THE BIMESE CONCEPT: A STUDY OF MISSION AND ECONOMIC OPTIONS

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12.15.99

A FINAL REPORT SUBMITTED TO:
NASA LANGLEY RESEARCH CENTER
HAMPTON, VIRGINIA

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NOMENCLATURE

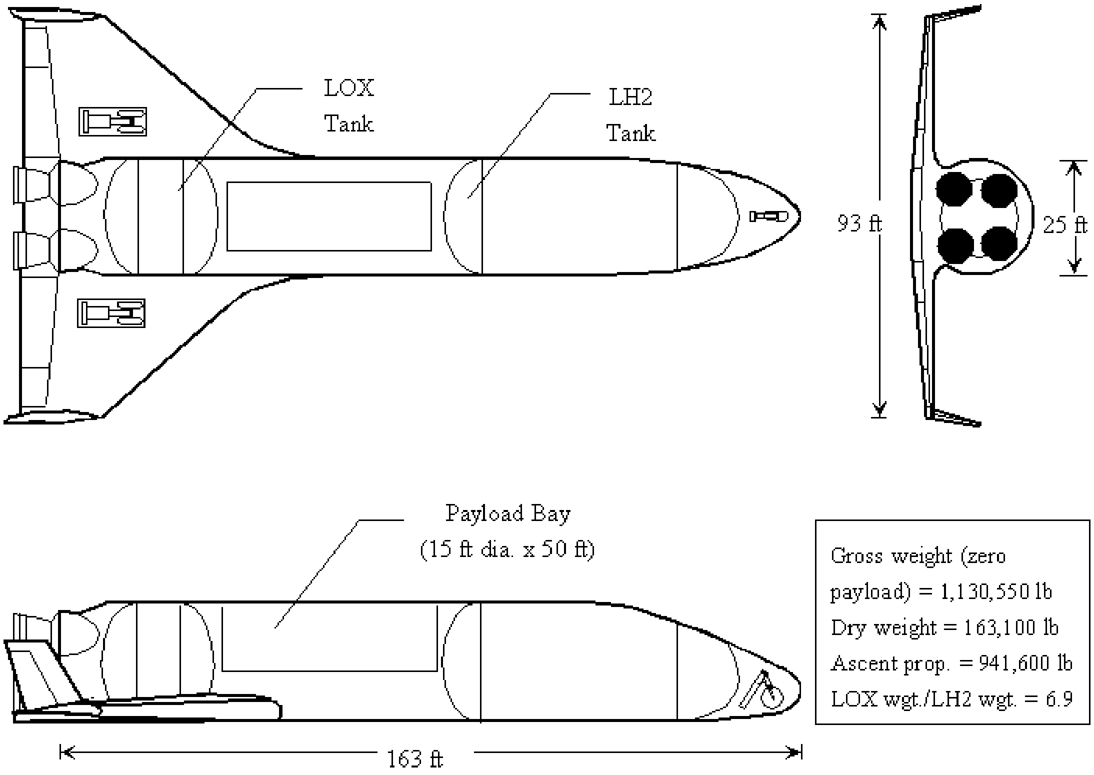
AATe	Architecture Assessment Tool enhanced
CABAM	Cost And Business Analysis Module
CSTS	Commercial Space Transportation Study
DDT&E	design, development, testing and evaluation
GEM	graphite epoxy motor
IRR	internal rate of return
KSC	Kennedy Space Center
LEO	low Earth orbit
LH2	liquid hydrogen
LOX	liquid oxygen
NASA	National Aeronautics and Space Administration
OMS	orbital maneuvering system
POST	Program to Optimize Simulated Trajectories
T/W	Thrust-to-weight
TFU	theoretical first unit
SRB	solid rocket booster
SRM	solid rocket motors

I. INTRODUCTION

The ideal NASA space transportation system of the future consists of a fleet of low cost vehicles that can provide a wide variety of payload options while leveraging future commercial launch markets. The Bimese concept, a NASA Langley design for a reusable Earth-to-orbit space transportation system, tries to fill this future by attempting to, "provide the broadest range of payload and mission capabilities with the minimum number of architectural developments (Talay)." Creating a vehicle that meets this requirement can minimize development costs because the same vehicle design (and hence the same development cost) can be used to support various missions. Such a transportation system can also result in a more efficient operational and manufacturing scenario by creating a learning curve effect on these processes. A vehicle that can perform various missions also has the advantage of early initial operating capability because it can be phased in over time with early missions consisting of the simplest configurations. These characteristics of the Bimese space transportation system make it a candidate for a future NASA supported launch vehicle. The intent of this paper is to analyze the performance and economics of the Bimese space transportation system in terms of trying to fulfill NASA's ideal future.

II. THE BIMESE LAUNCH VEHICLE

The Bimese is a conceptual design for a fully reusable wing-body launch vehicle. It is the vehicle that will be used as the base element for all architectural development in the Bimese space transportation system, hence the name. In Figure II.1 the Bimese is pictured in a three-view along with vehicle specifications. Although all of the given specifications are for a fully fueled vehicle with zero payload, not all configurations will use these parameters (e.g. in the case of ascent propellant off-load). Designed by NASA Langley Research Center it was sized to deliver 60 klb of payload launched from Kennedy Space Center (KSC) to a 100 nmi x 50 nmi at 28.5° inclination orbit in what is called the mated (Bimese) configuration (discussed in Section III.5).



Gross weight (zero payload) = 1,130,550 lb
Dry weight = 163,100 lb
Ascent prop. = 941,600 lb
LOX wgt./LH2 wgt. = 6.9

Figure II.1 – Bimese Three-view

With four conceptual liquid oxygen (LOX)/liquid hydrogen (LH2) engines the Bimese relies on the development of a new propulsion system with the parameters listed in Table II.1.

Table II.1 – Conceptual LOX/LH2 Engine Parameters

Sea level thrust (lb)	384,000
Vacuum I_{sp} (s)	443
Sea level T/W	74.6
Engine throttle	30%
Mixture ratio	6.9
Lifetime (flights)	250

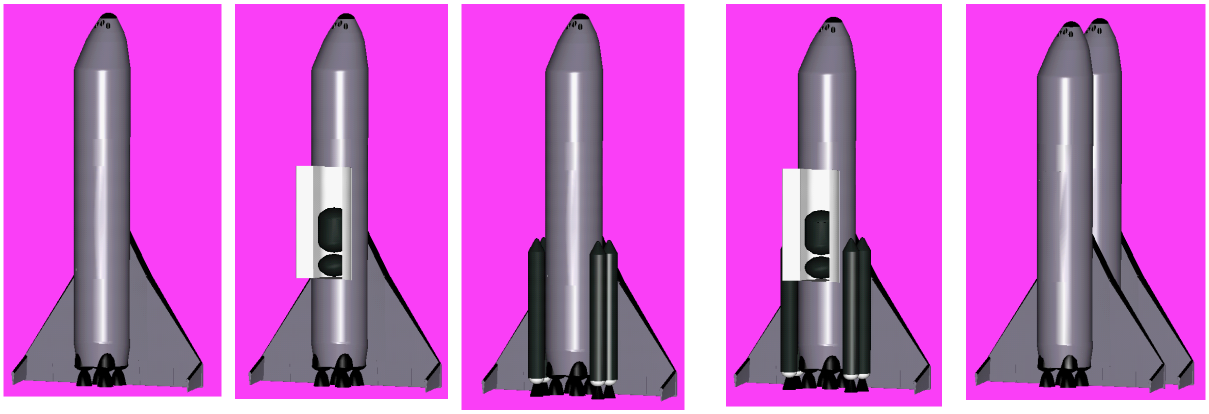
Other design parameters that are important for the analysis of the vehicle are listed in Table II.2.

Table II.2 – Design Constraints

Acceleration limit (g)	3
Maximum wing normal force (lb)	379,000
Maximum dynamic pressure (lb/ft^2)	1,000

III. MISSION AND PAYLOAD OPTIONS

The mission options of the Bimese transportation system will be analyzed in terms of trying to fill NASA and the commercial markets demand for a wide variety of payload capabilities with minimum architectural development. In this study there are five varieties of the Bimese element being explored: single element, fuel-augmented, thrust-augmented, fuel/thrust-augmented, and the mated (Bimese) configurations. These five varieties are shown in Figure III.1. Other variants that exist, but are not being investigated, are the heavy lift concepts that are characterized by the addition of a large second or third expendable stage to any of the previous configurations. Quantifying the performance of each configuration will be done in terms of two parameters: point-to-point range capability for 1 klb to 28.5° latitude; and low Earth orbit (LEO) payload delivered to a 100 nmi x 50 nmi at 28.5° inclination orbit. For the LEO case there is enough orbital maneuvering system (OMS) propellant on the Bimese to circularize to 100 nmi x 100 nmi at 28.5° inclination orbit.



Single element Fuel-augmented Thrust-augmented Thrust/fuel-augmented Mated (Bimese)

Figure III.1 – Bimese Space Transportation System Mission Options

For these missions all of the trajectory analysis is done using three degree-of-freedom Program to Optimize Simulated Trajectories (POST). For the LEO missions POST is used to optimize the controls for maximum burnout weight. For point-to-point missions POST simulates a ballistic boost-glide trajectory, while optimizing alpha (limited to 40 degrees) for maximum range. For fuel and thrust augmentation new component weights are analyzed using mass estimating relationships. More on the specifics of the vehicle trajectory and component weights will be introduced as each configuration is studied.

III.1. SINGLE ELEMENT BIMESE

The single element configuration consists of the Bimese flown without any other components.

III.1.1. Single Element Bimese: LEO

It is determined that the single element configuration cannot make it to LEO before burning out of ascent propellant. In the simulation the single Bimese must use about 40,000 lb of non-propellant mass to make it to orbit.

III.1.2. Single Element Bimese: Point-to-Point

For the single element point-to-point configuration 6,200 lb of propellant is off-loaded which corresponds to the OMS fuel needed to circularize and de-orbit. The single element point-to-point simulation shows that the Bimese can transport 1 klb of payload to 28.5° latitude with a range of 3,900 nmi. A ground track of the trajectory is shown in Figure III.2. Also shown in this figure are the approximate landing locations for launches in all directions and the single element ranges loaded with 60 klb of payload. The figure depicts that the added payload weight reduces the range by about 30% and launching in a westerly direction (as compared to an easterly one) reduces the range by approximately 30%.

