Is it Worth It? - The Economics of Reusable Space Transportation

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OUTLINE

- **Introduction**
- **Key Considerations**
  - **Who Cares?**
    - Stakeholders - Users and Suppliers of space transportation
  - **Why Are You Doing This?**
    - Motivations for investing in reusable space transportation
  - **If You Build It They Will Come. . .**
    - Demand for space transportation
  - **A Matter of Degree**
    - Degrees and types of reusable transportation systems
  - **How Many**
    - Fleet size
  - **Size Matters**
    - Size and cost – ramifications for reusable systems
- **Conclusions**

INTRODUCTION

- **The Quest for Low Cost Space Transportation**
  - Reusable versus Expendable Systems
    - Central Thesis: " It's cheaper if you don't throw stuff away, especially expensive stuff like rocket engines and avionics".
    - Is it true?
      - Industry has been at it for over 50 years.

"Costs of Reusable Launch Vehicles: Should We Pay Up Front to Build in High Reliability or Pay Later to Buy More Vehicles?": demonstrated that there is no scenario in which the economics of reusable launch vehicles makes them preferable in cost to expendable launch vehicles."
Dr. Stephen Book, PARAMETRIC WORLD, Winter 2012

"If one can figure out how to effectively reuse rockets just like airplanes, the cost of access to space will be reduced by as much as a factor of a hundred. A fully reusable vehicle has never been done before. That really is the fundamental breakthrough needed to revolutionize access to space."
--Elon Musk, SpaceX.com, 3/31/2013

The payoff of a reusable rocket is only possible if the launcher is flown many times, and market outlooks in the commercial sector and with European institutional missions do not add up to tip the scales in favor of reuse (he said).
--Stephen Israel, Chairman an CEO, Arianespace, Spaceflight Now.com, 1/11/2016

Commercial space exploration can advance at the fast pace of Internet commerce only if the cost is reduced through advances in reusable rockets.
Jeff Bezos, Amazon CEO, bloomberg.com, 4/12/2016

- ***After 50 years, still no consensus.***

INTRODUCTION

- **Where We've Been**
  - Early Concepts - Ehricke, Bono, Sanger, Hunter, others
  - Space Shuttle – more than a "reusable launch vehicle"
    - Buran- USSR Shuttle - Energia
  - Significant investments in multiple large scale development programs

Program	Approx. Invest (TY$)
X20 Dynasoar	~ $400M
Project START	~ $1B
Space Shuttle	~12B
X30 National Aerospace Plane (NASP)	$3 - $5B
Delta Clipper Flight Experiment	$50M
X33 Advanced Technology Demonstrator	$1B
X34 Technology Testbed Demonstrator	$219M
X37 Advanced Technology Flight Demonstrator	$301M

Source: National Space Transportation Policy Issues for the Future, Hogan and Villhard, WR-105-OSTP, October 2003

- **Where We Are**
  - Commercial Investment
    - SpaceX, Blue Origin, Virgin Galactic, Others
  - Government Investment
    - XS-1

- ***Over $10B invested so far***
- ***Investment continues***

WHO CARES?

- **Users of space transportation**

DEMAND	STAKEHOLDERS	PRIMARY USES
Civil Government	NASA, ESA, NOAA, etc.	earth sciences, astrophysics, planetary exploration, manned exploration, ISS
Military Government	US Department of Defense, Foreign Governments	communications, intelligence, treaty verification
Commercial - Geosynchronous Orbit (GSO)	Communications & broadcast companies	communications and direct broadcast satellites
Commercial - Low Earth Orbit (LEO)	Mobile communications & remote sensing companies	communications constellations, remote earth sensing
Commercial - Other (LEO)	New/current commercial companies; cube/nano sats; small sats	remote sensing, telecom, broadband internet

Adapted from: ACHIEVING RESPONSIVE ACCESS TO SPACE-- MARKET, MONEY, MECHANICS, AND MANAGEMENT LESSONS FROM X-33, Meade, Lane, Webb, 1st Responsive Space Conference, April 1–3, 2003

WHO CARES?

- **What Users Value**
  - Transportation is a means, not an end
  - Some or all of:
    - Low Price, High Availability, High Reliability
  - Cost (***price***) per pound *not necessarily most important*
    - Users pay a *price* per *flight*, not a price (or cost) per pound
      - Smaller payloads ≡ smaller vehicle ≡ lower price ≡ less cash out
    - Example: NASA PCEC Launch Services ROM Estimator (M15$)

Destination:

Mass (kg):	GEO	Planetary	Polar	Lunar	LEO	Helio
< 3,000	$ 120					
> 3,000	$ 140					
< 1,000		$ 80				
1,000 to 2,000		$ 110				
> 2,000		$ 175				
< 1,000			$ 55			
1,000 to 2,000			$ 85			
> 2,000			$ 130			
< 500				$ 85	40	
> 500				$ 160	80	
All						$ 100

- Approximate price per flight based on destination and mass

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COST PER MASS vs. COST PER FLIGHT

