

# Concept Documentation

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## Bimese TSTO ETO RLV

Concept Overview  
and

Model Operation: Reduced Order Simulation for Evaluating Technologies and Transportation Architectures (ROSETTA)

ROSETTA Model Version 1.22.III

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# Overview



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## Concept Overview: Bimese TSTO



# Concept Description



Item	Characteristics
Concept	Bimese Two-Stage-To-Orbit (TSTO) reusable launch vehicle (RLV)
Configuration	<p>“Bimese” or “twin” approach where both stages are identical and interchangeable</p> <p>The vehicle has wing-body configuration</p> <p>Vertical takeoff, un-powered horizontal landing with parallel burn of stages with cross feed of propellants</p> <p>External payload pod for cargo missions and external Crew Transfer Vehicle (CTV) for crewed missions</p>
Reference Mission	<p>35klb in a 15 x 55 ft payload bay (reference orbit: 248nm. circular x 51.6 degrees inclination)</p> <p>Cargo delivery and return</p> <p>Booster vehicle docks with ISS</p> <p>Crew rotation with requirements based on DAC-7</p> <p>Crew Transfer Vehicle (CTV) carried by booster to LEO and separates from booster for ISS rendezvous</p> <p>Mission duration of ~10 days + 2 days margin</p>
Flight Performance	<p>Human rated</p> <p>Crew survivable abort capability</p> <p>Automated rendezvous and docking</p> <p>Two engine out (1 per Bimese element) capability to make mission</p> <p>Cross range capability of several hundred nmi</p> <p>Flight performance reserve: 1% of <math>\Delta V</math></p>
Programmatic	<p>Fully commercially venture</p> <p>IOC of 2010 with a technology freeze date of 2005</p>

# Concept Configuration



Single element



Mated





# EMBEDDED and ENABLING Technology Application: Structures / TPS



Type	Sub-type	No.	Technology	Notes, Compatibilities and Prerequisites
Airframe Structures	Wing	A.1	Gr-Ep exposed wing and carry-through, primarily stiffened skin construction, Gr-Ep elevon control surfaces	
	Tail	A.2	Wing-tip vertical tails constructed of Gr-Ep stiffened skin. Conventional rudders, sized for directional stability at low speeds	
	Body	A.3	Gr-Ep stiffened skin construction for nose, intertank, payload pod, and aft body, Gr-Ep carrier panels for TPS attachment in tank areas, Aluminum thrust structure, Gr-Ep body flap	
Main Propellant Tanks	Fuel Tank	A.4	Al-Li 2195, waffle construction with external ring frames, spray-on foam insulation (SOFI)	
	Oxidizer Tank	A.5	Al-Li 2195, stiffened skin structure with external ring frames, spray-on foam insulation (SOFI), aft tank installation	
Undercarriage		A.6	Steel struts, Aluminum wheels, hydraulically actuated	
Thermal Protection	Wind and Vertical Tail	A.7	C-C leading edges, AETB TUFU tiles on wing lower surfaces and combination of TUFU tiles and AFRSI blankets on upper surfaces, TUFU tiles on vertical tails	
	Fuselage	A.8	C-C nose cap, AETB TUFU tiles on lower surfaces and AFRSI blankets on upper surfaces, TUFU tiles on base.	
	Body flap	A.9	AETB TUFU Tiles and AFRSI blanket TPS	
		A.10	AETB TUFU tiles	

# EMBEDDED and ENABLING Technology Application: Propulsion



Type	Sub-type	No.	Technology	Notes, Compatibilities and Prerequisites
Main Propulsion	Engines	A.11	SSME Block II with Inconel honey comb heat shields	
	Gimbal and Valve Actuation	A.12	Hydraulic TVC and engine valves (pneumatic backup for valves)	
	Feed system	A.13	Stainless steel and Aluminum with new flange design	
	Pneumatic and purge system	A.14	Helium system with Titanium tanks w with Kevlar overwrap	
	Propellants	A.15	NBP hydrogen, NBP oxygen	
Reaction Control System (RCS)		A.16	MMH-N2H4 pressure-fed system, Titanium tanks, independent forward and aft modules	
Orbital Maneuvering System (OMS)		A.17	MMH-N2H4 pressure-fed system, Titanium tanks	