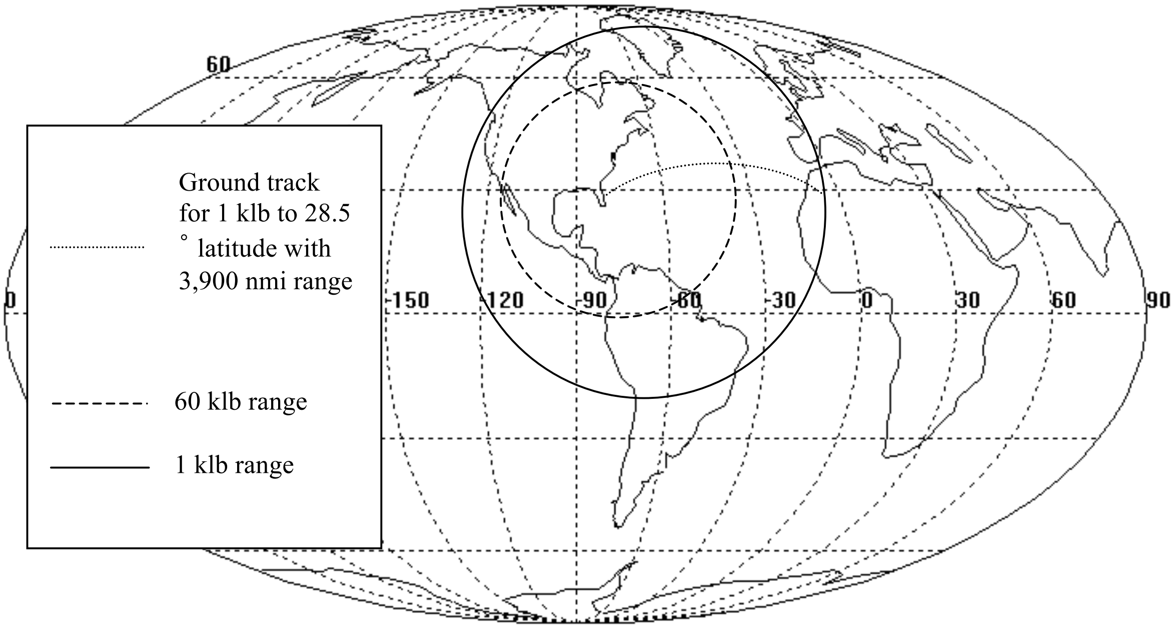


Figure III.2 – Ranging and Ground Track for Single Element Bimese

Five plots of the reference point-to-point trajectory are seen in Figure III.3a through III.3e. The plots show, in order, a time history of the vehicle's altitude, range, angle of attack, acceleration, and velocity. Figure III.3a shows that the trajectory stops at an altitude of 50,000 ft; once the vehicle has reached this altitude and a Mach number of about 1 the trajectory is assumed to be an automated loiter and landing phase that is not simulated. Another feature of this plot is the skipping trajectory; by skipping across the upper atmosphere the vehicle can obtain maximum range. As can be seen from the range plot most of the ranging is done during this skipping phase. Unfortunately this skipping also corresponds to high aerodynamic heating. Also note that the vehicle travels 3,900 nmi in 37 minutes, which gives an average speed of 8,000 miles per hour. This high average flight speed is important for applications of the point-to-point trajectories and will be discussed in more detail later.

III.1.3 Single Element Bimese Conclusions

The single element Bimese has no LEO capability, but it does have a decent point-to-point range. This ballistic trajectory would be excellent for testing a Bimese prototype, putting it through a lot of the extremes an orbital vehicle would encounter. The moderate range will also allow it to be used for the point-to-point mission analyzed in Section IV.

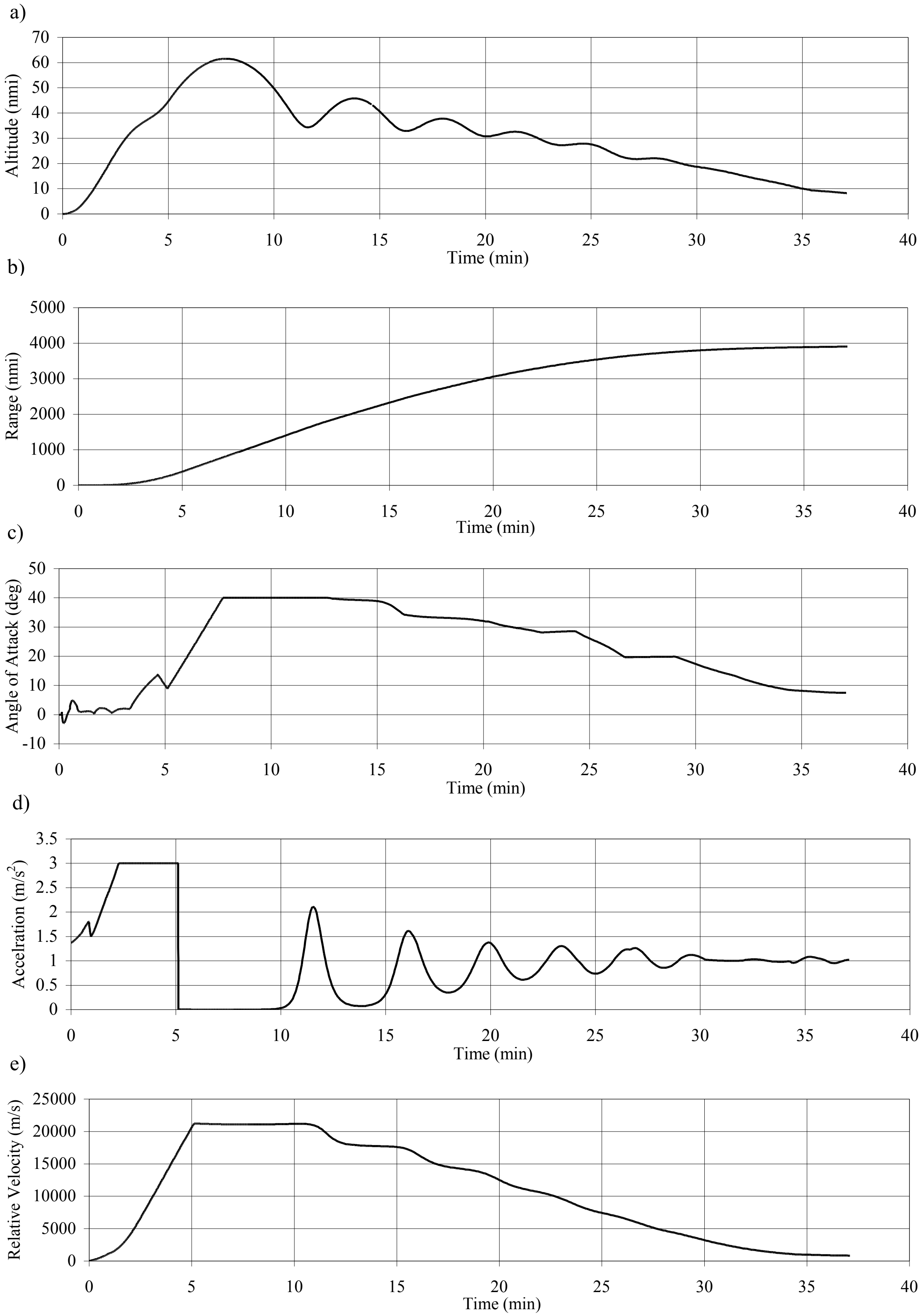


Figure III.3a-e – Time History Plots for Single Element Bimese Point-to-Point

III.2. FUEL-AUGMENTED BIMESE

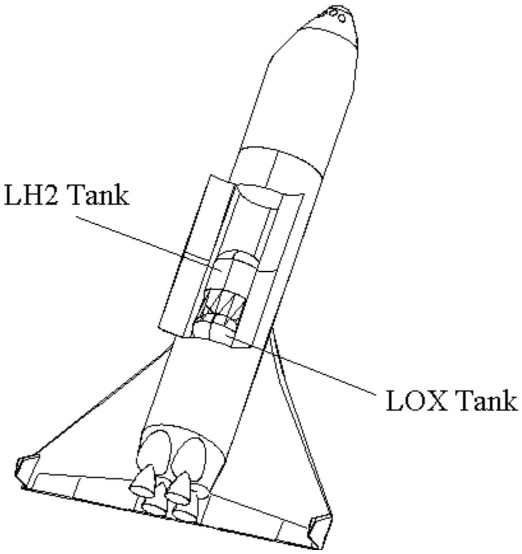
The fuel-augmented Bimese configuration consists of a single element with an extra LOX and LH2 tank in its payload bay. The payload bay is a cylinder, 50 ft long with a 15 ft diameter. If it is fully loaded with propellant it could hold about 200,000 lb of fuel. The choice of how much fuel to actually put in the bay is deferred to some analysis.

III.2.1. Fuel-Augmented Bimese: LEO

The LEO mission for the fuel-augmented Bimese cannot get any payload to orbit. Although the increased fuel add velocity increment capability, the fact that no additional thrust is added causes the overall thrust-to-weight (T/W) to decrease as propellant is added. Even assuming that a T/W of 1.05 is adequate for a margin the fuel-augmented Bimese must burn about 20,000 lb of non-propellant mass to get to orbit.

III.2.2. Fuel-Augmented Bimese: Point-to-Point

Simulation of point-to-point fuel-augmented trajectories show that even a payload bay stuffed full of fuel only increases the point-to-point range by about 400 nmi. Combine this with the fact that for minimum architectural developments, the same payload tanks will be used for the fuel/thrust-augmented vehicle (which is expected to have a capability of about 20,000 lb to LEO) leads to the choice of filling three-fifths of the payload bay with tanks. This leaves room for about 20,000 lb of payload and adds 200 nmi in range to the fuel-augmented point-to-point trajectory. A line drawing of the fuel-augmented Bimese along with payload tank specifications is shown in Figure III.4. The fuel-augmented point-to-point range for 1 klb to 28.5° latitude is 4,100 nmi, no plots will be shown for this because they are very similar to the single element plots.



Payload Tank Parameters	
LOX fuel (lb)	87,300
LOX tank weight (lb)	590
LH2 fuel (lb)	12,600
LH2 tank weight (lb)	890
Structure/feeds (lb)	1,000
Total weight (lb)	104,480
Length of Apparatus (ft)	30

Figure III.4 – Fuel-Augmented Bimese with Payload Tank Parameters

III.2.3. Fuel-Augmented Bimese Conclusions

The fuel-augmented Bimese offers little advantage over the single element Bimese, it too has no LEO capability and the point-to-point range is only increased by a few hundred nautical miles. In addition it has the operational disadvantage of having to install, fill, and purge during ascent the payload bay tanks.

III.3. THRUST-AUGMENTED BIMESE

The thrust-augmented Bimese configuration consists of a single element with Solid Rocket Motors (SRMs) strapped to the side of the Bimese. A new motor will need to be designed to fill this piece of the transportation system. Keeping the design realistic the new motor is modeled as a derivative of the Graphite Epoxy Motor (GEM), which is currently used on the Delta II 7925. The GEM is chosen because of its good performance and lightweight structure, which are shown in Table III.1.

