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Space Transportation Analysis

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Charles Cook

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PREFACE

This briefing was prepared for the Office of Science and Technology Policy under a task titled "Market Structure of U.S. Civil Space Launch."

CONTENTS

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EXECUTIVE SUMMARY

Current U.S. space launch capabilities remain both expensive and unreliable in terms of schedule and, to some extent, launch success. While much of this cost and unreliability can be traced to the risk and complexity inherent in space launch activities, it is often speculated by space launch professionals that the regulatory environment and current one-size-fits-all approach to launch systems contribute inordinate cost to civilian space activities. In addition, questions have been raised regarding the objectives and approach to assuring access to space through the use of multiple, largely redundant launch systems.

In this paper, the authors analyze the state of the current U.S. space launch industry, including the market environment, regulatory constraints, and the drivers of space launch costs and of launch vehicle reliability. The authors also conduct extensive analysis of the current policy of maintaining multiple launch vehicles in order to assure access to space as required, including evaluation of potential consolidation options and analysis of payload scheduling under multiple scenarios for maintaining U.S. space launch capabilities.

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Space Transportation Analysis

Conducted for: OSTP

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Background

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In the process of conducting fact-gathering interviews and data collection, the team uncovered a number of insights regarding the current regulatory environment for space launch activities.

Task Participants

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- Science and Technology Policy Institute
  - Dan Garretson (Task Leader)
- Cost Analysis Research Division
  - James Woolsey
  - Bruce Harmon
  - Emile Ettedgui
  - Shaun McGee
- Science and Technology Division
  - Marshall Kaplan
- Systems Evaluation Division
  - Charles Cook

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The analysis that follows was conducted by a cross-divisional team from the Institute for Defense Analysis.

Tasking

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- STPI is a federally funded research and development center operated by the Institute for Defense Analyses
- This work was commissioned by OSTP on January 7, 2004, and is intended to address:
  - U.S. launch requirements (including government, commercial, and civil/science) over the next 10 years.
  - Options for managing ongoing U.S. investment in the Evolved Expendable Launch Vehicle (EELV) program.
  - The costs and benefits of maintaining 2 EELV providers.

This study examined the space launch market in order to characterize demand (including commercial, civil, and military demand) for launch services through 2015, assess current launch capabilities, and evaluate trade-offs among potential options for addressing launch service demand.

This briefing is divided into 4 major sections:

1. Regulatory insights
2. Market analysis
    a. Overview
    b. Small launch vehicle market
    c. Large launch vehicle market
3. Multiple EELV analysis
    a. EELV option analysis
    b. Launch delay analysis
    c. Launch delay analysis: 2% failure rate
    d. Alternative switching options
    e. EELV reliability discrimination
4. Launch vehicle reliability analysis

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Regulatory Insights

In the process of conducting fact-gathering interviews and data collection, the team uncovered a number of insights regarding the current regulatory environment for space launch activities.

Interview Caveats

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- Insights are based on a limited number of interviews
  - Primarily commercial launch providers
  - No direct range safety or regulatory input
- Insights involve limited, if any, independent analysis – primarily reporting what was heard

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The team deemed the regulatory findings from preliminary interviews interesting enough to be reported to OSTP. But because regulatory issues were outside the primary scope of the task, the team did not pursue follow-up interviews or in-depth analysis.

Launch Market Observations

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- Common interview thread: government interventions distort the market
  - National interest creates excess capacity
  - Subsidization distorts pricing
  - Export controls limit flexibility
- The result: supply is regulated but demand is not so that launch rate capacity is >2x launch demand
- Anecdotal evidence suggests launch prices are down 40% to 50% in the last 3 years
- At <30 launches per year, economies of scale aren't likely to materialize

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Interviewees made a number of observations about the global space launch market, as noted above. The principal observation reflected in multiple interviews is that most spacefaring countries see space launch capabilities as a matter of national security. As a result, countries push capability development even though launch capacity is currently more than double launch demand. Overcapacity then drives commercial launch prices down as suppliers compete for limited commercial business, limiting opportunities for companies to amortize infrastructure development and vehicle design with launch service revenues.

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Models of Government Support

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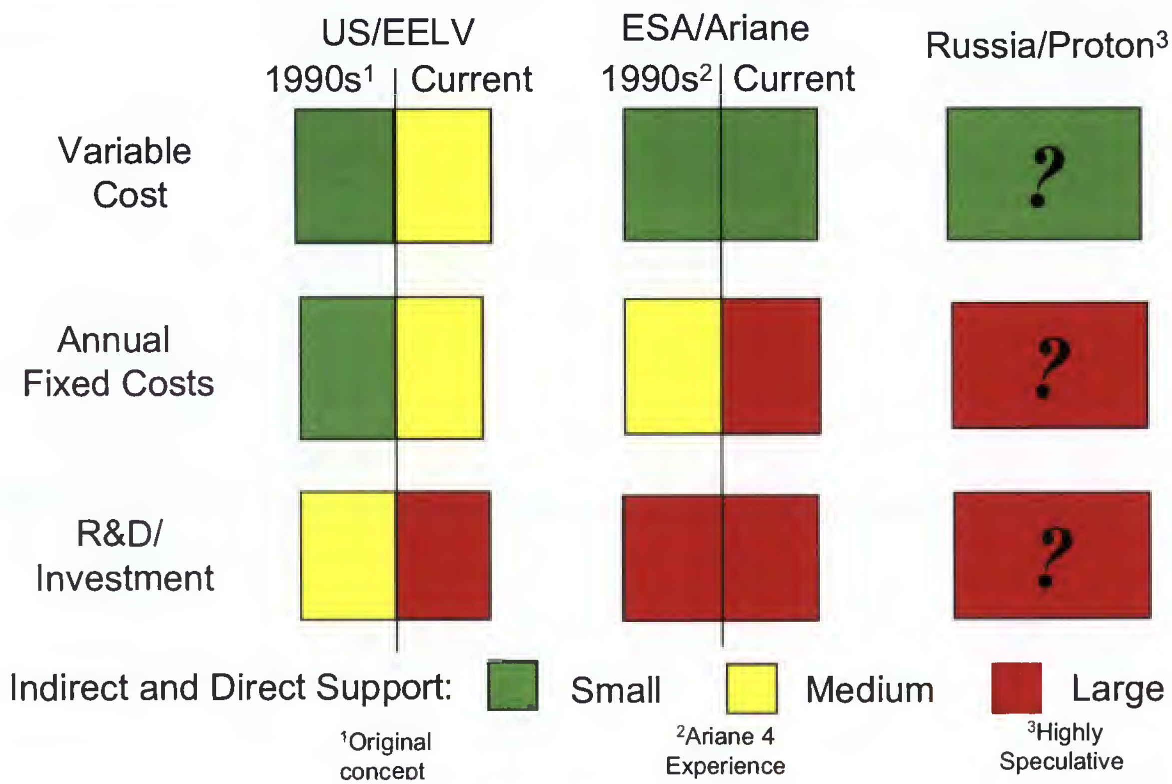

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To ensure that suppliers maintain capabilities, government customers typically subsidize launch service providers in some form. The form of these subsidies, however, varies substantially. Based on limited open source data, the team has characterized the level of subsidies as shown; further research would be required to characterize the actual value of the subsidies.

Example of subsidization include:

- With demand down, commercial prices have decreased. To sustain launch providers, the government has increased launch service payments for government launches: a variable cost subsidy.
- US launch policy currently keeps two launchers in business in order to ensure redundancy. Overall demand, however, would likely not support even one.
- Europe directly subsidizes launch vehicle development. On February 6, 2004, the European Guaranteed Access to Space (EGAS) program provided 960M Euros for further Ariane 5 development.

Key findings from the team's interviews and research include:

- The level of government subsidies increased as the commercial market collapsed.
- Due to the significant variation in the form of subsidies, it would be very difficult to directly compare launch subsidies in order to successfully negotiate with other nations to manage/rationalize the global launch market among countries.

Launch Market Insights

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	Insight	Implication
Market Elasticity	• For most products/services that rely on space, launch costs are a minor component → non-elastic markets – Satellite TV – Fixed communications • Few potential products/services are dominated by launch costs – University experiments – Tourism	• Even significant launch cost reductions may result in minimal market impact • There may be no reasonable near-term prescription for launch services providers
Applications	• Applications drive (and will continue to drive) launch services demand. Possible future applications include: – Mobile radio and data – Broadband to rural subscribers – Mobile video	• Regulations that impact satellite-delivered services may drive launch demand – Universal access
Technology Impact	• External technology changes may fundamentally alter demand picture – Better transponders could make satellite-based mobile communications more competitive with ground-based mobile – Micro-Electro-Mechanical Systems (MEMS) technologies may increase the satellite value without increasing weight	• Investments that focus on external technologies may drive launch demand. However, these opportunities seem to be limited over the near term.

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Despite the cost of launch services, these costs represent a relatively small fraction of satellite-based business models. In most cases, even if launch costs were zero, launch service demand would not increase significantly—almost the definition of an inelastic market.

For example: DirectTV maintains 7 satellites. But with annual costs that are >$7 billion, satellite-related costs represent less than 5% of total costs. Clearly, satellite and launch costs do not substantively affect DirectTV's overall business.

While new applications and technologies may drive increased demand (as indicated in the chart), the team believes these opportunities are limited and will result in minimal impact over the near term.

Regulatory Issues – ITAR

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- ITAR affects all commercial launch scenarios
  - Even a U.S. satellite on a U.S. launcher out of a U.S. site requires tech transfer approval
- ITAR approval processes are confusing
  - People don't know who to talk to or how long it will take
  - Rules are ambiguous – outcome of license requests is dependent on who the reviewer is
- It is widely believed that ITAR has harmed the U.S. space launch and satellite industry rather than limiting any other country

Many interviewees focused on the alleged detrimental effects of International Traffic in Arms Regulations (ITAR) on the commercial launch market (and the commercial satellite industry in general). Given other priorities of the study, the team did not conduct a more detailed investigation of the impact of ITAR.

Regulatory Issues – Immigration

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Claim from interviews: Immigration policies and practices enable foreign technology development while limiting US companies

Issue	Claim	Implications
U.S. Work Force Limitations	• US companies face substantial barriers to hiring foreign talent	• US companies can't hire from the broadest pool of talent
Foreign Skills Development	• Talented foreign engineers often can't pursue training in the U.S. • When they can, they are often forced to return home after completing their studies	• Launch professionals develop capabilities and technologies elsewhere • Foreign nationals take US expertise home with them

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A small number of interviewees claim that immigration policy also harms the U.S. launch industries by limiting opportunities for U.S. use of foreign labor. As a result, foreign workers who would like to work on space launch development end up supporting the development of foreign launch capabilities.

Because of study priorities, the team did not conduct further research or analysis on immigration issues.

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Regulatory Issues – Environment

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Claim from interviews: The environmental burden on space launch providers is high

- Launch services providers have to provide environmental certification for every launch
  - Cost impact: hundreds of thousands of dollars per launch
- Aircraft enjoy a categorical exclusion for essentially equivalent fuels

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Most interviewees agree that environmental concerns add substantial cost to launch services and could be mitigated through logical exclusions, but the impact of these costs varies. For large launch providers, these costs are a nuisance, representing only a small fraction of launch costs. Small launch providers and startups, however, see these costs (and the associated approval times) as a significant barrier to innovation.

Because of study priorities, the team did not conduct further research or analysis on environmental compliance issues.

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Range Safety Requirements

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- Claim from interviews: No range safety incentives to ensure timely launches
  - Alleged result: the imposition of many requirements that impose substantial cost but result in, at best, marginal safety benefits
- Range safety equipment requirements are allegedly obsolete and costly:
  - Piece part traceability assumes small component production runs with limited reliability
  - Destructive termination requirements assume inability to effectively terminate thrust
    - May increase ground risk
- Result: Significant cost burden on small launch services providers (e.g., ~10% of launch costs for the Falcon I (SpaceX))

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Some interviewees believe range management practices limit launch responsiveness and impose significant additional time and cost for little benefit. As with environmental protection, this is seen primarily as a nuisance issue. However, range safety regulations can drive significant cost increases for entrepreneurial launch service providers, limiting opportunities for new entrants into the launch markets.

Because of study priorities, the team did not conduct further research or analysis on range management issues.

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Market Analysis: Introduction

Developing an understanding of launch markets and opportunities was a primary focus. This section provides an overview of this launch market analysis.