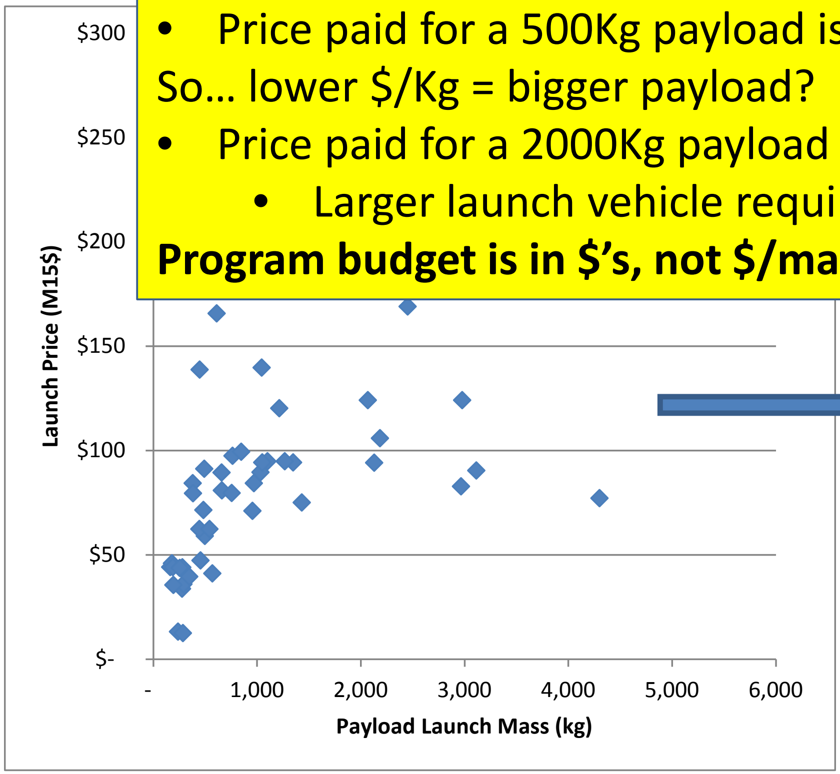
- **Cost (Price) per kilogram (pound) to orbit is not necessarily the "most important metric" to users of space transportation**
  - Price is function of mass versus available ETO transportation systems

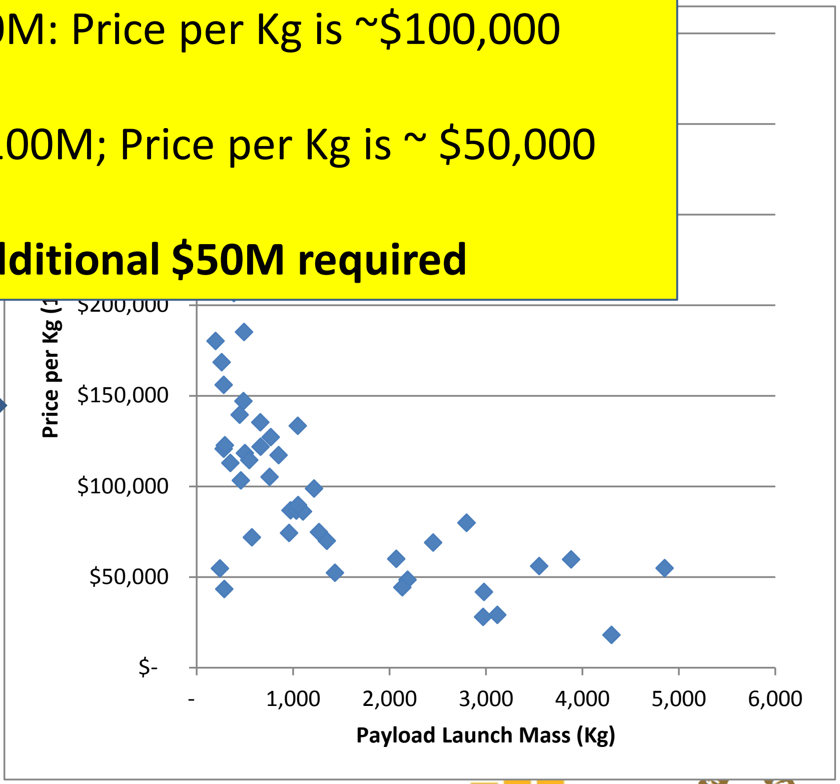
- Price paid for a 500Kg payload is ~ $50M: Price per Kg is ~$100,000

So… lower $/Kg = bigger payload?

- Price paid for a 2000Kg payload is ~ $100M; Price per Kg is ~ $50,000
  - Larger launch vehicle required

Program budget is in $'s, not $/mass: Additional $50M required





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WHO CARES?