Table III.1 – GEM Performance and Design Parameters

Propellant mass (klb)	25.8
Gross mass (klb)	28.6
Sea level thrust (klb)	99
Sea level I_{sp} (s)	265
Burn time (s)	63.0
Expansion ratio	10.7
Overall length (ft)	42
Core diameter (ft)	3

Scaling the GEM involves the use of simple scaling equations. To increase the burn time of the GEM more propellant is added, while the dry weight is scaled linearly with the fuel weight (dry weight is calculated to be ~10% of the propellant weight). Linearly increasing the nozzle exit area and fuel flow rate while keeping a constant expansion ratio scales thrust. Specific impulse remains a constant for all of the scaling.

A few changes are made to the single element trajectory for the simulations with SRMs. First a 10% drag rise is included while the motors are attached to capture some of the aerodynamic effects of the SRMs. Also because the SRMs provide added T/W the Bimese accelerates much faster resulting in violation of the dynamic pressure constraint listed in Table II.2. To alleviate this problem the main engines are throttled to a constant value while the SRMs are thrusting; this throttle value is optimized within the trajectory simulation.

III.3.1. Thrust-Augmented Bimese: LEO

With thrust augmentation the Bimese can finally make it to orbit. In order to investigate the ability of the thrust-augmented Bimese to ferry payload to LEO a design of experiment is performed. Both SRM burn time and total SRM sea level thrust are varied and LEO payload is observed. Based on initial simulation experimental ranges of 75 to 125 s for burn time and 1,500 to 2,000 klb for total SRM sea level thrust are chosen. The lower limits are set by zero payload capability. The upper limits are set by throttle limit violation when trying to meet the dynamic pressure constraint. Table III.2 shows the results of the design of experiment (a negative payload indicates the vehicle cannot make it to orbit).

Table III.2 – Experimental Design for thrust-augmented Bimese

SRM burn time (s)	Total SRM Sea Level Thrust (klb)	Payload to LEO (lb)
75	1,500	-7,896
100	1,500	-1,727
125	1,500	1,123
75	1,750	-1,553
100	1,750	5,742
125	1,750	8,712
75	2,000	3,651
100	2,000	11,939
125	2,000	17,077

A response surface with a mean square of 0.999 is generated and plotted in Figure III.5.

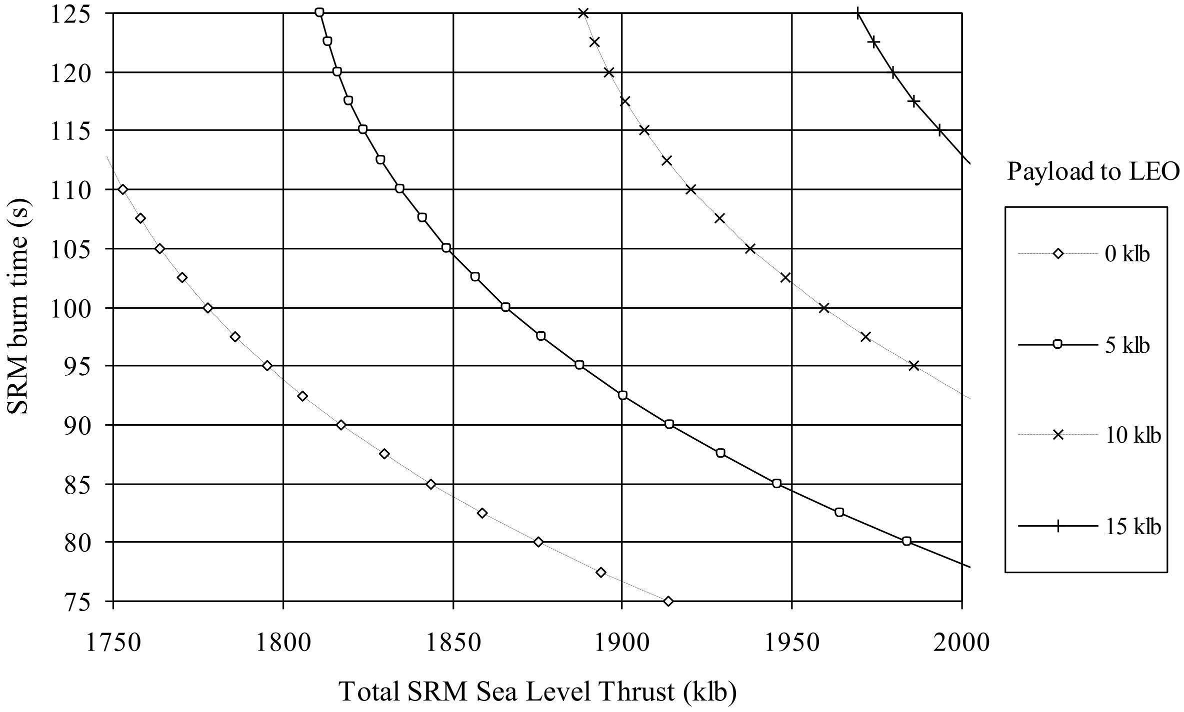


Figure III.5 – LEO Payload to Orbit for Thrust-Augmented Bimese

This figure illustrates that the thrust-augmented Bimese can get anywhere between 1 and 20 klb to LEO. It also shows that many SRM designs can fill a single payload requirement to LEO. To determine which SRM design is best (in terms of weight) for each payload capability a plot of SRM gross weight for the 5 and 10 klb payload thrust-augmented Bimese is introduced in Figure III.6.

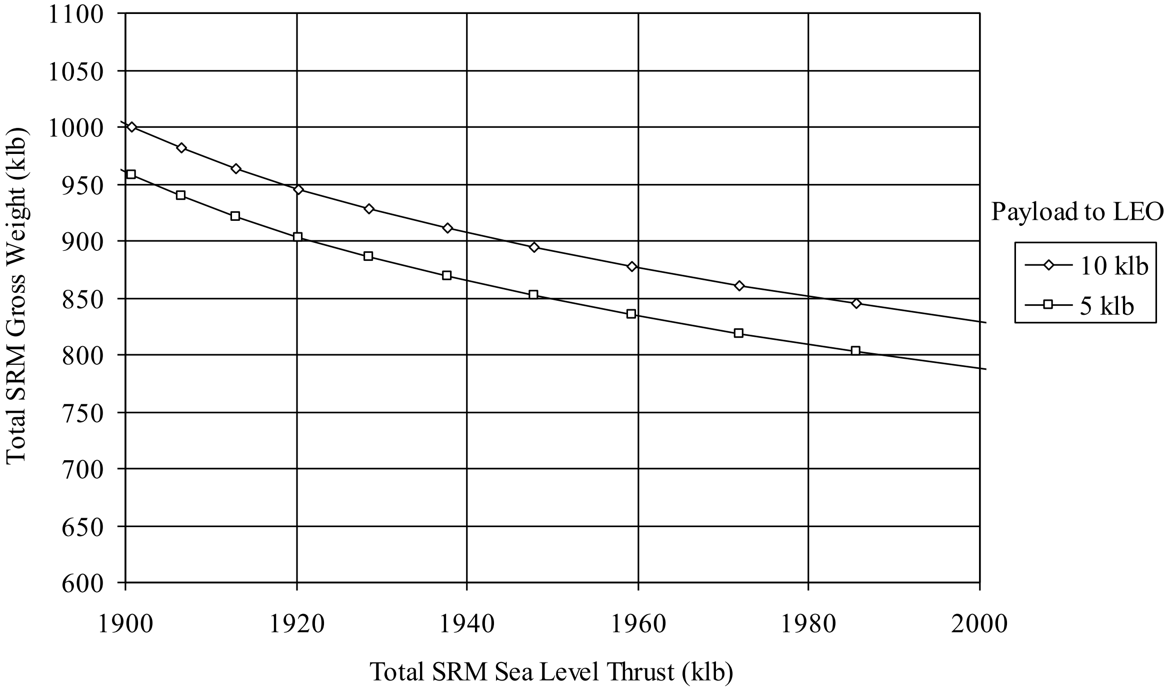
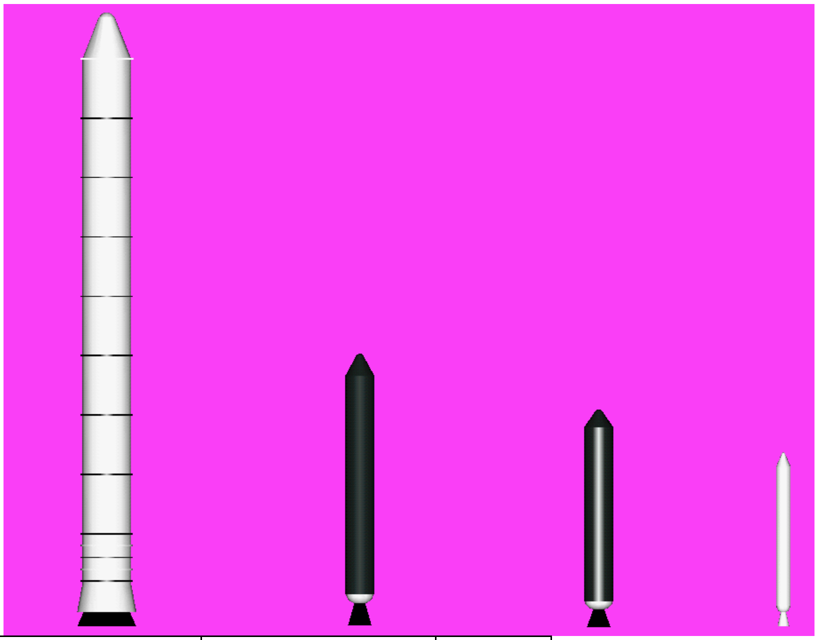


Figure III.6 – SRM Gross Weight Change for Constant Payload to LEO

For a constant payload the minimum weight occurs with maximum allowable thrust, therefore the maximum thrust value that is within the ranges of the experimental design will be used for thrust augmentation.

Choosing the number of SRMs for the 5 and 10 klb cases to be 4, the two GEM derivatives in Figure III.7 are obtained. The figure also compares the Bimese GEMs with the Shuttle SRB and the GEM.



SRM name	Shuttle SRB	GEM-10	GEM-5	GEM
Vehicle use	Two on the Space Shuttle	Four on 10 klb to LEO thrust-augmented Bimese	Four on 5 klb to LEO thrust-augmented Bimese	Nine on Delta 7925
Propellant mass (klb)	1,107	190	155	25.8
Gross mass (klb)	1,300	210	175	28.6
Sea level thrust (klb)	2,650	500	500	98.9
Sea level I_{sp}	267	274	274	274
Burn time (s)	124	92.8	78.2	63.0
Expansion ratio	7.5	10.7	10.7	10.7
Overall length (ft)	150	60	50	43
Core diameter (ft)	12	6	6	3

Figure III.7 – SRM Size and Performance Comparison Chart

The Bimese with four GEM-10s, seen in Figure III.8, will be used as the reference thrust-augmented Bimese.