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Three Launch "Markets"*

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Market	Approximate Weight Range	Current U.S. Capabilities
Small Sat	• Less than ~1,200 kg to LEO • Less than ~900 kg to SSO	• Orbital Sciences Corporation – Pegasus ($23M - $27M) – Commercial Taurus ($38M - $46 M)
Medium Sat	• ~1,500 kg to ~4,500 kg to LEO • ~1,000 kg to ~3,300 kg to SSO • Less than ~2,200 kg to GTO	• Boeing Corporation – Delta II ($50M - $72M)
Large Sat	• ~5,000 kg to ~23,000 kg to LEO • ~3,500 kg to ~21,000 kg to SSO • ~2,500 kg to ~13,000 kg to GTO	• Boeing Corporation – Delta IV ($87M - $160M) • Lockheed-Martin – Atlas V ($96M - $124M)

*Defined by capabilities. Excludes the Shuttle

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The team identified three primary launch markets and associated launch capabilities, as outlined in the chart.

Key Insights

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- Space launch is difficult
- Launch requirements are almost entirely driven by governments
- Reliability is almost entirely based on experience
- Launch volume is the critical driver of reliability and cost

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As the team's interviews and analysis showed, it is difficult to overstate the complexity of space launch.

In this context, it is useful to understand the key drivers of launch costs and reliability. These include:

- Government requirements. As the primary buyer of launch services, governments determine the specifications and requirements and, as a result, key components of the costs.
- Launch vehicle reliability is highly dependent on the level of experience with the vehicle – vehicles that have been in service longer have had more time for flaws to be identified and eliminated.
- High launch volume allows companies to amortize the substantial fixed costs associated with launch services and increases experience levels with launch vehicles.

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Small Launchers - Summary

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- Current market provides little incentive for commercial entry
- Government has two programs to create low-cost launchers
- Several stimulus options, but significant uncertainties remain for all options

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The small launch market is a particularly difficult market. Despite possible growth in demand (e.g., U.S. responsive launch needs), there is currently little commercial or government demand for small satellites. While the government has some options for stimulating the growth of the small launch vehicle market, the team identified no compelling rationale for doing so in the current demand environment.

Large Launchers - Conclusions

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- Current market provides no incentive for commercial investment
- EELV program currently structured on a philosophy of assured access – but benefits may be illusory
- Higher launch rates should drive increased reliability and lower launch costs – but few obvious mechanisms for increasing volumes
- NASA payloads may provide opportunities for increasing EELV volumes over the next 15+ years

The large launch vehicle market also poses significant challenges, but government requirements dictate that significant capabilities be maintained. However, the current approaches to maintaining the capability may not provide the benefits that government buyers believe.

Given that large launch vehicles are required, increased reliability and decreased launch costs are desirable, but few obvious mechanisms exist to create these benefits. One possibility: using existing launch services for future launches (e.g., associated with the vision for space exploration announced in January 2004).

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Market Analysis: Small Launch Vehicles

This section provides the small launch vehicle analysis.

Smallsat Overview

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- Smallsat manufacturers face unattractive launch prospects
  - Few dedicated launch alternatives
    → dedicated launches are high cost
    (> $10,000/lb)
  - Limited opportunities to piggyback on larger launchers
    - Primary requirements outweigh secondary requirements
    - Primary launch buyers resist secondary payloads
  - Foreign launchers
    - Salvaged Russian ICBMs reported to be 1/3 of Pegasus cost
    - Export controls raise barriers → increase costs

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The smallsat market is extremely unattractive for both satellite manufacturers and launch service providers. As already noted, current smallsat launch options are high cost and relatively limited.

Providers' Perspective

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- Hypothetical business model in today's environment:
  - $10,000 per pound launch prices
    - ➢ Corresponds to reported price of Pegasus launch
  - Low launch rates
    - ➢ Orbital Sciences' Pegasus has averaged 3 launches per year
  - 5-year development time
  - Varied a number of assumptions
    - ➢ 10- or 15-year time horizons
    - ➢ Cost per launch from $7M to $12M
      - Range of public estimates for Pegasus
    - ➢ Development cost from $50M to $150M
      - Range of estimates for Pegasus

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But while many entrepreneurs have tried to enter the smallsat launch service market, the business environment poses extremely large challenges. To understand the business environment, the team constructed a hypothetical business model for smallsat launch services.

Small Launch Biz Case – 10 Yr Horizon

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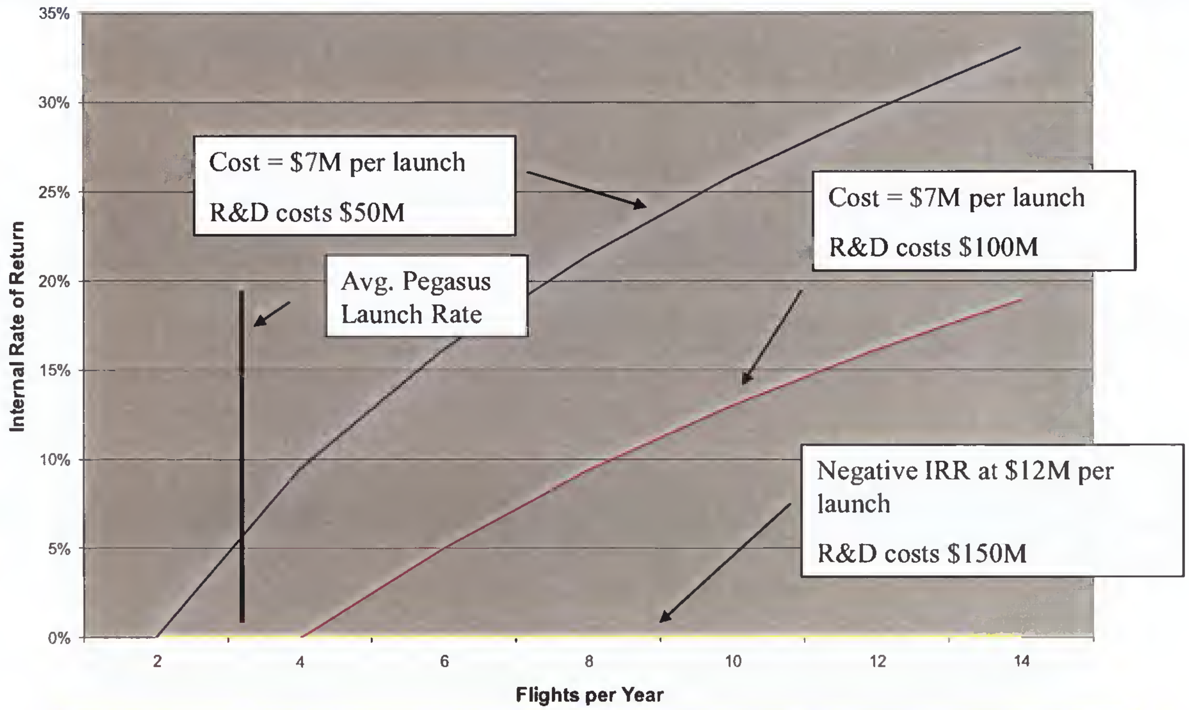

It is difficult to make a strong 10-year business case

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Given the high risk associated with developing a new launch capability, investors would reasonably expect a minimum of a 20% to 30% rate of return. But even aggressive assumptions regarding development (e.g., R&D costs of $50 million and a 10-year payback horizon) require extremely high launch rates relative to historical launch rates for small launch vehicles to achieve these returns. Higher development costs quickly make it virtually impossible to achieve a reasonable business case.

Small Launch Biz Case – 15 Yr Horizon

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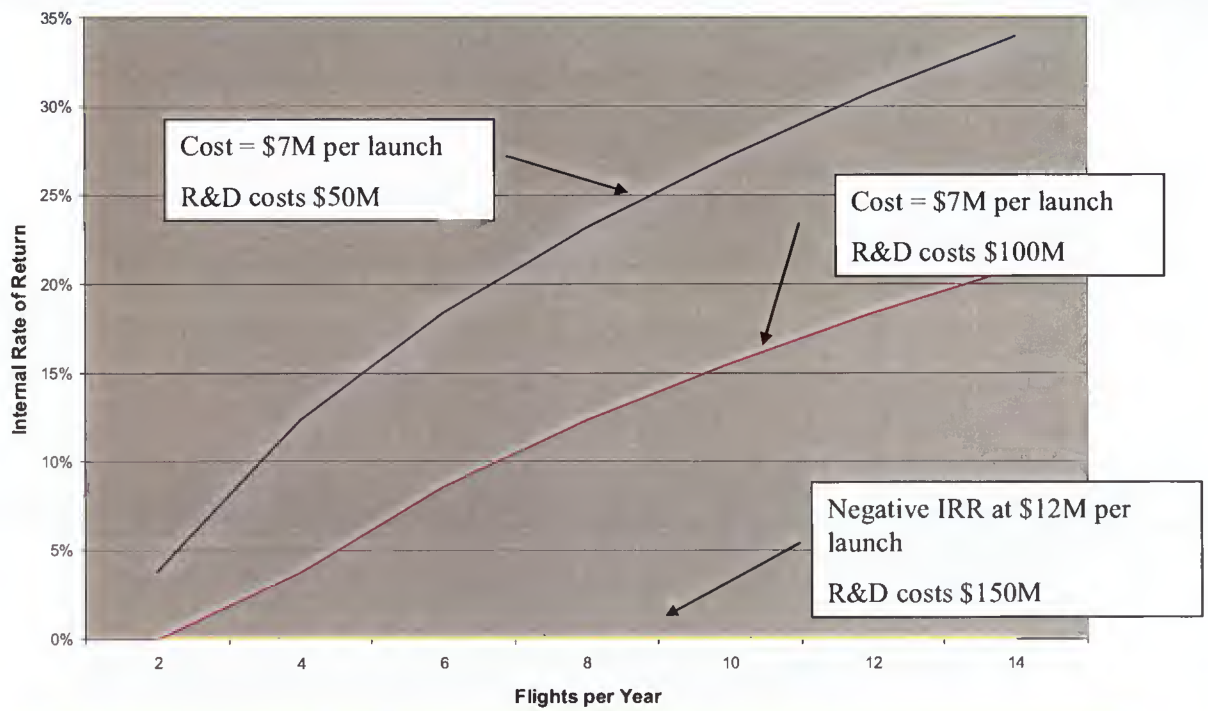

15-year horizon improves IRR but can only make a strong case at high launch rates

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Increasing the payback horizon to 15 years provides only marginal improvements in the business case.

Business Case at Lower Prices

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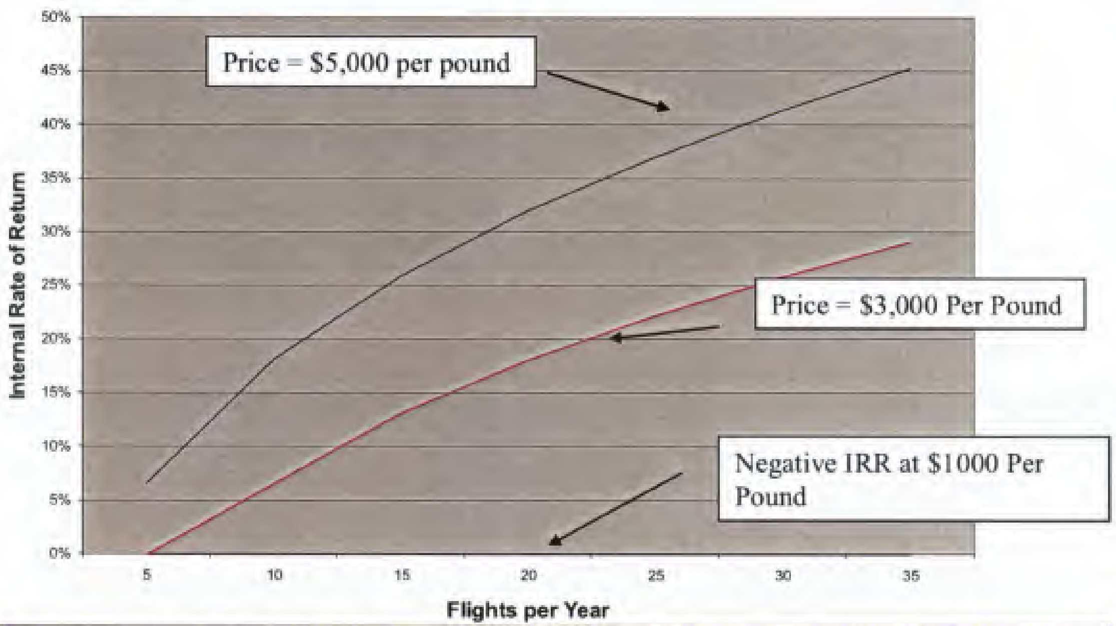
Return on Investment for Small Launchers



Must make extremely optimistic assumptions about demand and costs to create a viable case

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At lower prices per pound than those achieved by current providers (specifically, Orbital Sciences with the Pegasus launch vehicle), a workable business case requires extremely high demand. The team believes that such high levels of demand are very improbable at these prices.

