Interactions Between Future Launchers & Their Users

Final Presentation
ESA HQ
March 28, 1995

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Presentation Overview

Introduction & assumptions

Reusable launcher flight rate requirements

Interaction method of assessing payload demand

Relationship between payload costs and launch costs

Mission concepts for reusable launchers

Estimation of space transportation demand elasticity

Conclusions & recommendations

Rationale for the Study

- Future reusable launchers hold the potential to fundamentally improve access to space.
- However, before any decision is made to build such a vehicle, it is first necessary to answer two critical questions:

1. Are the critical technologies sufficiently mature to minimise the technical and programmatic risk ?
2. Is there sufficient demand for space access to warrant the investment required to develop such a launch capability ?

→ First question to be addressed by FESTIP and national activities

→ **Search for preliminary answers to second question is the objective of this study.**

Approach Adopted for this Study

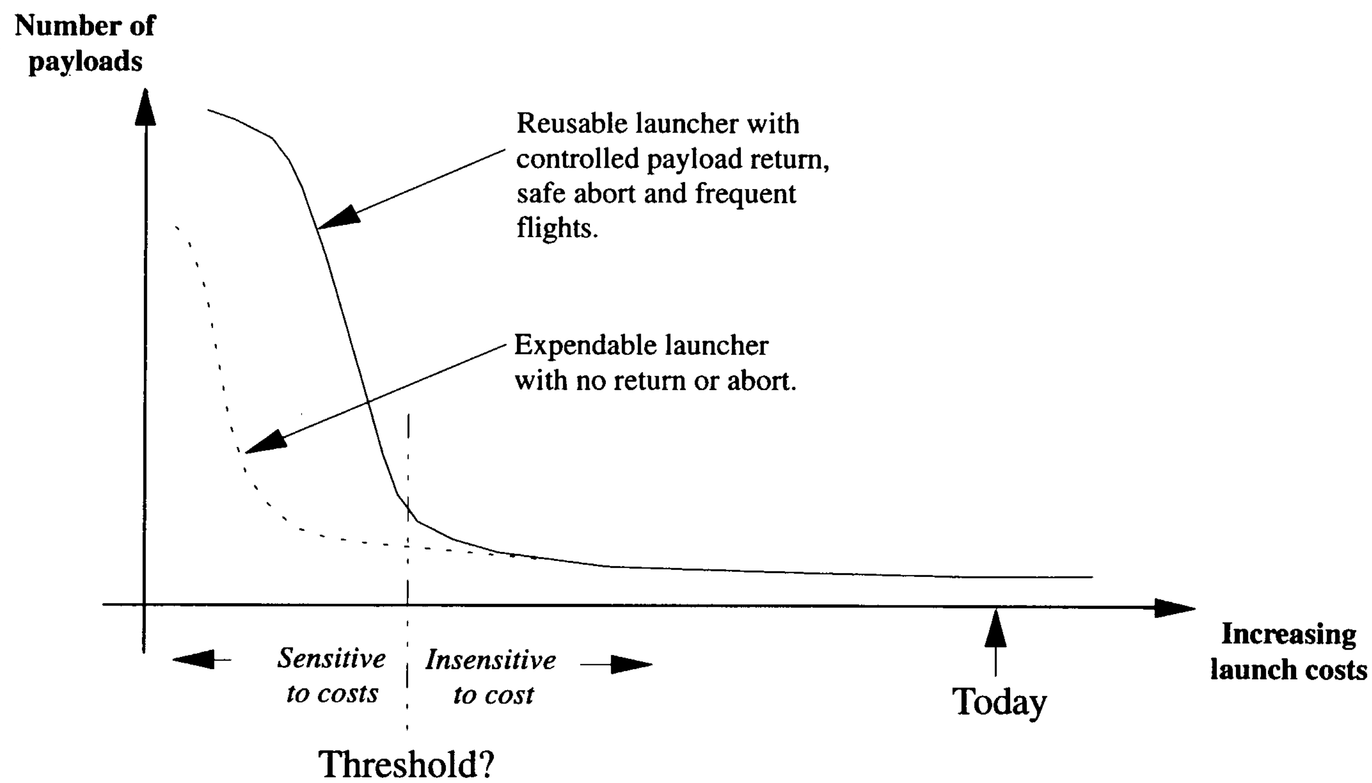
1. Understand relationship between payload design and launcher (WP 1000)
2. Quantify the way current payloads may respond to reusable launcher (WP 2000)
3. Model demand elasticity as a function of different launcher capabilities (WP 3000)
4. Estimate the scale of benefits to space activities. (WP 4000)

