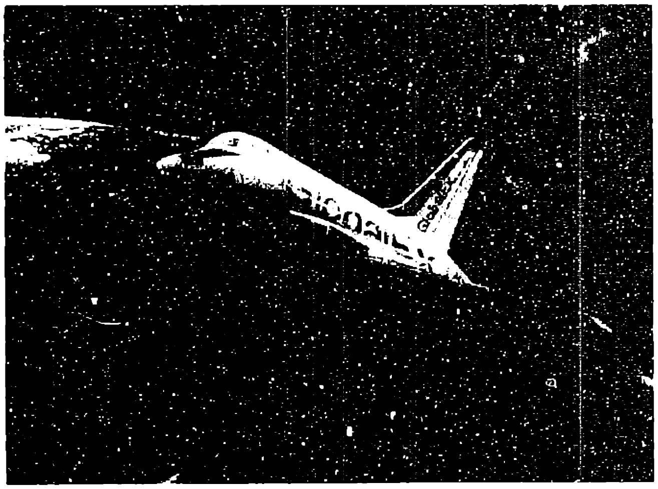


Figure 4.4-1, Pioneer Rocketplane , Pathfinder
Source: Pioneer Rocketplane Homepage

Although Pathfinder seems like it would be stiff competition for the fast package market, it is in fact not suited for the role. The primary reason is its lack of a long distance capability. Pathfinder does not have the range to reach the Far East from Los Angeles. Skeptics doubt the range versus payload plot in Figure 4.4-2, predicting that the actual range is much lower. Even at the ranges where Pathfinder could operate, the payload size is to large to meet the on-demand market. Therefore, Pathfinder would either need to wait until more payload is collected, which would hinder on-demand delivery times, or operate well below full cargo capacity, which will drive up the dollar per pound predictions.

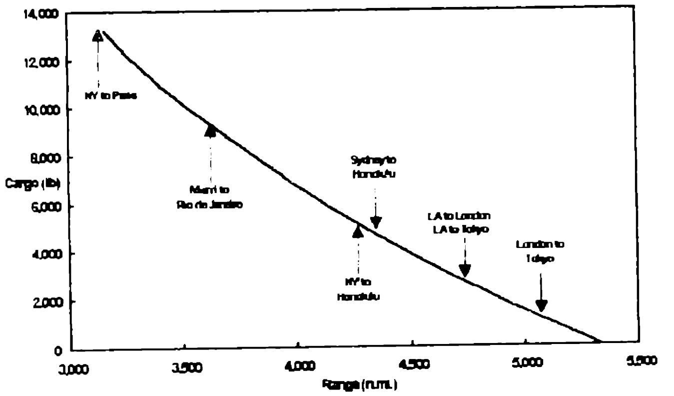


Figure 4.4-2, Pathfinder Payload Vs Range
Source: Pioneer Rocketplane Homepage

4.5 Orbital Science Corporation - Pegasus

The Pegasus was designed by Orbital Science Corporation to launch small payloads into LEO (See Figure 4.5-1). The Pegasus uses a L1011 or B-52 as a first stage. Pegasus is not reusable making it expensive for fast package delivery. The main benefit of Pegasus is that it is a proven system, and that it is a relatively simple design. It may be possible to create a partially reusable Pegasus which would improve its utility in the FPD role.

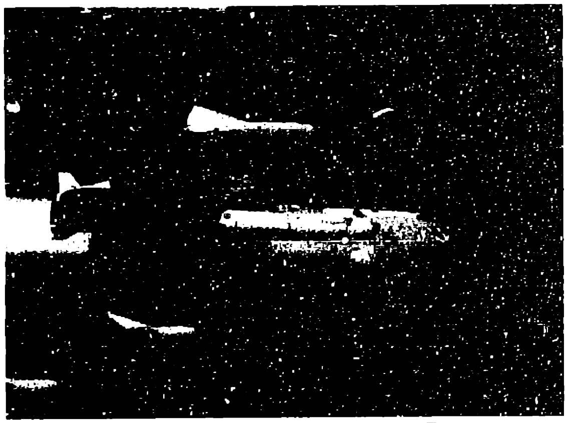


Figure 4.5-1, Orbital Science, Pegasus
Source: Orbital Science Homepage

4.6 Lockheed Martin, VentureStar

The VentureStar is a reusable launch system being designed by Lockheed Martin Corporation to deliver payloads of up to 25,000 pounds to space station orbit. The VentureStar is scheduled to enter service in 2005 (See Figure 4.6-1). The program is expected to cost between five and eight billion dollars and be able to deliver payloads at $1,000 per pound. The proposed launch site is Edwards Air Force Base [9].

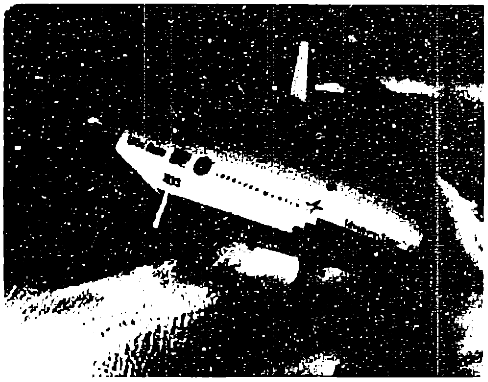


Figure 4.6-1, Lockheed Martin X-33
Source: Lockheed Martin Homepage

The main disadvantage of VentureStar is its purchase price. VentureStar will most likely only be operated by the government. VentureStar's payload is also not suited to the commercial fast package role. Last, VentureStar requires a spaceport for launch. It is unlikely that VentureStar could be stationed close enough to major population centers to provide timely service. Although, there is some discussion about VentureStar spin-offs performing rapid response missions for the military

4.7 Other Competitors

The vehicles listed above are not meant to be an exhaustive list, but merely a brief sampling of systems which could address the FPD issue. In the remaining sections several other vehicle concepts will be introduced. Each concept has varying potential to fill the fast package market.

Chapter 5, Customer Needs and Technical Requirements

A Quality Function Deployment (QFD) matrix was used in both the scheduled and on-demand service cases to determine the design drivers. Two levels of QFD matrices were completed for each business case. The first level was used to translate the customer needs into broader system requirements. The system requirements were then entered into the second level matrix in order to generate a list of technical requirements. Later, in Sections 6 and 7, the system requirements will be used to rate possible concepts against an existing benchmark design.

5.1 Quality Function Deployment QFD

The primary goal of QFD matrices, is to translate customer needs into technical requirements. QFD matrices help to minimize human biases in systems design by providing a structured method for identifying technical requirements. Conflicting technical requirements can be prioritized according to relative scores.

Each customer need has a weighting factor, between one and ten, which represents its hierarchy in relation to the remaining customer needs. A ten means the customer need is necessary while a one represents an item which would be helpful but not necessary. The relationship strength (strong, mild, weak) between each technical requirement and each customer need was then determined. Scores were computed by multiplying the relationship strength by the weighting factor and then summing the results.

5.2 Scheduled Service

The following customer needs and rankings were obtained from the Boeing and CSTS studies as well as several interviews with express delivery personnel. The customer needs tend to relate to two areas, faster delivery time and high degrees of reliability.

Customer Need	Weighting
Faster Delivery Time	10
Minimize Non-Recurring Costs	8
Minimize Operating Costs	8
Minimize Infrastructure Costs	8
Turnaround Time (24 hours)	9
Aircraft-Like Reliability	10
High Dispatch Reliability	9
High Reliability Against Loss of Payload	10
Global Flight Coverage	10
Use Standard Cargo Containers	5
6000 Pounds Payload	NA
FAA Certification	NA

Faster Delivery Time - Existing express delivery networks are able to provide three day service to the Far East. In order to achieve "faster delivery time," the system must be able to provide door-to-door delivery in less then three days.

Minimize Non-Recurring Costs - The vehicle purchase price should be kept as low as possible to minimize initial start-up costs.

Minimize Operating Costs - All costs associated with vehicle operations (fuel costs, repair cost, crew costs) should be kept to a minimum.

Turnaround Time - For a scheduled service vehicle, it is assumed that the operator would continue with once-a-day delivery service. This will allow for a maximum turnaround time of 24 hours minus the mission time. This assumes one vehicle per destination point.

Aircraft-Like Reliability - Express delivery providers currently operate aircraft out of commercial airports. The vehicle should integrate into such a system while providing reliability levels equal to or greater than existing aircraft.

High Dispatch Reliability - The vehicle must be ready for operation when needed, once a day assuming one vehicle per destination point.

High Reliability Against Loss of Payload - Loss or damaged payload is considered to be a mission failure. It is extremely important that the payload reaches its destination without any damage.

Global Flight Coverage - The vehicle should have a long enough range as to enable global routes.

Use Standard Cargo Containers - During shipping, packages are loaded into standard LD cargo containers at the beginning of their journey. A time penalty is incurred if the packages are unpacked and repacked several times during the delivery process.

6000 pounds/node/day payload - Initial cargo estimations predict that each major destination (node) will require a payload of six thousand pounds of payload per day.

FAA Certification - The vehicle must comply with existing airport regulations while integrating into the current air traffic network.

The two levels of QFD matrices were then completed for the scheduled service business case (See Figure 5.2-1 & Figure 5.2-2).

5.3 On-Demand Service

As in the case of the scheduled service, the customer needs below were derived from the Boeing Study and the CSTS as well as discussions with express personnel. The customer needs for the on-demand business case are almost identical to the scheduled service case except for a few changes.

Customer Need	Weighting
Faster Delivery Time	10
Minimize Non-Recurring Costs	8
Minimize Operating Costs	8
Minimize Infrastructure Costs	8
Turnaround Time (24 hours)	9
Aircraft Like-Reliability	10
High Dispatch Reliability	9
High Reliability Against Loss of Payload	10
Global Flight Coverage	10
Wide Collection Radius	5
200 Pounds Payload	NA
FAA Certification	NA

Wide Collection Radius - Wide collection radius refers to the radius which can be covered within the allotted collection time from the launch site.

200 Pounds Payload - Through discussions with on-demand service providers, an average payload weight of 200 pounds was determined.

The two levels of QFD matrices were then completed for the on-demand business case (See Figure 5.3-1 & Figure 5.3-2).

5.4 Technical Requirements Comparison

From the QFD matrices, the main customer needs and system requirements remain nearly the same. Their meanings, however, are different. In both cases minimized flight time was cited as a system requirement. In the scheduled service this relates to a nine hour flight time. In the on-demand case, minimize flight time, requires a flight time of less then four hours. Although the system requirements and technical needs are similar, there are still two different systems.

The system requirements correlate well with discussions with express delivery operators which state, "time is everything!" Looking back at the customer needs, the highest weightings were on reliability and time items. These priorities relate to the top technical requirements which address reliability and speed.

	Weightings	Min Flight Time	Min Load / Unloade Time	Min Material Costs	Min Design Costs	Min Manufacturing Costs	Min Fleet Size	Max Flight Hrs / Maint Hrs	Min Fuel Cost	Max Vehicle Reusability	Nominal Ground Crew	Max Use of Existing Facilities	Min Use of Support Equipment	Max System Reliability	Max Fleet Size	Max Payload Protection in Flight	All Weather Capability	Day / Night Capability	Long Ragne	Accommodate Standard LD Containe	Accommodate 6000 pound Payload	Accommodate Payload Size	Conform to Noise Levels	Conform to Emission Levels	Safe Abort
Faster Delivery Time	10	9	1														1		1						
Minimize Non-Recurring	8			9	9	9	9						3												
Minimize Operating Cost	8						9	3	9	9	1			1											
Minimize Infrastructure Cost	8						1					9	9												
Turnaround Time (24 Hours)	9							9		9															
Aircraft-LikeReliability	10													9											
High Dispatch Reliability	9							3						9	9		9	9							
High Reliability Against Loss of Payload	10													9		9									
Global Flight Coverage	10	9										9	9		3				9						
Use Standard Cargo Containers	5																			9					
6000 lbs Payload	NA															X					X				
600 ft^3 Payload	NA																					X			
FAA Certification	NA																						X	X	X
Score		180	10	72	72	72	152	132	72	153	8	162	186	269	111	90	91	81	100	45	N/A	N/A	N/A	N/A	N/A
Rank		3	18	13	13	13	6	7	13	5	19	4	2	1	8	11	10	12	9	17	N/A	N/A	N/A	N/A	N/A
Next Level Weightings		8	1	3	3	3	7	6	3	7	1	7	8	10	5	4	4	4	4	2	N/A	N/A	N/A	N/A	N/A

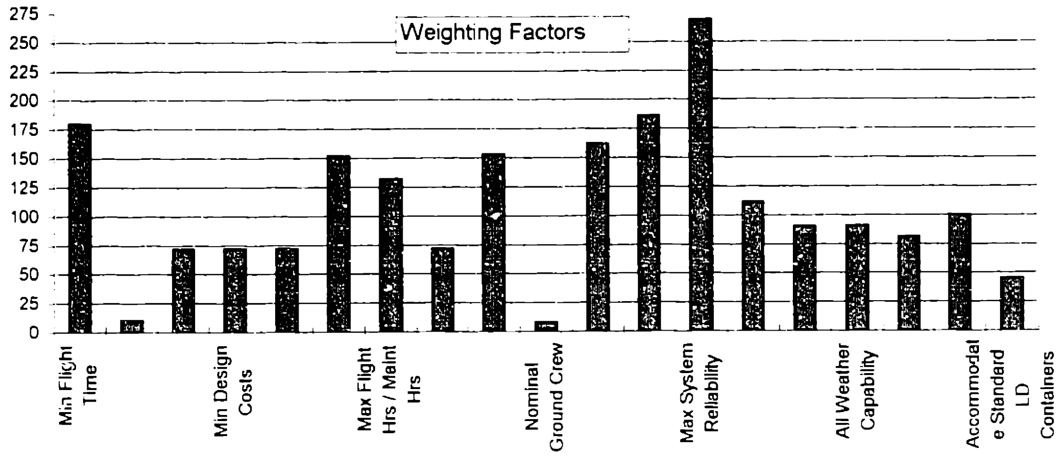


Figure 5.2-1, Scheduled Service Translation Matrix

	Weightings	Max Cruise Speed	Min Time To Cruise	Min Landing Time	Max Access to Cargo Bay	Min Cooling Time	Max Use of Standard Materials	Max Use Off-the-Shelf Components	Min Subsystem Reusability	Min Assembly Effort	Min Part Count	Min Manufacturing Effort	Min Fault Diagnostic Effort	Min Part Replacement Effort	Max Use of Inexpensive Fuels	Min Fuel Transport / Storage Cost	Use Multiple Stages	Max Fuel Efficiency	Max Use of Composite Materials	Autonomous Flight operations	Provide Satellite Comms/Data Link	Max Subsystem Reusability	Unassisted Taxi Capability	Min. Number Of Stages	Nominal Take-Off/Landing Distance	Max Integration With Grd Veh	Min Use of Hazardous Materials	Min Start Up Effort	Nominal g Loads	Nominal Env Conditions in Bay	Min Effect of Weather on Mission	Max Functional Redundancy	Max L/D	Carry 200lb Payload	Accom 2'X2'X4' Payload	Min Sonic Boom Audibility on Groun	Min Operating Noise	Min Undesirable Noise	Alternate Landing Site Capability	Integrate With Air Traffic
n Flight Time	8	9	1	1																													9							
n Load / Unload Time	1				9	9																				1														
n Material Cost	3						9				3																		1											
n Development Costs	3						3	9	9		3									9									1											
n Manufacturing Costs	3						3	3		9	9	9															3		1											
ax Flight hrs / Maint hrs	6										1		9	9										1								1								
n Fuel Cost	3														9	9	9	9	9	9													3							
ax Vehicle Reusability	7																					9																		
n Ground Crew	1				1								3	3									9			1		3												
ax Use of Existing Facilities	7																						3		9	9	9													
ax System Reliability	10												9								1			9				1	1			9								
ovide Payload Protect in Flight	4																												9	9										
-Weather Capability	4																			9	1										9									
ay / Night Capability	4																			9	1																			
ng Range	4	9									3						9	9	9		3								1				9							
ccommodate Standard LD Containers	2																																							
rry 6000 Pounds Payload	N/A				X																													X						
ccommodate 2' X 2' X 2' Payload	N/A				X																														X					
nform to Noise Level	N/A																																			X	X			
nform to Emission Level	N/A																																					X		
fe Abort	N/A																																						X	
Score		108	8	8	10	9	45	36	27	27	63	27	147	57	27	27	63	63	63	126	30	63	30	96	63	65	72	13	59	36	36	96	117	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Rank		4	31	31	29	30	17	18	23	23	9	23	1	16	23	23	9	9	9	2	21	9	21	5	9	8	7	26	15	18	18	5	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A