# EMBEDDED and ENABLING Technology Application: Avionics / Power / IVHM



Type	Sub-type	No.	Technology	Notes, Compatibilities and Prerequisites
Electrical	Power	A.18	28 VDC alkaline fuel cells, vacuum jacketed tanks: Al/Inconel LO2 tank, Al/Al LH2 tank	
	Conversion and Distribution	A.19	28 VDC/115 VAC system, copper cabling, teflon insulation, MIL-STD-1553 buses, fiber-optic network for IVHM, composite wire trays and brackets	
Hydraulic	Power	A.20	Hydrazine fueled APU's with Titanium tanks	
	Conversion and Distribution	A.21	3000 psi system	
Actuation		A.22	Surface Controls: Quad-redundant hydraulic actuators, jack-type for elevons and rudder, rotary-type for body flap	
Avionics		A.23	X-33 Equivalent Technology for GN&C, RF communications, Data Systems, Instrumentation Sensors, Range Safety, and Controllers	
ECS and Thermal Control		A.24	Shuttle technologies: cold plates, freon coolant loops, space radiator, flash evaporator, ammonia boiler, and water spray boiler, bulk fibrous and multilayer blanket internal insulation	
Purge, Vent, and Drain		A.25	Shuttle technologies: Kevlar-Epoxy purge and vent ducts, electromechanically actuated vent doors	
Flight Termination		A.26	Electrically initiated pyrotechnic destruct charges	

# ENHANCING Technology Description



No.	Technology	Notes	Compatibilities and Prerequisites
B.1			
B.2			
B.3			
B.4			
B.5			
B.6			
B.7			
B.8			
B.9			
B.10			
B.11			
B.12			

# Model Operation: Reduced Order Simulation for Evaluating Technologies and Transportation Architectures (ROSETTA)



# ROSETTA Model



- Reduced Order Simulation for Evaluation of Technologies and Transportation Architectures (ROSETTA)
  - A spreadsheet-based meta-model that is a representation of the design process for a specific architecture (ETO, in-space LEO-GEO, HEDS, etc.)
  - Each traditional design discipline is represented as a contributing analysis in the Design Structure Matrix (DSM)
  - Based upon higher fidelity models (i.e. POST, APAS, CONSIZ, etc.) and refined through updates from such models
  - Executes each architecture simulation in only a few seconds
    - » Requirement for uncertainty analysis through Monte-Carlo simulation
  - Architectures are modified through influence factors
    - » PIFs: Programmatic Influence Factors (i.e. govt. contribution, market growth, etc.)
    - » VIFs: Vehicle Influence Factors (i.e. Isp, wing weight, T/We, cost, etc.)
  - Outputs measure progress towards NASA Goals (\$/lb, safety, etc.)
    - » Standard deterministic outputs as well as probabilistic through Monte Carlo

ROSETTA models contain **representations** of the full design process.  
Individual developer of each ROSETTA model determines **depth** and **breadth** of appropriate contributing analyses.  
More assumptions, fewer DSM links than higher fidelity models due to need for faster calculation speeds.