→ Essentially independent of reusable launcher configuration and feasibility

→ Relies only on current space mission types to ensure credibility

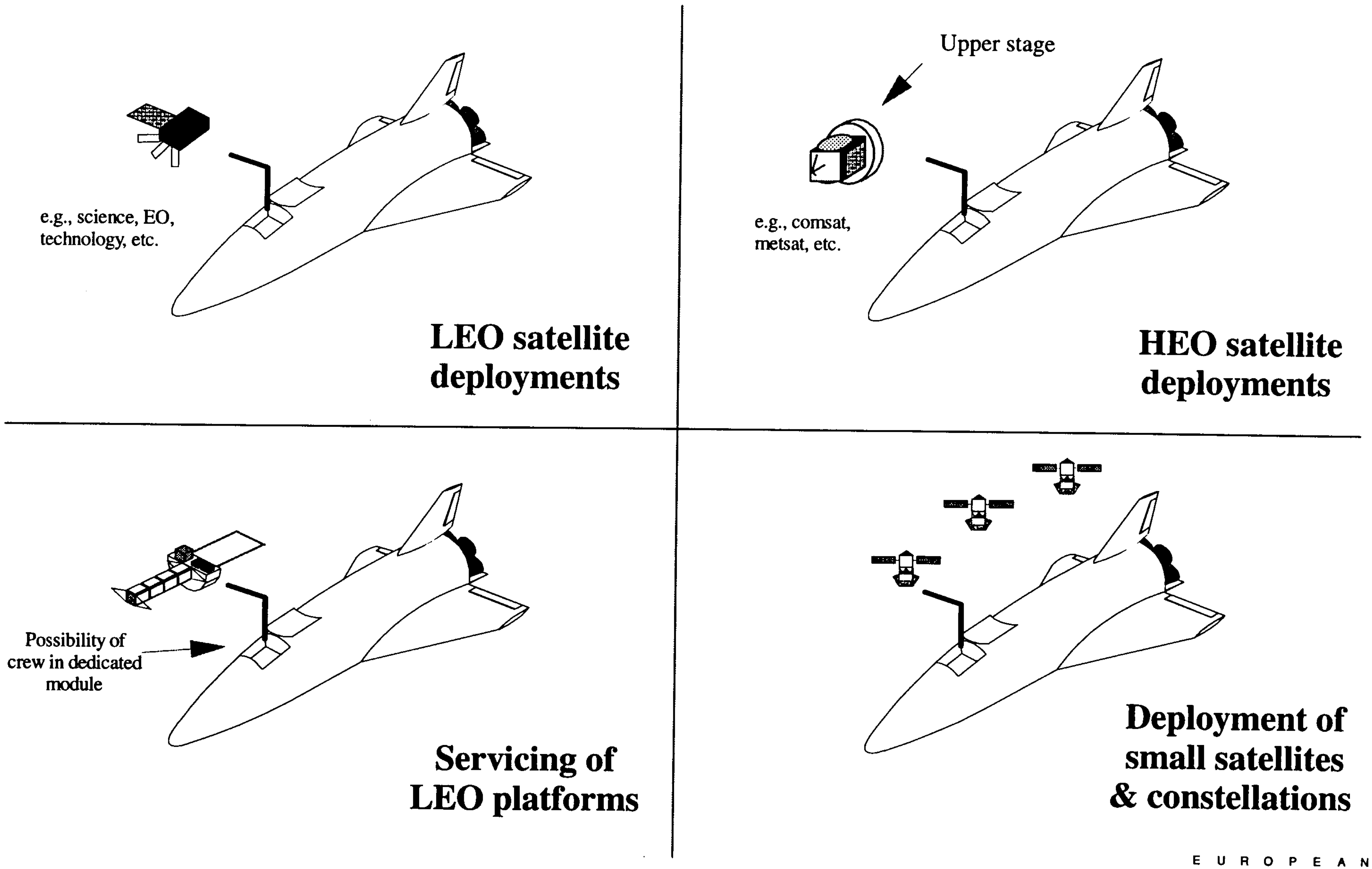
→ Interested in first years following introduction of a reusable launcher.

Possible Form of Demand Elasticity



May need to reduce launch costs very significantly to stimulate increased demand for space access, especially for transportation-intensive commercial missions.