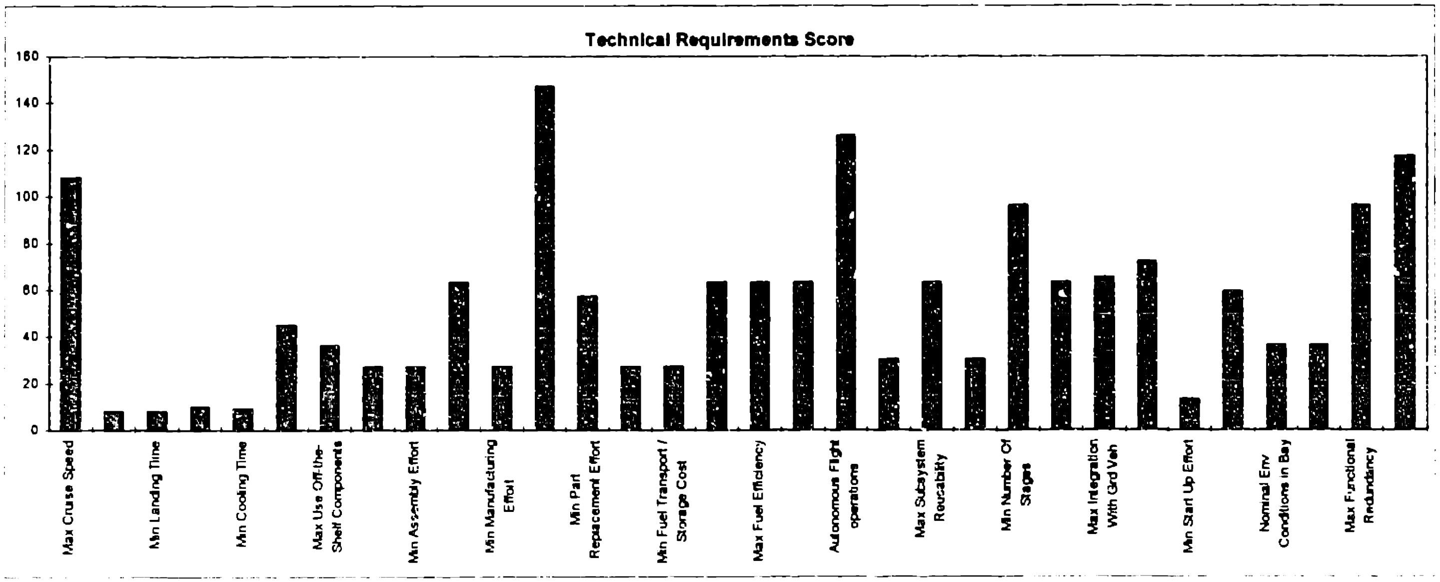


Figure 5.2-2, Scheduled Service Technical Requirements

	Weightings	Min Flight Time	Min Processing Time	Min Load / Unloade Time	Min Transit Time	Min Material Costs	Min Design Costs	Min Manufacturing Costs	Min Fleet Size	Max Flight Hrs / Maint Hrs	Min Fuel Cost	Max Vehicle Reusability	Min Ground Crew	Max Use of Existing Systems	Min Use of Support Equipment	Min Vehicle Prep Time	Max System Reliability	Max Fleet Size	Max Payload Protect in Transit	Max Payload Protection in Flight	All Weather Capability	Day / Night Capability	Long Range	Max Pakage Collect Radius	Accommodate 200 pound Payload	Accommodate Payload Size	Conform to Noise Levels	Conform to Emission Levels	Safe Abort
Faster Delivery Time	10	9	1	1	9											9					1		1						
Minimize Non-Recurring	8					9	9	9	9						3														
Minimize Operating Cost	8								9	3	9	9	3			1	1												
Minimize Infrastructure Cost	8								1					9	9														
Quick Turnaround Time	9									9		9				9													
Aircraft-LikeReliability	10																9												
High Dispatch Reliability	9									3							9	9			9	9							
High Reliability Against Loss of Payload	10																9		9	9									
Global Flight Coverage	10	9												9	9			3					9						
Wide Collection Radius	5	1	1	1	9									3							3			9					
200 lb Payload	NA																		X	X					X				
(2' X 2' X 2') Payload	NA																									X			
FAA Certification	NA																										X	X	X
Score		185	15	15	135	72	72	72	152	132	72	153	24	177	186	179	269	111	90	90	106	81	100	45	N/A	N/A	N/A	N/A	N/A
Rank		3	22	22	8	16	16	16	7	9	16	6	21	5	2	4	1	10	13	13	11	15	12	20	N/A	N/A	N/A	N/A	N/A
Next Level Weightings		8	1	1	6	3	3	3	7	6	3	7	1	8	8	8	10	5	4	4	5	4	4	2	N/A	N/A	N/A	N/A	N/A

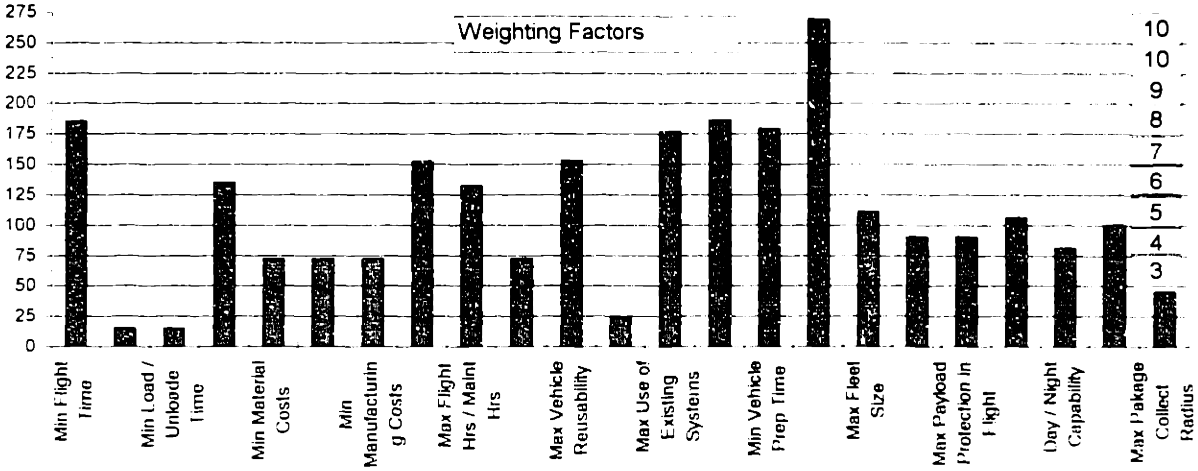


Figure 5.3-1, On-Demand Service Translation Matrix

	Weightings	Max Cruise Speed	Min Time To Cruise	Min Landing Time	Max Concurrent Processing Activiti	Max Access to Cargo Bay	Min Cooling Time	Real Time Info on Traffic / Route	Min Collect / Dist Radius	Max Velocity of Transfer Mech	Max Use of Standarc Materials	Max Use Off-the-Shelf Components	Min Subsystem Reusability	Min Assembly Effort	Min Part Count	Min Manufacturing Effort	Min Fault Diagnostic Effort	Min Part Replacement Effort	Max Use of Inexpensive Fuels	Min Fuel Transport / Storage Cost	Use Multiple Stages	Max Fuel Efficiency	Max Use of Composite Materials	Autonomous Flight operations	Provide Satellite Comms/Data Link	Max Subsystem Reusability	Unassisted Taxi Capability	Min Number Of Stages	Nominal Take-Off/Landing Distanc	Max Integration With Grd Veh	Min Use of Hazardous Materials	Min Fuel Time	Min Start Up Effort	Nominal g Loads	Nominal Env Conditions in Bay	Min Effect of Weather on Mission	Max Functional Redundancy	Max L/D	Carry 200lb Payload	Accom 2'X2'X4' Payload	Min Sonic Boom Audibility on Grour	Min Operating Noise	Min Undesirable Noise	Alternate Landing Site Capability	Integrate With Air Traffic
Min Flight Time	8	9	1	1																																		9							
lin Processing Time	1				9																																								
lin Load / Unload Time	1					9	9																							1															
Min Transit Time	6							3	9	9																																			
lin Material Cost	3										9				3																			1											
lin Development Costs	3										3	9	9		3									9										1											
Min Manufacturing Costs	3										3	3		9	9	9															3			1											
Max Flight hrs / Maint hrs	6														1		9	9										1									1								
lin Fuel Cost	3																		9	9	9	9	9	9														3							
Max Vehicle Reusability	7																									9																			
lin Ground Crew	1					1											3	3									9			1			3												
Max Use of Existing Facilities	8																										3		9	9	9														
Min Vehicle Prep Time	8						1										9											9				9	9												
Max System Reliability	10																9								1			9					1	1			9								
rovide Payload Protect in Flight	4																																	9	9										
All-Weather Capability	2																							9	1											9									
Day / Night Capability	4																							9	1																				
Long Range	4	9													3						9	9	9		3									1				9							
Max Package Collection Radius	2	1	1	1	1			1		1																																			
Carry 200 Pounds Payload	N/A					X																																	X						
ccommodate 2' X 2' X 2' Payload	N/A					X																																		X					
Conform to Noise Level	N/A																																								X	X			
Conform to Emission Level	N/A																																										X		
Safe Abort	N/A																																											X	
Score		110	10	10	11	10	17	20	54	56	45	36	27	27	63	27	219	57	27	27	63	63	63	108	28	63	33	168	72	74	81	72	85	59	36	18	96	117	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Rank		4	35	35	34	35	33	31	20	19	21	22	26	26	12	26	1	18	26	26	12	12	12	5	25	12	24	2	10	9	8	10	7	17	22	32	6	3	N/A	N/A	N/A	N/A	N/A	N/A	N/A

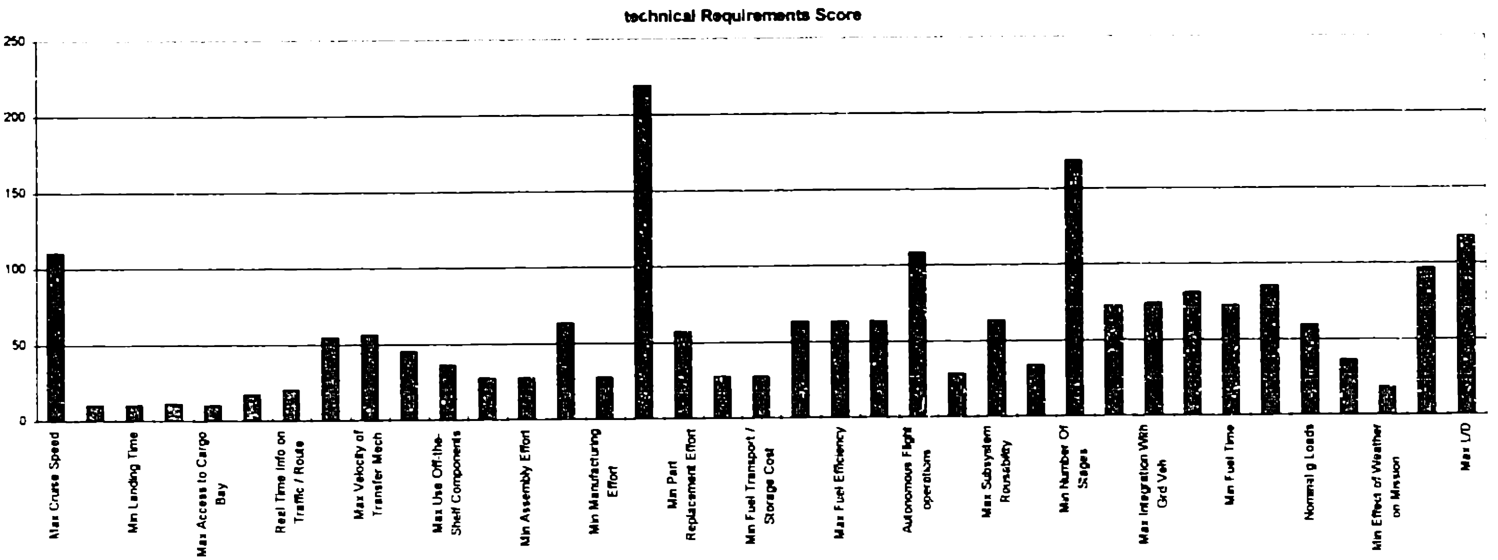


Figure 5.3-2. On-Demand Service Technical Requirements Matrix

Chapter 6, Scheduled Service Concept

Current scheduled service delivery systems are able to provide three day service to the Far East. Figure 6-1 graphically outlines the functional flow for the current process. The goal is to reduce the three day delivery time while minimizing the impact to this process since doing so would require changes to the existing infrastructure. The vehicle will carry 6000 pounds of payload per node and would replace the existing A310 and 747 aircraft (the boxed section in Figure 6-1).