Government Involvement

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- Building business case on non-government demand requires great amount of speculation
- Therefore: if firms are to become interested (and build a better mousetrap), U.S. Government will have to demonstrate commitment to Smallsat launches
  - Government is SpaceX's first customer
  - US Government is 67% of Orbital's business
  - Is TACSAT a precursor to this higher commitment?
  - Could responsive launch be another?
- Creating demand is the kind of blunt instrument government uses well
  - WW2 created demand for airplanes
- As opposed to lower-level involvement
  - X-33, Oil Shale, pick your failure

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Development of a viable small launch vehicle market would likely require significant speculation and, in particular, government interest in small launch capabilities. Some current ideas may offer promise (e.g., the push for responsive launch), but specific requirements have yet to be worked out.

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Stimulating the Smallsat Market

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- Subsidize supply
  - Subsidize launch costs
  - Develop low-cost launchers
  - Use retired ICBMs
  - Lower regulatory burdens
- Pump up demand
  - Military applications
  - Science grants and subsidies

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Creating a robust small launch vehicle capability could be pursued either by subsidizing vehicle supply or driving increased demand.

Supply-Side Subsidy Options

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Option	Description	Strengths	Weaknesses
Launcher Subsidy	• Subsidize the cost of twenty 500–1,000 lb launches to create a $3,000/lb launch price • Total cost: ~$100M–$250M	• Creates demand elasticity data point • May create incentives for launcher innovation (if market emerges)	• Short-lived experiment • May not create demand • May show demand at unrealistic cost levels
Cheap launcher development	• The Federal Government foots the bill for development of a low-cost launcher	• Government takes the risk for launcher development	• Programs of this sort (both commercial and government) have been tried regularly over the last 2 decades – and ***none*** so far have succeeded • Significant demand to justify the investment may not exist at resulting price levels
Excess ICBM Conversion	• The Federal Government makes excess missile assets (MinuteMan and PeaceKeepers) available to industry for refurbishment and re-use as launchers	• Takes advantage of existing assets that otherwise would be destroyed • May reduce launch costs for small satellites for many years (>400 Minuteman launchers)	• May be cost-prohibitive relative to other options • If practical, would be competitive with commercial small-launcher development activities • Payload capacity would be limited

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The U.S. government has a number of options for subsidizing small launch vehicle development, but all options have significant weaknesses.

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Issues with Refurbishing ICBMs

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- Nearly as bad as starting over on a launcher development program:
  - Must create payload interfaces and fairings
  - May have to perform extensive refurbishment of ICBM stages
  - May have to add new stages to ICBM stages
  - Must upgrade avionics and guidance systems
  - Must add flight termination systems (FTS)
  - Requires extensive testing for qualification
- Refurbishment costs would likely be at least $5 million to $10 million per launch plus one-time development costs
- Ultimately, the payload environment (in terms of vibration and acceleration) may still be unacceptable for most satellites

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The use of excess intercontinental ballistic missile (ICBM) assets has been proposed for small launch vehicles, but this option would be unlikely to significantly reduce launch costs.

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Demand Side Subsidy Options

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Option	Description	Strengths	Weaknesses
Subsidize university small sat development	• Allocate funds for university small sat programs, e.g.: – 10/yr at $15M–$20M per satellite + $6M per launch = $210M–$270M	• Provides educational opportunities for new satellite development • Supports experimentation with both satellite and launch vehicle technology	• Not likely to produce significant scientific results – focus is on education • Possibility of low-cost (~$6M) launchers remains unproven • May not lead to sufficient launch rates to drive innovation
Fund ORS testing and development	• Allocate funding for ORS development – Test program – Satellite technology development	• Low initial investment required to validate concepts • May not require additional allocation due to DOD activities already in process	• Not clear that satellite technologies can provide sufficient capabilities in small payloads • May require significant investment to create operational capabilities

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As with supply-side subsidies, demand-side subsidy options have significant weaknesses.

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Operationally Responsive Spacelift

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- Operationally Responsive Spacelift (ORS) is not well defined at present
  - DoD Space Architect working on requirements
- Requirements under discussion focus on:
  - Time: Rapid deployment (hours to days)
  - Technology: Highly capable small satellites
  - Cost: Low-cost space launch services for small satellites

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Some military planners deem operationally responsive spacelift to be increasingly important for future national security space capabilities. ORS requirements could conceivably stimulate the small launch vehicle market, but these requirements remain undefined at present.

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Hypothetical ORS Scenarios

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Increasing Launch Rate ↓

Program Type	Description	Examples/Example Scenarios	Launch Rate
Technology Demonstrator	• Test new capabilities for possible future deployment	• TacSat	• ~1 launch/year
Asset Replacement	• Smallsat constellation replaces failed or damaged assets	• Large, critical capabilities unexpectedly fail • Adversaries disable or destroy assets on orbit	• Rarely used surge capability of ~5–10 launches • Average <5 launches/year
Contingency Capability	• Smallsat constellation allows rapid capability deployment as needed	• Remote sensing intelligence needed for emerging, high-priority "hot spots" • Military action requires surge communication capability	• Occasionally (~ once per year) used surge capability of ~5–10 launches • Average 5–10 launches/year
Routine Capability	• Smallsat constellation allows regular, rapid capability deployment	• Remote sensing intelligence needed for emerging "hot spots" • Military action requires surge communication capability	• Regularly (several times per year) used surge capability of ~5–10 launches • Average 10–30 launches/year

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A number of scenarios have been proposed for ORS.

ORS-Related Programs

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- Several programs are in-process to develop and test applicable capabilities
  - One ongoing commercial project
    - ➢ SpaceX (Falcon)
      - Goal of $6M launch of 1400 lb to LEO (~$4,300/lb)
      - First launch projected this year (Q2 or Q3)
  - Two government projects
    - ➢ RASCAL
      - 100-300 lb to LEO at $5000/lb
      - First launch planned for 2006
    - ➢ FALCON
      - Goal of 1000 lb for $5M by 2010
      - 6+ competing contractors (including SpaceX)

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A number of programs are currently being pursued for the development of ORS capabilities.

Small Launchers - Conclusions

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- Current market provides little incentive for commercial entry
- Government has two programs to create low-cost launchers
- Several stimulus options, but significant uncertainties remain for all options

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Market Analysis:
Large Launch Vehicles

This section provides the market analysis for large launch vehicles.

Medium/Large Launcher Overview

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- Market environment has soured significantly
  - Decreasing demand
  - Increasing launch rate capacity
- Foreign launchers significantly underprice domestic capability
  - Boeing has pulled out of the commercial market – it simply isn't cost competitive with other suppliers
- No commercial incentive for further development

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The market environment for large launch vehicles has soured significantly—at least relative to projections—over the last 5 years. As a result of inflated market projections in the late 1990s, launch vehicle suppliers built the capability to support high launch rates, but the projected launch rates never materialized.

In addition, foreign launch service providers significantly underprice domestic providers, with the immediate result that Boeing is not selling Delta IV services to the commercial market.

Given these conditions, there is essentially no commercial incentive for further development. Domestic launch providers are willing to supply launch services for the government only if the government covers all costs.

Business Case that Created EELV

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- Current EELV Two-Launcher program created in 1998
- Contractors could justify investment based on launch prices and projections at that time

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The primary U.S. large launch services are based on the Boeing Delta IV family of launch vehicles and the Lockheed Martin Atlas V family of launch vehicles. Together, these launch vehicle families make up the Evolved Expendable Launch Vehicle program.

When the EELV program was created in 1998, the justification rested on projections at the time of relatively high demand for launch services.

Changes to Worldwide Demand

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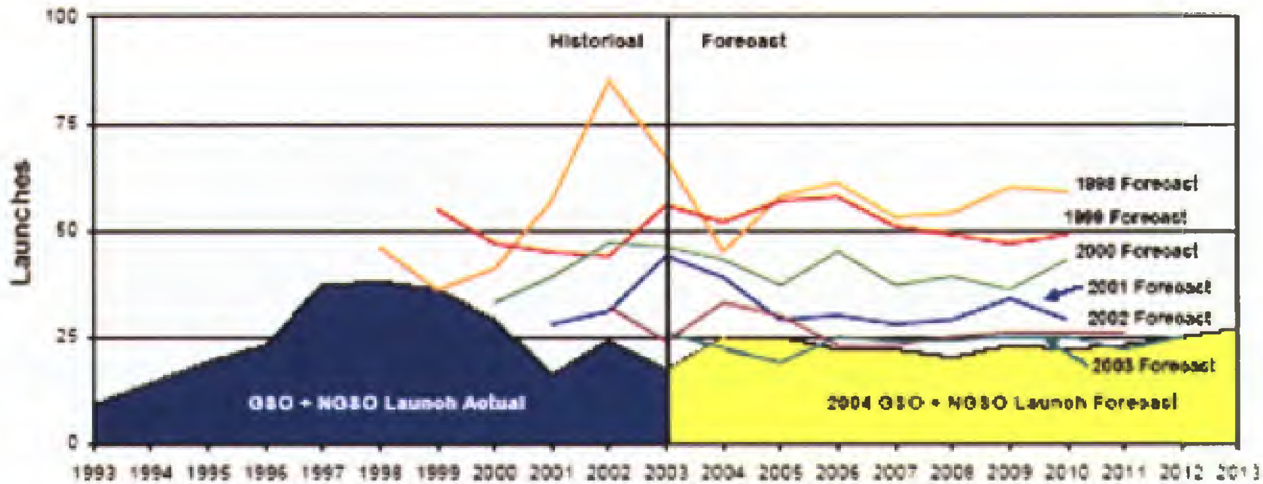
COMSTAC Forecast Trends for Commercial Launches



Projected demand has dropped dramatically since 1998 EELV decision

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A major source of launch service demand has been the Commercial Space Transportation Advisory Committee (COMSTAC) of the Federal Aviation Administration. In 1998, COMSTAC projected average commercial launch service demand of 64 launches per year (including both geosynchronous and non-geosynchronous launches).

By 2004, the projected average was fewer than 24 commercial launches per year.

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Launch Prices

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- General agreement that prices have dropped significantly since 1998
  - One interviewee estimated that prices have dropped 35% from late 1990s peaks
  - Proton prices reported to have been as high as $90M per launch, recently as low as $48.3M (MEASAT III)
- Dropping prices are characteristic of market with excess supply
- Expiration of treaty with Russia has also contributed to falling prices

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As a result of the lower demand for launch services than projected in the late 1990s, launch prices have dropped substantially.

In 1995, the U.S. signed a START I SLV (Space Launch Vehicle) Revision that limited Russia's ability to convert excess missile assets to space launch vehicles. This treaty provision has since expired, allowing Russia to increase its use of excess missile assets and thereby increase launch capacity even further.

Consequences of Changing Market

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- EELV suppliers are facing money-losing businesses
  - Boeing has already written off $0.8 billion and declared exit from commercial launch business
- EELV launches beyond the current contract must come at higher prices
- No contractor will make investment in new or improved launch systems

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As a result of these market dynamics, the EELVs have become money-losing businesses for the EELV providers. In this context, launch service providers have no incentive to make investments in the systems beyond what the government will pay for, generally through higher prices for launch services.

Large Launcher Imperatives

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- Maximize reliability/availability
- Minimize cost
- One key to both: Maximize the launch rate per launcher
  - Directly impacts costs per launch
  - Indirectly impacts reliability

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Although launch service suppliers are reticent to invest, the U.S. government has an ongoing need for launch services. U.S. imperatives with respect to launch services are to maximize reliability and availability while minimizing cost.

But the central problem for the large launch vehicle industry in this context is that higher launch frequencies are critical to reducing costs and, ultimately, increasing reliability.