- **Suppliers of space transportation**
  - Many and varied
  - 86 2015 earth-to-orbit launches
    - 21 vehicles; 7 countries
      - Commercial
      - Government
      - Both
- **What Suppliers Value**
  - Depends *significantly* on motivation
  - *Generally* $$: Transportation *generally* the end
    - Metrics depend greatly on *market segment* being served
      - Supplier values what customer values
  - Non-Recurring Investment: Capital Budgeting ~ Discounted Cash Flow
    - Internal Rate of Return (IRR), Net Present Value (NPV), Payback time
  - Recurring Operations: Return on Sales = Profit = High Price – Low Cost
    - Tradeoff versus other attributes
  - *Strategic suppliers may value other metrics*

Vehicle	Country	2015 Flights	Vehicle	Country	2015 Flights
CZ (DF-5)	China	17	Zenit	Russia	1
R-7	Russia/EU	16	GSLV	India	1
Atlas 5	US	9	H-2B	Japan	1
Proton	Russia	8	Delta 2	US	1
Falcon 9	US	7	Dnepr	Russia	1
Ariane 5	EU	6	CZ-6	China	1
PSLV	India	4	CZ-11	China	1
H-2A	Japan	3	Safir 1B	Iran	1
Delta 4	US	2	Soyuz 2-1v	Russia	1
Rokot/Briz KM	Russia/EU	2	Super Strypi	US	1
Vega	EU	2	TOTAL		86

SOURCE: spacelaunchreport.com, Ed Kyle

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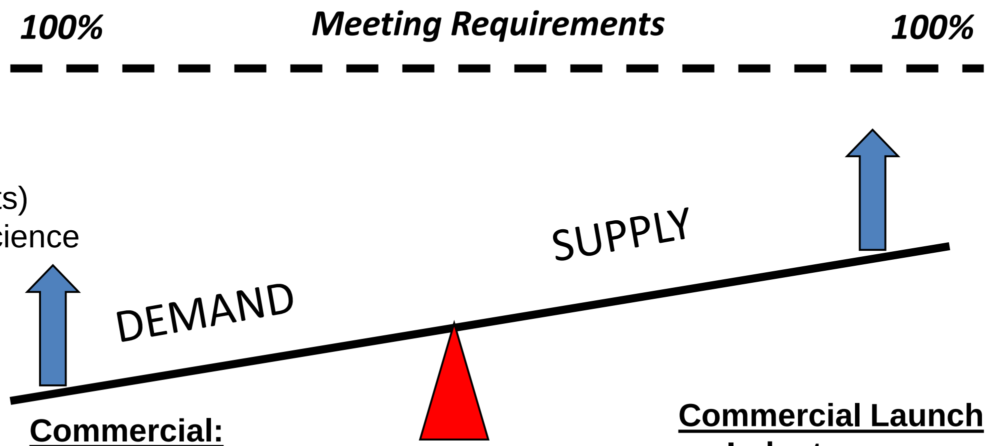
WHO CARES?

- **Becomes a balancing act between multiple, often competing interests of Users and Suppliers**
  - User's lower cost ≡ Supplier's lower price; lower ROS
  - User's higher availability & reliability ≡ Supplier's higher cost



Civil Government:
- Safety (Human Flights)
- Mission Reliability-Science Payloads
- Low Recurring Price

Government Launch Systems:
- Low Cost
- Maintain Industrial/Engineering Base

DOD:
- Mission Reliability
- Quick Response
- On Time Delivery

Commercial:
- Low Recurring Cost
- High Availability
- On Time Delivery

Commercial Launch Industry:
- Acceptable Investment Return
- Recurring Profitability

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WHY ARE YOU DOING THIS?

- **Approach to providing transportation services depends on interplay of several key considerations**
  - What missions are you supporting?
    - Up: Earth-to-orbit, in-space, sortie
    - Down: Return missions – e.g. X37, X38
      - Requires an earth-to-orbit system to perform mission
    - Where: Altitude and Inclinations
      - Orbital versus suborbital, Polar, due East, Geosynchronous Transfer, Low Earth, Space Station, other

- ***This discussion addresses earth-to-orbit transportation.***

  - A word about Shuttle – a unique system, performed multiple missions
    - Delivered earth-to-orbit payloads to multiple destinations
      - Civil governments, military, commercial
      - LEO, ISS, GTO
    - Other missions
      - Down payload, human transport, satellite service/rescue, on-orbit laboratory, etc.

WHY ARE YOU DOING THIS?

- **What is your motivation?** - Ultimately investments in reusable space transportation depend significantly on investors' motivations.
  - Financial: typically public company, shareholder value, end = make $
  - Capital investment decisions based on DCF or similar metrics