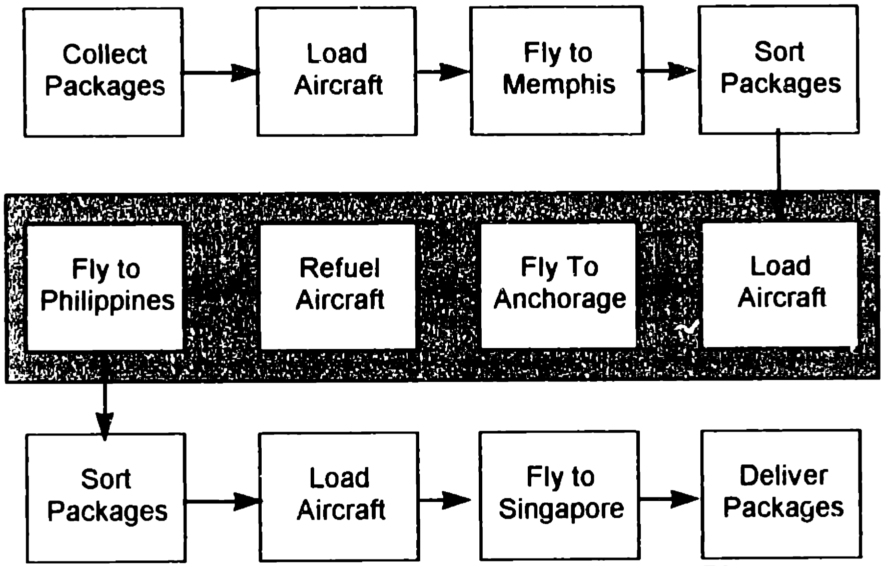
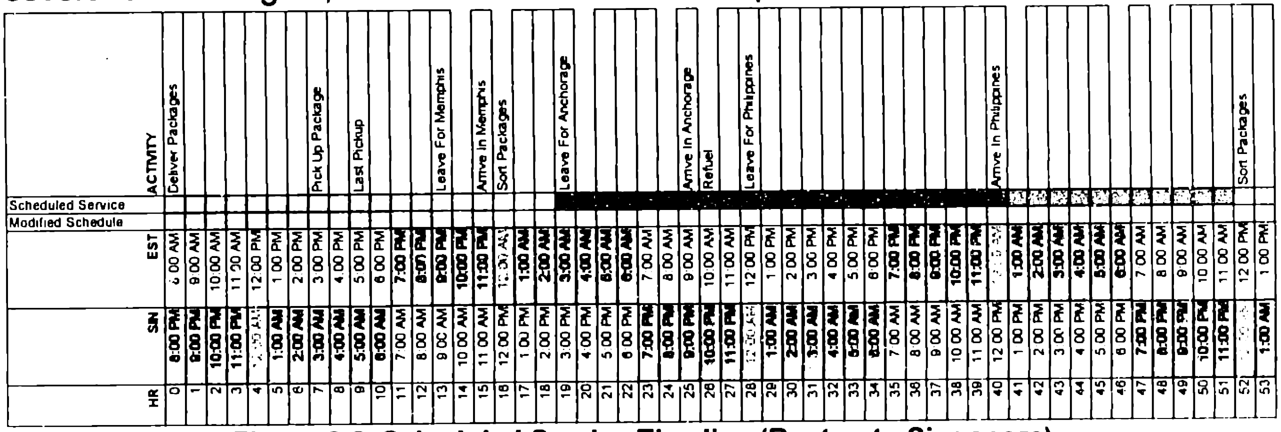


Figure 6-1, Scheduled Service Functional Flow Diagram

By looking at the current timeline, it is possible to see where time may be saved (See Figure 6-2). In order to save time, the vehicle must arrive at the international hub before the earliest sorting period. Sorting periods at the international hubs take place between midnight and 3:00 a.m. The modified schedule in Figure 6-2 outlines the needed timeline to insure the vehicle reaches the international hub in time for the earliest possible sorting. In order to meet such a schedule, the vehicle must fly between Memphis, Tennessee and the Philippines within nine hours. This may be achieved by either a direct flight or by several shorter flights, but the total time must be equal to or less then nine hours.

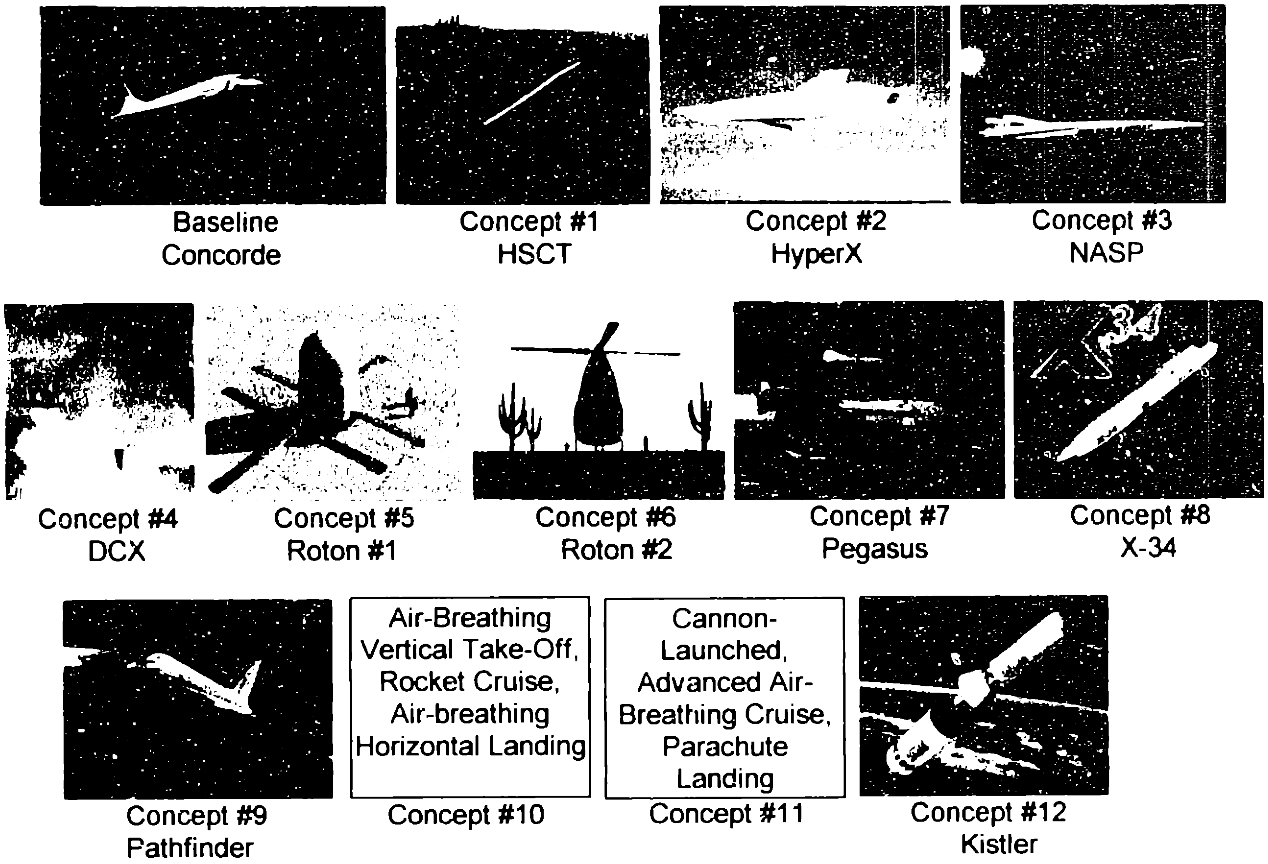


ACTIVITY	Deliver Packages							Pick Up Package		Last Pickup				Leave For Memphis		Arrive In Memphis	Sort Packages			Leave For Anchorage						Arrive In Anchorage	Refuel
Scheduled Service																				■	■	■	■	■	■	■	■
Modified Schedule																											
EST	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM	12:00 AM	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM
SIN	8:00 PM	9:00 PM	10:00 PM	11:00 PM	12:00 AM	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM
HR	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26

ACTIVITY		Leave For Philippines												Arrive In Philippines												Sort Packages	
Scheduled Service	■	■	■	■	■	■	■	■	■	■	■	■	■	■	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨		
Modified Schedule																											
EST	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM	12:00 AM	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM
SIN	11:00 PM	12:00 AM	1:00 AM	2:00 AM	3:00 AM	4:00 AM	5:00 AM	6:00 AM	7:00 AM	8:00 AM	9:00 AM	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM	3:00 PM	4:00 PM	5:00 PM	6:00 PM	7:00 PM	8:00 PM	9:00 PM	10:00 PM	11:00 PM	12:00 AM	1:00 AM
HR	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53

Figure 6-2, Scheduled Service Timeline (Boston to Singapore)

Several concepts ranging from reusable two stage rockets to advanced cannon-launched vehicles were proposed for the scheduled service vehicle (See Figure 6-3). Proposed vehicles were placed in a concept matrix and rated against the system requirements as specified in Section 5.2



Baseline Concorde

Concept #1 HSCT

Concept #2 HyperX

Concept #3 NASP

Concept #4 DCX

Concept #5 Roton #1

Concept #6 Roton #2

Concept #7 Pegasus

Concept #8 X-34

Concept #9 Pathfinder

Air-Breathing Vertical Take-Off, Rocket Cruise, Air-breathing Horizontal Landing

Concept #10

Cannon-Launched, Advanced Air-Breathing Cruise, Parachute Landing

Concept #11

Concept #12 Kistler

Figure 6-3, Proposed Vehicle Concepts for Scheduled Service

Concorde was chosen as a baseline since it is the only existing concept. The remaining concepts received a ranking between plus three and minus three compared to Concorde. A plus value represents a vehicle attribute which is better than the baseline at the proposed requirement while a negative value represents a vehicle attribute which is worse than the baseline. These rankings are relative and should not be taken as criticisms or endorsements of the above concepts. They merely represent the perceived view of the team in light of fast package delivery. The rankings were used to give the general vehicle trends which enable the system measure of effectiveness to be maximized (See Figure 6-4).

	Weighting	Concorde (Baseline)	High Speed Aircraft, Mach 2 - 5 (High Speed Civil Transport)	Hypersonic Aircraft, Mach 5 - 8 (Hyper X)	Ultra High Speed Aircraft, Mach 8+ (National Aerospace Plane)	Vertical Take-Off and Landing Rocket (DC-X)	Rocket Powered Rotor Tips (Roton)	Airbreathing Rotor, Rocket Cruise	Aircraft Drop TO, LH/LOX Cruise, Parachute Landing (Pegasus)	Air Dropped, Kerosene/LOX Cruise, Powered Landing (X-34)	Horiztontal Airbreathing Take-off, Rocket Cruise, Horizontal Landing (Pioneer)	Air Breathing Verticle Take-Off, Rocket Cruise, Horizontal Landing	Cannon Launched, Advanced Airbreathing Cruise, Parachute Landing	Two Reusable Stages, Parachute Landing (Kistler)
Min Flight Time	8		1	1	1	1	1	1	1	1	1	1	1	1
Max System Reliability	10		1	-1	-3	-1	-3	-2	-1	-1	-1	-2	-3	-2
Min Development Costs	3		0	-1	-3	0	-3	-3	1	0	0	-1	-3	1
Min Manufacturing Costs	3		1	-1	-2	1	-1	-1	3	2	1	1	-2	2
Max Flight Mile / Maint Hours	6		0	0	-1	-1	-3	-3	-1	-1	-1	-1	-1	-1
Min Fuel Costs	3		0	-1	-2	-3	-2	-2	-2	1	0	-1	2	-2
Max Reusability	7		0	0	-1	-2	-2	-2	-3	-3	-3	-3	-3	-3
Min Ground Crew	1		0	0	-1	0	-1	-1	-2	-2	-1	-2	-1	-3
Max Use of Existing Launch Facilities	7		0	0	0	-1	-1	-1	-3	0	0	0	-3	-2
Min Need For Support Equipment	8		0	0	0	-1	-1	-1	-3	-3	-3	-2	-1	-3
All Weather Capability	4		0	0	0	1	-1	-1	-2	0	0	0	-1	-1
Noise Regulations	N/A					X	X						X	X
	Score		21	-11	-57	-39	-92	-82	-78	-46	-51	-60	-92	-81
	Rank		1	2	6	3	11	10	8	4	5	7	11	9

Figure 6-4, Scheduled Service Concept Matrix

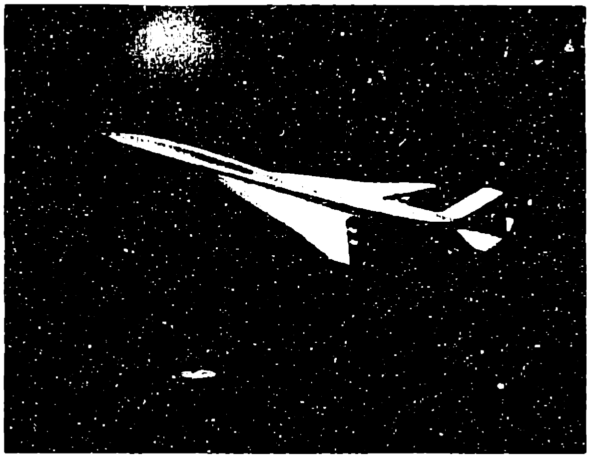


Figure 5-5, High Speed Civil Transport
Source: High Speed Civil Transport Homepage

From the concept matrix, the High Speed Civil Transport has a clear advantage over the other concepts (See Figure 6-5). The key reason why the HSCT is a suitable option for scheduled service FPD is that speed is not critical in this market. The vehicle only has to fly fast enough to reach the international hub before the next sorting. Second, aircraft technology has evolved beyond current space technologies in areas of reliability and reusability. Third, an aircraft will be able to operate near major populations and out of international airports unlike proposed rocket concepts.

The HSCT will require some modifications to the existing timeline. It is assumed that the HSCT will be unable to fly supersonically over land. The debate is still continuing on this issue, but at this time the more limiting case was analyzed. Due to the restriction of a sub-sonic cruise from Memphis to Anchorage, the HSCT vehicles will need approximately ten hours to reach the Philippines (See Figure 6-6).