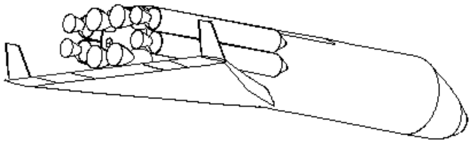


Figure III.8 – Thrust-Augmented Bimese with four GEM-10s

To obtain the actual payload instead of the regressed payload the trajectory is simulated again using four GEM-10s with the parameters in Figure III.7. The thrust-augmented Bimese can insert 9,740 lb of payload into LEO.

Altitude, throttle setting, dynamic pressure, and acceleration of the simulated ascent trajectory are seen in Figures III.9a through d. In Figure III.9b notice the throttle setting for the main engines is set to a constant value at twenty seconds up until the solids are dropped. Also notice in Figure III.9d the high liftoff T/W of about 1.75; this is what causes the dynamic pressure violation and the need for throttling.

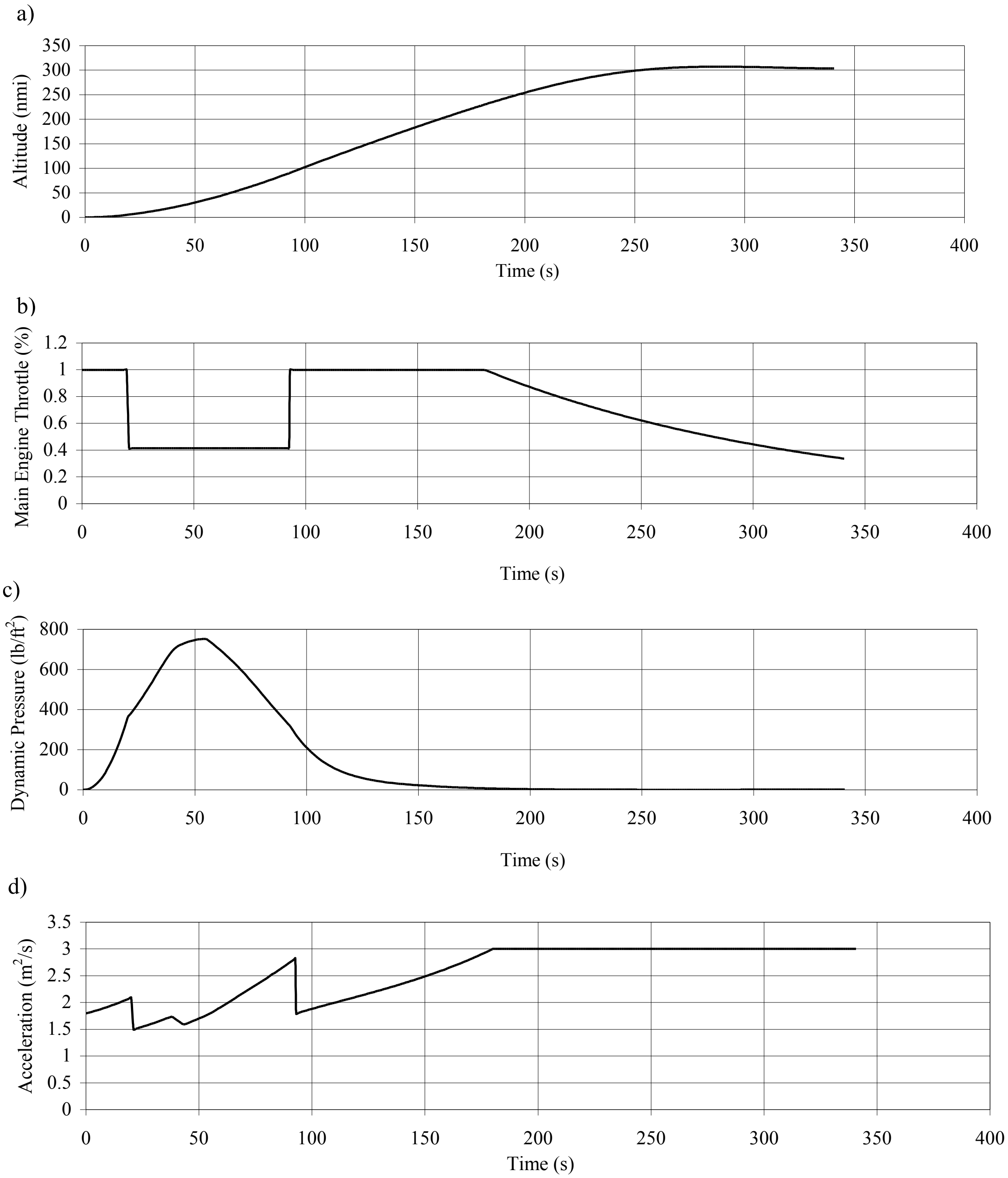


Figure III.9a-d – Time History Plots for Thrust-Augmented Bimese with Four GEM-10s

III.3.2. Thrust-Augmented Bimese: Point-to-Point

The thrust-augmented Bimese with 4 GEM-10s cannot fly a ballistic point-to-point trajectory while meeting all of the constraints listed in Table III.2. Therefore the trajectory is simulated with 2 GEM-10s. For the point-to-point configuration 6,200 lb of propellant is off-loaded which corresponds to the OMS fuel needed to circularize and de-orbit. The single element point-to-point simulation shows that the thrust-augmented Bimese can transport 1 klb of payload to 28.5° latitude with a range of 6,050 nmi. A ground track of the trajectory is shown in Figure III.10. Also shown in this figure are the approximate landing locations for launches in all directions. The same graphic has range capabilities for the thrust-augmented Bimese with 60 klb of payload. One can see that the added payload weight reduces the range to a point where it is similar to the range of the 1 klb single element Bimese point-to-point range.

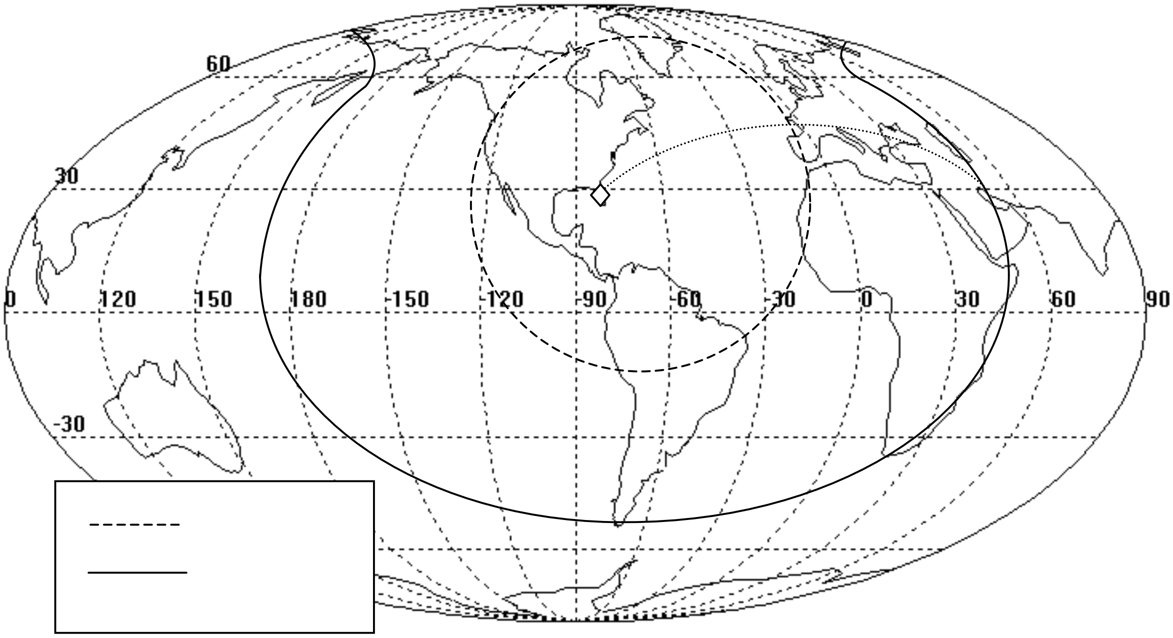


Figure III.10 – Ranging and Ground Track for Thrust-Augmented Bimese

Four plots of the point-to-point trajectory are seen in Figure III.3a through III.3e. The plots show in order a time history of the vehicles altitude, acceleration, angle of attack, and velocity profile. Another feature of the trajectory is the extreme altitude (80 km) to which the vehicle ascends. The trajectory takes about 45 minutes. There are abrupt peaks in the velocity profile (Figure II.11d) which would indicate severe heating loads. Because the vehicle appears to be at the limit (or perhaps even beyond in the case of aeroheating) of its ballistic capability, no more configurations will be used for the point-to-point simulations.