Future Launchers & Their Users



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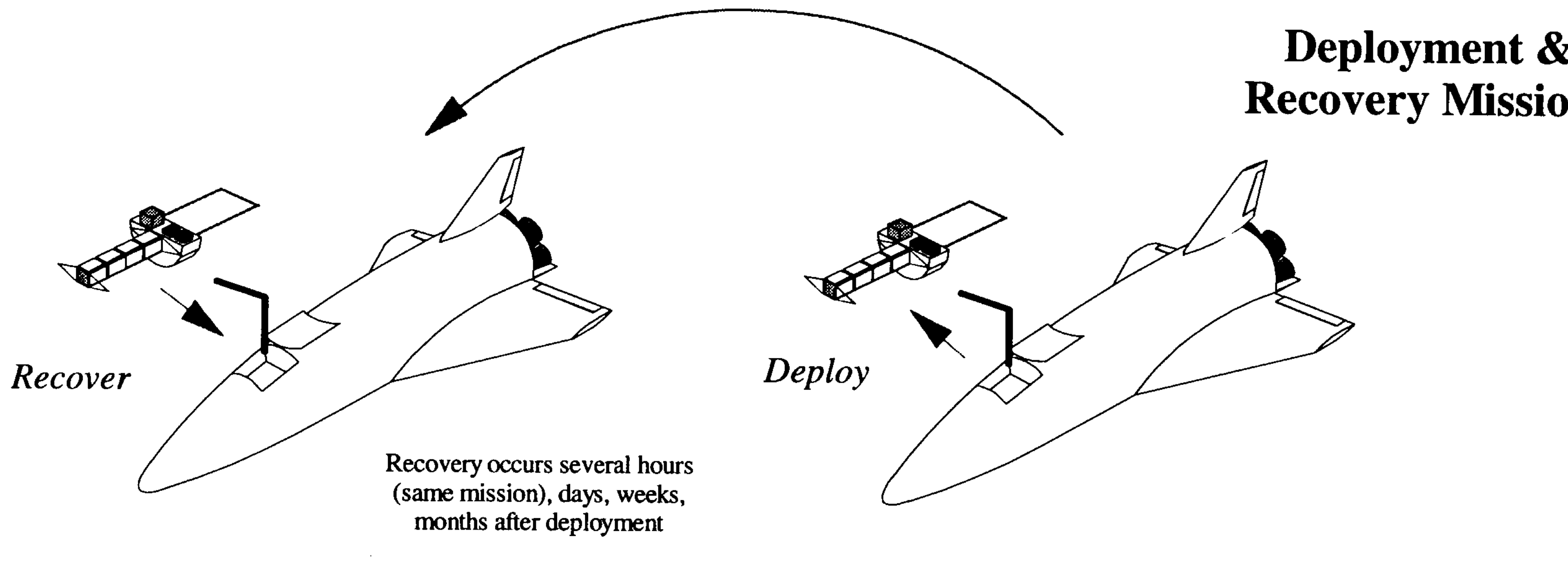
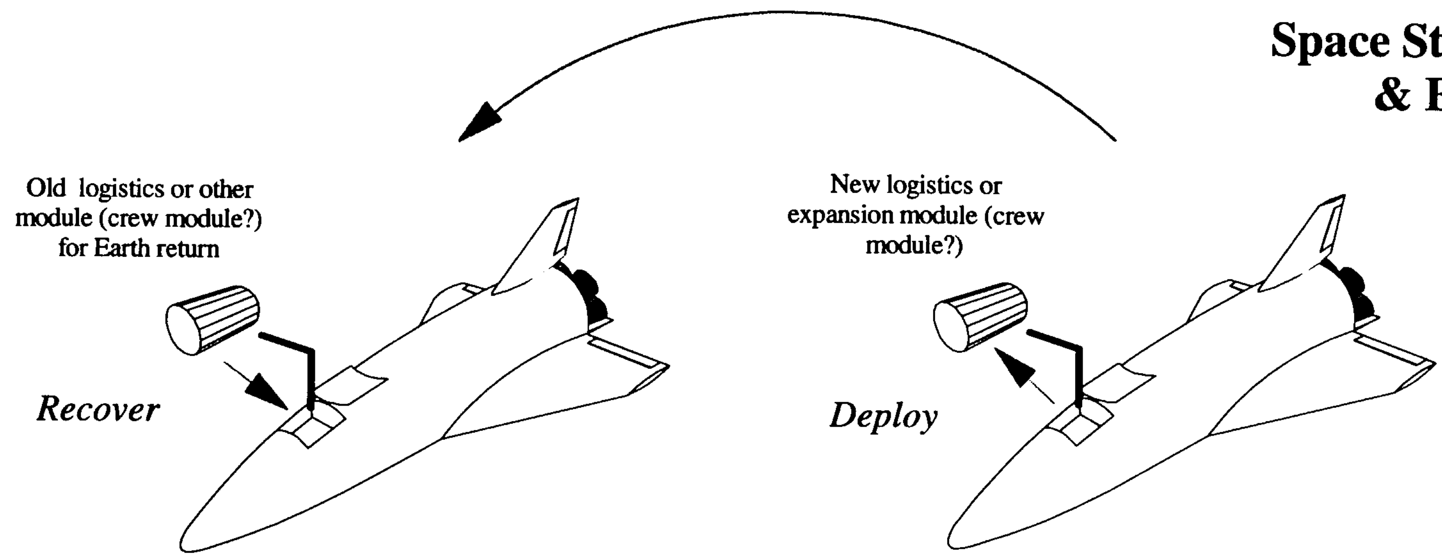
Future Launchers & Their Users