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Options for Increasing EELV Volume

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Option	Description	Strengths	Weaknesses
Consolidate Delta II Volume on EELVs	• Encourage NASA to develop future payloads for EELVs – *not* the Delta II	• Increases launch volumes for the EELV – *May* bring launch costs for medium EELV in line with Delta IIs • Excess EELV capacity may allow: – Additional science opportunities on NASA missions – Piggyback payloads at low incremental costs	• The Delta II has proven to be extremely reliable – payload costs are such that the risk of using an unproven launcher is seen to outweign the benefit • Excess capacity may lead to scope (and budget) creep, outweighing cost savings • Science missions are one of a kind – may be difficult to coordinate multiple payloads
Keep exploration missions in the EELV payload range	• Direct NASA to size exploration missions for current EELV capacity	• Increases launch volumes for the EELV – Reduce costs for EELV launches – Increase experience (and, thus, reliability) with EELV system • May accelerate development of technologies/capabilities required for sustainable exploration infrastructure	• Requires multiple launches for placing required infrastructure in space (even for lunar landing) • Requires new (undemonstrated) staging capabilities in orbit (LEO or other appropriate altitude)
Use EELV for ISS support	• Modify EELV launchers to support cargo lift • Possibly develop down-mass capabilities for the EELV	• Increases launch volumes for the EELV – Reduce costs for EELV launches – Increase experience (and, thus, reliability) with EELV system • May accelerate development of technologies/capabilities required for sustainable exploration infrastructure • Already under consideration by NASA	• Requires modifications to the EELV • Requires new (undemonstrated) robotic docking capabilities

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The team evaluated a number of options for increasing EELV launch volume, but all options come with significant drawbacks. The options identified generally rely on NASA to move launches onto the EELV, but this approach may not fit with NASA priorities for a variety of reasons (as identified above).

Large Launchers - Conclusions

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- Current market provides no incentive for commercial investment
- Higher launch rates should drive increased reliability and lower costs – but there are few obvious mechanisms for increasing launch frequency
- NASA payloads may provide opportunities for increasing EELV volumes over the next 15+ years

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In sum, the large launch vehicle market, like the small launch vehicle market, poses significant challenges, but government requirements dictate that significant capabilities be maintained in this market.

Given that large launch vehicles are required, increased reliability and decreased launch costs are desirable, but few obvious mechanisms exist to create these benefits. One possibility: using existing launch services for future launches (e.g., associated with the vision for space exploration announced in January 2004).

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Market Analysis: Launch Vehicle Reliability

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STPI evaluated launch vehicle reliability trends over time to try to understand the effect of launch experience on reliability.

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Reliability Comes With Experience

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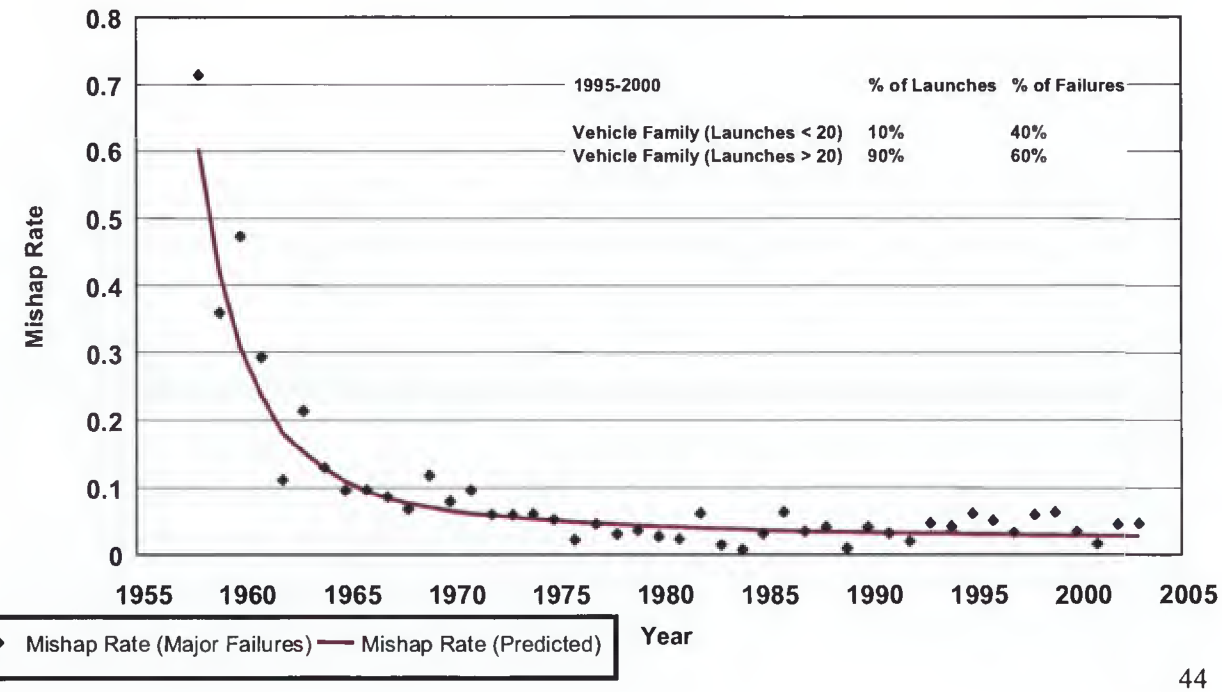
Fleet Mishap Rate



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The historieal launch vehicle mishap rate closely follows a standard learning curve: the mishap rate has fallen steadily over time from over 50% failures in the late 1950s to around 5% starting in the 1980s. The mishap rate has not noticeably decreased since then.

Break-in Pattern for New Launchers

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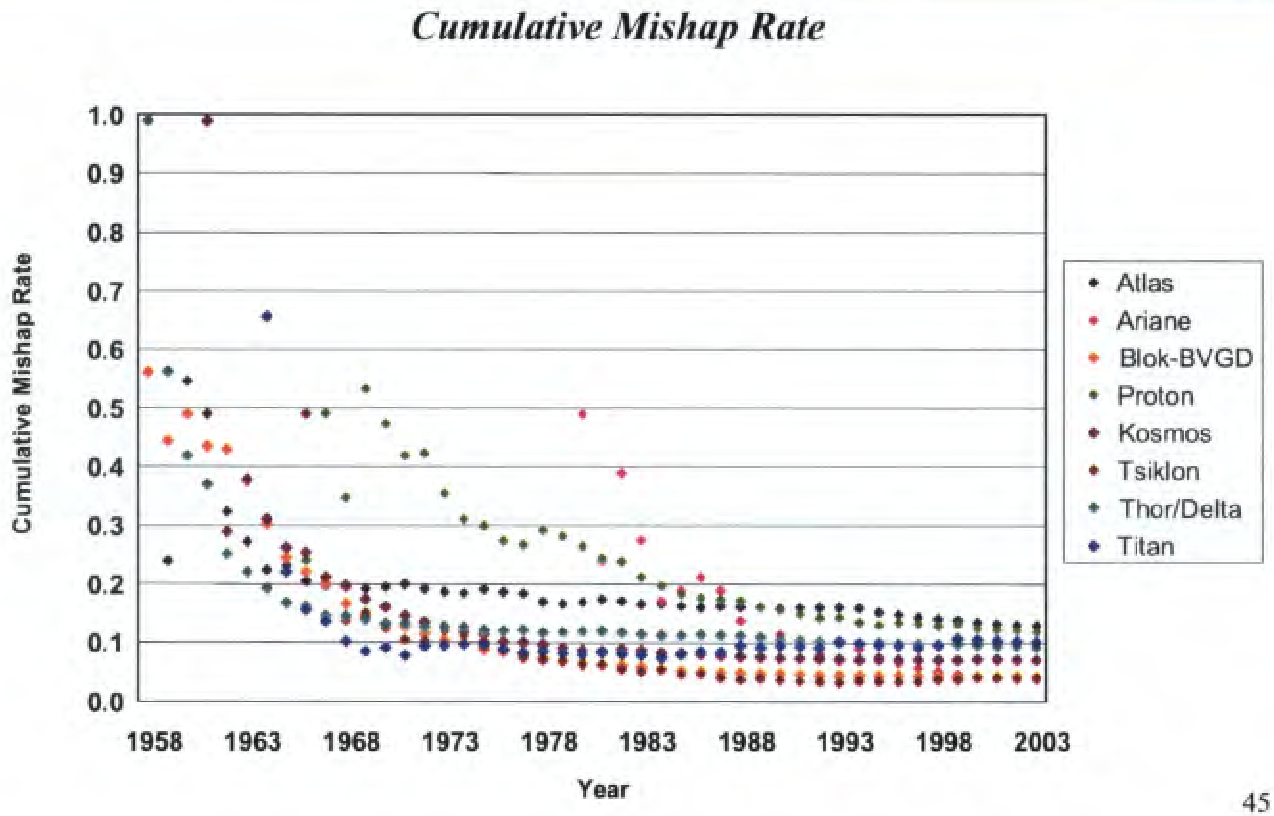

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Further analysis of launch statistics revealed that the learning curve also appears to apply to separate launch vehicle families, indicating that launch vehicle operators also follow a learning curve as they gain experience with the vehicle.

Reliability Improvement with Experience

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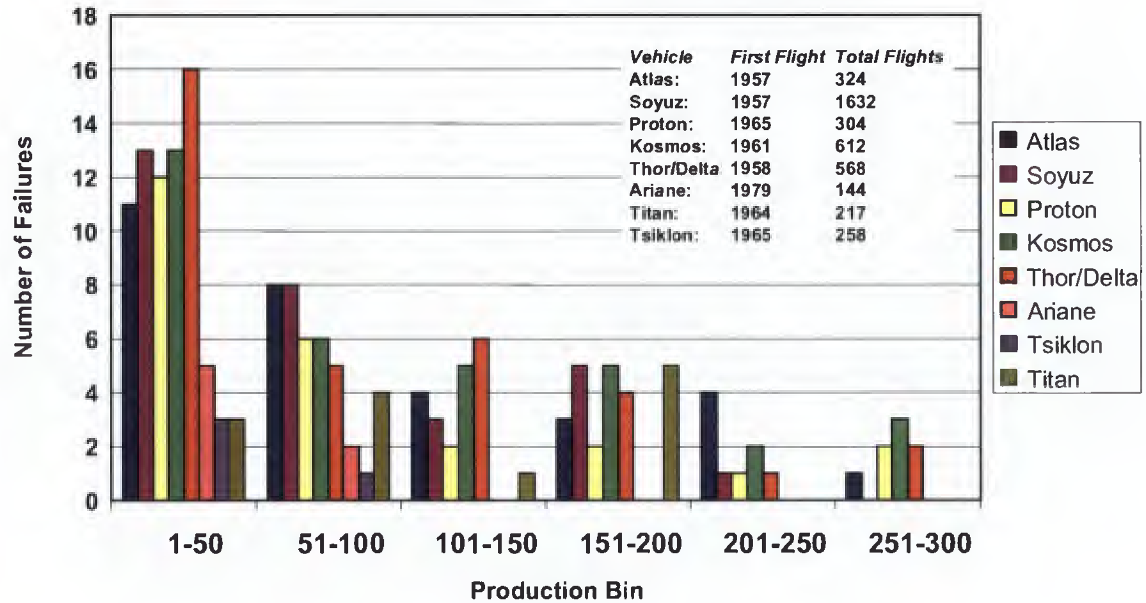
Launch Failures by Production Bin

(Launch vehicles with more than 100 flights)



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To understand the learning curve within families, STPI sorted launch failures from vehicle families according to total launches since the beginning of the vehicle program. While the failure statistics do not decrease monotonically with launch number, the overall trend of decreasing failure rates with launch number is apparent.

Reliability Implications

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Experience explains most of the improvement over time

- There may not be a lot to gain from simplicity
- Starting a new launch vehicle program solely to develop a simple, reliable rocket appears to be misguided

This analysis strongly indicates that failure rate is much more readily explained by experience than by any inherent simplicity of a given launch vehicle. As a result, it may be misguided to try to increase reliability by beginning a new program to design a "simpler" launch vehicle.

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Multiple EELVs: Analysis of Current Approach

One objective of the study was to understand the current approach to maintaining large launch vehicle capabilities and to evaluate the benefits. This section outlines that analysis.