# ROSETTA Model Categories



## ➤ Category I

- Produces traditional physics-based outputs such as transportation system weight, size, payload and the NASA metric in-space trip time

## ➤ Category II

- In addition to above, adds additional ops, cost, and economic analysis outputs such as turn-around-time, LCC, cost/flight, ROI, IRR, and the NASA metric price/lb. of payload

## ➤ **Category III**

- **In addition to above, adds parametric safety outputs such as catastrophic failure reliability, mission success reliability, and the NASA metric probability of loss of passengers/crew**

# ROSETTA Model Operation: Bimese TSTO



- The ROSETTA spreadsheet model for this concept contains 6 disciplinary worksheets, an Inputs / Outputs (I/O) worksheet sheet, and a Programmatic Influence Factor (PIFs) worksheet
  - The six disciplinary worksheets and the off-line models upon which they are based include:
    - » Trajectory (POST 3-DOF, NASA LaRC)
    - » Weights (GT-Sizer CONSIZ MERs, Georgia Tech - various sources including NASA LaRC)
    - » Operations (AATe, NASA KSC)
    - » Cost (NAFCOM, NASA Marshall)
    - » Economics (CABAM, Georgia Tech)
    - » Safety (GT-Safety, Georgia Tech)
  
- Any changes of the PIFs and VIFs result in the concept needing to be reconverged both physically (through vehicle length) and financially (through market prices)

# ROSETTA Model Operation: Sizing Concept Using Vehicle Length

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- The concept is assumed to maintain the same payload capability
- When some performance parameter (i.e. a VIF) affects the mass ratio as calculated from the weights and sizing worksheet, there may be a discrepancy between this mass ratio and the one required for trajectory
- In this case the vehicle length has to be manipulated in order to make both mass ratios equivalent
- Manipulation is done through MS Excel Solver
- MS Excel VBA macro written (called by pressing CTRL+I)

# ROSETTA Model Operation: Closing Financial Case Using Price [\$/lb]

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- An input to the model is the required financial return of the project on top of that required to be minimally acceptable
- Financial return based upon costs and the price per lb charged for delivery of payload
- Any change that results in a change to project cash flows results in a change of the price required to converge the economic model to the desired financial return
- Thus the vehicle sizing optimization is done first through MS Excel Solver, then the required financial case is converged in a separate tasking of MS Excel Solver

# Category I Modeling Assumptions: Trajectory



- Baseline ascent trajectory optimized using POST-3D
  - Launch from KSC with two SSME Block II's out (one per element)
    - » Throttle 18 remaining engines from 104% to 109% at failure
  - MECO at 50 x 248 nmi. X 51.6° ISS transfer orbit
  - All engines use booster propellants up to staging (cross-feed); orbiter is full at staging near Mach 3.3; booster glides back to KSC unpowered
  - Reference ascent Mass Ratios (MR) and relative velocity losses established
    - » Since stages are identical, propellant masses are the same
    - » Required 5 or 6 iterations with baseline Weights model to converge
  - Flyback and orbiter entry trajectories was not explicitly analyzed
  
- Trajectory sheet in ROSETTA model assumes MR = constant during simple resizing
  
- Use simple rocket equation relationship to model the effects of changing  $I_{sp_{vac}}$  or changes in individual velocity losses
  - Mixture ratio assumed to be constant and is set in Weights sheet

# Category I Modeling Assumptions: Propulsion



- 20 Block II SSME's (10 per element)
  - Propellants: NPB LOX, NPB LH2
  - Staged-combustion cycle
  - $I_{sp_{vac}} = 452.5$  sec. (held constant for 104% and 109% throttle)
  - $T/W_e = 51.53$  at sea-level (104% throttle,  $W_{eng} = 7675$  lb for Block II)
  - $T @$  sea-level = 395,500 lb per engine (104% throttle)
  - $T @$  vacuum = 489,660 lb per engine (104% throttle)
  - $A_{exit} = 44.5$  ft<sup>2</sup> per engine
  - Nozzle area ratio = 69:1
  - Throttle range = 67% - 109%
  - Chamber pressure = 3028 psia
  - Mixture ratio (O/F) = 6
  
  - Engine life = 50 mean flights before replacement
  - Reliability = 250 mean flights between failure