Deployment & Recovery Missions



Space Station Logistics & Expansion



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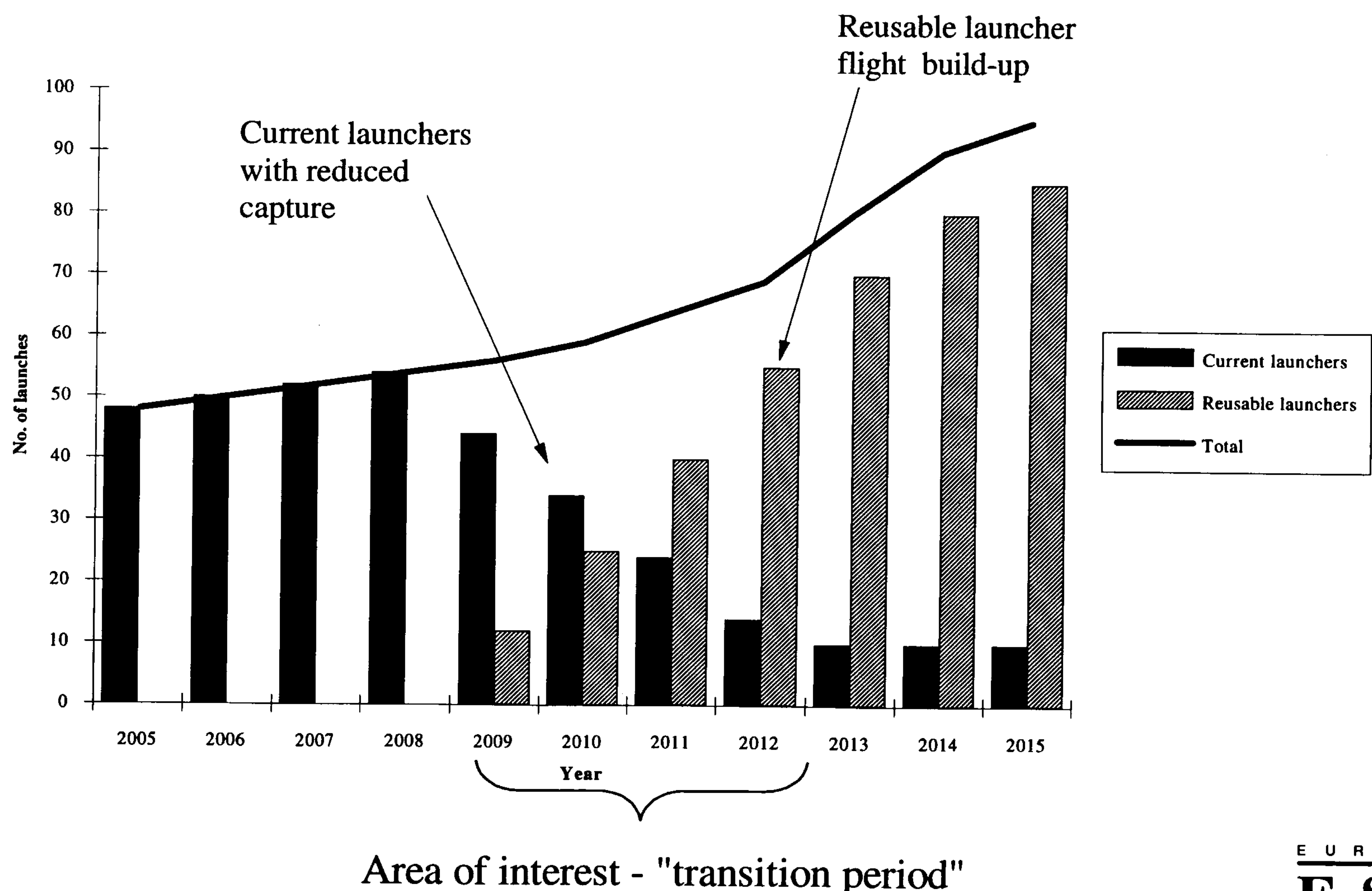
Current Space Mission Types to be Assessed