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Rationale for Multiple Launch Vehicles

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- Primary objective: Maximize the probability that the U.S. always has the ability to launch critical payloads to space
- Mitigate against risk factors that include:
  - Failure in a primary launch system
    - ➢ Downtime due to launch vehicle failure
    - ➢ Downtime due to destruction of ground infrastructure
  - Supply disruption in a primary launch system
    - ➢ Inability of suppliers to deliver critical subsystems
      - Inability to purchase critical manufacturing inputs
      - Destruction of manufacturing facilities
    - ➢ Geopolitical instability that prevents purchase of critical subsystems

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Based on multiple interviews with DoD stakeholders and launch service providers, the team identified the primary objective as stated above. This objective is often referred to as an objective of maintaining "assured access" to space.

The critical assumption implicit in this rationale is that, in the event of a failure in one launch system, a secondary launch system will allow launch service buyers to shift their payload to the alternate system and thereby eliminate launch delays associated with the failure.

Current Approach to Multiple LVs

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- Sustain two independent launch systems for the EELV
  - Minimize commonality among EELV systems
  - Maintain two independent manufacturing capabilities
  - Maintain two independent launch operation infrastructures (including operations centers and launch pads)
- Require U.S.-based production of (or, minimally, the *ability* to produce) all critical subsystems
  - The USAF and Pratt & Whitney are currently pursuing development of RD-180 production capabilities in the U.S. (estimates of availability dates and costs vary)
- Maximize the ability to shift critical government payloads between EELV systems
  - Ensure dual-compatibility across launch vehicles during early design and development
  - Dual-integrate critical payloads as appropriate (there is no uniform policy across satellite programs)

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The core requirement for achieving assured access is to maintain multiple launch vehicles. This approach is realized in the current EELV program and its push to maximize the independence of both launch vehicles.

In addition to maintaining two independent systems, the current approach focuses on U.S.-based production of all critical subsystems in order to minimize dependence on foreign sources. Such dependence, possibly resulting from political instability or the reduced ability to influence foreign suppliers relative to domestic suppliers, could result in supply disruptions.

The third major component of the multiple launch vehicle approach to achieving assured access is maximizing the ability to shift payloads between EELV systems by focusing on creating comparable payload environments and requirements across the launch vehicles and through "dual integration," as appropriate. However, the team determined that, at this time, there does not exist a uniform approach to dual integration across DoD payloads.

Integration Realities

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Integration time and cost is highly dependent on
- How much integration has been accomplished prior to the switch decision
- Availability of launch vehicles

Integration Scenario	Description	Time	Additional Cost
Dual-integrated payload	• All necessary integration work (loads analysis, etc.) has been carried out for both launch vehicles	• As little as 45 days (assumes launch vehicle, fairing, and adapter are available at the launch site)	• Essentially the cost of a full, additional launch service
Previously integrated payload	• An equivalent payload has previously been integrated on the other system (e.g., DSCS)	• 12–24 months	• $10 million (could be greater, depending on the complexity of the payload), but assumes that additional launch hardware is available
No prior integration work	• No effort has previously been expended to integrate the payload to the other system	• 24 months	• Minimal, assuming that the primary launch hardware is not yet paid for or reserved (consistent with the fact that launch hardware commitment usually occurs about 24 months prior to launch)

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The team investigated the ease of shifting payloads from one EELV to the other. While integration scenarios vary considerably in practice, they can be roughly divided into three categories:

1. If payloads are dual-integrated and additional launch hardware is available at the launch site, payloads can be shifted in as little as 45 days, but this requires an investment that is roughly equal to the cost of a full, additional launch service.

2. If payloads have been previously integrated on the secondary system, the payload can typically be shifted to the secondary system for an investment of an additional $10 million over the basic launch costs (for carrying out the coupled loads analysis, primarily). This approach requires significant lead time for launch hardware acquisition and launch slot availability, resulting in 12–24 month lead times (in some cases, this could be as little as 6 months if hardware is readily available).

3. If there has been no prior integration work, payloads can be shifted from the primary system to the secondary system at minimal cost *if* the decision is made at least 24 months prior to launch. To the extent that any additional integration work has already been carried out on the primary system or launch hardware has been acquired, this investment will be lost.

Cost of Maintaining Multiple LVs

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- Hard Costs
  - Dual-integration
  - Two production facilities
  - Two launch operations capabilities
- Soft Costs
  - Reduced volumes for both launchers
    - ➢ Stretched out learning/experience timeline
    - ➢ Loss of volume efficiencies
  - Oversight complexity
    - ➢ Competitive issues
    - ➢ Administrative intensity (payload distribution, etc.)

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The extra capability gained by maintaining multiple launch vehicles does, of course, come with additional cost. These include the costs outlined above.

Benefits and Weaknesses

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Issue	Benefits	Weaknesses
Launch Vehicle Backup	• Limits impact of launch vehicle failure to the fraction of the launch manifest scheduled on the failed system • Allows payloads to be shifted from one vehicle to the other if necessary – If the failed vehicle is down for an extended time period, payloads can, in principle, be moved to the alternate vehicle	• Integration times limit the ability to shift payloads from one vehicle to the other
Launch Vehicle Independence	• Limits US exposure to launch vehicle failure – Assuming the failed subsystem(s) isn't (aren't) common to both vehicles, only payloads scheduled for launch on the failed vehicle will be delayed	• Exposure isn't eliminated – Systems aren't completely independent – common subsystems (such as the RL-10) remain

To summarize, maintaining multiple launch vehicles does bring some benefits but the benefits are limited. Because of redundancy, additional challenges include:

1. Integration times
2. Residual system commonality

Benefits and Weaknesses – Continued

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Issue	Benefits	Weaknesses
Manufacturing Redundancy	▪ Limits the ability of natural or man-made disaster to wipe out US launch capability at the manufacturing source (however, there is a fairly low probability of long-term factory destruction)	▪ The U.S. government is bearing the full overhead cost of supporting two separate launch vehicle manufacturing capabilities – Minimal demand provides little opportunity to recover fixed costs through commercial sales
Launch Operations Redundancy	▪ Limits the ability of natural or man-made disaster to wipe out U.S. launch capability at the launch site (however, there is a low probability of long-term launch pad or launch operations center destruction)	▪ The U.S. government is bearing the full overhead cost of supporting two separate launch operations

With regard to operations and manufacturing, benefits are limited primarily because the government is bearing the full cost of supporting both launch vehicles. This drawback should be weighed against the generally low probability of long-term manufacturing or launch operations destruction.

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Benefits and Weaknesses – Continued

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Issue	Benefits	Weaknesses
Workforce Management	• Maintaining multiple launch vehicles increases demand for technical workforce – May help ensure a large skilled workforce is retained as future needs emerge	▪ May result in substantial extra cost if multiple launch operations lead to significant workforce redundancy
Industrial Base Management	• Having multiple providers supports increased competition – May reduce launch services prices – May drive increased innovation in capability and reliability	• Foreign competition may already provide the desired price pressure on U.S. providers • The U.S. government may be able to create the same benefits as competition by appropriately managing the single source – Indeed, the U.S. already manages single suppliers for other major defense systems and may be able to apply learning from these programs to managing launch service providers

Additional considerations pertain to workforce and industrial base management. While maintaining multiple launch vehicles may help to ensure retention of a large skilled workforce and allow multiple companies to participate, these benefits, again, should be weighed against the cost and the fact that the U.S. government does have experience managing workforce and industrial base issues with sole-source suppliers.

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EELV Option Analysis

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In addition to conducting the high-level benefits analysis, the team attempted to lay out the range of options for reducing the cost and scope of the EELV program.

Options for EELV

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Option	Description
Maintain two EELV launchers	• Retain both Lockheed Martin and Boeing as EELV providers
Consolidate EELV launch operations	• Combine Delta IV and Atlas V launch operations – Absorb EELV launch operations under a single contractor – Turn EELV operations over to the United Space Alliance or a similar joint entity
Consolidate EELV manufacturing capabilities	• Relocate vehicle manufacturing from both contractors to the same (probably existing) facility • Close existing excess manufacturing facility
Downselect to one EELV launcher	• Select a single launch vehicle and launch-services provider for all EELV class payloads

The team identified the following primary options:

1. Status quo: maintain two EELV systems
2. Consolidate launch operations
3. Consolidate manufacturing capabilities
4. Downselect from two EELVs to one

Downselect to One EELV System

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- Downselecting would allow lower prices for the remaining system
  - High fixed costs (production and launch operations) mean that launch prices are very sensitive to launch rates
- Downselecting should bring higher reliability sooner
  - Flight experience appears to be a strong predictor of launch vehicle reliability
  - Reliability affects costs
    - ➢ Lost spacecraft
    - ➢ Insurance rates

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The team believes that a full downselect would bring several benefits, including:

1. Lower prices for the remaining system
2. Higher reliability on the remaining system in a shorter time

These benefits must, of course, be weighed against the aforementioned benefits of maintaining two systems.

Consolidation

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- Consolidation would combine as much of the two EELV operations (including manufacturing and launch operations) as possible, while retaining launch vehicle redundancy
- Opportunities for consolidation include:
  - Factory operations
  - Launch operations

But the government can pursue more limited options than a full downselect. The team believes that there may be opportunities to consolidate factory operations and/or launch operations and thereby achieve at least some of the savings of a full downselect.

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Consolidation – Cost Savings for Plant Closure

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- Fixed costs at underutilized plants are major cost component of excess capacity
- Analyze fixed cost using overhead costs at a typical plant
- Perform regression on overhead costs vs. direct labor
- Intercept is the fixed cost of that plant
  - Fixed cost could be saved by closing that plant

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A detailed analysis of plant closure was beyond the scope of this study. However, there are a number of sources of savings from such a closure and these savings can be analyzed in detail. The savings come, primarily, from the fact that some (probably significant) fraction of the fixed costs at one plant can be eliminated by closing the plant and combining its operations with the manufacturing operations of the alternate system.

Reliability Impact from Consolidation

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Scenario	Advantages
Consolidated Ops and Manufacturing	• Launch teams gain launch experience more quickly • Launch and engineering teams can more easily apply lessons learned across systems • Fewer up/down workload cycles for both launch and engineering workforces
Unconsolidated Ops and Manufacturing	• Maintain redundant manufacturing and ops – reduce exposure to infrastructure damage • Avoid potential system confusion errors (e.g., workforce errors due to switching between systems) • Decrease likelihood of mistakes due to common processes/suppliers • Decrease likelihood of surge workloads

In addition to affecting cost, consolidation has potential implications for reliability that flow primarily from the experience of the launch teams. While there are definite advantages to consolidation, from the standpoint of reliability there are also significant advantages to keeping launch and manufacturing operations unconsolidated. Assessing the full impact of either option would require substantial additional analysis.

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EELV Option Analysis: Impact on Launch Delays

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To understand the benefits of two launch vehicles vs. one launch vehicle, the team modeled the impact of maintaining two launch vehicles on the possibility of launch delay as a result of launch vehicle failure.

Analysis Approach

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- Objective
  - Estimate the probability that a given launch will be delayed due to launch vehicle downtime
- Simulate:
  - Launch scheduling incorporating:
    - ➢ One or more launch vehicles
    - ➢ Total capacity by launch vehicle
    - ➢ Launch rate by launch vehicle
  - Launch failures incorporating:
    - ➢ Vehicle downtime after failure
    - ➢ Impact on schedule due to recovery from failure
  - Switching between launch vehicles incorporating:
    - ➢ Payload priority (as appropriate)
    - ➢ Delays due to integration
  - Switching to an auxiliary launch capability incorporating:
    - ➢ Payload sensitivity (i.e., "sensitive" payloads are not allowed to switch)
    - ➢ Delays due to integration

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The team developed a launch scheduling simulation to estimate the probability that a given launch would be delayed because of launch vehicle downtime. The simulation included:

1. Launch scheduling for one or more vehicles, incorporating overall launch rate and launch rate constraints by vehicle.
2. Random launch failures with an associated recovery time during which no subsequent launches were allowed to occur. The simulation adjusted the launch scheduling as necessary to account for these delays (ensuring that subsequent launch rates do not exceed constraints).
3. Switching between launch vehicles as allowed by launch rate constraints. The simulation included delays to account for integration requirements on the new vehicle and allowed for reworking the launch queue to allow for high-priority payloads.
4. Switching to auxiliary (e.g., foreign) launch capabilities, as appropriate. Once again, this switching incorporated integration delays and accounted for payload sensitivity (i.e., the notion that sensitive payloads may not be allowed to switch to auxiliary vehicles), as appropriate.