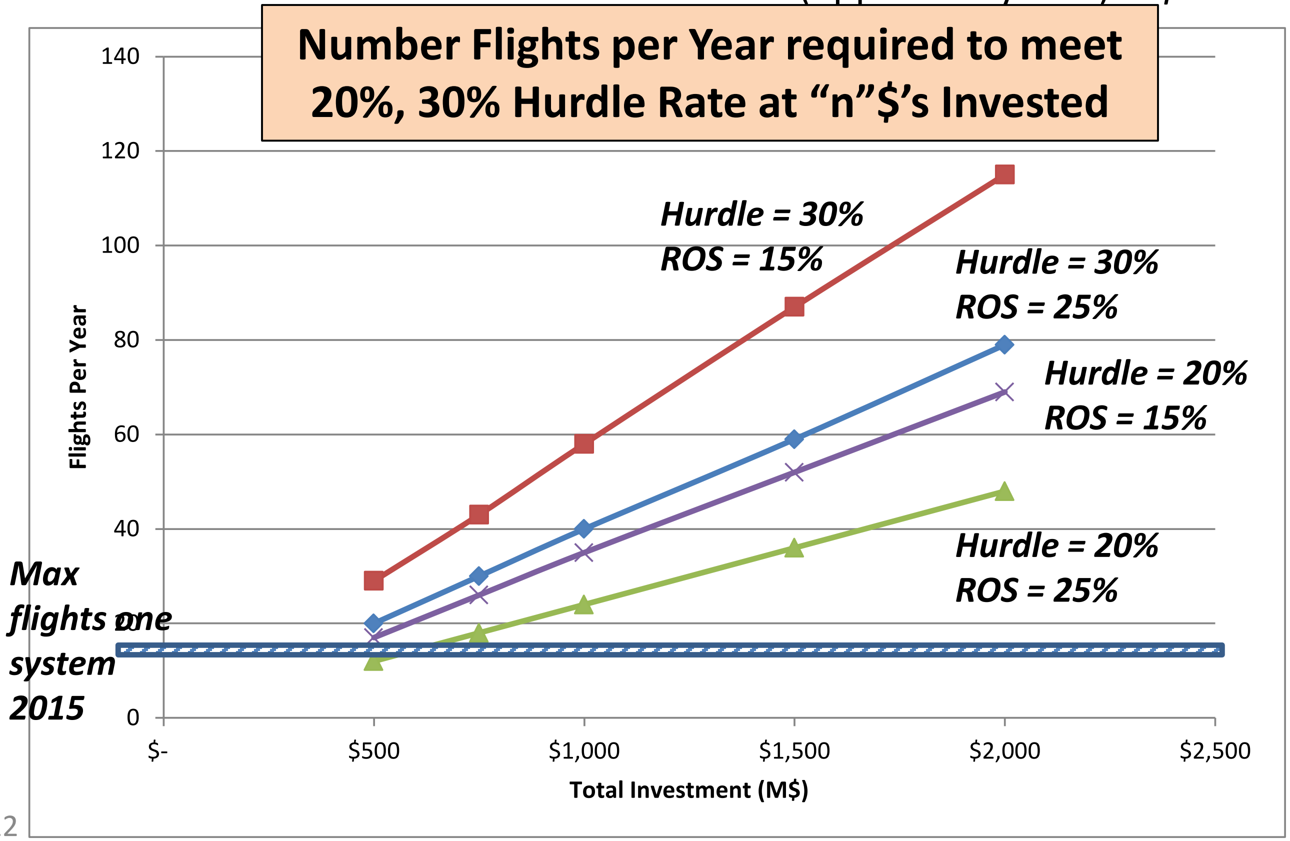
  Versus

  - Strategic: typically private company, means to make $ some other way (size of aperture) – anchor tenant, own means
  - Capital investment decisions can be based on other broader strategic considerations
    - DCF may be lesser priority

- **Other considerations**
  - Culture – risk tolerance
    - DCX, X33 compared to Falcon 9
  - Altruism – Ultimately economics must work
    - Altruism is unsustainable without subsidy

DCF AND REUSABILITY

- **Discounted Cash Flow (DCF) metrics generally work against investments in reusable systems**
  - Internal Rate of Return (IRR): Present value discount rate at which Net Present Value (NPV) is $0 = *quantitative*
  - Hurdle Rate: Decisional discount rate (opportunity cost) = *qualitative*



Assume:
- **Time Horizon: 10 yrs**
- **Years to IOC: 5 years**
- **Return on Sales (ROS): 25% and 15%**
  - **Price = $80M; Cost = $60M**
  - **Price = $80M; Cost = $68M**

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IF YOU BUILD IT THEY WILL COME . . .

- **Demand – arguably most important variable**
  - And most debated

- **Key considerations regarding demand for space transportation**
  1. Demand is *not* monolithic – market segmentation very important
     - Users (values), destination, weight, etc.
  2. "If you build it . . ." (implicitly at least) assumes new markets/users and/or significant expansion of existing users result from lower prices
     - Circular problem: high transportation cost prevents development of new space enterprises, keeps demand lower, transport cost high
       - E.g. Bigelow Aerospace
     - Low-cost-enabled ≡ the "killer app"
       - Nano/cube satellites (?): Exploding demand; over 100 launched in 2014 - See Spaceworks "2014 Nano / Microsatellite Market Assessment"

  3. **The "Holy Grail": ELASTICITY of DEMAND**

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Demand Elasticity

- **DEFINITIONS: Elasticity of Demand = % change in quantity demanded for a given % change in another variable (e.g. price)**
  - Typically discussed regarding price; but price is not only application
    - Increase in demand given changes in (for instance) availability
  - Elasticity is *not necessarily* constant for the same curve
    - Inelastic: % increase in demand less than % decrease in (price)
      - E.g. cigarettes, gasoline, national security space assets
      - Marginal Revenue < $0
    - Elastic: % increase in demand greater than % decrease in (price)
      - E.g. sports cars, vacations, cubesats (?)
      - Marginal Revenue > $0
    - Unitary Elasticity: inflection point between elastic and inelastic
      - Marginal Revenue = $0