# Category I Modeling Assumptions: Weights



- ROSETTA model includes full three-level GT-Sizer spreadsheet and WBS for this concept
- Both elements are identical and scale photographically to match required orbiter MR
  - Change fuselage length to recalculate new available MR
- MER's originally based on a mixture of Talay (NASA LaRC VAB) MERs for Rocket-type RLV's adjusted + and - by Technology Reduction Factors approximated at SEI for Gen2-era
  - Used 15% overall dry weight margin
  - Added 10% to structures weights and 50% to subsystem weights to reflect Gen2 philosophy of added safety margin in those elements
  - MER's are generally higher than similar Gen3 MER's used at SEI , e.g.
    - » Beefed up TPS weight by 40% vs. standard Gen3 assumptions for added margin
    - » Beefed up Pressurization & Feed by 40% to account for cross-feed hardware
  - Block II SSME weights are not scaled as vehicle resizes

# Category II Modeling Assumptions: Operations



- Operations worksheet heritage from the NASA-KSC model AATe (Architecture Assessment Tool-enhanced)
  - AATe requires both quantitative inputs and qualitative order of magnitude comparison of the concept vehicle to the Space Shuttle
  
- Response Surface Equation (RSE) from AATe
  - Inputs
    - » Overall Vehicle Reliability, Airframe Life, Payload Weight, Dry Weight, Vehicle Length, Payload Demand Per Year
  - Outputs
    - » Ground Turn-Around-Time (Days), Facilities Cost, Labor Cost Per Flight, Labor Personnel Required, LRU Cost Per Flight, Total Propellant Costs
  
- Propellant costs based upon production rate effects over current propellant prices
  - Accounted for extra propellant required at launch site (1.5 \* vehicle required amount)
  
- The total labor personnel required per flight based on total yearly labor cost (from the AATe RSE), yearly flight rate, and a Full Time Equivalent (FTE) salary of \$150K (FY\$1999)
  
- Operations Flow:
  - Vehicle Turnaround: land, single-stage, then turnaround, process at pad
  - Vehicle Assembly / Integration: no element assembly/integration required
  - Expendables, Payload, and Crew: Internal Payload but no crew or active passengers

# Category II Modeling Assumptions: Cost



- NAFCOM weight-based Cost Estimating Relationships (CERs) with complexity factors at subsystem level
- Assumes development of near full-scale, non revenue generating prototype
- Includes programmatic “wraps”
  - System Test Hardware (STH), Integration, Assembly, & Checkout (IACO), System Test Operations (STO), Ground Support Equipment (GSE), System Engineering & Integration (SE&I), Program Management (PM)
- 20% cost margin applied to all DDT&E and TFU costs
- No DDT&E cost for Block II SSMEs

# Category II Modeling Assumptions: Economics (1)



- Two available pricing schemes (a PIF)
  - Same price for government and commercial missions (default)
  - Different prices for government and commercial mission
    - » Set commercial price at \$ 800/lb
  - Manipulate price to obtain the commercial Incentive Return-IR (a PIF)
  - Commercial Incentive Return-IR
    - » Return above the the return at which the project is acceptable
    - » Measure of attractiveness of project
  
- Weighted Average Cost of Capital (WACC) method used to determine the required discount rate
  - This is the return at which the project is minimally acceptable
  - Based upon three kinds of firms: Aerospace, Air Transport, and E-commerce
  
- Project cash flows based upon income from operations (total operating expenses – gross profit) - taxes
  - Referred to EBI (earnings before interest)
    - » Effect of any financing (loan rate) is not included in the calculation of the FCF upon which target IRR is based
    - » Normally, the effect of financing is included in the discount rate which is used to calculate NPV
  - Target for Solver: New Present Value (NPV) based upon WACC rate + IR rate
  - Input Debt-to-Equity ratio (a PIF) reflection of financing situation