Operation of the Simulation

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- Simulates single-vehicle and dual-vehicle operations
- Inputs include average monthly launch rate, launch capacity, and failure rate
- Simulations cover >80,000 missions
- Each mission is assigned a planned launch date
- Missions fail at random
- Following a failure, the launch site temporarily shuts down
- Missions queue up until the launch site becomes available
- Simulation compares actual launch date with planned launch date to determine delay

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The simulation is intended to create a reasonable model of launch scheduling while incorporating appropriate constraints. Typical simulation runs cover more than 80,000 missions in order to develop a reasonably accurate profile of launch delay statistics.

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Critical Assumptions

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- Launch vehicles are interchangeable
  - No consideration given to heavy, medium, or light launchers
- Launch sites are interchangeable
  - No consideration given to the launch site
- Launch vehicle downtime is known immediately after a launch failure
- Switching occurs after a failure and depends on three factors
  - Expected delay must exceed the amount of time needed for the mission to switch lines
  - A given mission may only switch lines once
  - Missions may only switch lines if the launch rate capacity of the other line can accommodate them

A number of key assumptions, as outlined above, are made in the operation of the simulation. In addition to making the analysis tractable within the time constraints of the study, these assumptions provide "best case" results in terms of the usefulness of maintaining multiple launch vehicles. In general, removing any of these assumptions will reduce the positive impact of maintaining a second launch capability.

Simulation of Launch Vehicle Downtime

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Used an exponential distribution

- Often used in queuing theory to explain delay times
- Simple distribution – only 2 free parameters:
  - ➢Minimum downtime
  - ➢Mean downtime
- Although most of the downtimes are short, allows for very long very low probability downtimes
  - ➢~10% of delays are greater than 1 year
  - ➢~0.5% of delays are greater than 2 years

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As indicated, the simulation used an exponential distribution to model vehicle downtime following a failure. This distribution makes sense from queuing theory and, despite the limited statistics available for launch failures, delays during actual launch failures appear to be consistent with the distribution (see next page).

Downtime Distribution vs. Observed

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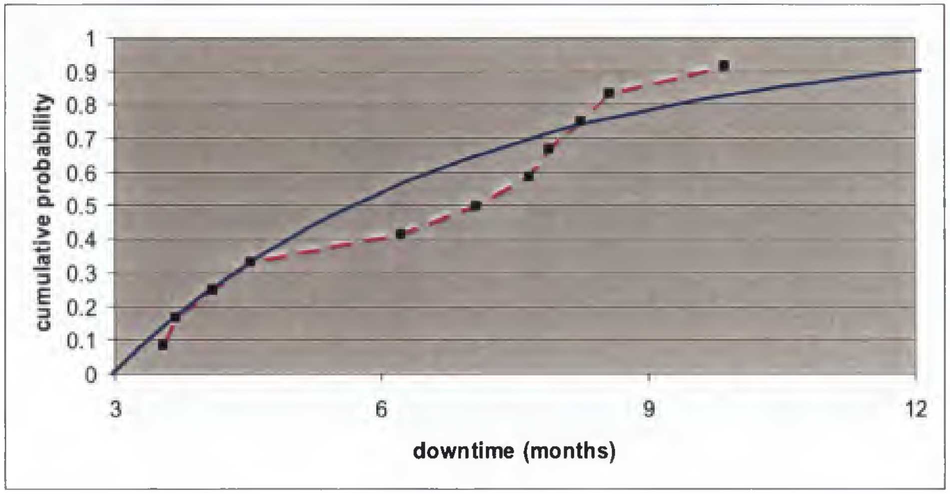
Exponential distribution fits the historical cumulative probability

- Mean downtime: 7 months
- Minimum downtime: 3 months



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The exponential distribution appears to be generally consistent with actual delay statistics.

Overview of Initial Findings

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- Two launch lines with the same launch rate capacity as a single launch line provide more on-time launches
  - Splitting a launch line into two independent launch lines reduces the number of delayed launches by half
- Switching missions between two launch lines during downtime improves on-time launches, but only marginally compared with the impact of splitting one launch line into two
  - Very few missions (<3%) actually cross over

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The largest impact from maintaining two launch vehicles comes from the ability to split the manifest into two independent launch manifests rather than from the ability to switch payloads between launch vehicles. Simply stated, the impact of two manifests is that half of the overall manifest is not affected by a launch failure in one of the vehicles.

This does assume that the launch vehicles are independent. If the launch vehicles are not, in fact, independent, then a failure in a common component may delay launches on both vehicles.

Scenario Description

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Parameter	One Launch Vehicle	Two Systems	Two Systems with Switching
Launch Capacity	17 launches/year	~10 launches/year (varies by system)	~10 launches/year (varies by system)
Launch Volume	10 launches/year	5 launches/year each	5 launches/year each
Failure Rate	5%	5%	5%
Switching Allowed	N/A	No	Yes, based on capacity availability
Integration Time	N/A	N/A	Probabilistic: – 3 months (20% of the time) – 6 months (60% of the time) – 18 months (20% of the time)
Priority	N/A	N/A	N/A

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The above table summarizes the scenarios used to model launch scheduling. For the initial analysis, we analyzed three basic scenarios:

1. Maintaining a launch schedule of 10 launches per year on a single launch vehicle.
2. Maintaining two launch vehicles and splitting the manifest in half, with 5 launches per year on each vehicle. Payloads on 1 vehicle cannot be switched to the other vehicle.
3. Same as (2), except that payloads can be switched from one vehicle to the other if launch capacity is available.

The critical parameters for our simulation are the annual launch capacity of each vehicle, the annual launch volume, and the launch failure rate. For these scenarios, we assumed an overall annual launch volume of 10 launches and an overall failure rate of 1 out of every 20 launches.

One System Results

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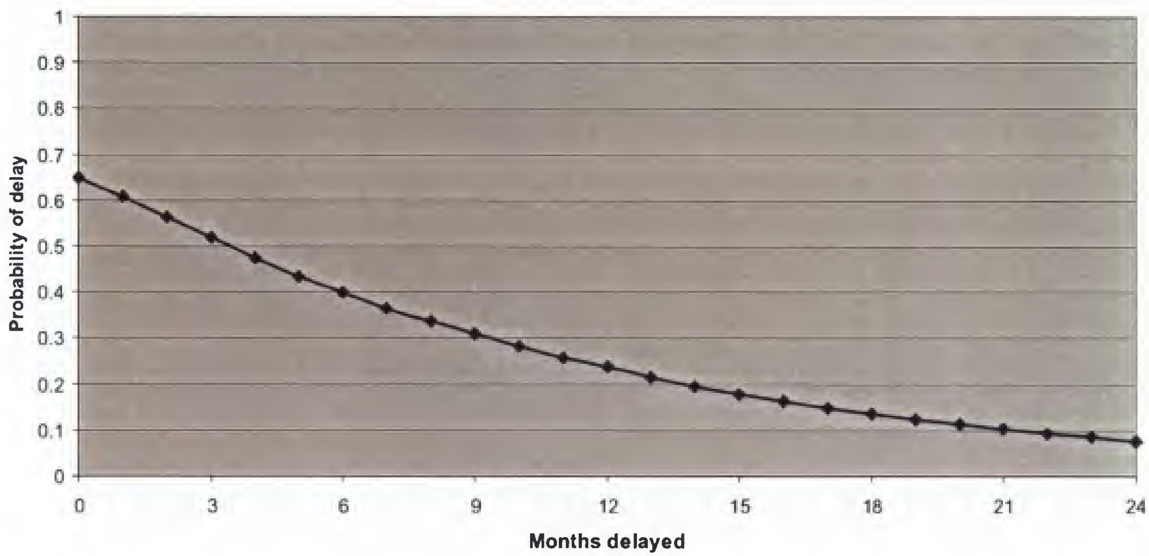
Probability that launch has not yet occured



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In the above chart, the vertical axis gives the probability that a given payload will be delayed by the number of months indicated on the horizontal axis. Thus, roughly 65% of all launches are expected to be delayed with only one launch vehicle, and any given payload has only a 50% chance of being launched within 3 months of the scheduled launch date.

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Dual Launch Vehicles Cut Delays

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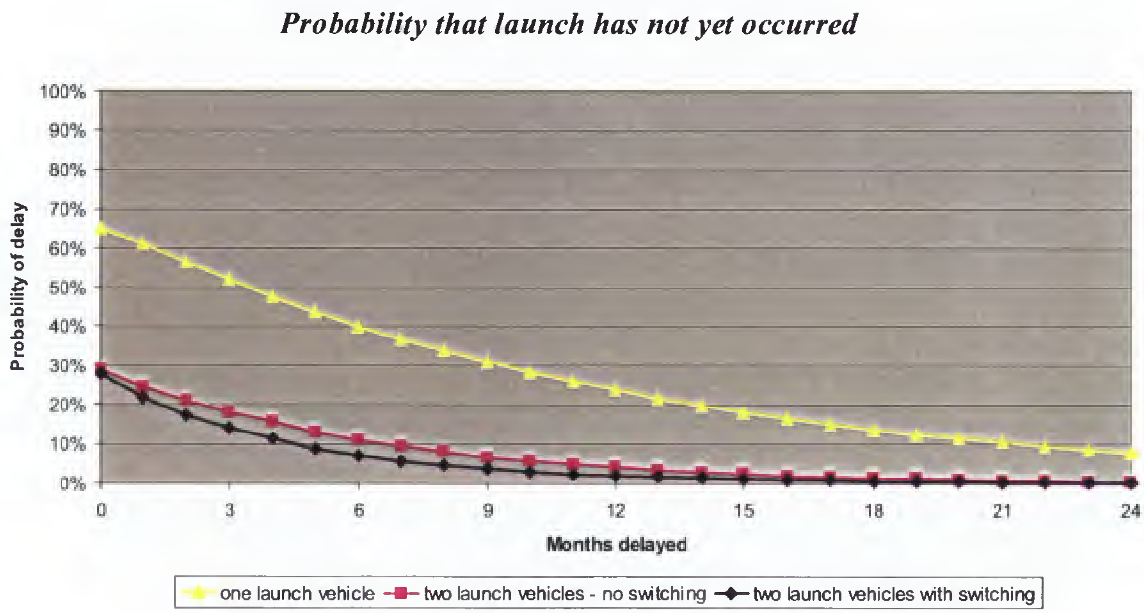

With two launch vehicles, the probability that any given launch will be delayed falls significantly from about 65% to about 30%, even without allowing payloads to switch from one launch vehicle to the other.

While simply splitting the launch manifest onto two vehicles provides the greatest improvement in launch timeliness, allowing payloads to switch also provides modest improvement in statistics. Thus, while approximately 11% of payloads will be delayed 6 months with a split manifest, only about 7% of payloads will experience a 6-month delay when payloads are allowed to switch vehicles.

Using Priority to Improve Timeliness

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- Approach:
  - A subset of missions becomes high priority
  - High-priority missions move past low-priority missions whenever they are in a queue together
- Sensitivity:
  - Simulated schedule impact for a range of assumptions about the percentage of missions that are considered high priority
  - Increasing percentage of missions that are considered high priority had minimal impact up to 25% of missions

While prior simulation results assume a first-in-first-out queue, we also model the impact of payload prioritization on launch scheduling. In these scenarios, we designate a specific percentage of overall payloads as "high priority". These missions are then allowed to launch before low priority missions when in a queue together.

The percentage of high priority payloads is varied between 0% and 25% of total payloads, but, in general, variations in this percentage have only a minor impact on the overall trend with prioritization (as discussed on the next several charts).

Scenario Description

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Parameter	One Launch Vehicle	One Launch Vehicle with Prioritization	Two Launch Vehicles with Prioritization
Launch Capacity	17 launches/year	17 launches/year	~10 launches/year (varies by system)
Launch Volume	10 launches/year	10 launches/year	5 launches/year each
Failure Rate	5%	5%	5%
Switching Allowed	N/A	N/A	N/A
Integration Time	N/A	N/A	N/A
Priority	N/A	Percentage of missions that are deemed high-priority missions = 5% of total missions	Percentage of missions that are deemed high-priority missions = 5% of total missions

We first modeled a comparison between a single launch vehicle without prioritization and a single launch vehicle with prioritization. The results that follow assume that high-priority payloads represent 5% of missions.