- ***One of most important questions surrounding reusable/expendable decisions is: What is the (price) elasticity of demand for mission segments being served?***

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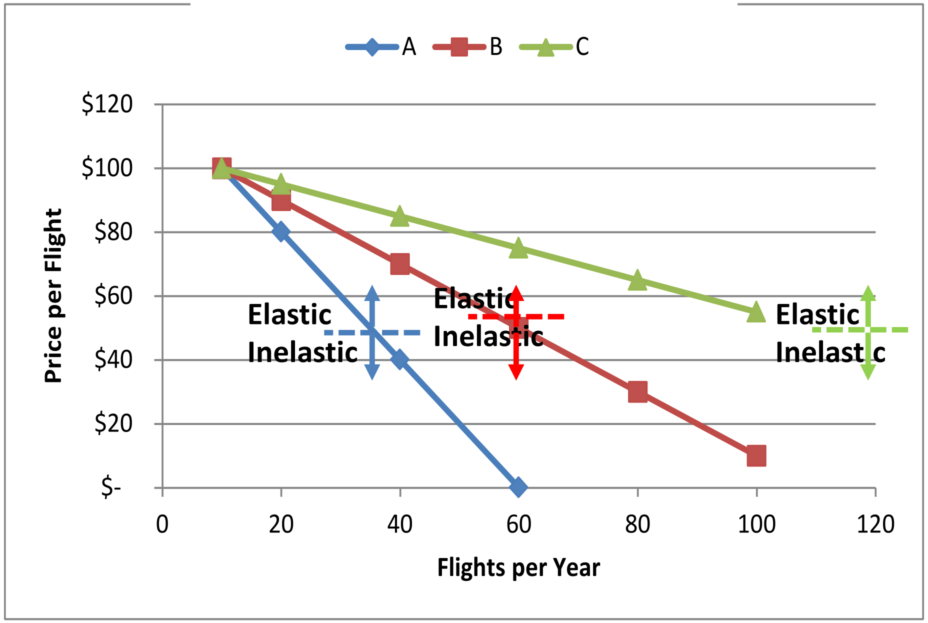
Demand Elasticity

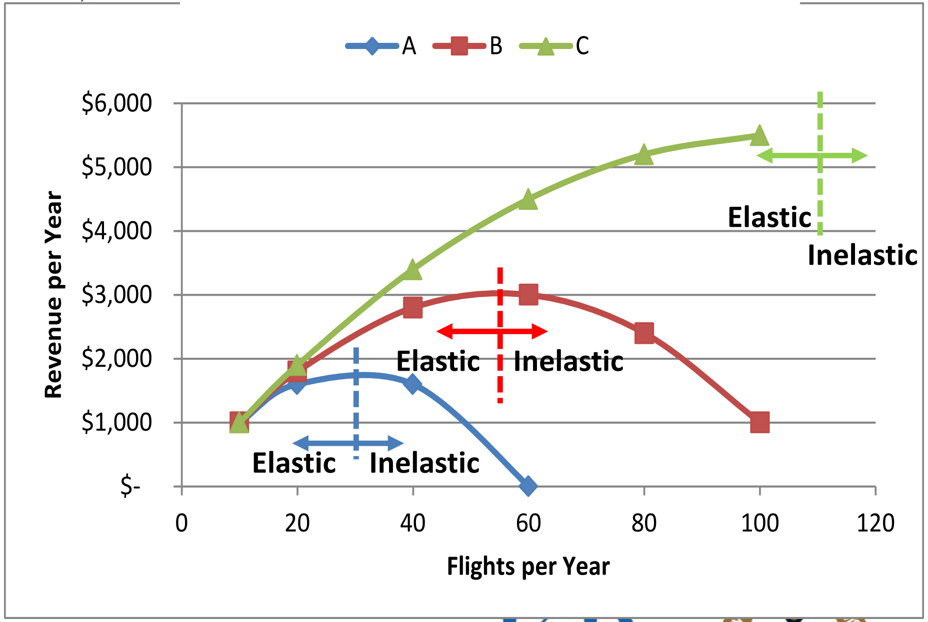
- At some point, "Order of Magnitude" reductions in <u>cost</u> per flight may or may not decrease <u>price</u> per flight

- ***Even if achievable, economics suggest there is a point at which reductions in price per flight will not increase quantity demanded sufficiently to support reductions.***
  - ***i.e. marginal cost > marginal revenue***

Demand (Flights) vs. Price



Revenue vs. Demand (Flights)



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Matter of Degree

- **Reusability is not monolithic**
  - What is reused? How many times is it reused? How is it recovered?
  - Rule of thumb: *The higher, faster, and farther a rocket stage goes, the more difficult and expensive it becomes to reuse it*
    - SSTO versus first stage versus multiple stages vs. components
  - Most current reusable developments are focused on recovering first stages or parts thereof
    - Falcon 9 (SpaceX): first stage powered vertical return (barge/land)
      - Reuse engines, first stage avionics, structures & mechanisms(?)
    - SMART (ULA): first stage engine/avionics module only, parachute return, recovered by helicopter
    - Adeline (Arianespace/ Airbus-Safran): first stage engines/avionics module only, glideback/propeller-driven, horizontal landing
      - *(Note – Blue Origin New Shepard and Virgin Spaceship II are sub-orbital)*