HR	ACTIVITY	Sched. Fast Package	EST	SIN
0	Deliver Packages		8:00 AM	**8:00 PM**
1			9:00 AM	**9:00 PM**
2			10:00 AM	**10:00 PM**
3			11:00 AM	**11:00 PM**
4			12:00 PM	**12:00 AM**
5			1:00 PM	**1:00 AM**
6			2:00 PM	**2:00 AM**
7	Pick Up Package		3:00 PM	**3:00 AM**
8			4:00 PM	**4:00 AM**
9	Last Pickup		5:00 PM	**5:00 AM**
10			6:00 PM	**6:00 AM**
11			**7:00 PM**	7:00 AM
12			**8:00 PM**	8:00 AM
13	Leave For Memphis		**9:00 PM**	9:00 AM
14			**10:00 PM**	10:00 AM
15	Arrive in Memphis		**11:00 PM**	11:00 AM
16	Sort Packages		**12:00 AM**	12:00 PM
17			**1:00 AM**	1:00 PM
18	Leave For Anchorage		**2:00 AM**	2:00 PM
19			**3:00 AM**	3:00 PM
20			**4:00 AM**	4:00 PM
21			**5:00 AM**	5:00 PM
22			**6:00 AM**	6:00 PM
23	Arrive in Anchorage		7:00 AM	**7:00 PM**
24	Refuel	■	8:00 AM	**8:00 PM**
25	Leave For Philippines	■	9:00 AM	**9:00 PM**
26		■	10:00 AM	**10:00 PM**
27		■	11:00 AM	**11:00 PM**
28	Arrive In Philippines		12:00 PM	12:00 AM
29	Sort Packages		1:00 PM	**1:00 AM**
30			2:00 PM	**2:00 AM**
31	Leave For Singapore		3:00 PM	**3:00 AM**
32			4:00 PM	**4:00 AM**
33	Arrive in Singapore		5:00 PM	**5:00 AM**
34	Deliver Packages		6:00 PM	**6:00 AM**
35			**7:00 PM**	7:00 AM
36			**8:00 PM**	8:00 AM
37			**9:00 PM**	9:00 AM

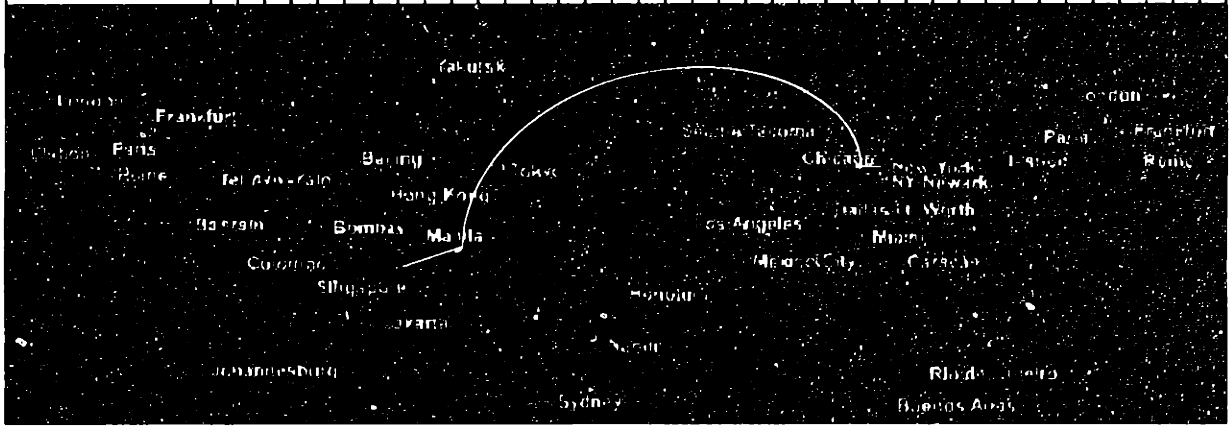


Figure 6.6, Scheduled Service Modified Timeline

In order to achieve a ten hour flight time, the fast package vehicle should be given priority during loading and take-off. This allows the vehicles to take-off first and ultimately arrive in Anchorage first. The trip from Memphis to Anchorage is a 3440 mile trip requiring a block speed of Mach 0.95. The aircraft would then land at Anchorage for refueling. The trip from Anchorage to the Philippines will allow the HSCT to use its high cruise speed. The trip is approximately 5160 miles and requires a block speed of Mach 2.25. The fast package aircraft would arrive in the Philippines shortly after midnight and would be unloaded.

The fuselage of the HSCT will most likely be long and slender due to the high speed cruise. This will mean that existing cargo containers will not provide effective usage of interior space. New containers will need to be designed specifically for the HSCT.

Fast package versions of the HSCT could serve cities located along the proposed HSCT routes (See Figure 6.7). They lie along major commercial routes with the majority of the distance consisting of flight over the ocean where the HSCT will be allowed to take advantage of its high speed cruise. One such route may be Memphis to Honolulu and then Honolulu to the Philippines (See Figure 6.8).

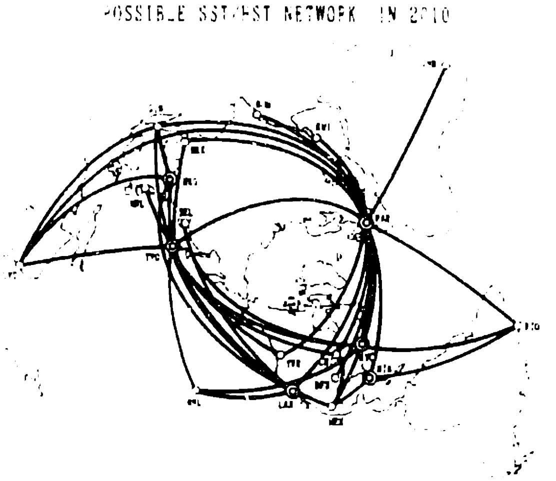


Figure 6.7, HSCT Routes
Source: High Speed Commercial Flight, Proceedings of the Second Commercial Flight Symposium.

HR	SIN	EST	Sched Fast Package	ACTIVITY
0	8:00 PM	8:00 AM		Deliver Packages
1	9:00 PM	9:00 AM		
2	10:00 PM	10:00 AM		
3	11:00 PM	11:00 AM		
4	12:00 AM	12:00 PM		
5	1:00 AM	1:00 PM		
6	2:00 AM	2:00 PM		
7	3:00 AM	3:00 PM		Pick Up Package
8	4:00 AM	4:00 PM		
9	5:00 AM	5:00 PM		Last Pickup
10	6:00 AM	6:00 PM		
11	7:00 AM	7:00 PM		
12	8:00 AM	8:00 PM		
13	9:00 AM	9:00 PM		Leave For Memphis
14	10:00 AM	10:00 PM		
15	11:00 AM	11:00 PM		Arrive in Memphis
16	12:00 PM	12:00 AM		Sort Packages
17	1:00 PM	1:00 AM		
18	2:00 PM	2:00 AM		Leave For Honolulu
19	3:00 PM	3:00 AM		
20	4:00 PM	4:00 AM		
21	5:00 PM	5:00 AM		Reach Pacific Coast
22	6:00 PM	6:00 AM	■	
23	7:00 PM	7:00 AM	■	Arrive in Honolulu
24	8:00 PM	8:00 AM	■	Refuel
25	9:00 PM	9:00 AM	■	Leave For Philippines
26	10:00 PM	10:00 AM	■	
27	11:00 PM	11:00 AM	■	
28	12:00 AM	12:00 PM	■	Arrive In Philippines
29	1:00 AM	1:00 PM		Sort Packages
30	2:00 AM	2:00 PM		
31	3:00 AM	3:00 PM		Leave For Singapore
32	4:00 AM	4:00 PM		
33	5:00 AM	5:00 PM		Arrive In Singapore
34	6:00 AM	6:00 PM		Deliver Packages
35	7:00 AM	7:00 PM		
36	8:00 AM	8:00 PM		
37	9:00 AM	9:00 PM		

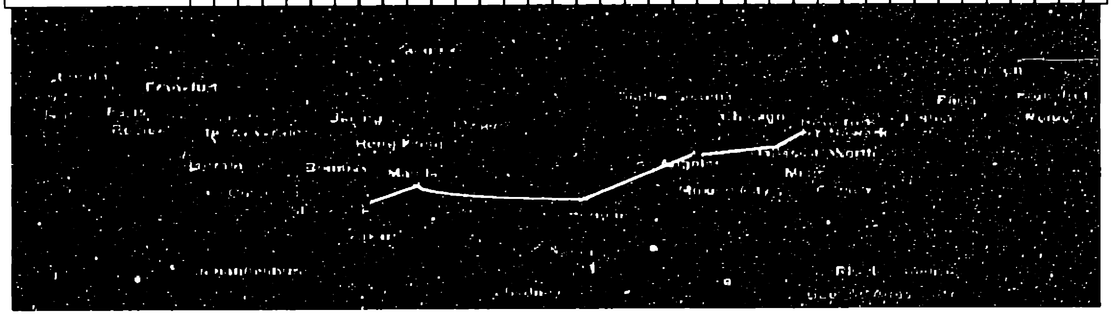


Figure 6.8, Scheduled Service Honolulu Timeline

Chapter 7, On-Demand Service Concept

7.1, Vehicle Layout

The goal of the on-demand case is to provide a four hour door-to-door delivery time at maximum range. In order to take advantage of the vehicle's speed, the system should operate over transoceanic routes where no speed limitations exist. The main customers for on-demand service include manufacturing and investment companies with forty-five percent of all on-demand service originating in the United States. For these reasons the on-demand vehicle was designed to operate out of the Los Angeles area with service to the Far East and Pacific Rim. The longest possible route would be Los Angeles to Singapore which is approximately 9,000 miles with a maximum payload of 200 pounds.

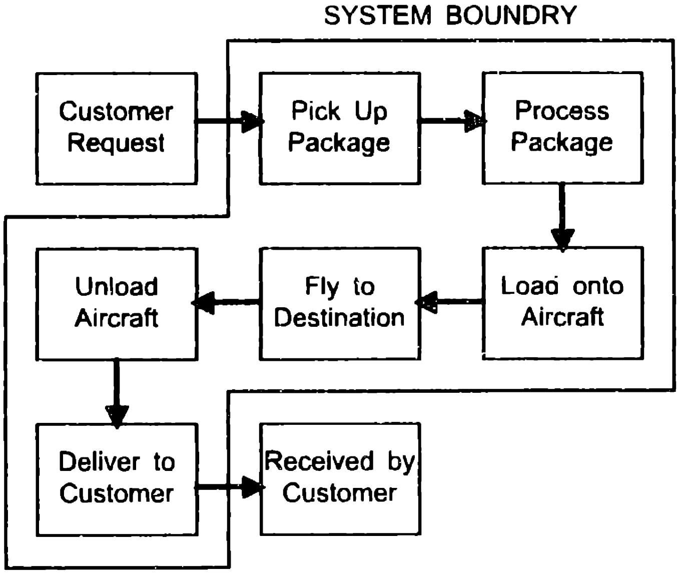


Figure 7.1-1, On-Demand Functional Flow

Due to federal aviation regulations, the vehicle must stay subsonic over land or within a 100 mile radius of airports. The vehicle should integrate and operate within the existing air traffic as much as possible. Failure to do so may prevent the vehicle from operating near major population areas and thereby jeopardize service.

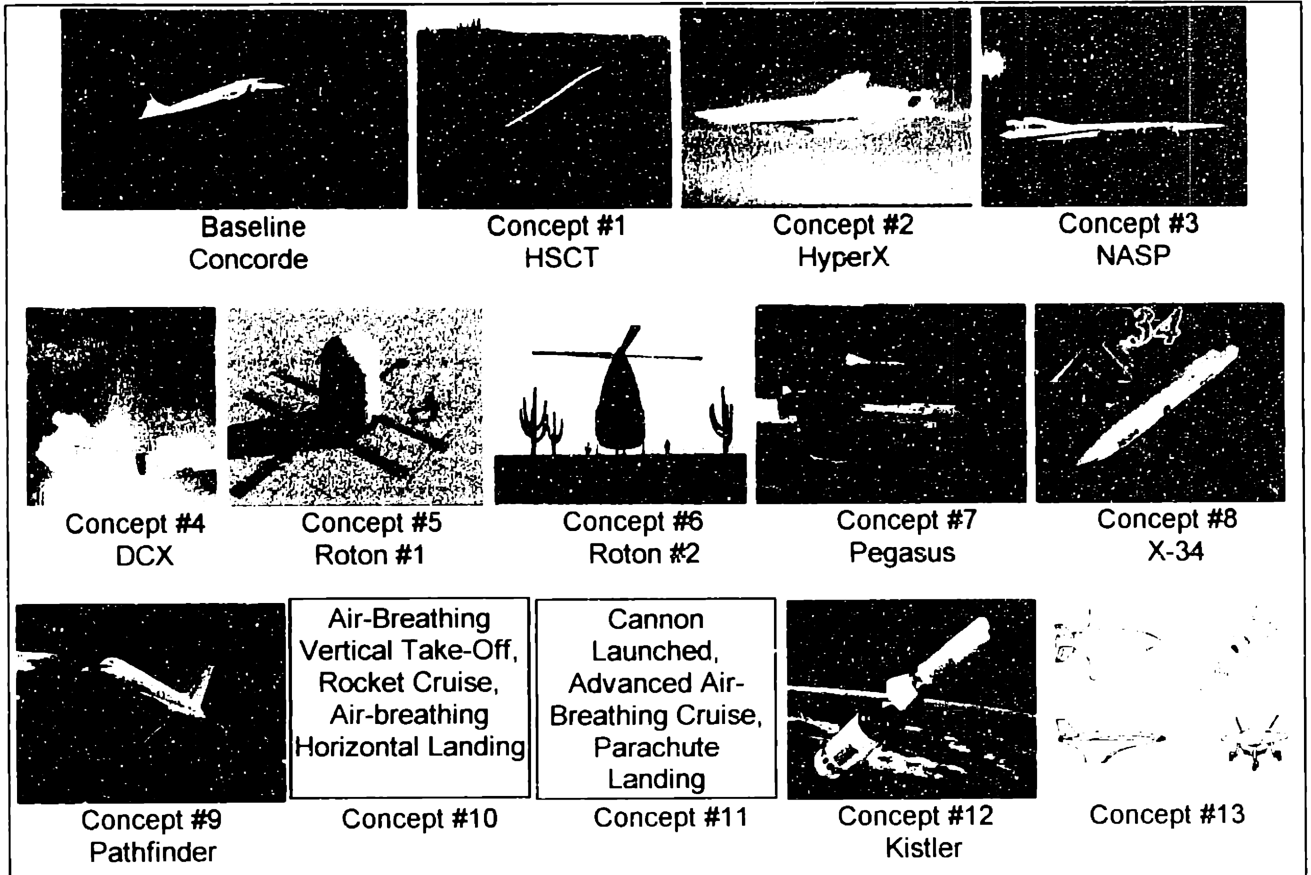
It is assumed that the delivery coverage area at either end of the flight is set by a one hour service radius. The radius' distance is dependant upon the speed at which the pick-up vehicle travels in one hour. For example, a delivery truck averaging forty-five miles per hour would have a delivery service radius of twenty-two miles from the airport where flight operations are taking place. The pick-up service radius is only half the delivery radius since the pick-up vehicle must make a round trip to the customer and back. Faster ground service systems would be utilized to increase the service radius at either end of the system. The pick-up radius could be double if the customer were to drop the package off at the airport since this would require a one way trip.