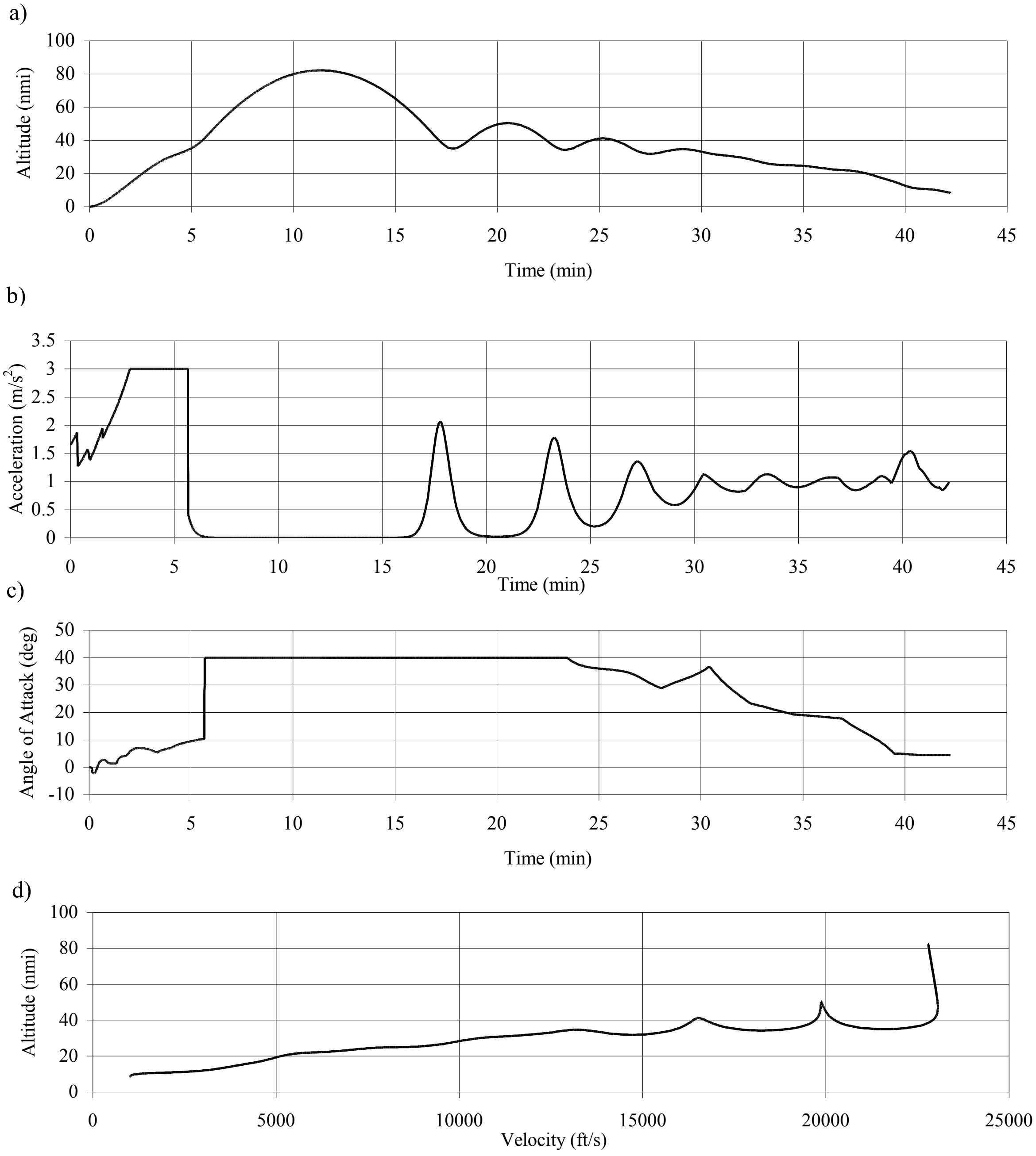


Figure III.11 – Ranging and Ground Track for Thrust-Augmented Bimese

III.3.3. Thrust-Augmented Bimese Conclusions

The thrust-augmented Bimese is a success both in terms of LEO payload and point-to-point range. Delivering 10,000 lb to LEO has been proven commercially viable and NASA can use this payload capability for some of its smaller missions. The point-to-point ability has significant range with the ability to thrust to such places as western Europe and the tip of South America from KSC. Its drawback is the requirement of the use of large solids that will need to be purchased and integrated for every flight.

III.4. FUEL/THRUST-AUGMENTED BIMESE

The fuel/thrust-augmented Bimese configuration consists of a single element with fuel tanks in the payload bay and SRMs strapped to the side. The same designs for the fuel-augmented Bimese's payload tanks and thrust-augmented Bimese's SRMs are used on this vehicle.

III.4.1. Fuel/Thrust-Augmented Bimese: LEO

Similar to the thrust-augmented Bimese a design of experiment is performed on the thrust/fuel-augmented Bimese to test its LEO capability. The same range of 75 to 125 s for burn time and 1,500 to 2,000 klb for total SRM sea level thrust are chosen. Table III.3 shows the results of the design of experiment (a negative payload indicates the vehicle cannot make it to orbit).

Table III.3 – Experimental Design for Fuel/Thrust-Augmented Bimese

SRM burn time (s)	Total SRM Sea Level Thrust (klb)	Payload to LEO (lb)
75	1,500	-1,751
100	1,500	4,507
125	1,500	7,774
75	1,750	3,562
100	1,750	10,179
125	2,000	15,566
75	2,000	9,960
100	2,000	19,672
125	2,000	22,323

A response surface with a mean square of 0.985 is generated and plotted in Figure III.12.

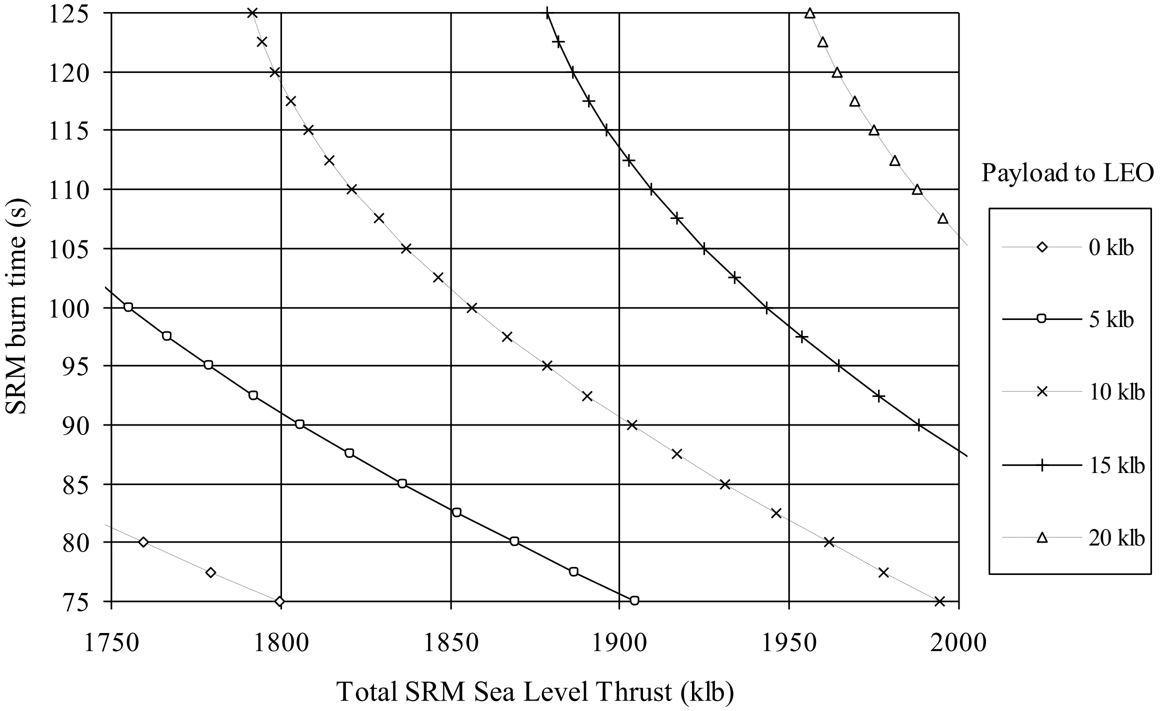


Figure III.12 – LEO Payload to Orbit for Fuel/Thrust-Augmented Bimese

This figure illustrates that the fuel/thrust-augmented Bimese can get anywhere between 1 and 25 klb to LEO. For similar sized SRMs it can deliver about five thousand more pounds of payload over the thrust-augmented Bimese. Like the thrust-augmented Bimese the reference design will use 4 GEM-10s. Simulating the trajectory again with these SRMs gives a payload of 15,900 lb. A picture of this architectural development is shown in Figure III.13.

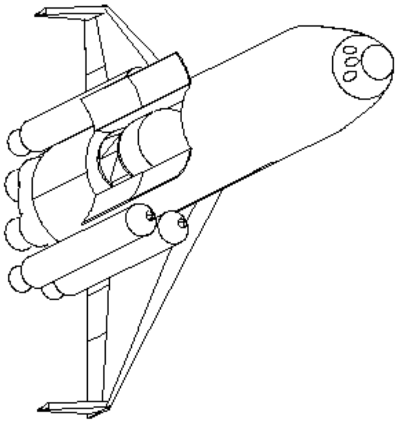


Figure III.13 – Fuel/Thrust-Augmented Bimese

Although there are tanks in the payload bay there is still a 20 ft long 15 ft diameter space in the bay, which is enough room for the reference payload. Time history plots of the ascent trajectory are not shown because they are very similar to the thrust-augmented Bimese plots.

III.4.2. Fuel/Thrust-Augmented Bimese Conclusions

Fuel augmentation increases the payload of thrust augmentation by about 5,000 lb, which is decent considering the only added costs are fuel tanks, operational complexity, and fitting the Bimese with proper payload feed lines. Similar to the thrust-augmented Bimese the fuel/thrust-augmented Bimese is able to deliver payload that for both commercial and government customers have been proven profitable.

III.5. MATED BIMESE

The mated Bimese configuration consists of two single elements attached to each other. Pictured in Figure III.14 the mated Bimese has the following characteristics: propellant cross-feed, un-powered fly back, and commonality between booster and orbiter.

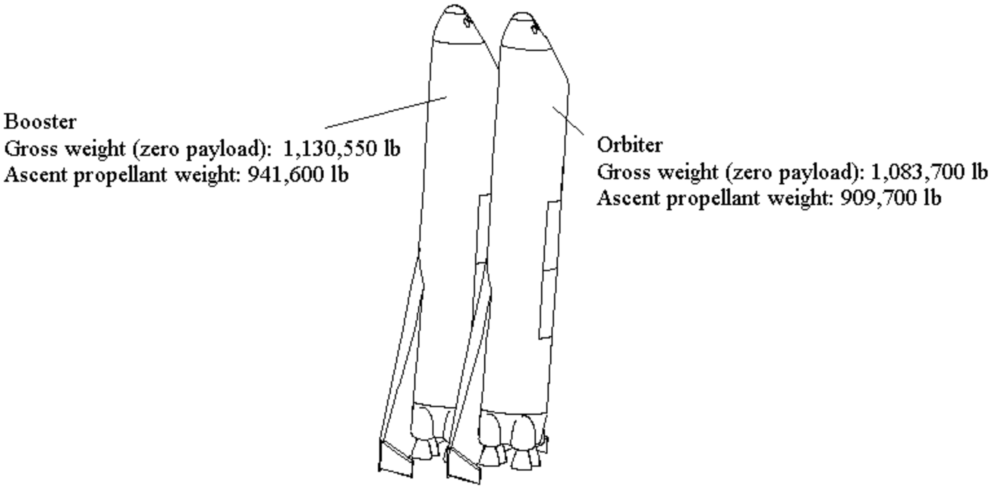


Figure III.14 – Mated Bimese

III.5.1. Mated Bimese: LEO

The Bimese was designed so that the mated configuration could lift 60 klb to LEO. Upon launch fuel is cross-fed from the booster Bimese to the orbiter Bimese, while all eight engines are ignited. The booster stages at Mach 3.2 (propellant must be off-loaded to do this) and then performs a hypersonic turn and glides back to the launch site. From here the orbiter ascends to orbit, with the benefit of a Mach 3.2 boost. Plots of the ascent trajectory are seen in Figure III.15a-c.