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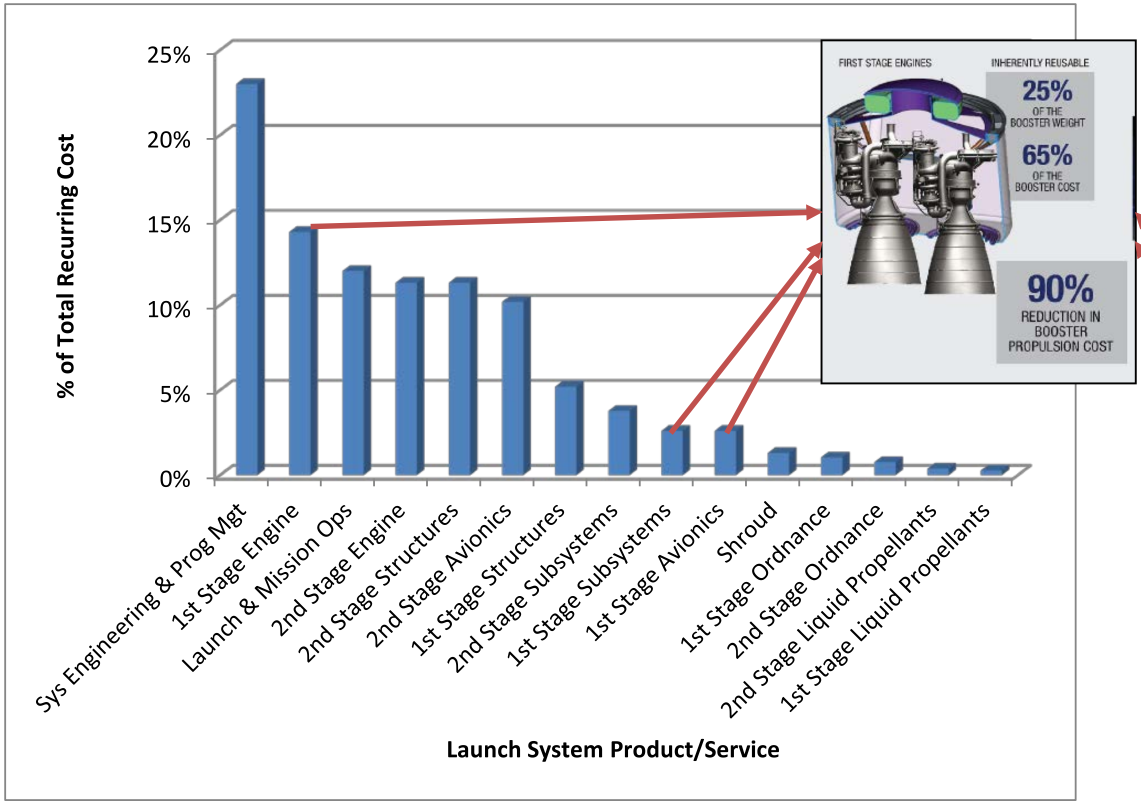
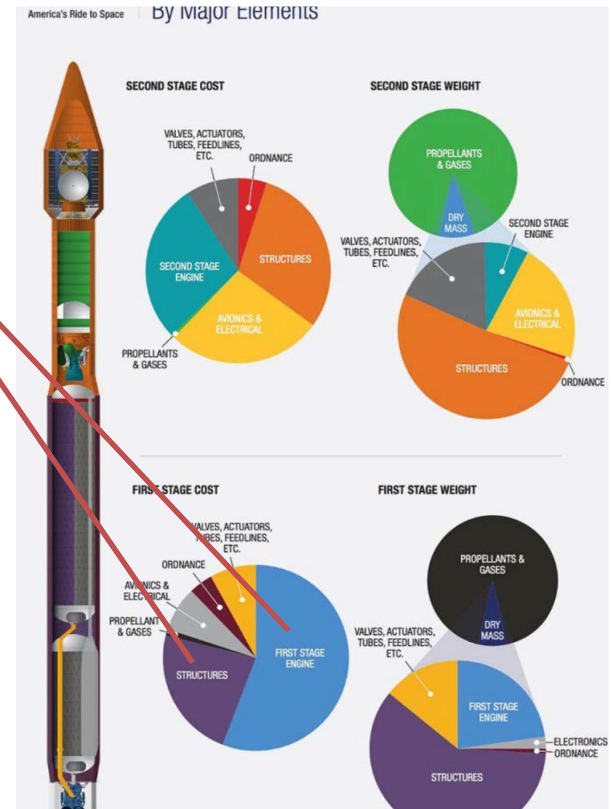
Cost of Transportation Systems

- **Recurring cost (not price), combined with cost-to-recover is a significant determinate for decisions regarding what to reuse.**





Source: www.soaceflightinsider.com/

- ***Recurring cost (not price), combined with cost to recover, significant determinate of decisions regarding what to reuse.***

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HOW MANY?