HR	SIN	EST	Scheduled Service	ACTIVITY
0	8:00 PM	8:00 AM		Deliver Package to Airport
1	9:00 PM	9:00 AM	■	Flight
2	10:00 PM	10:00 AM	■	
3	11:00 PM	11:00 AM		Deliver Package
4	12:00 AM	12:00 PM		
5	1:00 AM	1:00 PM		

Figure 7.1-2, On-Demand Timeline

From the time of the customer's call, to the time the package arrives at the airport, the ground crew would prepare the vehicle for flight. This would consist of refueling the vehicle, performing any preflight checks, and preparing the necessary paperwork. Therefore, the vehicle must have a maximum of a one hour preperation time.

Smaller versions of the scheduled service vehicles, plus a few additional concepts, were considered for the on-demand service role (See Figure 7.1-3). The proposed vehicles were placed in a concept matrix and rated against the system requirements as specified in Section 5.3.



Baseline Concorde

Concept #1 HSCT

Concept #2 HyperX

Concept #3 NASP

Concept #4 DCX

Concept #5 Roton #1

Concept #6 Roton #2

Concept #7 Pegasus

Concept #8 X-34

Concept #9 Pathfinder

Air-Breathing Vertical Take-Off, Rocket Cruise, Air-breathing Horizontal Landing

Concept #10

Cannon Launched, Advanced Air-Breathing Cruise, Parachute Landing

Concept #11

Concept #12 Kistler

Concept #13

Figure 7.1-3, Proposed Vehicle Concepts for Scheduled Service

Once again, Concorde was chosen as a baseline since it is the only existing concept. The remaining concepts received a ranking between plus three and minus three when compared to Concorde. A plus value represents a vehicle attribute which is better than the baseline at the proposed requirement while a negative value represents a vehicle attribute which is worse than the baseline. These rankings are relative and should not be taken as criticisms or endorsements of the above concepts. They merely represent the perceived view of the team in light of fast package delivery. The rankings were used to give the general trends which enable the systems measure of effectiveness to be maximized (See Figure 7.1-3).

	Weighting	Concorde (Baseline)	Small High Speed Aircraft, Mach 2 - 5 (High Speed Civil Transport)	Small Hypersonic Aircraft, Mach 5 - 8 (Hyper-X)	Ultra High Speed Aircraft, Mach 8+ (National Aerospace Plane)	Vertical Take-Off and Landing Rocket (DC-X)	Rocket Powered Rotor Tips (Roton)	Airbreathing Rotor, Rocket Cruise	Aircraft Drop TO, LH/LOX Cruise, Parachute Landing (Pegasus)	Air Dropped, Kerosene/LOX Cruise, Powered Landing (X-34)	Horizontal Airbreathing Take-off, Rocket Cruise, Horizontal Landing (Pioneer)	Air Breathing Verticle Take-Off, Rocket Cruise, Horizontal Landing	Cannon Launched, Advanced Airbreathing Cruise, Parachute Landing	Two Reusable Stages, Parachute Landing (Kistler)	Wing Assisted Horizontal Take-Off, Ramjet, Rocket, Glide, Powered Land
Min Flight Time	8		1	1	2	3	2	2	2	2	3	3	3	3	3
Max System Reliability	10		1	-2	-3	-1	-3	-2	-1	-1	-1	-2	-3	-2	-1
Min Development Costs	3		0	-2	-3	-1	-2	-1	1	0	0	0	-3	1	0
Min Manufacturing Costs	3		1	-2	-2	1	-1	-1	3	2	1	1	-2	2	2
Max Flight Mile / Maint Hours	6		0	0	-1	-1	-2	-2	-1	-1	-1	-1	0	-1	-1
Min Fuel Costs	3		0	-1	-2	-3	-2	-2	-2	1	0	-1	2	-2	1
Max Reusability	7		0	0	-1	-2	-2	-2	-2	-2	-2	-2	-2	-3	-1
Min Ground Crew	1		0	0	-1	0	-1	-1	-2	-2	-1	-2	-1	-3	-2
Max Use of Existing Launch Facilities	8		0	0	0	1	1	2	1	2	2	2	-3	-2	3
Min Need For Support Equipment	8		0	0	0	-1	-1	-1	-3	-3	-3	-1	-1	-3	-1
Min Prep Time	8		0	0	-1	-1	-1	-1	-3	-3	-1	-1	0	-3	-2
All Weather Capability	5		0	0	0	1	-1	-1	-2	0	0	0	-1	-1	0
Long Range	4		0	0	0	0	3	3	3	3	0	3	3	3	2
Noise Regulations	N/A			X	X	X	X						X	X	
	Score		21	-27	-57	-18	-57	-36	-48	-27	-20	-6	-55	-80	16
	Rank		1	6	11	4	11	8	9	6	5	3	10	13	2

Figure 7.1-4, ON-Demand Service Concept Matrix

In the on-demand role, speed becomes a more important factor with reliability issues remaining important design drivers. Two vehicles ranked very high compared to the others. First, a smaller version of the Mach 2 - 5 vehicle followed by the wing assisted rocket vehicle. Although the Mach 2 - 5 vehicle had a higher score, due to the opinionated nature of the evaluation process, the initial concept was chosen to reflect the wing-assisted rocket vehicle (See Figure 7.1-5 and Figure 7.1-6). The wing is used to provide a subsonic cruise phase just after launch and returns to the airport after the rocket vehicle has launched. Near the end of the mission the rocket is able to sustain subsonic flight, without the assistance of the wing, since the weight has been decreased through the burning of fuel. The rocket engine consists of several thousand micro-rockets bundled together in packs [12]. After rocket ignition, the engine acts as a ramjet until Mach 6 is achieved. The engine then switches to a scramjet mode and accelerates the vehicle until it leaves the atmosphere. At this point the vehicle operates in a pure rocket mode. After rocket burnout the vehicle proceeds on a parabolic trajectory until reentry into the atmosphere. In order to reduce speed prior to landing, the vehicle then glides. Once the vehicle is within 100 miles of the destination airport the vehicle turns on a fraction of the micro-rockets in order to provide a powered landing.

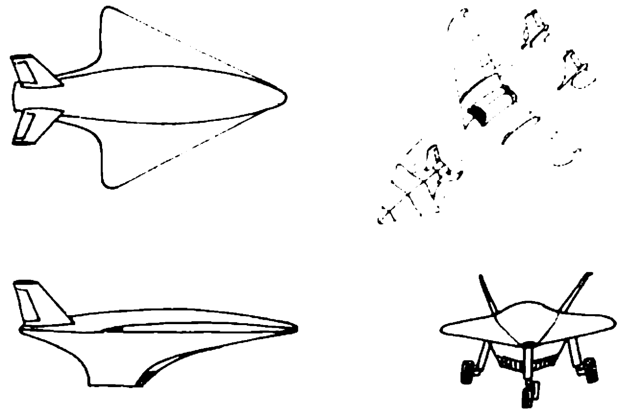


Figure 7.1-5, Wing-Assisted Rocket Vehicle

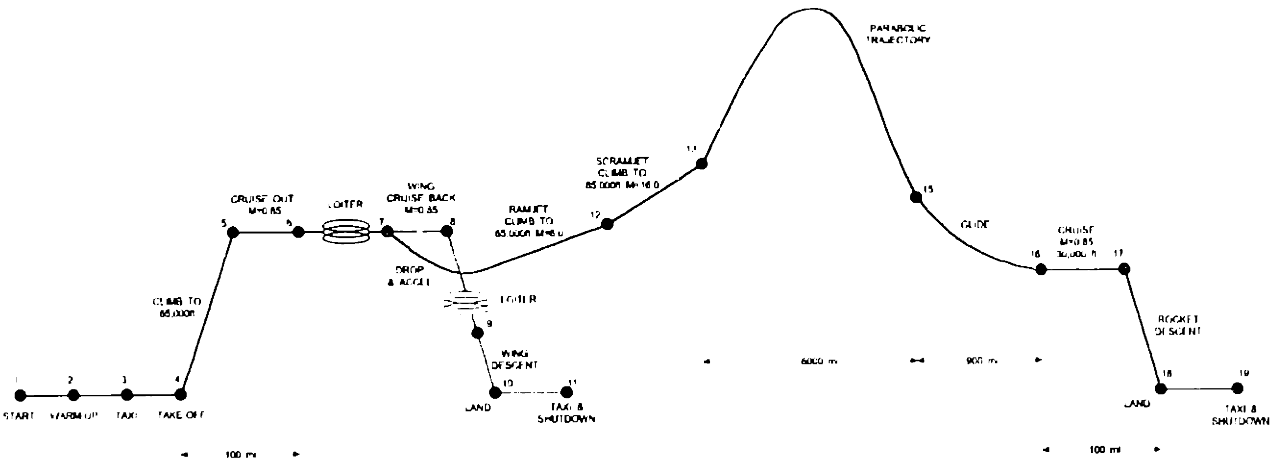


Figure 7.1-6, Wing-Assisted Rocket Vehicle Mission Profile

The Breguet range equation and the rocket equation were used to calculate fuel mass fractions for the various legs of the mission. The empty weight to take-off weight mass fraction was determined through statistical data (See Appendix A). This was only a crude approximation of the initial weight. No attempt was made to refine the weight estimate due to time constraints (See Table 7.1-1).

Rocket Weight Estimate

Payload	91	kg	200	lbs
Cruise Range	100	mile	528000	ft
Cruise Velocity	0,85	M	822,885	ft/s
Cruise Altitude	12,192	m	40,000	ft
c Cruise	7,2	1/hr	0,002002	1/s
L/D Cruise	4,0		4,0	

12	Ramjet Mode	0,9000
13	Scramjet Mode	0,7800
14	Rocket Boost	0,3700
15	Parabolic Trajectory	1,0000
16	Glide	1,0000
17	Cruise	0,7254
18	Descend	0,9900
19	Land, Taxi, Shutdown	0,9950
	W_{19}/W_{12} =	0,1856
	W_F/W_O =	0,8551
	W_E/W_{TO} =	0,1400
	W_{TOTAL}=	41073
	W_{EMPTY} =	5750
	W_{FUEL} =	35123

Wing Weight Estimation

Payload	18670	kg	41073	lbs
Cruise Range	100	mile	528000	ft
Cruise Velocity	0,85	M	822,885	ft/s
Cruise Altitude	19,812	m	65,000	ft
c Cruise	0,5	1/hr	0,000139	1/s
L/D Cruise	15,6		15,6	
Loiter Time	20	min	1200	sec
c Loiter	0,4	1/hr	0,000111	1/s
L/D Loiter	18		18	

1	Start & Warm-Up	0,9900
2	Taxi	0,9900
3	Take-Off	0,9950
4	Climb	0,8800
5	Cruise Out	0,9943
6	Loiter On Station	0,9926
7	Drop Rocket	1,0000
8	Cruise In	0,9943
9	Loiter	0,9926
10	Descend	0,9900
11	Land, Taxi, Shutdown	0,9950
	W_{11}/W_1 =	0,8234
	W_F/W_O =	0,1872
	Guess W_{TO} =	132424
	W_E/W_{TO} =	0,5027
	W_{TOTAL}=	132424
	W_{EMPTY} =	66566
	W_{FUEL} =	24785

Table 7.1-1, Wing Assisted Rocket Weight Estimation

The rocket vehicle had a gross weight of slightly more than 41,000 pounds and the entire system, wing and rocket, was approximately 132,000 pounds. It should be mentioned that the empty weight to take-off weight of the rocket vehicle is rather low at only 14 percent. Although some reusable launch vehicles are quoting empty weight to take-off weight fractions on the order of 10 percent, it is still uncertain whether such values are actually obtainable. Material considerations needed to achieve such low mass fractions will be discussed in Section 7.5.

From this initial starting point the vehicle design underwent a lengthy iterative process. The rocket vehicle required a large amount of fuel and two stages. It was decided to eliminate the rocket phase and remain in the scramjet mode in order to conserve fuel. From the fuel savings, it became possible to place a turbojet onboard the vehicle to provide for subsonic operations and to eliminate the wing stage. Considering the limits of scramjet technology the vehicle cruise speed dropped to Mach 12. However, this would require hydrogen to fuel the engine which is expensive and requires specialized handling and storage equipment. There are also concerns about operating hydrogen powered vehicles in and around airports due to the explosive nature of the propellant. Methane is less expensive and requires standard equipment to handle and store. It is possible to break methane down into acetylene and hydrogen through a heating process. Methods in which this process can be performed at high consumption rates are still experimental at best. In order to alleviate the need for hydrogen, the vehicle cruise speed dropped to Mach 8. However, Mach 8 is still within the scramjet mode, so by dropping to Mach 6 the vehicle is able to operate within the ramjet mode during the entire cruise phase and use kerosene for fuel.

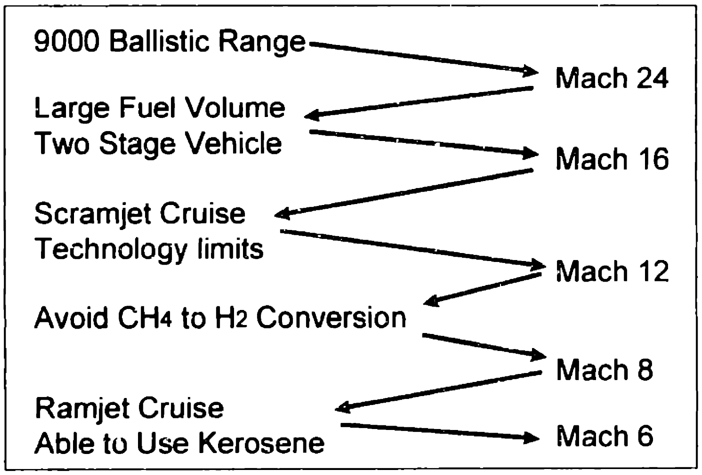


Figure 7.1-7, Design Iteration Process

A Mach 6 cruise speed results in a longer flight times than for other high-speed vehicles. From the concept matrix, however, it can be seen that speed is not the critical factor. The vehicle must effectively balance speed, reliable, and cost. Although the Mach 6 vehicle may not be able to meet the four hour delivery time to all locations, it was considered to be a reasonable trade with regards to the overall system performance.