- Communications satellites in low and high orbit
- Earth observation satellites
- Space science satellites and probes
- Microgravity research and production missions
- Space infrastructure missions
- Technology demonstration and test-bed satellites

Transition to Reusable Launchers

(For example purposes only)



Key Questions to Address

Future reusable launchers are likely to be expensive

Therefore, need to know:

1. **How frequently must they fly to be economically justified?**
2. **Is there sufficient demand for space access to cover the supply?**
3. **Will this demand emerge without increasing current space spending?**

Understand the relationship between supply and demand.

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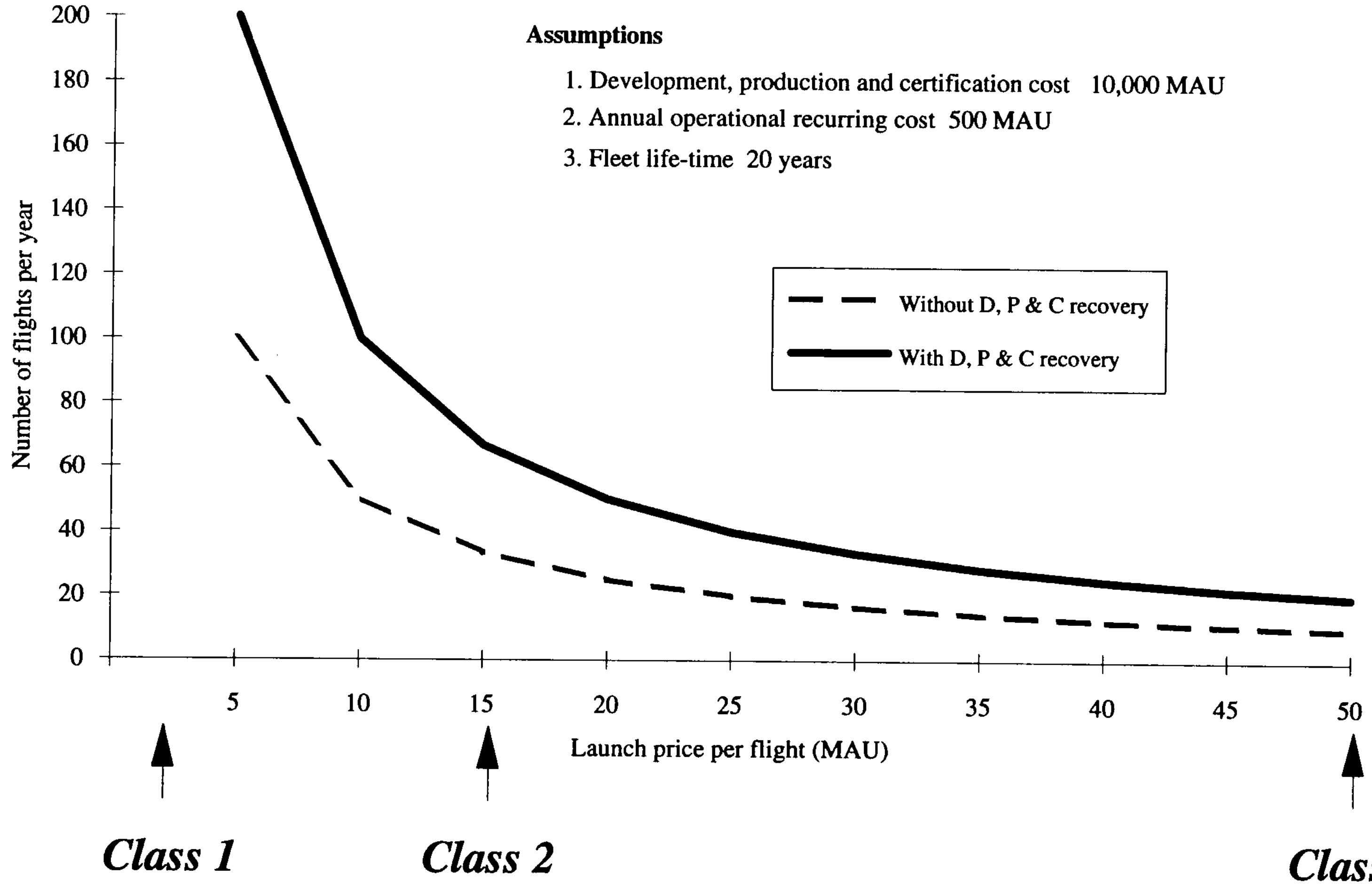
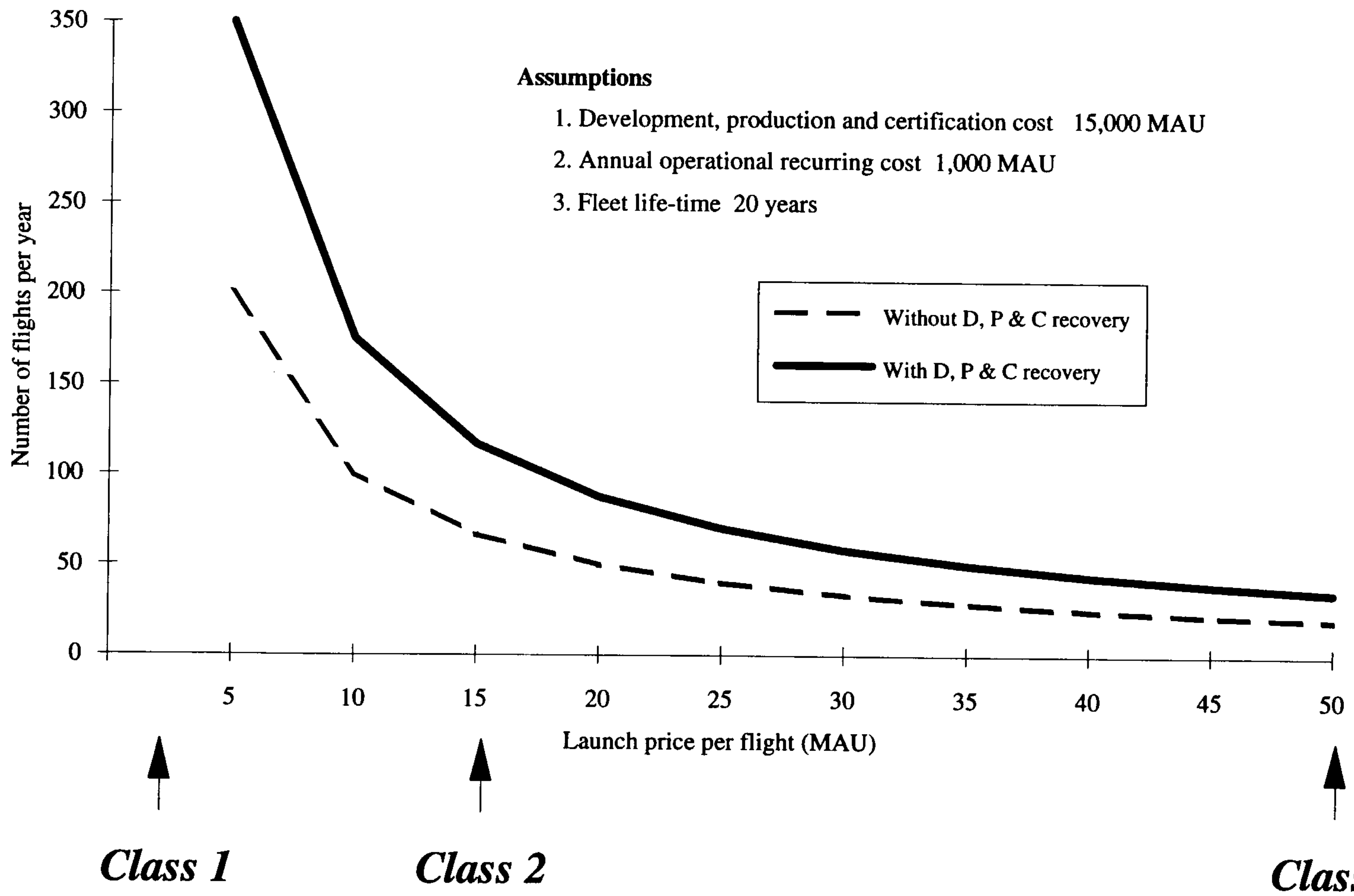
Notional Reusable Launcher (10 BAU)



Notional Reusable Launcher (15 BAU)



Reusable Launcher Flight Rate Envelope

	Class 1: 1-5 MAU	*Class 2: 10-20 MAU*	*Class 3: 50 MAU*
Flight rate with D,P&C recovery	200-350+	70-120	20-35
Flight rate with annual cost recovery only	100-200+	35-70	10-20

Area of interest for first generation operational reusable launcher

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Methods for Estimating Demand

Demand-Led Method

- Add up only exiting payloads and extrapolate at current growth rates
- Ignores the relationship between launch costs and capabilities
- Simplistic, first order approximation providing lower bound.

Critically, this approach is only valid for ***like*** *launchers.*

User Survey Method

- Go directly to end users to see what they want
- Present various capabilities and see how it would be utilised
- Should allow demand elasticity to be estimated
- NASA spending $2.5 million on such a study

Unlikely to receive a positive response simply because space is so unfamiliar.