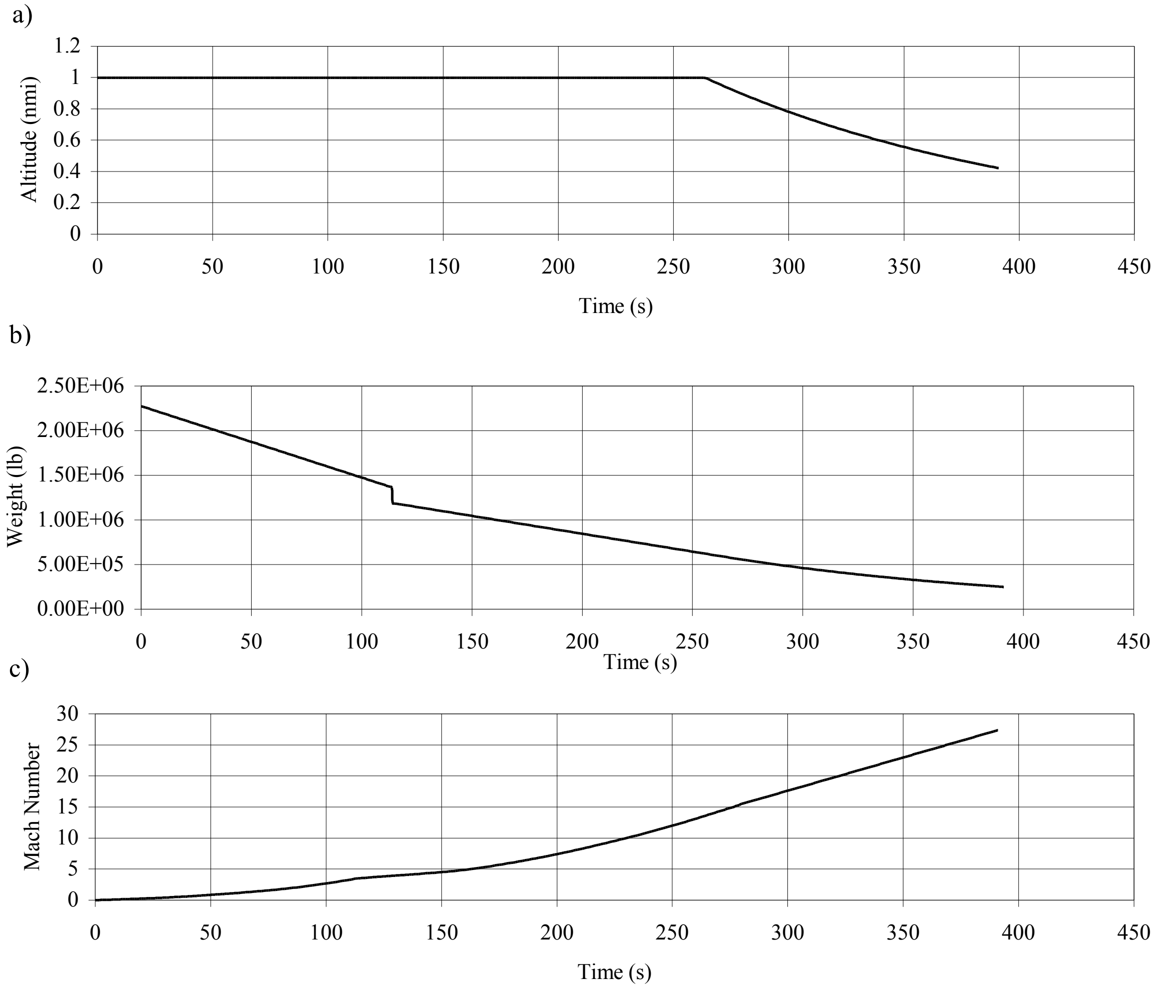


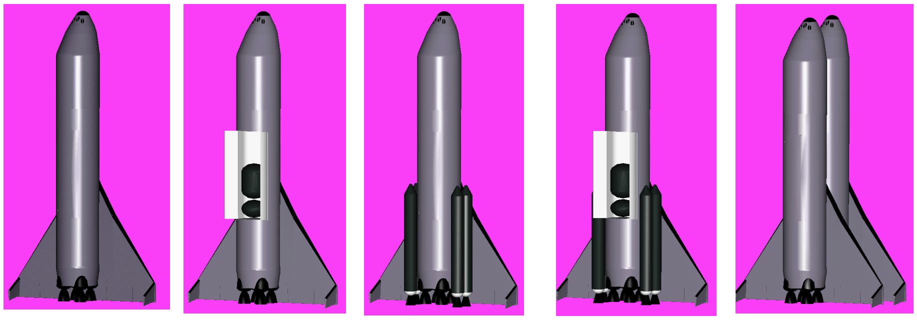
Figure III.15a-c – Time History Plots for Fuel/Thrust-Augmented to LEO

III.5.2. Mated Bimese Conclusions

The large payload capability of the mated Bimese makes it a candidate for NASA missions to the space station or large telescope deployment. Commercially the market for this size payload is unproven, but it is possible it could be used for multiple manifesting or geo-st.

III.6. SUMMARY OF MISSION OPTIONS

A fleet of vehicles has now been established that can deliver a wide range of payloads both to orbit and to another point. Except for the fuel-augmented Bimese each of the vehicle seems to have a niche where it could be used to enter the commercial or government launch market. The vehicles are shown in Figure III.16 along with the capabilities.



Mission	Single element	Fuel-augmented	Thrust-augmented		Thrust/fuel-augmented	Mated (Bimese)
			# GEM-10s			
			2	4		
LEO Capability (lb)**	0	0	0	9,750	15,900	60,000
Point-to-point capability (nmi)*	3,900	4,100	6,050	0	0	0

** Point-to-point range capability for 1 klb to 28.5° latitude*

*** LEO payload delivered to a 100 nmi x 50 nmi at 28.5° inclination*

Figure III.16 – Bimese Payload and Mission Options Summary

IV. ECONOMIC OPTIONS

The economic options of the Bimese transportation system will be analyzed in terms of trying to leverage future commercial launch markets. In this study the commercial markets that are looked at are the markets corresponding to the mission studies: point-to-point fast package delivery and LEO payload delivery. The success of these markets will be quantified in terms of Internal Rate of Return (IRR) of a startup company operating in these markets. Other markets that the Bimese could be used for are manned missions and geo-stationary payload delivery, but these are not investigated because no mission options were designed specifically for these capabilities.

All of the economic analysis will assume the creation of a startup company named Bimese, Inc. This company begins to develop the Bimese launch vehicle with government help in 2007; the entire Bimese program ends in 2037. The transportation system created is one full generation ahead of the Shuttle Transportation System in terms of the technologies utilized. Production and operations learning curves of 85% will be employed. All of the cost and business analysis is forecasted using Cost And Business Analysis Module (CABAM) and all of the operations modeling is performed using Architecture Assessment Tool-enhanced (AATe) v1.0. Monetary units will be given in terms of 1998 United States dollars.

IV.1. COST AND OPERATIONS ANALYSIS

The cost and operations of the Bimese launch vehicle is measured in terms of DDT&E (design, development, testing, and evaluation), theoretical first unit (TFU), facility, labor, line replacement unit, propellant, integration, and insurance costs along with turnaround time. Before any business analysis is done each of these parameters will be discussed for the Bimese.

The TFU and DDT&E for the Bimese launch vehicle were estimated using NASA Air Force cost model equations stored in CABAM. The results obtained for the Bimese airframe and engine are listed in Table IV.1. The engines are assumed to have a lifetime of 250 flights and the airframe has a life of 1,000 flights. For all business cases it will be assumed that at the very least the government pays for 20% of the airframe DDT&E and 100% of the engine DDT&E. For the mission option with payload tanks, the tanks are assumed to be reusable, and the DDT&E and TFU for these tanks are also listed in Table IV.1.

Table IV.1 – Bimese Launch Vehicle Costs

	DDT&E (M$)	TFU (M$)
Airframe	$6,950	$1,431
Main engine	$450	$109
Payload tanks	$95	$20

It is assumed that a separate company makes the GEM-10s and charges Bimese Inc. a fixed price for the motors. The GEM on the Delta has a fixed price of $1.2M, therefore the GEM-10, which is scaled by a factor of about five in terms of mass and thrust, will be assumed to cost $2M.

Using AATe the turnaround times are estimated and listed in Table IV.2. There is a slight increase in turnaround, as the integration becomes more complex. It is assumed for the mated Bimese that the preparations before launch and after landing can be done on the two elements simultaneously. Also it is assumed for the LEO missions the vehicle spends little time in orbit, it delivers its payload and quickly returns to Earth.

Table IV.2. – Turnaround Times for Five Missions

Architectural Configuration	Turn around time (days)	Yearly flight rate
Single element	12	31
Thrust-augmented	13	28
Fuel-augmented	13	28
Thrust/fuel-augmented	14	26
Mated	16	23

The non-recurring facilities cost is paid for by a local or national government investing in a spaceport for possible economic benefits to a region. From this spaceport Bimese, Inc. is assumed to account for 15% of the total flights.

Labor, line replacement unit, GEM-10, propellant, integration, and insurance costs sum up to total recurring costs. Figure IV.1 shows the relative magnitude of these costs with respect to the five configurations, along with the effect of learning curves as the flight rate increases.

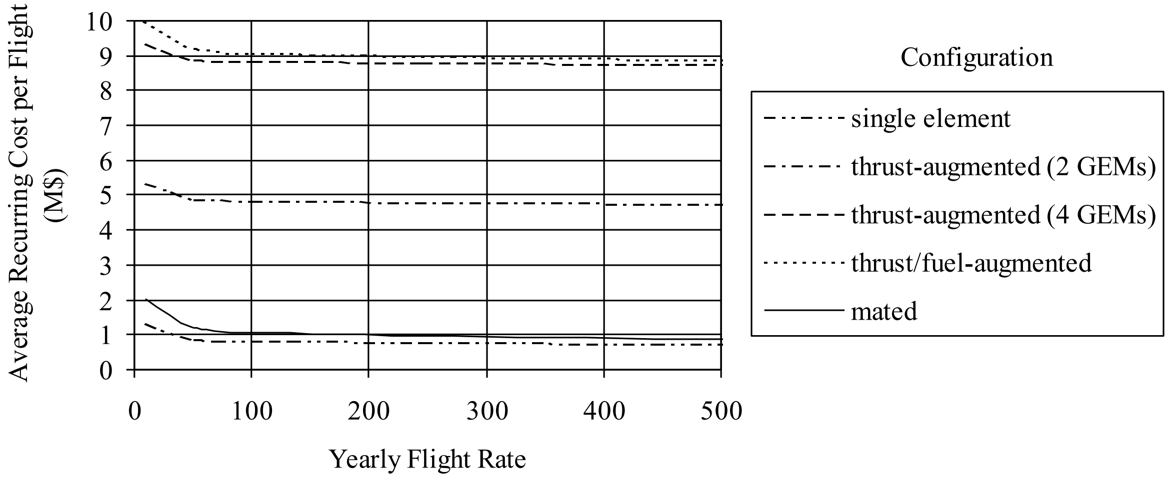


Figure IV.1 – Average Recurring Costs for Multiple Configurations

The major effect on the recurring cost is the GEM-10s at $2M each. Even though the mated Bimese can accommodate the most payload it is a factor of ten less than the fuel/thrust-augmented Bimese in terms of recurring cost. This would seem to eliminate the need for the thrust and fuel/thrust-augmented Bimese, but one needs to take into account the larger fleet size needed to accommodate the mated Bimese flights. This effect is not represented in the recurring cost, but instead in the fleet acquisition cost which will be discussed in the business analysis section.