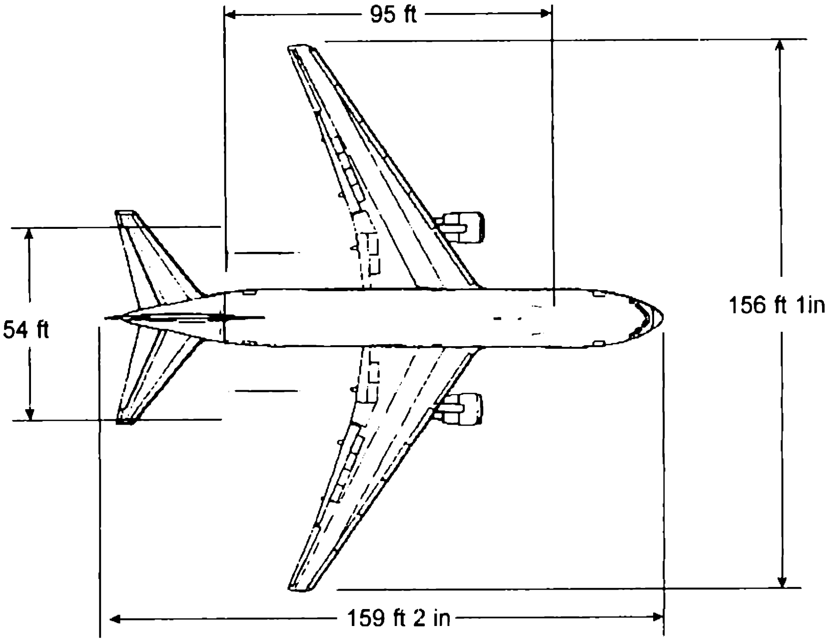
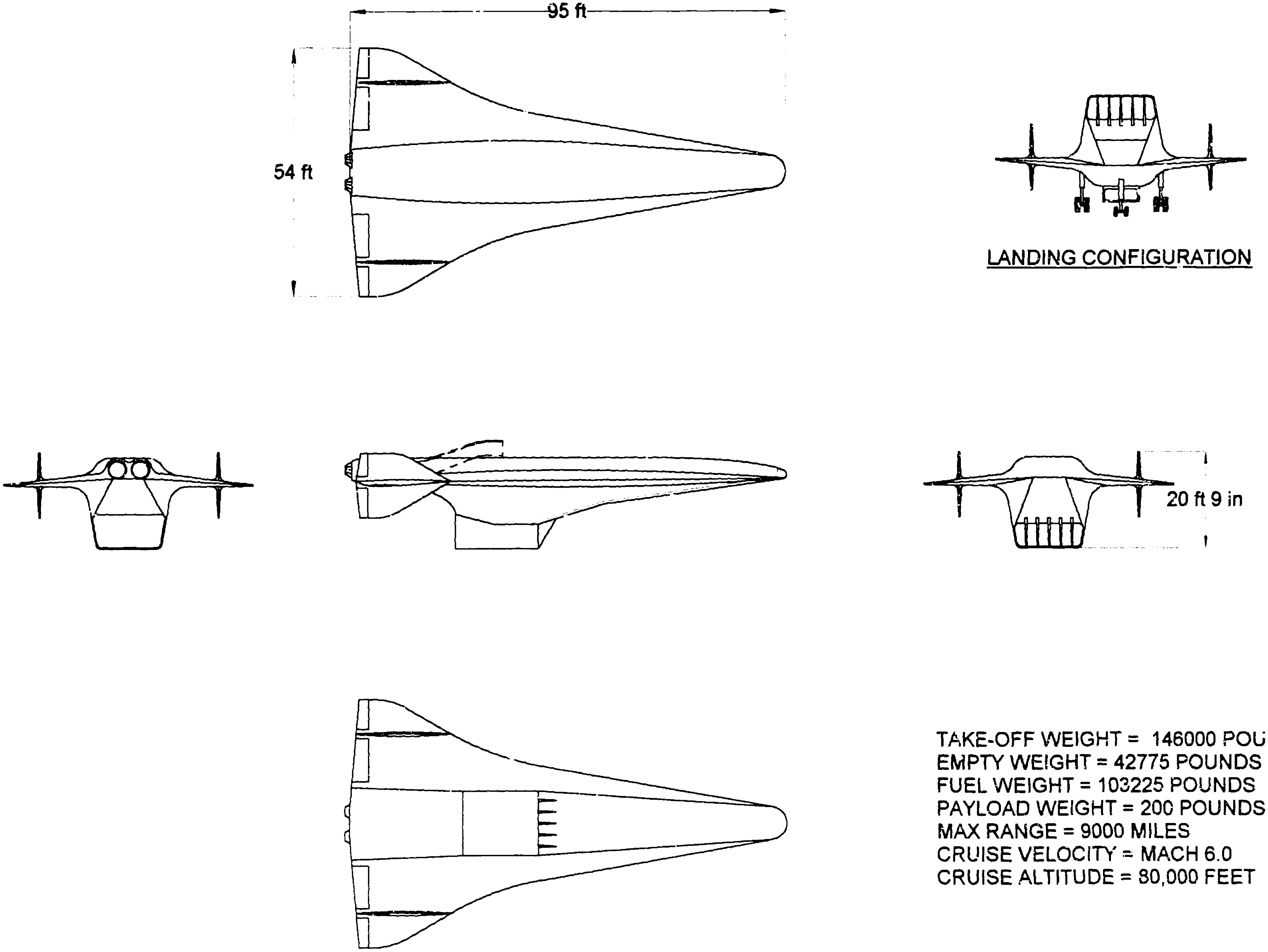


Figure 7.1-10, Ramjet Vehicle Size Comparison With Boeing 767

The ramjet vehicle was then laid out using the methods in References 16 and 17. These methods rely heavily on statistical data in order to start the design process (See Figure 7.1-8 and Figure 7.1-9). At first glance, it may be difficult to appreciate the size of this vehicle. Figure 7.1-10 shows the vehicle overlaid against the outline of a Boeing 767.

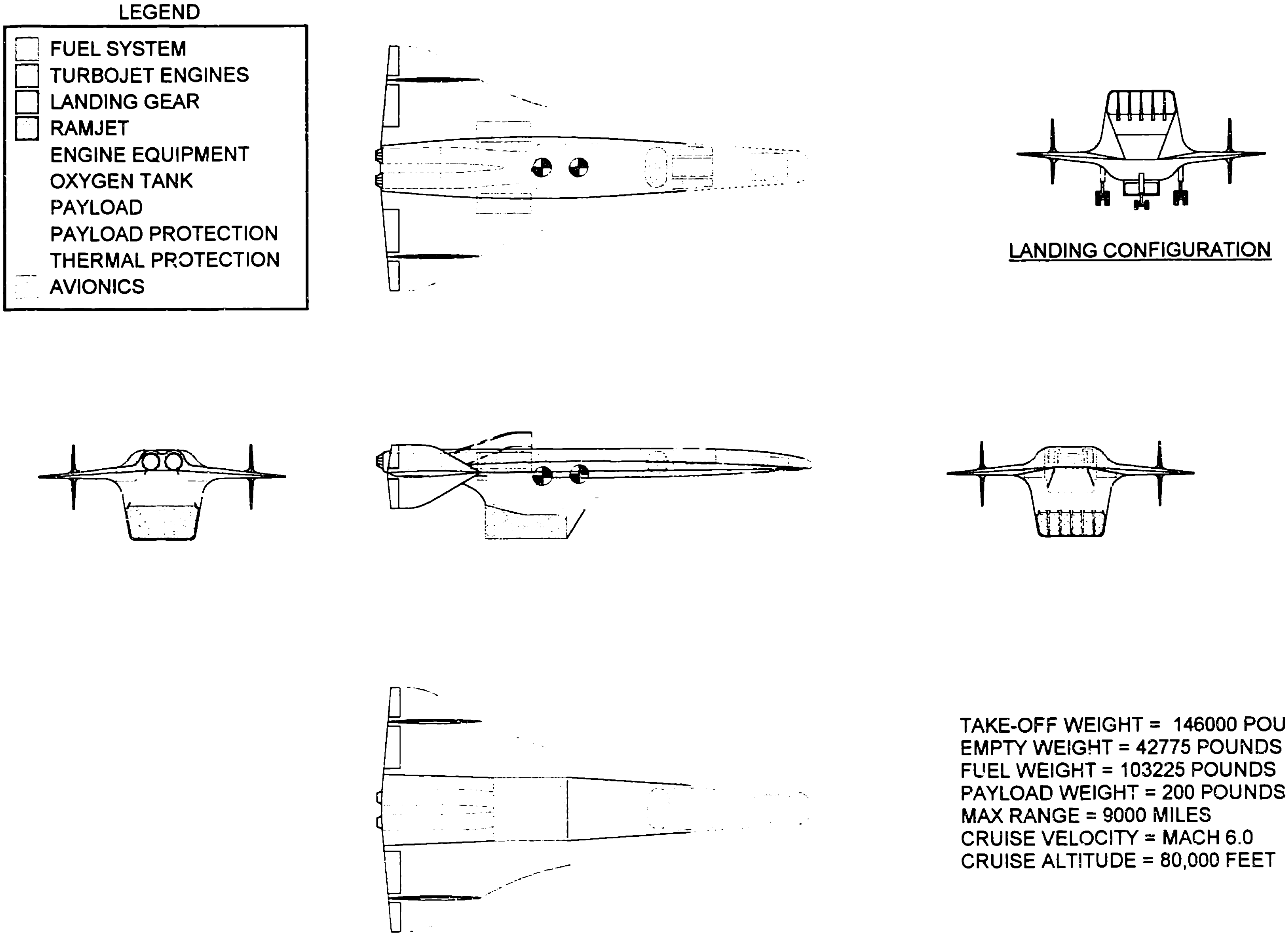
The mission profile was updated to reflect the ramjet cruise and the orientation change. During



TAKE-OFF WEIGHT = 146000 POUNDS
EMPTY WEIGHT = 42775 POUNDS
FUEL WEIGHT = 103225 POUNDS
PAYLOAD WEIGHT = 200 POUNDS
MAX RANGE = 9000 MILES
CRUISE VELOCITY = MACH 6.0
CRUISE ALTITUDE = 80,000 FEET

Figure 7.1-8, On-Demand Vehicle External View

ON-DEMAND CONCEPT
FAST PACKAGE DELIVERY
SCALE
1" = 30'
DRAWN BY: KURT PALMER
DATE: APRIL 28, 1998



TAKE-OFF WEIGHT = 146000 POUNDS
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FUEL WEIGHT = 103225 POUNDS
PAYLOAD WEIGHT = 200 POUNDS
MAX RANGE = 9000 MILES
CRUISE VELOCITY = MACH 6.0
CRUISE ALTITUDE = 80,000 FEET

Figure 7.1-9, On-Demand Vehicle Internal View

ON-DEMAND CONCEPT
FAST PACKAGE DELIVERY

SCALE 1" = 30'	DRAWN BY: KURT PALMER DATE: APRIL 28, 1998

take-off, the vehicle uses two turbojet engines. It then climbs to an altitude of 40,000 feet and remains in the subsonic regime until it has passed the 100 mile perimeter of the airport. At this point it, the vehicle rolls 180°. The design implications of this "flip" will be discussed later. After rolling, the vehicle performs a dive in order to accelerate past Mach 1 and initiate the ramjet. The vehicle then climbs to 80,000 feet and cruise at Mach 6 for a maximum of 8,200 miles. After cruising, the ramjet will then be turned off and the vehicle will glide from Mach 6 at 80,000 feet to Mach 0.85 at 40,000 feet. When the vehicle reaches the 100 mile perimeter of the airport, it will restart the turbojet engines and remain at Mach 0.85 until it descends and finally lands (See Figure 7.1-11).

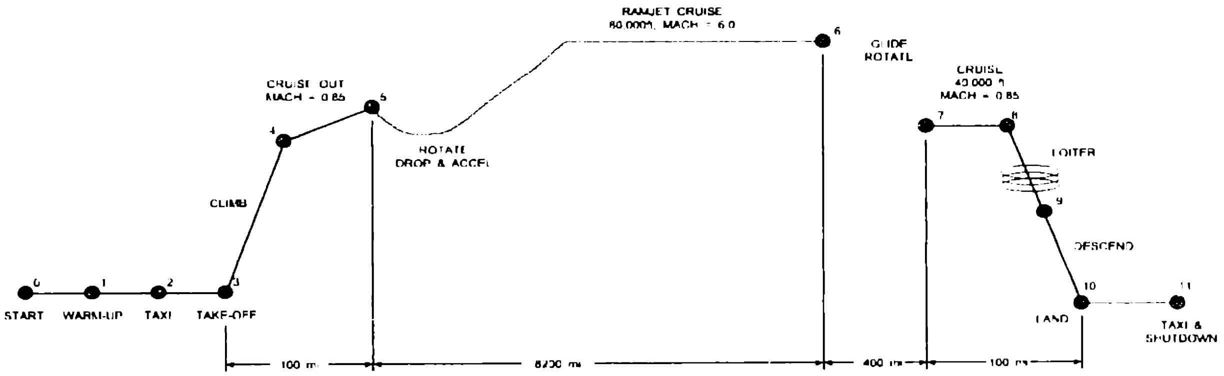

Figure 7.1-11, Ramjet Vehicle Mission Profile

Weight estimates were updated as new data became available (See Table 7.1-2). A plot of statistical weight trends for fast package delivery concepts and reusable launch vehicles can be found in Appendix A. Graphs for weight sensitivity can be found in Appendix B. The design point for the Mach 6 vehicle can be found in Appendix C.

Mission Data

Payload	91	kg	200	lbs
Range Ramjet	8200	mile	43296000	ft
Velocity Ramjet	6,0	M	6019	ft/s
Altitude Ramjet	24,384	m	80,000	ft
c Cruise Ramjet	1,775	1/hr	0,00049345	1/s
L/D Ramjet	4,3		4,3	
Range Jet	100	mile	528000	ft
Velocity Jet	0,85	M	823	ft/s
Altitude Jet	12,192	m	40,000	ft
c Cruise Jet	0,8	1/hr	0,0002224	1/s
L/D Cruise Jet	4,3		4,3	
Loiter Time	20	min	1200	sec
c Loiter	0,8	1/hr	0,0002224	1/s
L/D Loiter	5		5	

Fuel Fractions

1	Start & Warm-Up	0,9900
2	Taxi	0,9900
3	Take-Off	0,9950
4	Climb	0,8900
5	Cruise Out Jet	0,9676
6	Ramjet	0,4406
7	Glide	1,0000
8	Cruise In Jet	0,9676
9	Loiter	0,9480
10	Descend	0,9900
11	Land, Taxi, Shutdown	0,9950
	W11/W1 =	0,3343
	WF/WO =	0,7056
	Guess WTO =	145968
	WE/WTO =	0,2930
	WTOTAL=	145994
	WEMPTY =	42774
	WFUEL =	103019

Table 7.1-2, Ramjet Vehicle Weight Estimation

As mentioned earlier, a trade was made between cruise speed and reliability. This trade means that the system can only provide four hour door-to-door time to select areas. Figure 7.1-12 shows flight times for the proposed Mach 6 vehicle.