- **Fleet Size: Design Life versus Turnaround Time**
  - One or the other typically drives fleet size calculations
  - Depends upon what customer values – market segment
    - E.g. Fixed site versus "portable"; regular tempo versus sortie missions
- **"Hull insurance"**
  - Need to insure high value fixed asset – "fly through failure"
    - Experience has been must "self insure": build +1
      - Hull insurance (was; is(?)) not available from underwriters
- **Other significant considerations – the "sweet spot"**
  - Maintain production lines
  - Technology insertion points
  - Obsolescence
  - Fleet recapitalization
  - Attrition rate

- ***Determination of reusable system fleet size is very important decision***
  - ***Reusable vehicle is a fixed asset – needs to be utilized to peak capacity to maximize economics***

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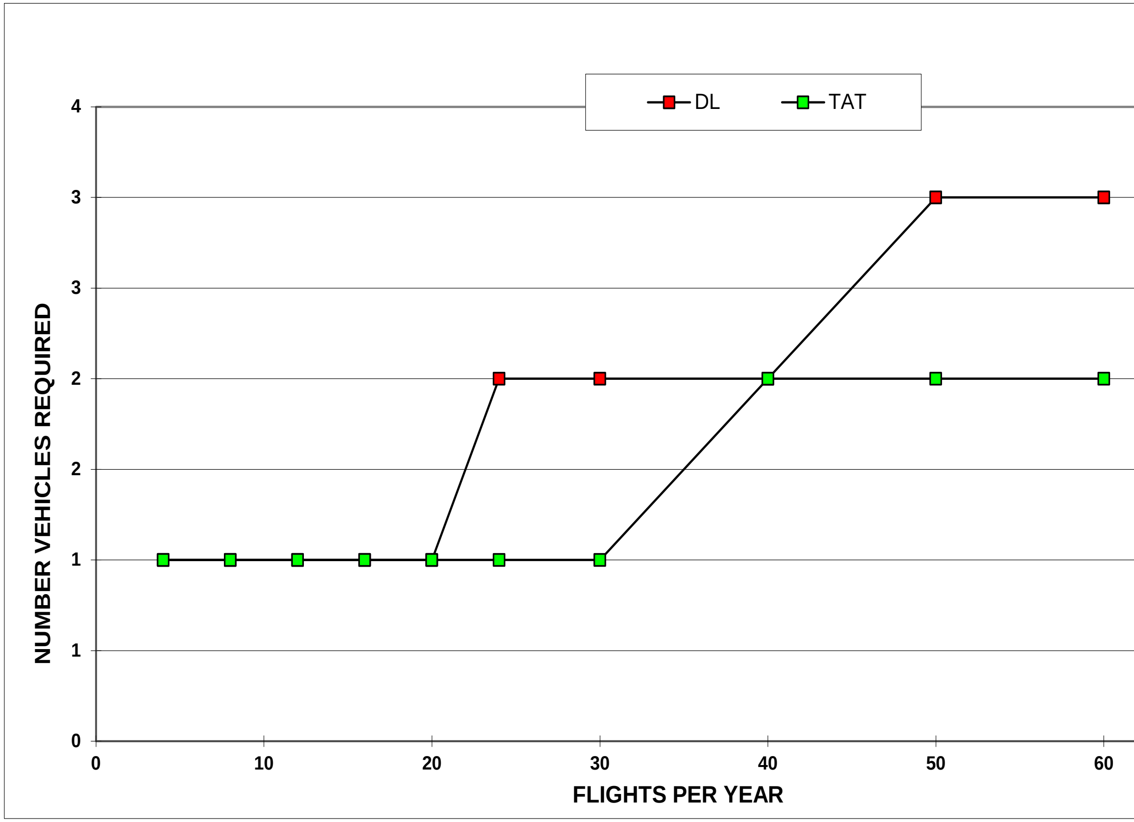
Design Life vs. Turnaround Time

- **Typically Design Life is determining factor**
  - Example: DL = 200 flights; TAT = 7 Days; 10 years operations



Number Years of Operations				10
Design Life (Total Flights)				200
Turnaround Time (Days/Flight)				7.0
Total Workdays/Year				250
		Vehicles Required:		
Flts/Yr	Cumul Flts	DL	TAT	Driving Reqt
4	40	1	1	Both
8	80	1	1	Both
12	120	1	1	Both
16	160	1	1	Both
20	200	1	1	Both
24	240	2	1	DL
30	300	2	1	DL
40	400	2	2	Both
50	500	3	2	DL
60	600	3	2	DL