# Category II Modeling Assumptions: Economics (2)

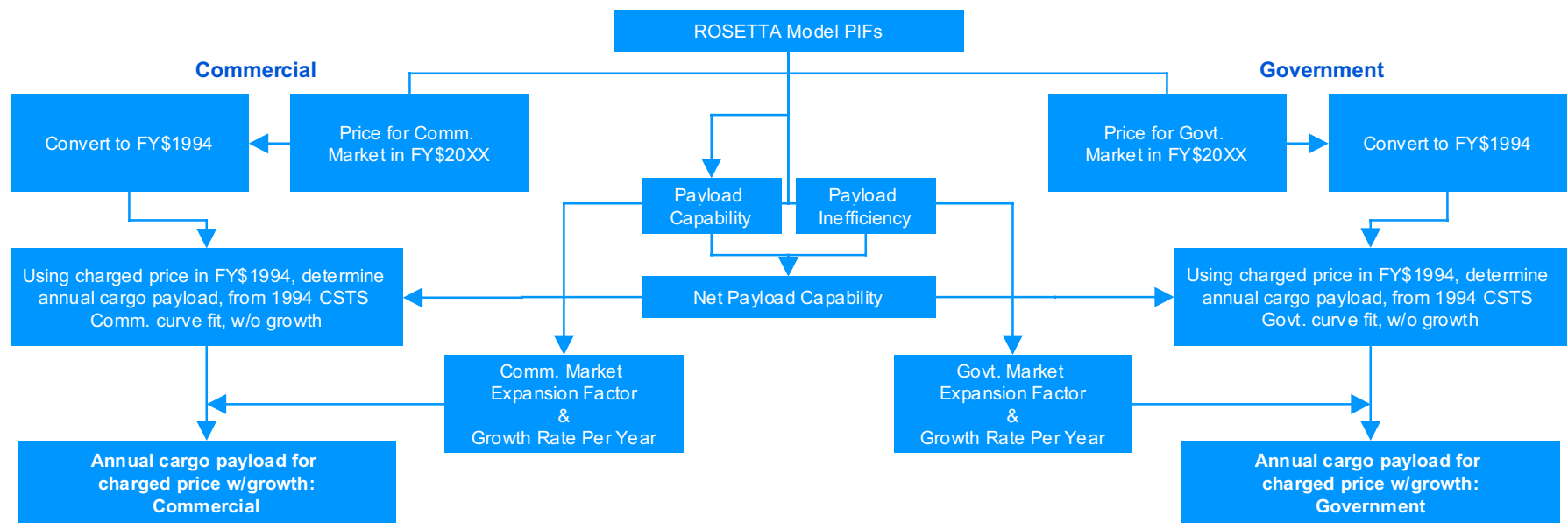


- Market assumptions in Economics worksheet originate from curve fits of Gen 2 elastic market data
  - Source: ITAC Gen 2 market demand based upon Commercial Space Transportation Study (CSTS) for commercial and government cargo markets (LEO-equivalent payloads)
  - Inelastic commercial and government passenger markets are included but not used
  - Market elasticities (price versus payload demand) curve fits include competition effects
  - Curve fits based on tabular data that did not include “0” payload captured points at high prices in order to generate curves with high  $R^2$ , result: small, marginal payloads captured at large prices
  - Elasticities include options for movement of entire demand curve (market expansion) and yearly market growth rate
  
- Production
  - Optional user input to determine number of years to produce airframes or can use estimation algorithm
  - Production starts 1 year after DDT&E phase ends, this year is set to be 1 year before IOC
  - Assumes total number of yearly flights required are evenly spread out over each flight year
  - Amortize total vehicle acquisition cost over production number of years
  - If the government buys any airframes, then those are the first versions off the assembly line
  - Production assumes vehicles are generally more turn-around-time limited than life limited
  - Learning curve input is aggregation of learning, production, and rate effects
  
- Depreciation
  - Based upon Double Declining Balance (DDB) method
  - User input for number of years to depreciate
  - Use input for salvage value of asset
  
- Any government contributions are accounted for as non-taxable revenue

# Category II Modeling Assumptions: Economics (3)



## ROSETTA MODEL PRICE ORIGATION CHAIN



Note: In the case of two prices, a higher fidelity economics model is used to pre-determine the commercial cargo price. The model can then manipulate only one price, gov't. cargo. The price in this market is manipulated to meet the required economic objective (in this case IRR).