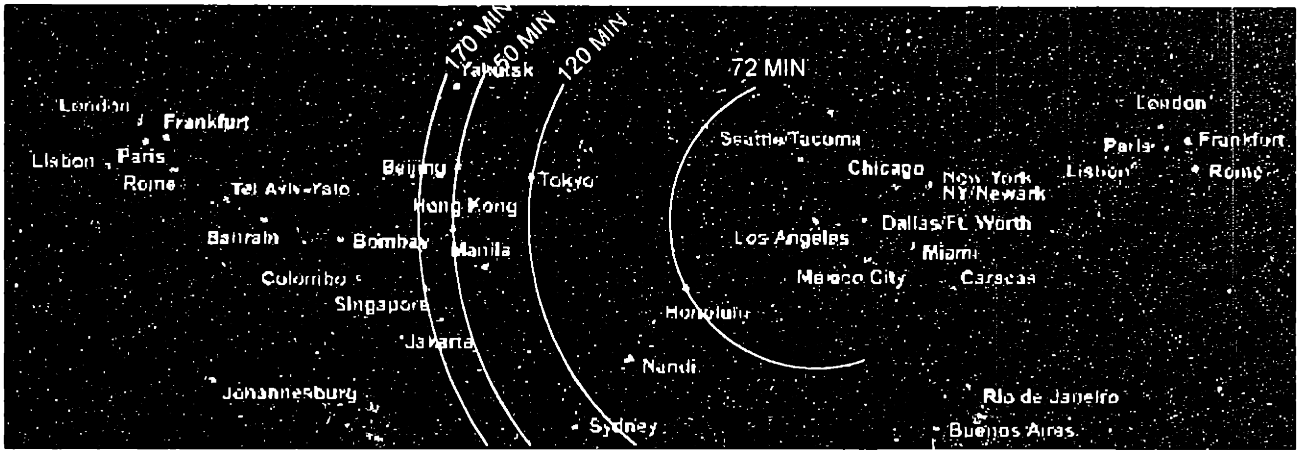

Figure 7.1-12, Mach 6 Flight Times

During shorter missions the vehicle could offset the reduced fuel weight with increased payload weight. Figure 7.1-13 shows payload weight versus range for the Mach 6 vehicle and compares it against the quoted values for Pioneer Rocketplane's vehicle.

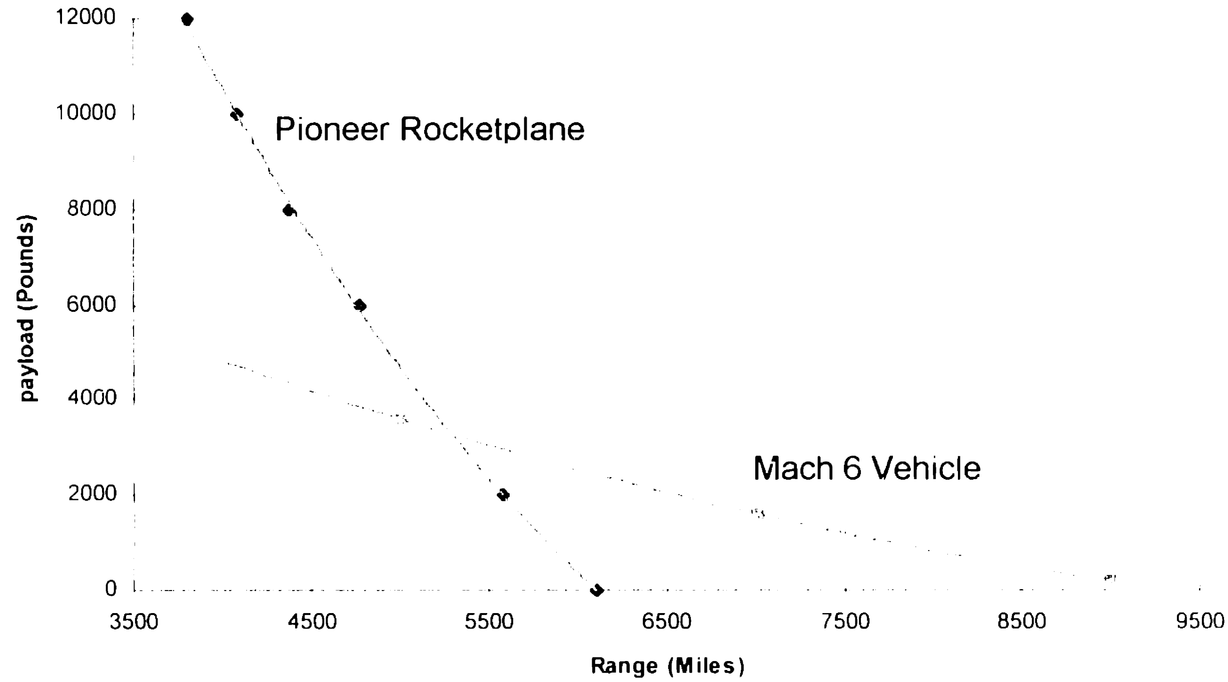

Figure 7.1-13. Payload Vs Range

There were several improvements being considered for the vehicle. These include the removal of the vertical tails. Instead, the vehicle would use split flaps to provide differential drag. However, the lack of time prevented these from formally entering the design.

7.2 Propulsion System

This section will briefly discuss the major design considerations of the propulsion system. The entire vehicle is integrated into the propulsion system with most of the vehicle shape being dictated by propulsion needs. For a more detailed look into the propulsion system of this vehicle, please refer to Reference 12.

As mentioned in Section 7.1, the vehicle uses two turbojets during subsonic flight. The vehicle is orientated with the ramjet up, during all subsonic phases of flight (Landing Configuration in Figure 7.1-6). A small retractable duct is extended to provide an inlet to the turbojet engines. This duct is then retracted during high speed flight.

During the Mach 6 cruise, the vehicle is then oriented such that the ramjet is towards the bottom (As drawn in Figure 7.1-6). The aircraft compresses the air using the forward body before it enters the ramjet. Upon exiting the ramjet, the exhaust expands over the rear surface of the vehicle which acts as a nozzle.

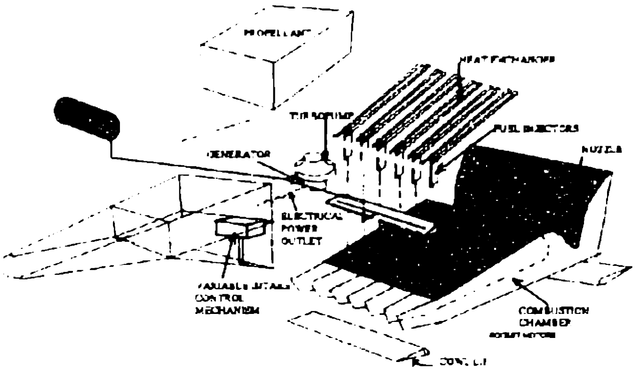

Figure 7.2-1, Ramjet Assembly
Source: Anand Karasi, 1998 [12]

All engines use Kerosene. since it requires no new handling equipment and is significantly less expensive than hydrogen. Second, it is currently available at all commercial airports.

Engine performance is one reason why the vehicle rotates during flight. If the subsonic inlet where positioned on top of the vehicle, the engines would have extremely poor performance at high angles-of-attack. If the ramjet were positioning on top, the vehicle's wings would be require to generate greater lift because of the downward force incurred from the forward body compression.

The critical issue with the propulsion system is the consequences of an engine flameout. The ramjet is broken into six separate compartments each with its own fuel injection and flame. However, if an engine flameout occurs, the shock wave will proceed forward out of the ramjet disrupting the air flow into the remaining sections. An engine flameout also produces a positive pitching moment due to the reduced pressure over the nozzle and the increased pressure over the vehicle nose. Further work needs to be performed to reduce the risks of engine out failure.

Due to the vehicle rotation, the fuel system must not rely on gravity for feed. All components must be designed to operate in any orientation. This could pose some difficulty in detailed design.

7.3 Avionics System

This section will highlight some of the significant design implications of the avionics system. For a more detailed explanation of the avionics and control system please refer to Reference 13.

With a payload of only 200 pounds, a crew and accommodations would outweigh the payload. For this reason, the vehicle is designed to be semi-autonomous. It will have the capability to be remotely piloted from a ground station. Even during autonomous operations, such as cruise, the human operator can override the flight control system.

The sensors are mounted on the top side (turbojet side) in order to shield them from the thermal environment during cruise, and allows the flight control system to communicate with satellites during cruise (See Figure 7.3-1). During inverted flight, the vehicle will communicate through line-of-sight means directly with a ground station.

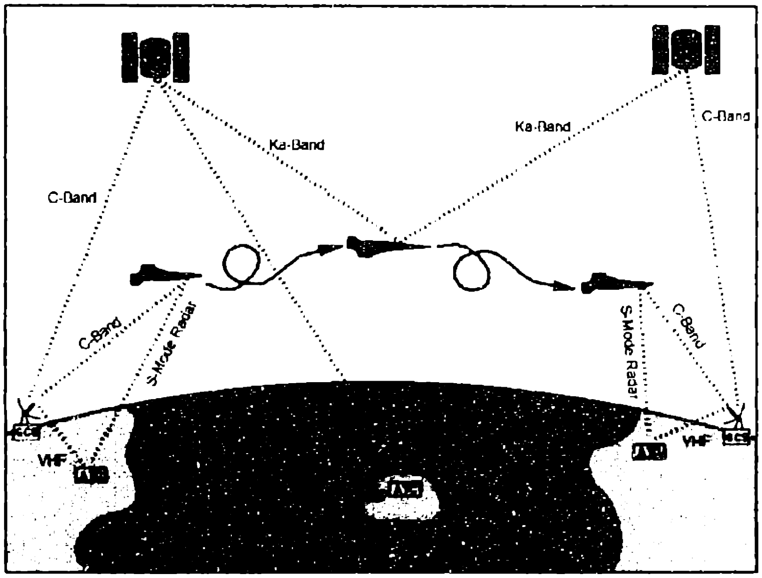

Figure 7.3-1, Vehicle Communication Links
Source: Dylan Glas, 1998 [13]

There are several critical issues regarding the autonomous flight of the vehicle. First, there are concerns about the reliability of the flight control system. This is primarily due to the fact that autonomous flight is a relatively new technology. However, with recent increases in unmanned air vehicles (UAV) experience will be gained in the development and operations of autonomous flight. Second, the implications of losing communications during landing are not fully understood. It is uncertain whether the vehicle, although fully capable of making an autonomous landing, would be allowed to do so at a commercial airport.

7.4 Thermal Heating

A thermal analysis of the vehicle at Mach 6 was completed in order to determine the thermal environment of the vehicle. Further details of the analysis may be found in Reference 11. The analysis only reflects thermal temperatures across the bottom of the vehicle. Temperatures across the top surface will be substantially lower and can be ignored. Thermal regions are outlined in Figure 7.4-1.

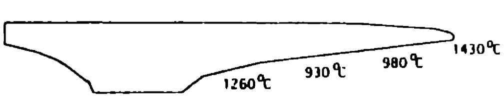

Figure 7.4-1, Thermal Heating Regions
Source: Martin Chan [11]

7.5 Materials

The material needs for the on-demand Mach 6 vehicle are very similar to those for proposed RLV's like Lockheed Martin's VentureStar or the National Aerospace Plane. Structural engineers are being forced to provide empty weight to take-off weight fractions on the order of 0.1. The proposed vehicle must also endure temperature extremes ranging from -200 to 2200 degrees Celsius. In each case, structural engineers are seeking materials which provide high strength-to-weight, high operating temperatures, high fracture toughness, and high oxidation resistance while minimizing manufacturing, development, and repair costs [20].

7.5.1 Existing High Temperature Materials

There are currently several high temperature materials: Superalloys and Titanium. Both are used in a wide range of current aviation applications. The Superalloys consist of: Inconel, Rene 41, and Hastelloy. These materials are used primarily in engine components but were also used extensively in the X-15.
The Superalloys have operating temperatures up to 1000°C and there are currently numerous coatings which may be applied to extend the life of superalloy components. Superalloys, however, are too heavy to achieve the weight fractions needed for future aerospace vehicles. They are also difficult to form.

Titanium is currently used in applications at temperatures below 800°C. Titanium provides a higher strength-to-weight ratio than other existing materials and there are numerous coatings commercially available. Titanium is used extensively in modern aircraft fuselages. There are several examples of aircraft which are primarily Titanium and include the B-70 Valkyrie and the SR-71 Blackbird. Titanium like the Superalloys is still too heavy for proposed aerospace vehicles and requires considerable effort to form. In addition, Titanium becomes brittle when subjected to hydrogen, oxygen, or nitrogen.

7.5.2 Future Technology and High Temperature Materials

There are several materials which are being studied and developed for future aerospace programs such as the HSCT, NASP, and VentureStar. Although these materials show promise there is little to no test data available. Even after significant testing has been performed there will be a prolonged learning curve as developers learn to design, manufacture, and repair these materials in real life applications. This section gives a broad overview of proposed materials for the next generation of air and space vehicles.

A group of materials which is showing promise is the Aluminides such as Ti_3Al and TiAl. They offer a fifty percent weight savings over Superalloys and can operate between 700 - 1000°C. The Aluminides also offer high stiffness and are resistant to oxidation. Further study is being conducted into using Aluminides in metal matrix composites. However, these materials tend to be very brittle at low temperatures.

	Ti3Al	TiAl
Density	0.16	0.14
Modulus (10^6)	18	225
Max Temp (Deg C)	815	1000

Table 7.5.2-1, Aluminides Properties

Ceramic matrix composites are able to endure thermal environments in the range of 1400-1900°C. They provide high strength-to-weight and are resistant to oxidation. However, they are not good in either thermal or mechanical shock. Currently, manufacturing costs are extremely high.