Prioritization Improves Timeliness

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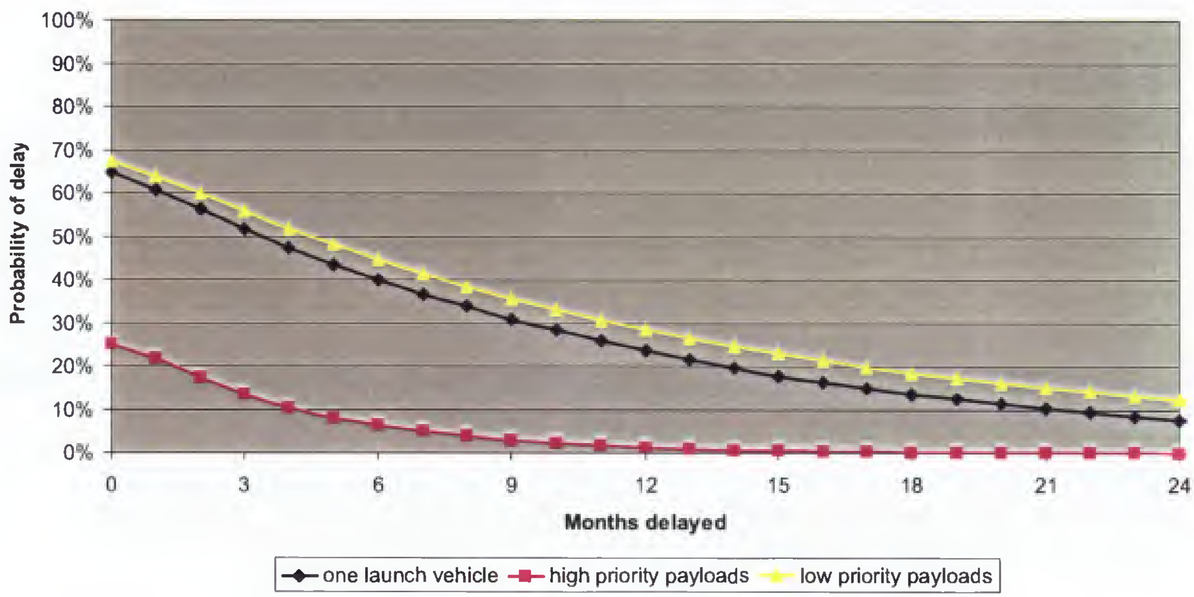
Probability that launch has not yet occurred



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For high-priority payloads, preferential treatment significantly reduces the probability that the payload will be delayed from roughly 65% of payloads to 25% of payloads. Low-priority payloads, on the other hand, experience a slightly increased probability of delay. The probability that a low-priority payload will be delayed at least 6 months, for example, rises from 40% without prioritization to 45% with prioritization.

Prioritization Helps With 2 Vehicles

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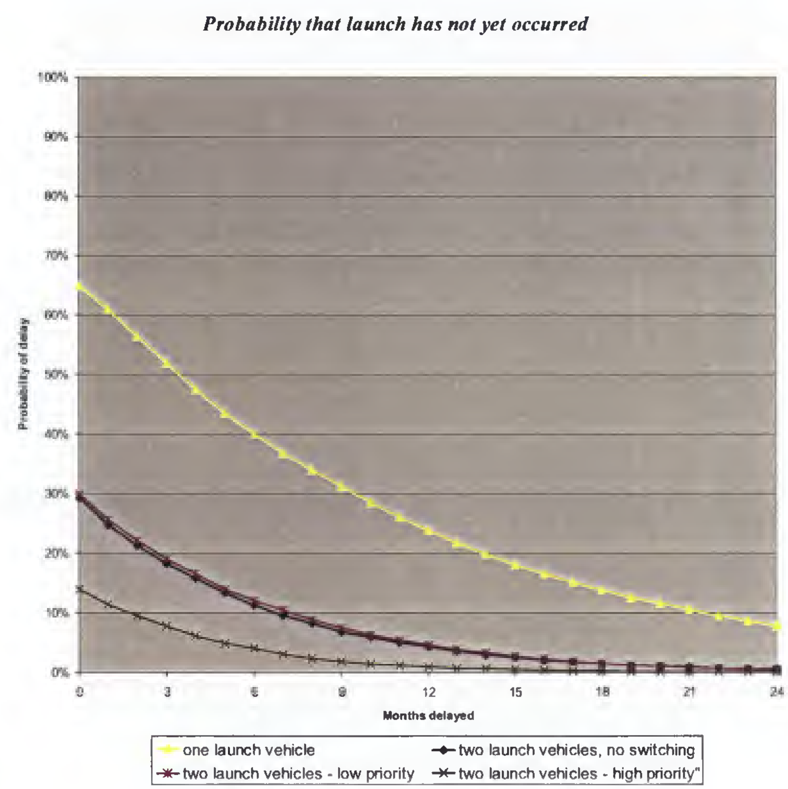

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Prioritization also reduces the probability of delay for high-priority payloads with 2 launch vehicles. The probability that high-priority payloads will experience some delay fell from 30% without prioritization to 14% with prioritization, with minimal impact on delay statistics for low priority payloads.

Switching Makes Little Difference

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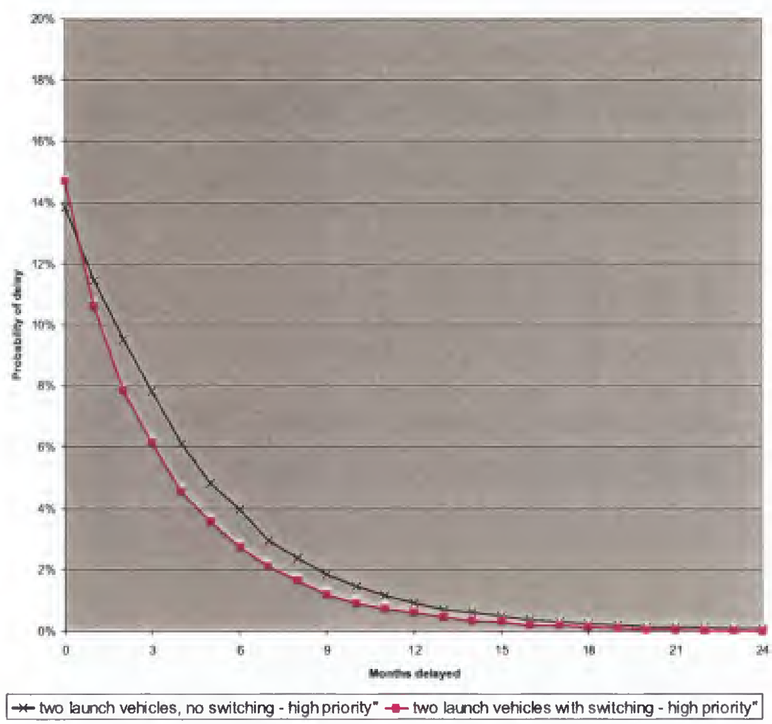
Probability that launch has not yet occurred



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As the graphic shows, allowing high-priority payloads to switch between launch vehicles had only a minor additional impact on delay probabilities. In general, the percentage of payloads delayed by a given amount of time shifted by less than 2%.

Impact of Auxiliary Launch Capacity

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- Approach:
  - "Sensitive" missions remain with original launch facility and are given high priority
  - "Nonsensitive" civil and commercial missions can shift to auxiliary launch system
- Provides significant improvement in timeliness of nonsensitive missions
- Does not affect sensitive (high-priority) missions

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STPI was also asked to analyze the impact of making use of alternative launch capabilities (e.g., foreign launch capability) while maintaining one EELV.

The primary assumption is that "sensitive" government payloads will not be placed on the auxiliary launch capability (indeed, this is how sensitive missions are defined for the purposes of this analysis). Instead, this launch capability will be used for "nonsensitive" missions, allowing the primary launch capability to work off a backlog faster in the event of an extended downtime after a catastrophic failure. A secondary assumption is that sensitive missions are high priority and thus will be moved first in the queue after a failure.

As the following charts demonstrate, this auxiliary launch capacity has a significant impact on the timeliness of nonsensitive missions but has no impact on sensitive missions (as should be expected).

Scenario Description

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Parameter	Primary Launch Vehicle	Auxiliary Capacity
Launch Capacity	17 launches/year	7 launches/year
Launch Volume	10 launches/year	N/A
Failure Rate	5%	5%
Switching Allowed	N/A	Yes, based on capacity availability
Integration Time	N/A	Probabilistic: – 3 months (20% of the time) – 6 months (60% of the time) – 18 months (20% of the time)
Priority	N/A	5% of payloads are sensitive (i.e., *can't* be switched)

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In this scenario, the primary launch vehicle is configured as in prior scenarios with a capacity of 17 launches per year and a failure rate of 5%. The expected launch volume is 10 launches per year.

In the event of a failure, scheduled payloads are considered for switching to the auxiliary launch capacity if:

1. The mission is not sensitive
2. Capacity is available on the auxiliary launch capability
3. Expected integration time is less than the expected downtime for the primary launch vehicle

Note that 5% of all payloads are considered sensitive and thus are not eligible for switching to auxiliary capacity.

Auxiliary Capacity Improves Timeliness

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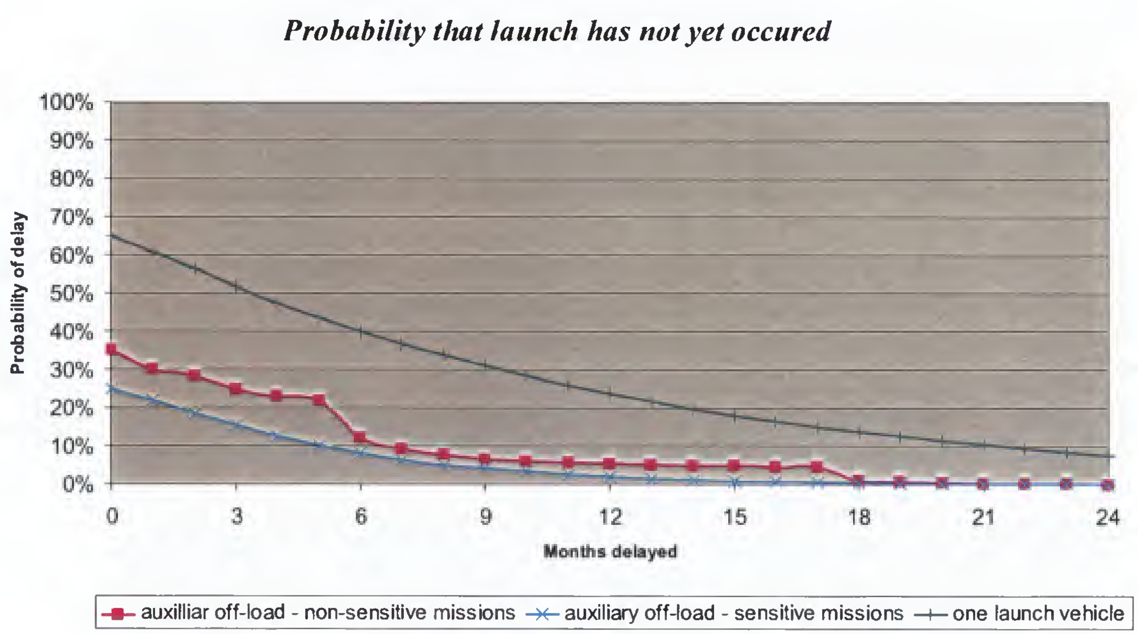

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The chart above shows the delay statistics for a single launch vehicle compared with the delay statistics for both sensitive and nonsensitive payloads when making use of auxiliary launch capacity. For sensitive missions, the delay statistics are the same as for a single launch vehicle where 5% of missions are considered high priority (see page 74). For nonsensitive missions (i.e., not high priority in this context), the use of auxiliary launch capability substantially improves timeliness.

Summary of Launch Analysis

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- The major impact of multiple launch vehicles comes from the ability to split the launch manifest
- The ability to switch payloads, *even with rapid switching from dual integration,* provides only marginal benefit
  - Expected changeover time compared with expected downtime appears to be a big barrier to switching
- The use of auxiliary launch services with one vehicle improves timeliness vs. one vehicle alone
  - Benefits are not as great as with two launch vehicles and a split manifest
  - Limiting switching to nonsensitive missions has limited impact on high-priority, sensitive missions – but improves timeliness for nonsensitive missions

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The conclusions of the queuing analysis are summarized above.

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Launch Delays with a 2% Failure Rate

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This section repeats selected simulations from the previous section with a 2% failure rate (recall that a failure rate of 5% was used in the previous section).