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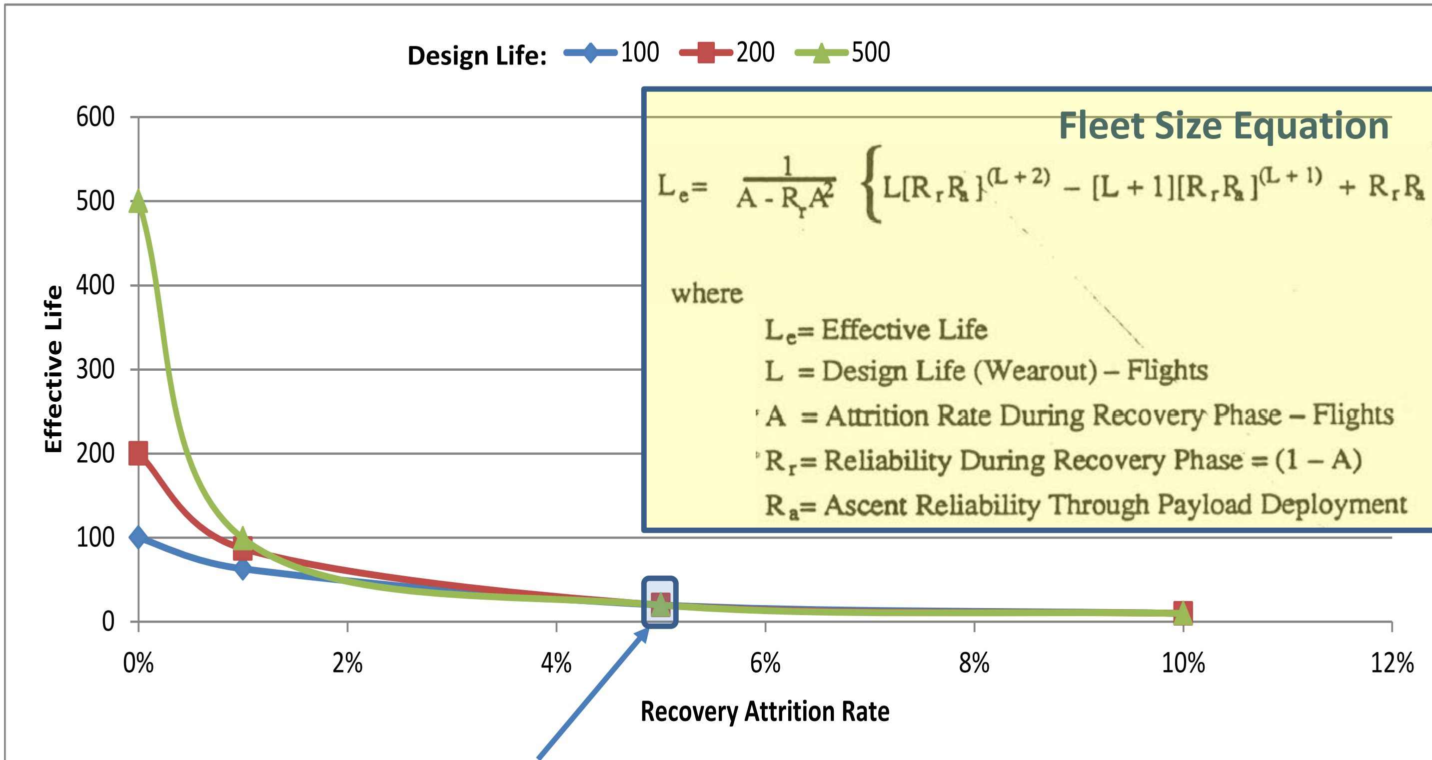
Design Life vs. Turnaround Time

- **Recovery attrition rate can have significant impact on fleet size requirement**
  - Same example: Add Recovery Attrition %
    - Assume ascent reliability = 100%



Fleet Size Equation

$$L_e = \frac{1}{A - R_r A^2}\left\{L[R_r R_a]^{(L+2)} - [L+1][R_r R_a]^{(L+1)} + R_r R_a\right\} + \left\{L[R_a]^{(L+1)}\right\}\left\{R_r^{\,L}\right\}$$

where

- L_e = Effective Life
- L = Design Life (Wearout) – Flights
- A = Attrition Rate During Recovery Phase – Flights
- R_r = Reliability During Recovery Phase = (1 – A)
- R_a = Ascent Reliability Through Payload Deployment

- ***At a design life of 200 flights, an ascent reliability of 100%, and a recovery attrition rate of 5%, the Effective Life of the system is 20 flights.***

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SIZE MATTERS

- **Truism: Cost increases as size increases**
  - Cost vs. mass for launch vehicles increases at increasing rate
    - Exponent > 1.00
    - Development and production
  - Reusability cost penalties as function of size
    - Additional subsystems:
      - Return (landing): landing gear and wings/tails, parachutes, retrorockets and landing legs, etc.
      - Thermal protection: max speed – staging (Mach "?") vs. orbital return (Mach 25)
    - Propellant reserve for powered return

- **Size is primarily determined by and factors into decisions regarding the other key considerations**
  - Meeting demand, degree, how many

CONCLUSIONS

- **Is Reusability Worth It?**

IT DEPENDS!

- **Important things to consider:**
  - **Who's doing it and why**
    - Motives matter – financial, strategic
  - **Demand for transportation**
    - Market Segmentation – customer valuations
    - Elasticity of Demand – price, other attributes
  - **Matter of degree**
    - Degrees and type – payload, stage, SSTO
  - **How many**
    - Fleet Size – design life and turnaround time
  - **Size matters**
    - Smaller the better