For extremely high temperatures, about 2200°C, carbon-carbon composites are used. They are currently used on the leading edge and nose of the shuttle. They are lightweight and offer good thermal and mechanical shock resistance. Their low thermal conductivity makes them excellent choices for thermal protection. The main disadvantage is that their properties are highly dependant on processing. It is difficult to produce large quantities of high quality material. Carbon-carbon composites also have oxidation issues and usually require coating for long life.

The materials mentioned above are all still in development. Very little testing has been performed on these materials and what little has been done has been on coupon size specimens. Further research must be completed in the area of failure mechanisms in order to allow for adequate structural designs. Even if these materials were available today, it would take a significant amount of time for the engineering community to develop design guidelines to produce realistic structures. Finally, it is uncertain if manufactures will be able to produce large enough quantities of high quality material to be utilized in applications. In general, more time is need before these materials will be available for use in aerospace applications.

7.6 Vehicle Costs

The total cost of the vehicle consists of both direct and indirect operating costs. Direct operating costs include: fuel costs, crew costs, maintenance costs, insurance costs, and depreciation. Indirect operating costs include: ground facilities, sales & customer service, and administrative & overhead.

Figure 7.6-1 outlines the total cost per flight with cost breakdowns. At a payload of 200 pounds, the price per pound is almost two and a half times more expensive then initial market forecasts. There is an additional problem with the on-demand service. Some providers charge for a round trip which prevents the vehicle from being stranded across the ocean. This would only cause further cost issues.

◆ **Vehicle Depreciation** ***($490 mil over 2000 cycles)***	**$246,600**
◆ **Fuel Cost per Flight**	**$20,700**
◆ **Crew (1) cost per flight**	**$1,900**
◆ **Maintenance cost /flight**	**$14,200**
◆ **Insurance per flight**	**$2,800**
◆ **IOC (0.7 DOC)**	**$198,000**
Total	**$484,000**

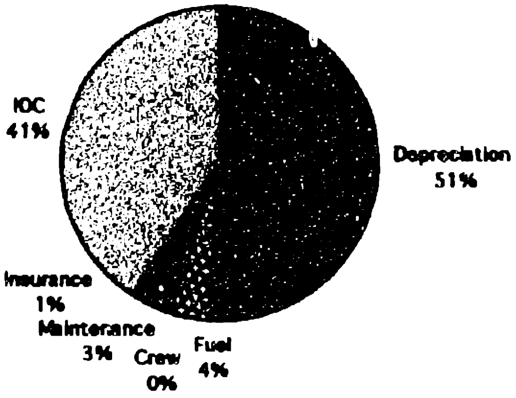

Figure 7.6-1, Cost Breakdown
Source, Martin Chan 1998 [11]

In order to bring down the flight costs, the vehicle cycle life must be increased and more vehicles must be produced. The current analysis was performed for a production run of fifty vehicles. In order to increase the production run, alternative applications of the vehicle must be found. One of the most promising applications of the proposed vehicle would be hypersonic research. For further information into the vehicle costs see Reference 11.

Chapter 8, Conclusion

The express package delivery market consists of two similar yet very different markets. These two markets, scheduled and on-demand service, both have the potential to implement a fast package delivery vehicle.

The scheduled service vehicle would provide eighteen hour delivery to the Far East from within the United States. This vehicle consists of a cargo version of the High Speed Civil Transport. Operators would provide their service for $11-$15 per pound.

A Mach 6 ramjet vehicle would be utilized to service the on-demand market. It would provide four hour door-to-door delivery from Los Angeles to Tokyo, Japan. Further research must be performed in the areas of materials, propulsion, and avionics before the Mach 6 vehicle could proceed to a more detailed design. Furthermore, a more in-depth market analysis would be required to validate the large startup costs associated with the vehicle. Last, in order to bring vehicle cost down, alternative applications for the proposed vehicle must be found.

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Curtis McNeal, NASA Future X

Appendix A, Fast Package Delivery Concepts and RLV Data

The following data was used to generate a statistical relationship between vehicle empty weight and vehicle take-off weight. This relationship was then used to calculate the estimated empty weight to take-off weight fraction proposed in the Mach 6 vehicle concept. Due to the lack of existing hypersonic vehicles, a combination of high speed aircraft, fast package delivery concepts, and reusable launch vehicles were used. All of these vehicles require similar amounts of energy in order to perform their missions.

Table A-1, Vehicle Weight Data

Vehicle	W_E	W_{TO}	W_E/W_{TO}
X-34	18000	48400	0.37
X-33	72250	289000	0.25
Boeing Concept #1	67500	350000	0.19
Boeing Concept #2	42500	350000	0.12
VentureStar	260000	2600000	0.10
SR-71	60000	170000	0.35
B-70A Valkyrie	190000	550000	0.35
Wave Rider	235000	917000	0.26

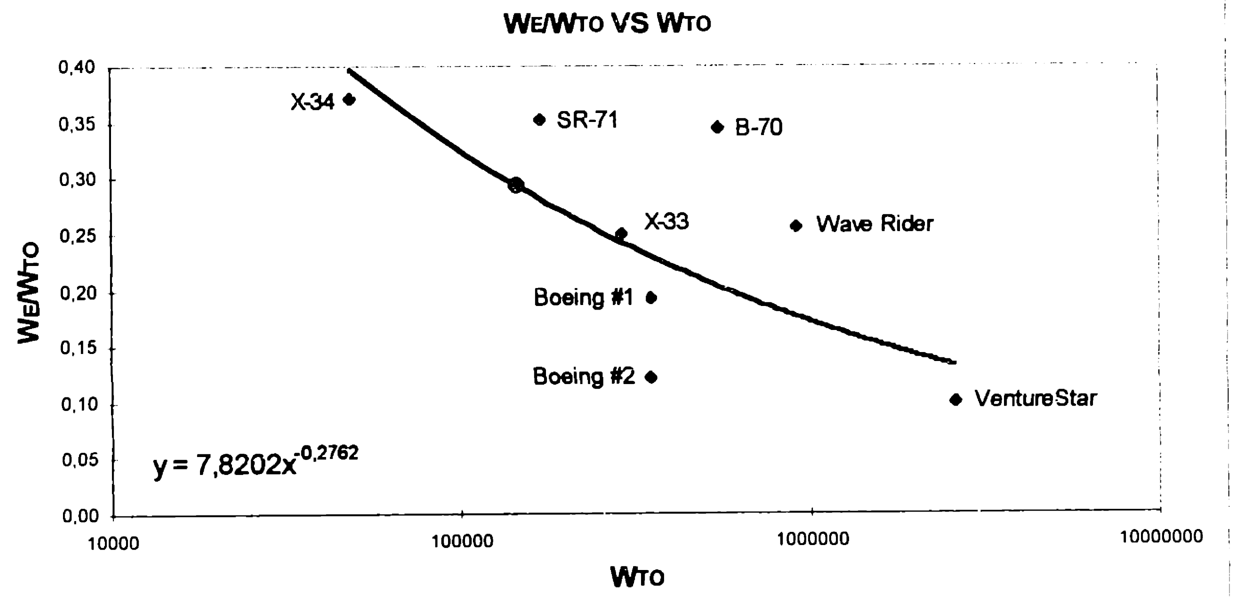

Figure A-1, Statistical Weight Trends For Fast Package and RLV Concepts

Appendix B, Take-Off Weight Sensitivity Analysis

The graphs below represent take-off weight trends for the proposed on-demand Mach 6 vehicle.

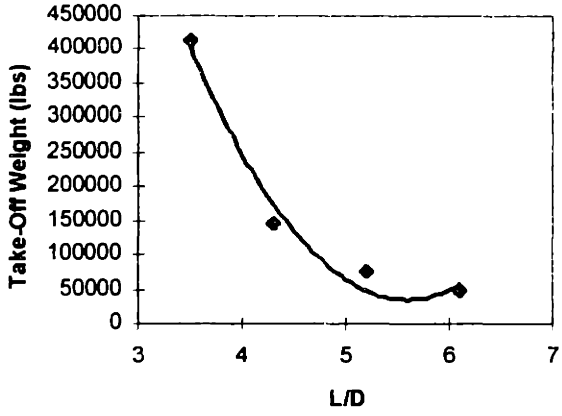

Figure B-1, Take-Off Weight Vs L/D

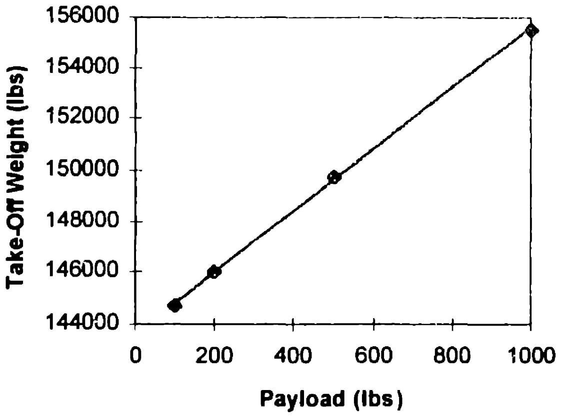

Figure B-2, Take-Off Weight Vs Payload

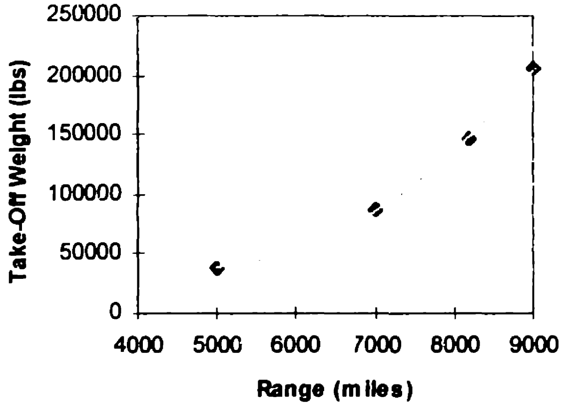

Figure B-3, Take-Off Weight Vs Range

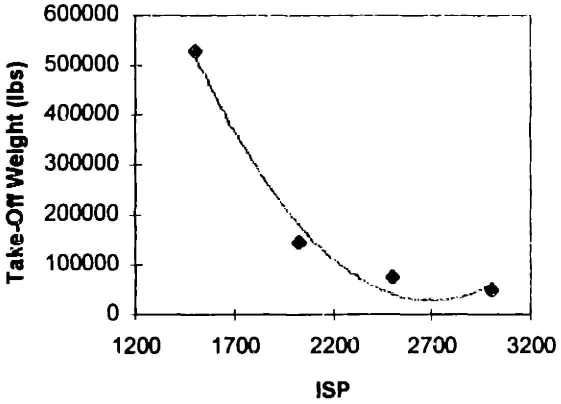

Figure B-4, Take-Off Weight Vs ISP

Appendix C, Mach 6 Design Point

The proposed Mach 6 ramjet vehicle has a wing loading of 55 pounds per square foot. The turbojet engines provide 52,000 pounds of thrust providing a thrust-to-weight ratio of 0.35 a take-off.

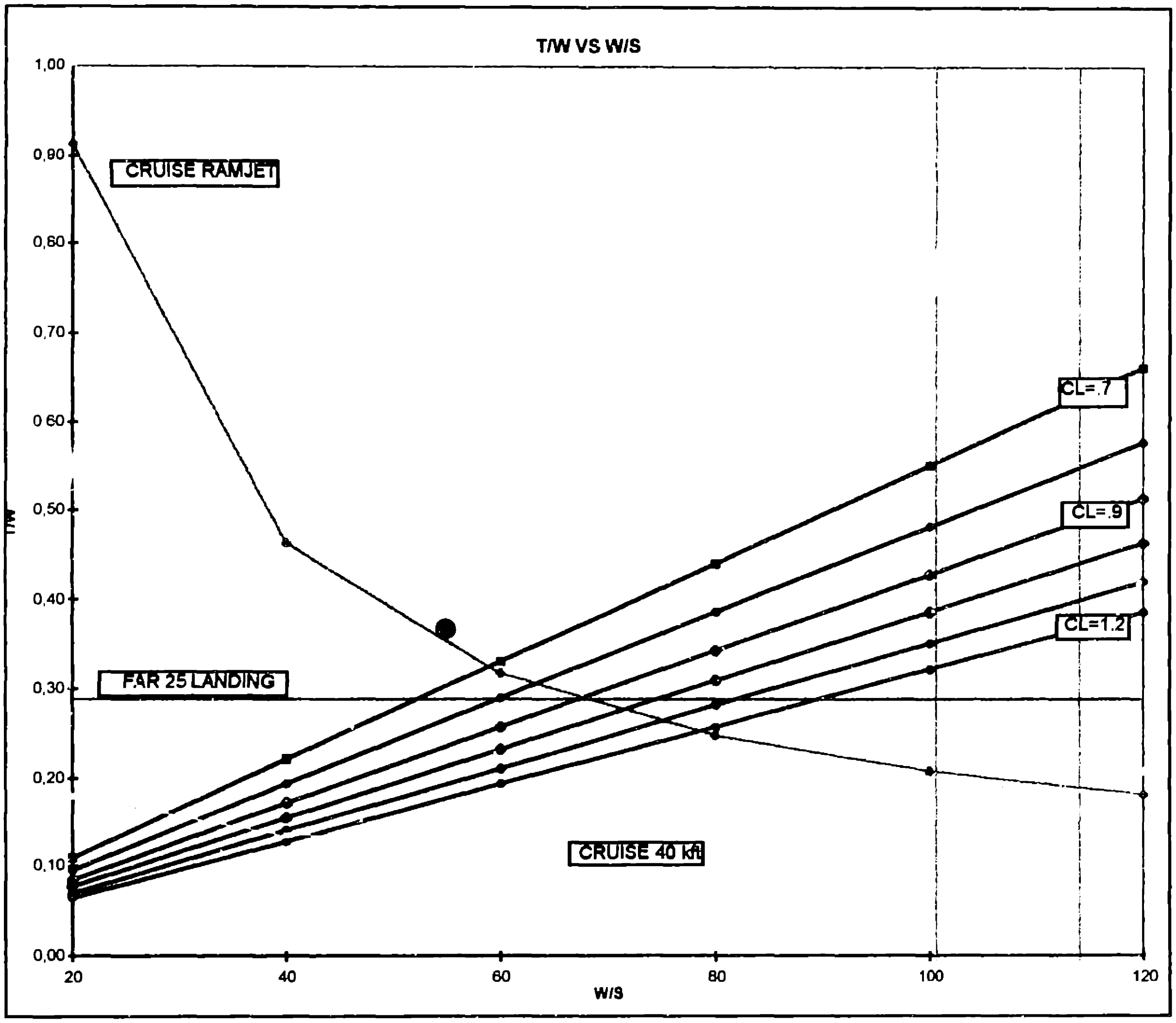

Figure C-1, Mach 6 Design Point

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