IV.2. POINT-TO-POINT BUSINESS ANALYSIS

Using the assumptions from Section IV.1 a business called Bimese, Inc. is setup to operate as a commercial package delivery company. Bimese Inc. will provide a fast package delivery service with options of using the single element Bimese and the thrust-augmented Bimese with two GEM-10s as the cargo carrying vehicles. Recall from Figure III.16 the ranges for these two Bimese derived launch vehicles are 3,900 nmi for the single element and 6,050 nmi for the thrust-augmented.

IV.2.1. Point-to-Point Market

The advantage for rocketry over aircraft delivery lies in the speed of flight. The time for checkout, truck delivery, and port delay for the two modes are the same. Therefore to see any real advantage over aircraft the Bimese must ship goods fast and far to places where there is a large difference between aircraft trip times and boost-glide trip times. Table IV.3 shows the advantage rocket delivery has over airplane delivery in terms of trip time.

Table IV.3 – Time of Flight of Aircraft versus Bimese

From	To	Approximate flight time (hr)	
		Aircraft	Bimese
KSC	Madrid	8	~ 0.7
KSC	Los Angeles	3	~ 0.5
KSC	London	8	~ 0.7
KSC	Rio De Janeiro	10	~ 0.7
KSC	Paris	9	~ 0.7

Of course the Bimese has many disadvantages compared to aircraft including no existing spaceports for vertical launch, high turn around time, high DDT&E, uncertain reliability, and unproven concept. Economically these disadvantages will be hard to overcome.

Bimese Inc. has a choice to offer launch services that includes charter flights, scheduled flights, or a hybrid of the two options. The charter flight scenario requires that a customer or customers buy an entire flight and choose the time of departure. For this case the Bimese will not have to fly every day, but in order to provide a consistent service and to maintain an advantage over aircraft delivery vehicles must be prepared to launch at all times. With a turnaround time of two weeks there should be at least four Bimese vehicles at each launch site at any given time, two being processed and two ready to fly. In the scheduled flight scenario a flight leaves at specific times each day. It would be considered unreliable to offer a service that departed only once or twice a week, therefore due to the turnaround time there must be at least ten vehicles per site in order to maintain a consistent daily launch rate of 1.2 to 1.5 per day. The hybrid flight scenario would provide both of these services, and would need about twelve vehicles per site to maintain its services given the two-week turnaround time.

In order to do economic analysis the price for shipping must be linked to market demand curves, but no reliable data exists for the hypersonic package delivery market. The Commercial Space Transportation Study (CSTS) does have market curves for fast package delivery, but they are outdated and uncertain, therefore they will only be used for order of magnitude analysis. Instead of using market demand curves IRR will be looked at in terms of varying both flight rate and price per flight.

IV.2.2. Point-to-Point Business Plan

From this qualitative information it is easy to see that Bimese Inc. will need to offer its customers a transoceanic and transcontinental shipment service that can quickly deliver packages to densely populated areas. In order for Bimese Inc. to make money all of this must be done for a cost per flight of under a million dollars.

Looking at the recurring cost for the Bimese with 2 GEMs in Figure IV.1 shows that using GEM-10s at $2 M each is going to be detrimental to the business. Trading this price for 2,000 nmi of extra range the thrust-augmented Bimese is immediately thrown out as an option. Another decision that is made is to operate using a charter flight strategy because of the stringent requirements on vehicles per site for the other two scenarios.

Bimese Inc.'s business plan is to offer chartered flights of the single element Bimese across the Atlantic Ocean. To begin the Bimese will operate from four launch sites and as the years go buy ramp up building sites inland on the two continents. Figure IV.2 shows a representative scenario for the Bimese fast package delivery system.

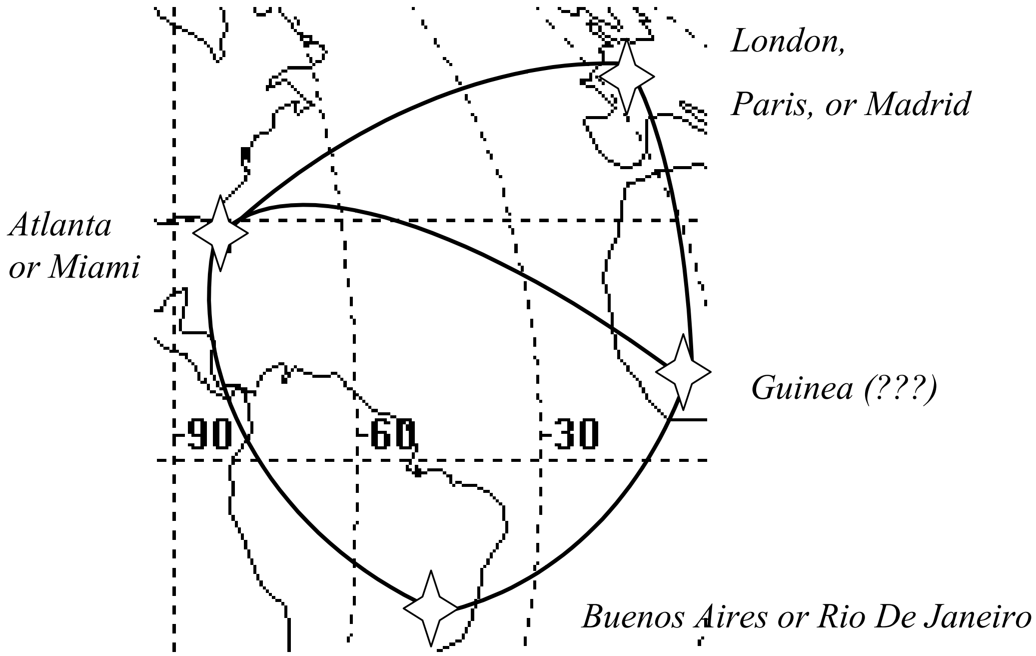


Figure IV.2 – Possible Initial Launch Sites for Bimese Inc. Fast Package Delivery

Given this scenario and the fact that an acceptable IRR is around 25%, Figure IV.3 shows that Bimese Inc. only reaches the 25% level when charging $7M per flight and having a flight rate of about 15 per day. At this price it is dubious, even with launch sites located all around the world, that the market will demand 15 flights a year, much less 15 a day. The CSTS shows that at this price the demanded flight rate would be about 10 per year two orders of magnitude from 5,000.

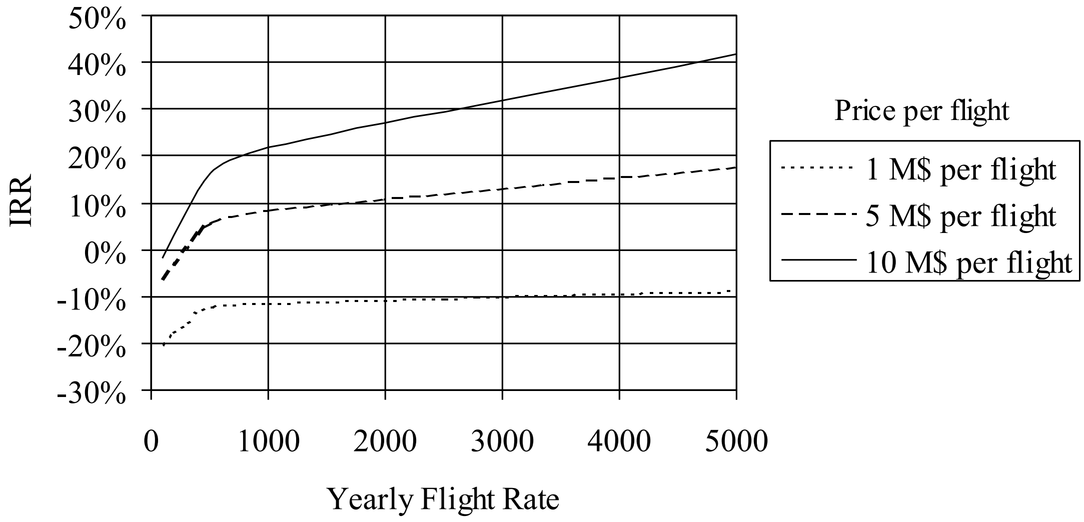


Figure IV.3 – IRR for Bimese Inc. Baseline Case

A possible modification of this scenario that could be made is to assume the turnaround time is reduced. In this case it is assumed that the turnaround time is one day. This immediately increases the variety of service the Bimese would offer resulting in an increase in market capture. Also, the fleet size would no longer be determined by airframes needed per launch site or turnaround time, but by airframe life. The IRR sensitivity in Figure IV.4 is obtained for this case.

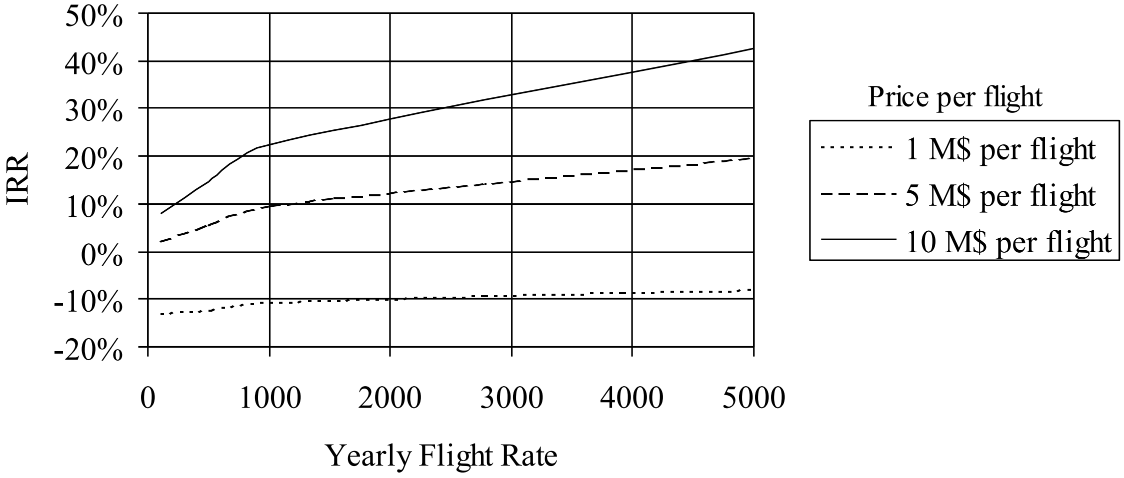


Figure IV.4 – IRR for Bimese Inc. with Reduced Turnaround Time

The IRR shows a remarkable improvement of over 10% at low flight rates, this is because at low flight rates the number of airframes purchased was being determined by the number of vehicles needed per launch site. With a rapid turn around time every time one lands it can take off a day later, so no vehicles need to pick up the slack from the turnaround lag. Charging $6M per flight with 5,000 flights per year can yield an IRR of 25%. Another pricing strategy of $10M per flight with 1,200 flights per year yields this 25% IRR. Once again these flight rates do not match with the charged price. Actually, the CSTS predicts no market for the $10M per flight price.