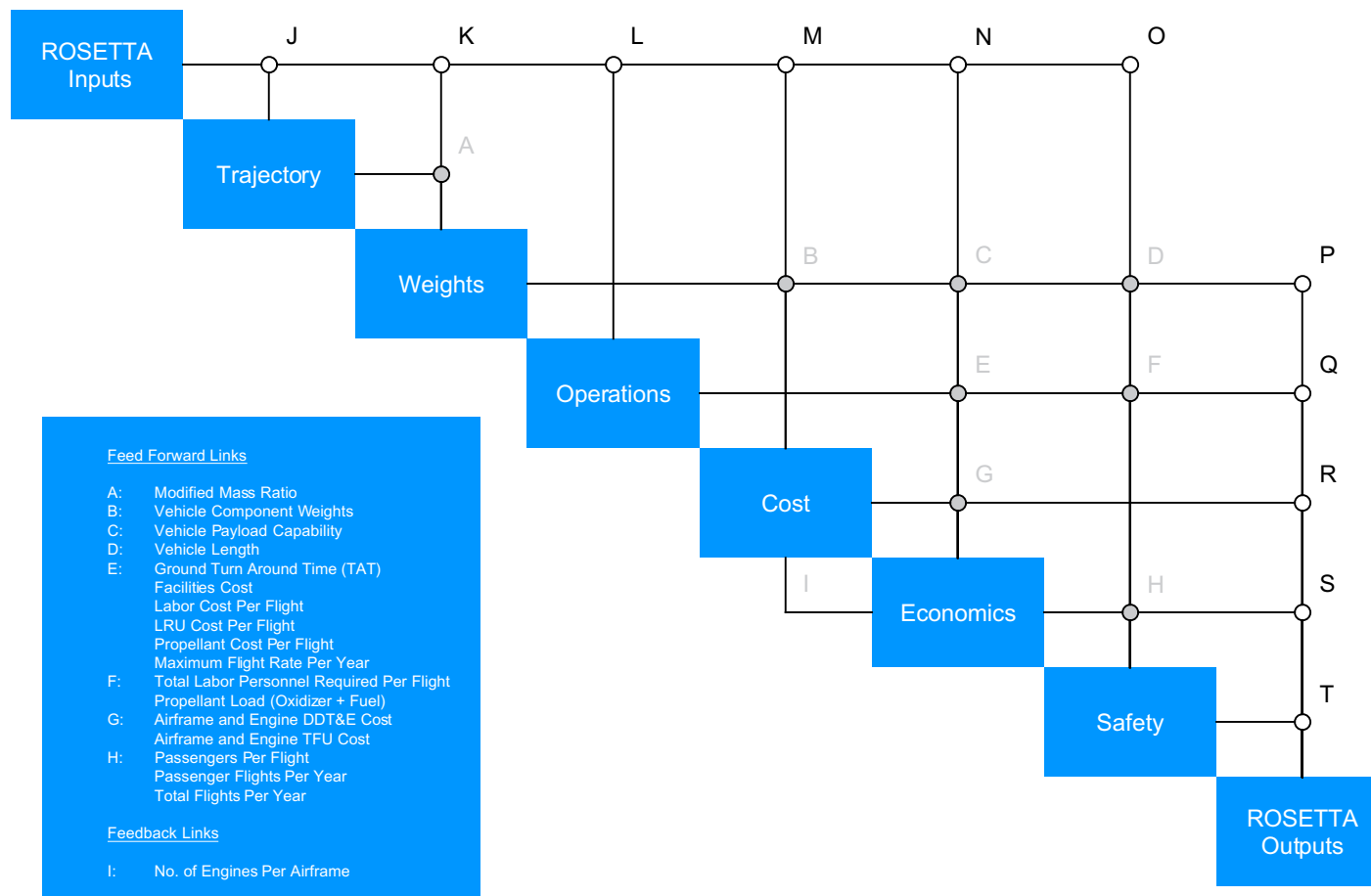
Note: The user pre-selects a price at which the government cargo market becomes completely inelastic and at which there are no more commercial flights. At this asymptotic point [nominally set at \$5000/lb in FY\$1994], any higher price results in the same number of government flights flown. If the economic objective (in this case IRR) requires higher prices to be charged, the same number of flights are flown but the price charged per flight now increases. This asymptotic price can be determined through examination of CSTS curve fit data.