The Interaction Method

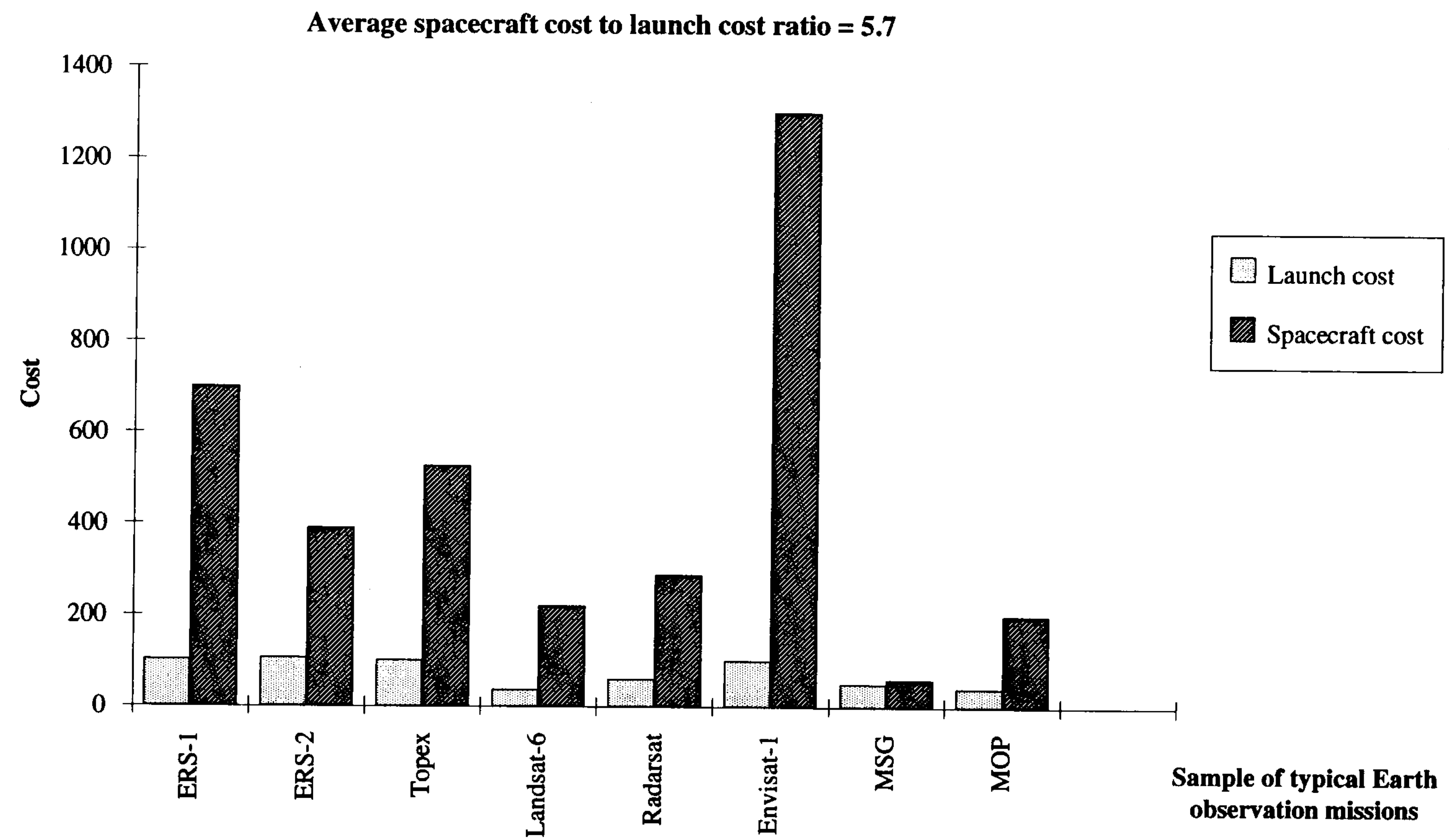
Rationale

- Space activities are intimately tied to the method of accessing space
- Reusable launchers provide a radical improvement in space access
- Lower dedicated and specific costs, higher flight rates, aborts, payload return
- Expected to allow space missions to be performed differently

Interaction Method

- Marries best features of demand-led and user-survey methods:
  - ✓ Concentrates essentially on existing mission types (like demand-led)
  - ✓ Allows missions to respond to improved space access (like user survey)

Earth Observation Satellites



Use new and unproven technology and only a few built.