Making further assumptions the values of TFU and DDT&E are reduced. Bimese Inc. now gets 100% of their airframe DDT&E paid by NASA and their TFU has been reduced by 20%, perhaps by a more cost-effective design or overestimating the cost. From this the IRR sensitivity in Figure IV.5 is obtained.

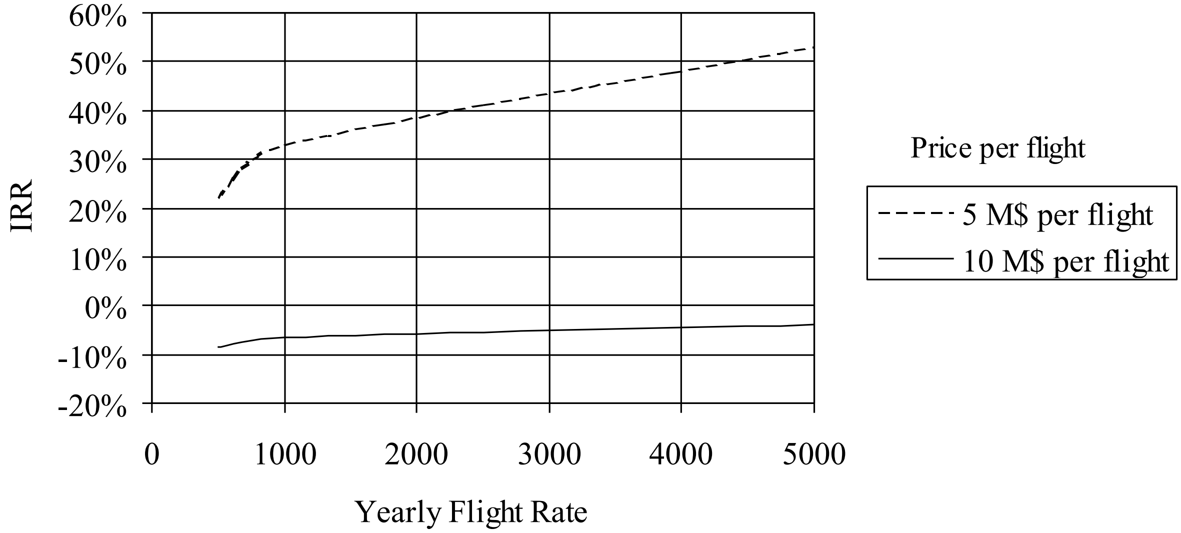


Figure IV.5 – IRR for Bimese Inc. with Reduced DDT&E and TFU

From this chart it is seen that the economics are becoming more reasonable, but the prices still do not match the demand. Charging a price per flight of $3M with 5,000 flights per year returns an IRR of 25%. This is still an order of magnitude off from the CSTS.

One final case is looked at with the extreme assumption of zero fleet acquisition cost. A plot of the IRR sensitivity for this assumption is seen in Figure IV.6. The only cost to overcome is the recurring cost per flight. Charging $0.75M a good return on investment can be obtained for about 2,500 flights per year, or 7 flights per day. From the CSTS the demanded flights at this price would be about 75 flights per year, an order of magnitude less than 2,500.

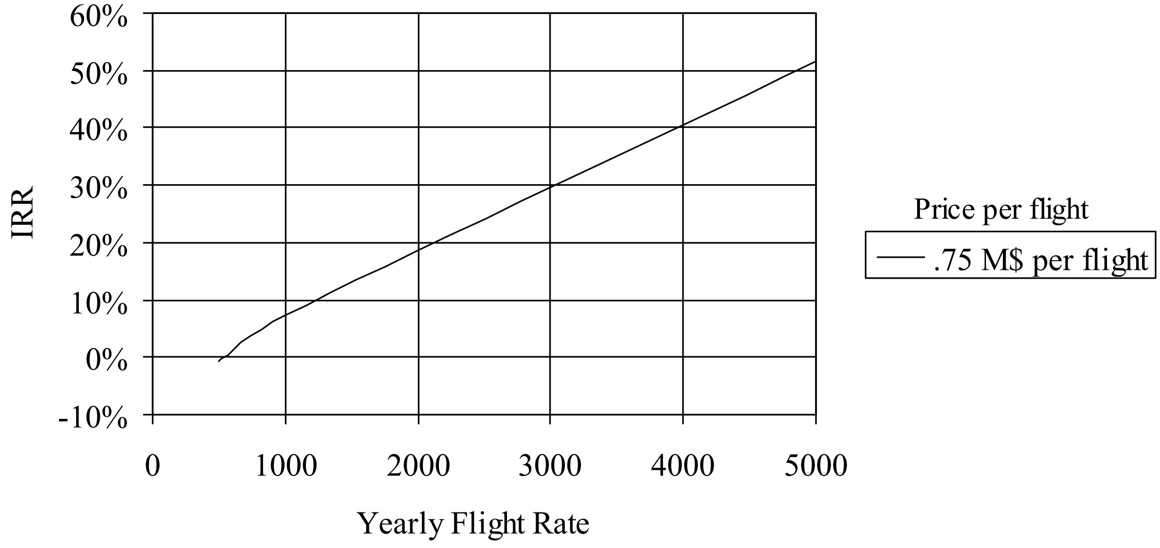


Figure IV.6 – IRR for Bimese Inc. with Recurring Cost Only

A more detailed breakdown of the economics of these four cases is given below in Table IV.3. Even with government contributions of $7.4 B and zero fleet acquisition costs the flights per year needed to make a return are unreasonable.

Table IV.4 – Economic Indicators for Four Cases

	Baseline	Reduced turn around time	Reduced DDT&E, TFU, and turn around time	Recurring Cost Only
Flights/year	5,000	5,000	5,000	3,000
Price/flight (M$)	$6.5	$6	$3	$0.75
IRR	~ 25%	~ 25%	~ 25%	~ 25%
Fleet size	171	144	144	74
Fleet acquisition (B$)	$154	$103	$ 67	$0
Turn around time (days)	14	1	1	1
DDT&E Government Contribution (M$)	$1,850	$1,850	$7,400	$7,400
TFU (M$)	$1,900	$1,900	$1,500	$0

IV.2.3. Point-to-Point Business Conclusions

From a qualitative point of view a good point-to-point vehicle must have a large range to capture the global market. It also must have aircraft like operations for fast turn around time and easily accessible launch sites. Minimizing the recurring costs (which includes eliminating expendables), TFU reduction (to offset large number of vehicles need), and rapid turn around time for maximum market capture are all essential elements of a point-to-point vehicle. The Bimese does not have these qualities and therefore is not a success in the point-to-point market.

IV.3. LEO ECONOMIC ANALYSIS

Using the assumptions from Section IV.1 a business called Bimese, Inc. is setup to operate as a commercial LEO payload delivery company. The thrust-augmented, thrust/fuel-augmented, and mated configurations will be used as the cargo carrying vehicles. Recall from Figure III.16 the LEO payloads for these launch vehicles are 9,750 lb, 15,900 lb, and 60,000 lb respectively.

IV.3.1. LEO market

The LEO market is well established and the ability to make money in this market has been proven. Market demand curves form the CSTS are used for both commercial and government LEO payload to simulate the business analysis.

IV.3.2. LEO Business Plan

The Bimese will deliver payloads to two markets, government LEO and commercial LEO. For the government missions it is assumed that the Bimese will be used for missions similar to the Space Shuttle, so 100% of the government missions will use the Bimese in the mated configuration. For the commercial markets it is assumed that smaller payloads will be needed per flight, so 50% of the flights will use the thrust-augmented Bimese and the other 50% will use the fuel/thrust-augmented Bimese.

Using CABAM to optimize the LEO prices it is determined that the prices in Table IV.5 should be charged to the government and commercial customers to achieve a maximum return on investment.

Table IV.5 – LEO Prices

	$/lb	Average cost per flight (M$)
Commercial LEO price	$1,700	$105
Government LEO price	$1,750	$20

Using these prices the economic indicators in Table IV.6 are obtained.

Table IV.6 – Economic Indicators for LEO Mission

Commercial flights/year	23
Government flights/year	5
IRR	6.9%
Fleet size	3
Fleet acquisition (M$)	$4,983
Turn around time (days)	14
DDT&E Government Contribution (M$)	$1,850
TFU (M$)	$1,900

IV.3.3. LEO Business Conclusions

The Bimese does not succeed in the LEO market. But by comparison no reusable launch vehicles have ever competed in the LEO market, therefore the Bimese suffers from the same problem that most other re-usable vehicles have, high DDT&E and high TFU.

V. CONCLUSIONS

A Bimese space transportation system has been created that can fill a wide variety of payload options, with only three architectural developments: the Bimese launch vehicle, GEM-10s, and payload tanks. With these three architectural developments the Bimese space transportation system can operate as a short and medium range point-to-point carrier; and a medium-light, medium, and heavy LEO launcher. The feasibility of the Bimese as an economic venture is not as successful, failing in both the point-to-point market and the LEO market. Of course, no vehicles to date have even tried to crack the point-to-point market and no re-usable vehicles have succeeded in the LEO market.

With the limited economic analysis done the Bimese lacks the ability to leverage future launch markets, and therefore in this initial analysis does not seem like the proper candidate for NASA's future space transportation system. In the introduction it was stated that the Bimese might provide a good option for the future of NASA because all of the common components allowed the development of many missions for minimal investment. And indeed the commonality does reduce investment needed by the government to obtain a fleet of vehicles with many mission options, but even with these effects it does not change the fact that the commercial companies still cannot make money from the vehicle. Perhaps to fully see the benefit of the effects, outlined in the Section I., for both government and commercial investors all of the options (including heavy lift variants, geo-stationary markets and passenger markets) need to be looked at simultaneously and compared to other options for NASA's future.

The importance of this study lies in the fact of looking at multiple missions and multiple economic scenarios early in the design phase of a transportation system design. By looking at all of the options early instead of as an afterthought later in the design phase one can make changes necessary to help the vehicle become more successful for performing multiple missions and capturing multiple markets and therefore becoming a more successful space transportation system.

ACKNOWLEDGEMENTS

The author would like to thank the following people for the help in the completion of this project: Ashraf Charania and Rebecca Cutri-Kohart for their help in the analysis of the Bimese launch vehicle; the students of the Space Systems Design Lab for general support; Dr. Olds for his guidance in the problem approach; and Dr. Ted Talay who proposed the Bimese concept as a project.

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