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Scenario Description

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Parameter	One Launch Vehicle	Two Systems	Two Systems with Switching
Launch Capacity	17 launches/year	~10 launches/year (varies by system)	~10 launches/year (varies by system)
Launch Volume	10 launches/year	5 launches/year each	5 launches/year each
Failure Rate	2%	2%	2%
Switching Allowed	N/A	No	Yes, based on capacity availability
Integration Time	N/A	N/A	Probabilistic: – 3 months (20% of the time) – 6 months (60% of the time) – 18 months (20% of the time)
Priority	N/A	N/A	N/A

The above table summarizes the scenarios used to model launch scheduling. For the initial analysis, we analyzed three basic scenarios:

1. Maintaining a launch schedule of 10 launches per year on a single launch vehicle.
2. Maintaining 2 launch vehicles and splitting the manifest in half, with 5 launches per year on each vehicle. Payloads on 1 vehicle cannot be switched to the other vehicle.
3. Same as (2), except that payloads can be switched from one vehicle to the other if launch capacity is available.

The critical parameters for our simulation are the annual launch capacity of each vehicle, the annual launch volume, and the launch failure rate. As in the last section, we assumed an overall annual launch rate of 10 launches per year. However, we reduced the assumed failure rate from 1 out of every 20 launches to 1 out of every 50 launches.

Dual Launch Vehicles Cut Delays

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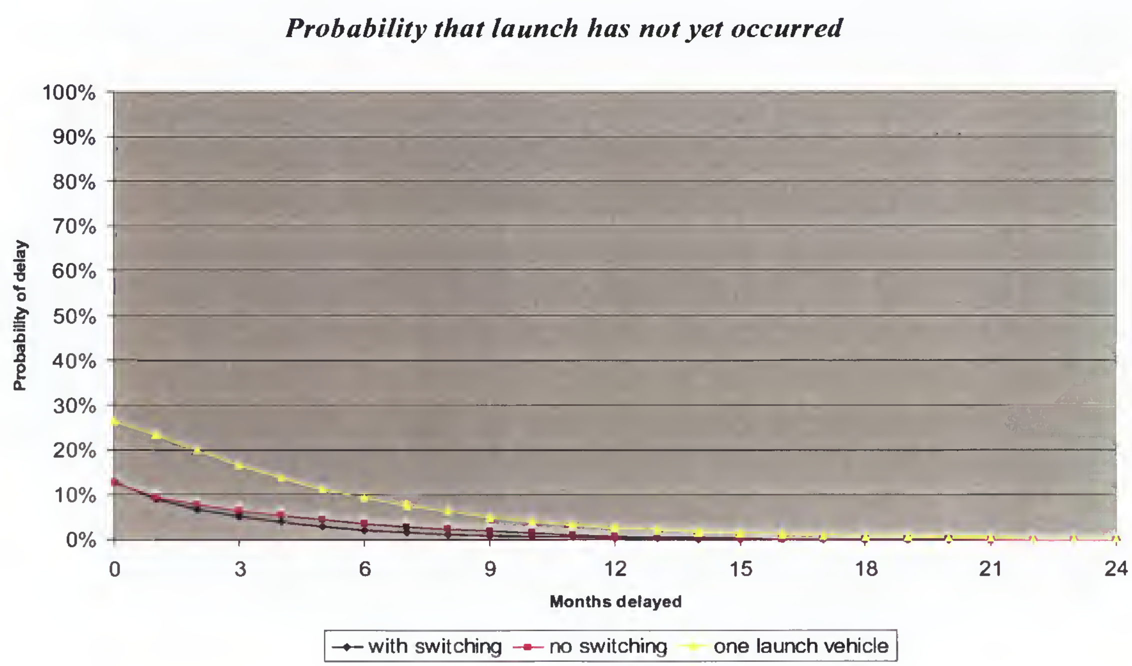

The above chart plots the delay probabilities both for a single launch vehicle and for two launch vehicles (without and with switching). For a single launch vehicle, roughly 27% of all launches are expected to be delayed (compared with 65% when we assumed a 5% failure rate) and only 17% of payloads are expected to be delayed more than 3 months after the scheduled launch date (compared with about 50% when we assumed a 5% failure rate).

With two launch vehicles, the probability that any given launch will be delayed falls significantly, from about 27% to about 13%, even without allowing payloads to switch from one launch vehicle to the other.

Similar to the situation with a 5% failure rate, while simply splitting the launch manifest onto two vehicles provides the greatest improvement in launch timeliness, allowing payloads to switch also provides modest improvement in statistics. Thus, while approximately 4% of payloads will be delayed 6 months with a split manifest, only about 2% of payloads will experience a 6-month or greater delay when payloads are allowed to switch vehicles.

Scenario Description

IDA STPI

Parameter	One Launch Vehicle	One Launch Vehicle with Prioritization
Launch Capacity	17 launches/year	17 launches/year
Launch Volume	10 launches/year	10 launches/year
Failure Rate	2%	2%
Switching Allowed	N/A	N/A
Integration Time	N/A	N/A
Priority	N/A	5% of total missions tare deemed high priority missions

As before, we also modeled scheduling delays when payloads were prioritized.

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Prioritization Improves Timeliness

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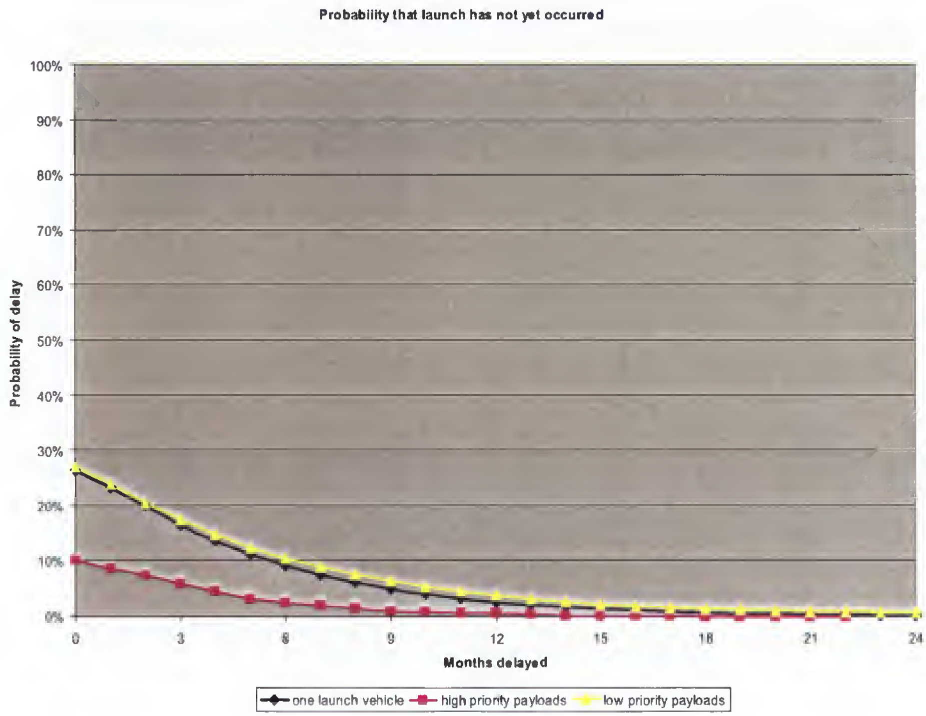

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Once again, preferential treatment significantly reduces the probability that high-priority payloads will be delayed—from 27% of payloads to 10% of payloads. Low-priority payloads again experience only a modestly increased probability of delay. The probability that a low-priority payload will be delayed at least 6 months, for example, rises from 9% without prioritization to 10% with prioritization.

Alternative Switching Options

STPI evaluated alternative launch providers as potential auxiliary launch capabilities.

Alternative Switching Options

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- Use of foreign/semiforeign launch capabilities
  - Sea Launch (Zenit) – 40% owned by Boeing
  - ILS (Russian Proton)
  - Arianespace (Ariane)

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STPI focused on three primary options, as outlined above.

Benefits of Foreign Backup of EELV

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- Eases pressure on the launch manifest in the event of a failure
  - Commercial satellites can be readily moved to other systems for nominal cost
  - U.S. Government payloads can be more easily scheduled post-recovery even without switching to secondary launch vehicles
- Provides possible launch alternative in the event of a long-term failure

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The potential benefits of developing launch relationships with alternate providers are outlined above. Notc that, if EELV manifests include commercial payloads, the use of foreign backup can provide benefits *even if* U.S. Government payloads are not allowed to switch (as outlined above).

Commercial Backup Arrangements

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- Arianespace/Sea Launch
  - Offers mission assurance clause. Pays for:
    - ➢Coupled loads analysis on both the primary and secondary launch vehicles
    - ➢Reservation in secondary launch manifest
  - Allows customers to switch payloads up to
    - ➢6 months prior to launch
    - ➢3 months prior to launch (higher fee)
  - Executed for May 5, 2004, DirectTV launch (switched from Ariane to Zenit (Sea Launch))

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Use of foreign backups can follow models already used for backing up the launch of commercial payloads. Arianespace and Sea Launch offer mission assurance clauses as outlined above.

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Commercial Backup Arrangements – 2

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- ILS (Atlas V/Proton)
  - Offers mission assurance clause. Pays for:
    - ➢Coupled loads analysis on both the primary and secondary launch vehicles
    - ➢Reservation in secondary launch manifest
  - Allows commercial customers to switch payloads up to
    - ➢12 months prior to launch
    - ➢Could switch in as little as 6 months if a standard bus is used

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Similarly, ILS offers mission assurance clauses for backup between the Atlas V and the Proton launch vehicles.

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Reliability Discrimination

STPI also estimated the number of flights required to determine which EELV is more reliable (assuming that one is, in fact, more reliable).

Reliability Discrimination

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- Ingoing hypothesis: both launch vehicles have equivalent reliability
- Question: If one has 98% reliability and the other has only 95% reliability:
  - → How many launches would be needed to tell the systems apart?
- Answer: it depends …

To evaluate the question of distinguishing reliability, the team posed the question as follows:

1. If we assume that both vehicles have the same level of reliability, but …
2. In reality, one vehicle is 98% reliable while the other is only 95% reliable …
3. How many launches would it take to determine that our ingoing assumption is incorrect?

As shown in the following charts, the answer depends on understanding exactly what we want to know.

Two Types of Errors

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Conclusion

Reality		One System is More Reliable	Both Systems are Equivalent
	Both Systems are Equivalent	*Type I Error: False Positive*	*Correct Conclusion*
	One System is More Reliable	*Correct Conclusion*	*Type II Error: False Negative*

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Several potential outcomes must be understood, as outlined above. As posed on the preceding chart, we are primarily concerned with the situation in which one system is more reliable than the other. As a result, we wish to minimize the probability of making a type II error (i.e., concluding that both systems have equivalent reliability when, in fact, one system is more reliable) and are willing to accept a higher probability of making a type I error (i.e., concluding that one system is more reliable than the other when, in fact, they are both equally reliable).

Discrimination Requirements

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Assume reliabilities, if different, are 98% and 95%

Probability of false positive	Probability of false negative	Number of tests (each system)
50%	10%	~350 launches (~70 years at current launch rates)
50%	20%	~235 launches (~47 years at current launch rates)
50%	33%	~150 launches (30 years at current launch rates)
20%	20%	~400 launches (~80 years at current launch rates)

For the first three entries in the above table, we are willing to accept a 50-50 chance that we incorrectly conclude one vehicle is more reliable than the other when, in fact, they are both equally reliable (the probability of a false positive).

However, we want to minimize the probability that we conclude they are equally reliable when, in fact, one is more reliable than the other (specifically, we assumed that, if they are different, one has a 98% reliability while the other has a 95% reliability). The results are shown above. As can be seen, even if we allow only a one in three chance of a false negative, it will take about 150 launches (or 30 years at current launch rates) before we determine if one is more reliable than the other.

In short, we will not have enough data to prefer one launch vehicle over the other based solely on launch reliability in any reasonable time frame.

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The authors review the current state of U.S. launch capabilities, including the market environment for space launch capabilities (including commercial, civil, and defense markets), regulatory constraints and their impact on the market, and the sources of launch reliability. In addition, the authors evaluate the strengths and weaknesses of the current policy of maintaining multiple launch vehicles in order to assure access to space when necessary by examining both policy and payload scheduling implications.

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