# Category III Modeling Assumptions: Safety



- Quantitative vehicle data coupled with linear base adjustments to Shuttle operating characteristics
  - Top down approach based on vehicle features at conceptual analysis level
  
- Input vehicle data
  - Required crew/flight, passengers/flight, passenger flights/year, total flights/year, propellant load, ground personnel, vehicle length, number of stages or elements, number of engines, base single engine and airframe reliability
  
- Outputs
  - Casualties and/or serious injuries per year (flight + ground)
  - Flights between Ascent Interruption Event
  - Flights between LOL and/or serious injury (flight + ground)
  - Flights between catastrophic loss of crew event
  
- Safety originates from safety calculations for three populations and weighted for overall metrics
  - Public/Collateral Safety
  - Ground Personnel Safety
  - Flight Crew/Passenger Safety

# ROSETTA Model DSM: Bimese TSTO



**Feed Forward Links**

- J: DV Flight / Drag / TVC / Isp Modifications
- K: Vehicle Length  
Payload Capability  
LH2 Density  
LOX Density  
Engine T/W  
Component Weights
- L: Airframe Life  
Facilities Cost
- M: Airframe and Engine DDT&E Cost  
Airframe and Engine TFU Cost
- N: Average Annual Interest Rate  
Tax Holiday Program Duration  
Commercial Market Growth Factor  
Overall Vehicle Reliability  
Vehicle Recurring Cost Per Flight  
Airframe and Engine DDT&E Cost  
Airframe and Engine TFU Cost  
Facilities Cost  
Operations and Maintenance Cost  
Payload Capability  
Government Cargo Flights Per Year  
Airframe Life  
Engine Life  
Static Government Cargo Launch price  
IRR Goal
- O: Overall Vehicle Reliability

**ROSETTA Outputs**

- P: Vehicle Length
- Q: Ground Ops Turn Around Time (TAT)
- R: DDT&E Cost
- S: Iterated NPV for Desired IRR
- T: Inverse Safety Metric

**Feed Forward Links**

- A: Modified Mass Ratio
- B: Vehicle Component Weights
- C: Vehicle Payload Capability
- D: Vehicle Length
- E: Ground Turn Around Time (TAT)  
Facilities Cost  
Labor Cost Per Flight  
LRU Cost Per Flight  
Propellant Cost Per Flight  
Maximum Flight Rate Per Year
- F: Total Labor Personnel Required Per Flight  
Propellant Load (Oxidizer + Fuel)
- G: Airframe and Engine DDT&E Cost  
Airframe and Engine TFU Cost
- H: Passengers Per Flight  
Passenger Flights Per Year  
Total Flights Per Year

**Feedback Links**

- I: No. of Engines Per Airframe

# References



- 
- “TSTO Bimese Reference Vehicle” by Roger Lepsch (NASA LaRC), Presentation made to ISAT Integrated Technology Assessment, September 12, 2000.
  - “The Bimese Concept: A Study of Mission and Economic Options” by Jeff Tooley (Georgia Tech SSDL), sponsored by NASA Langley Research Center – VAB.

# Configuration Management (1)



Note: There may be skips in version number due to intermediate changes by the user

Version	Date	Revisions and Comments	
1.22.III	04/15/01	<p>New Debt-To-Equity ratio PIF            Three output IRRs based upon different cash flows            More LCC and financing outputs            Solver updated to fix problems and increase speed            Removed PIFs sheet, moved functionality to I/O sheet            Add VIFs for propellant cost for each type (LH2 and LOX)            Zeroed out comm. and govt. passenger markets            Accounted for extra propellant at launch site (1.5* vehicle required)            Added PIFs for separate commercial and government overall market expansion factor (movement of the demand curve)            Added PIF for separate commercial and government market growth rate per year (yearly increase in demand from base year)            Replaced Response Surface Equation (RSE) in "Operations" with new fit            New "Operations" RSE for wider range on input reliabilities with demand input            Linked selected cells in "Economics" sheet directly to "I/O" sheet            Added numerical values for all "Min" "Nom" and "Max" columns            Added the G, PIF tags that were missing from the previous version            Added option to manually modify DDT&amp;E and TFU costs in "Cost" sheet            Added PIF for govt. contribution to offset engine DDT&amp;E cost (set at 100%)            Changed learning curve for both engine and airframe to 85%            Added nominal interest rate description to PIF for V.a in "Economics" sheet            Replaced word "free" from "cash flow" with more descriptive tags            New PIF for required return beyond project acceptance (commercial incentive)            Added number of booster and propulsion units as an output to "I/O" sheet            Removed NPV at 20% to NPV at 25%            Modified tax calculation to account for interest rate tax shield            Added new depreciation schedule, based on Double-Declining Method            For depreciation, added salvage value and years to depreciate option            Adding learning curve effect table for rates of production in "Economics"            Set LOX propellant cost at \$0.10/lb, LH2 \$1.00/lb (in FY\$1999)            LCC accounts for time value of money based on inflation and risk free rate            Added separate line item for capital expenditures in cash flow in "Economics"            Fixed reference year in principal calculation in "Economics"            Added "I/O" output: Magnitude of Incentive Return (IR)            Added "I/O" output: Total Govt. Contribution to Life Cycle Cost</p>	<p>Added PIF for number of airframes government buys (from first airframes built)            Minimum number of airframes purchased set to 3            Added more detail in fleet definition to reflect correct government purchases            Year to acquire airframes and engines set to 5, starting one year before IOC            New learning curve approximation, to be redone every time effect % changes            Made government contribution like revenue but non-taxable            Removed tax carryover provisions in cash flows            Added formulas to estimate years for production (starting 1 year before IOC)            Years to build a fleet now an explicit option            Changed VBA code for a different method of jumping a large range of prices            Changed LCC outputs on "I/O" to not be discounted            Added total number of flights in program as an output on "I/O"            Assumption is that vehicles are more turn-around-time limited than life limited            Set to "3%" the default value of incentive return            Added insurance cost to recurring cost per flight (item C.G on "Economics")            Changed VBA code pointer to references on "I/O"            Added option to depreciate a certain % of total non-recurring cost            Added LCC/lb per and post govt contribution as an output on "I/O"            Separated out demand curve fit, then applied growth / expansion            Captured % Eq. applied after growth and expansion base upon charged price            Govt. purchases PIF includes both airframe and engines for complete vehicles            Added years between loss metric for vehicle, mission, and crew as outputs            Set vehicle acquisition years to 5            Made government contributions non-taxable (changed cash flow calculations)            Changed VBA Solver code if statements for price jump            Changed jump_up parameter in VBA for target NPV &lt; Level_1 from 1.3 to 1.7            Separated Isp and Drag/TVC loss for Booster and Orbiter            Added V.j.7: Number of Common Bimese Stages in "Economics"            Changed C.4/C.5 on "I/O" to TFU            Added comments to Safety Sheet (for no. of engines and single engine/AF rel.)            Made passenger flights/year = 30% of total flights (only of "Safety")            Combined operational VIFs for Booster/Orbiter (TAT,MTBR)            Used medium demand curve fits            Government cargo includes ISS Servicing and exploration</p>