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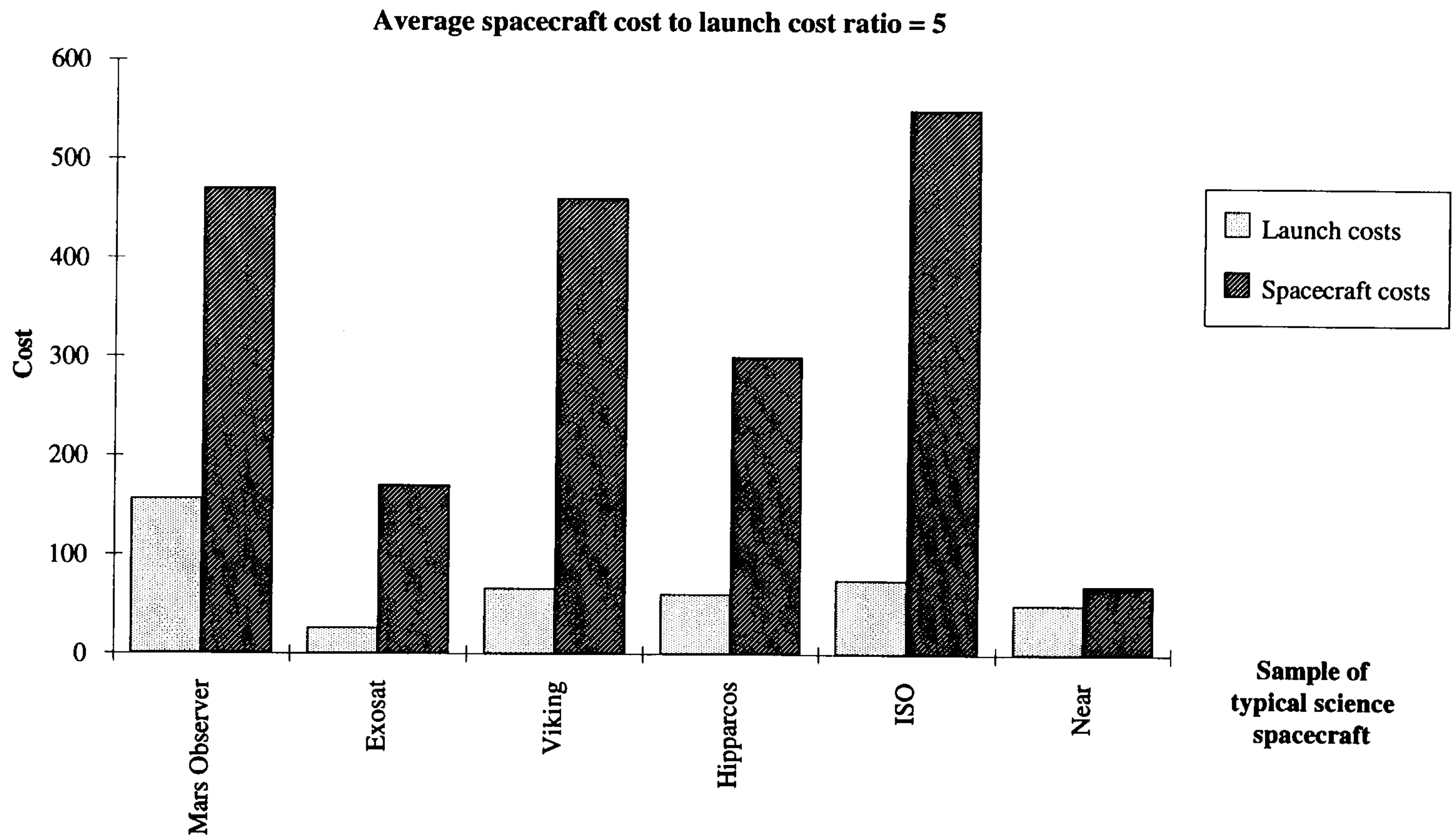
Scientific Satellites



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Assessing Changes in Demand

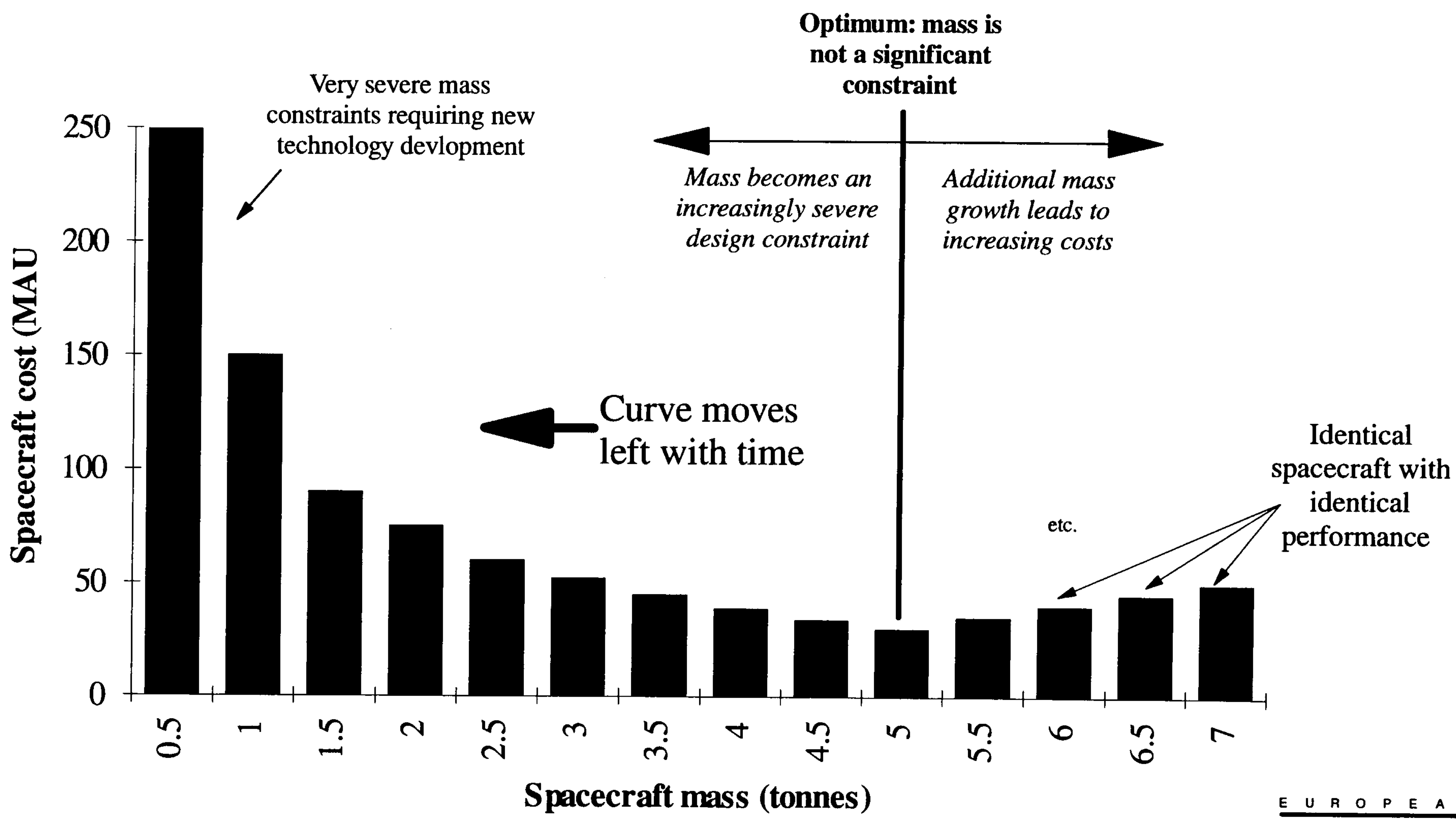
The Interaction Method estimates changes in demand as follows:

1. "**Re-investment and re-distribution**" of spacecraft and launch savings into additional missions. Two cases will be considered:
   - ➡ ***Case 1***: spacecraft/launcher (S/L) cost ratio ~ 1
   - ➡ ***Case 2***: spacecraft/launcher (S/L) cost ratio ~ 5.

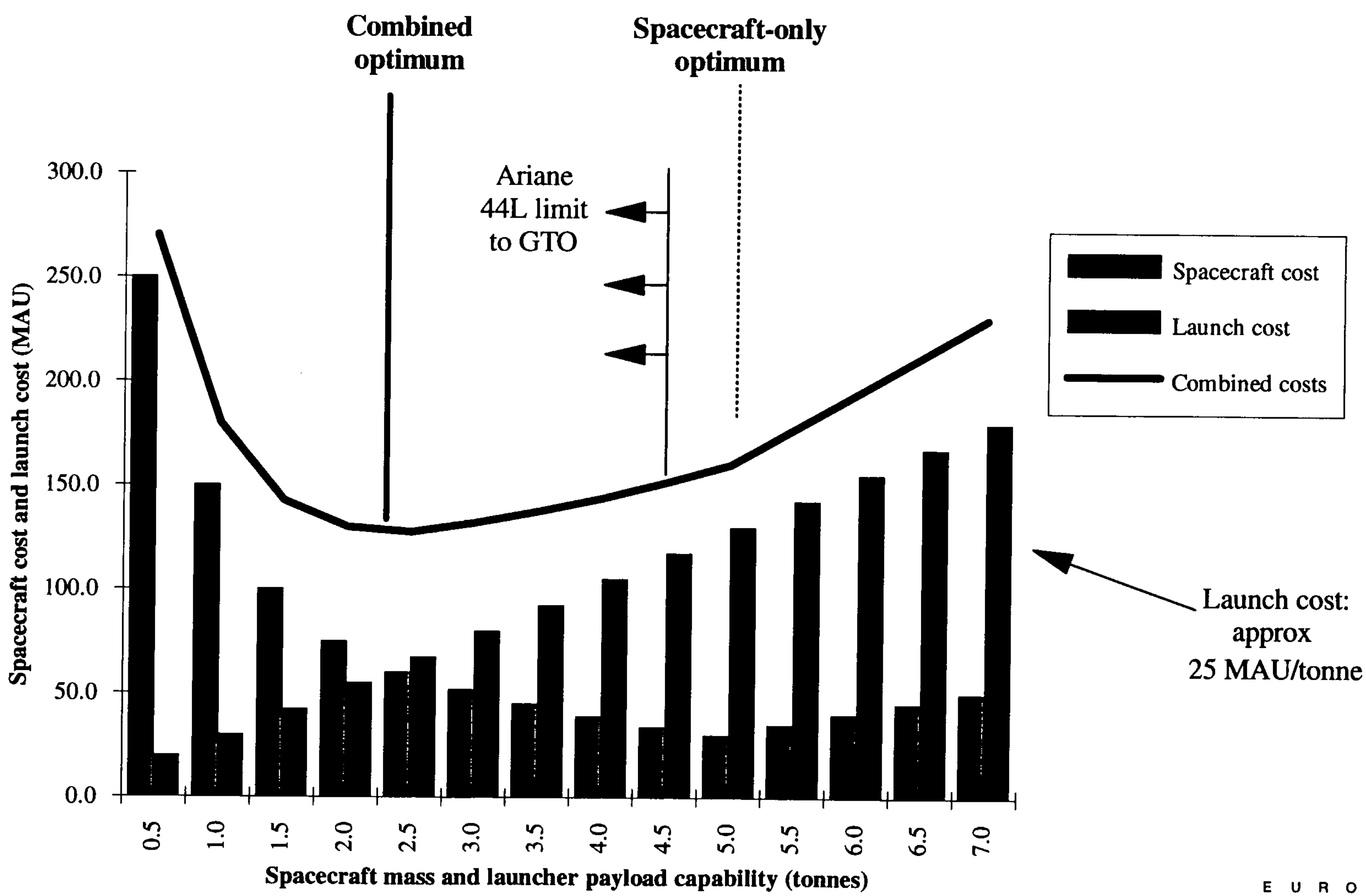
2. "**Provides the opportunity**" to perform lower-cost missions impractical today.

3. "**Re-optimise current missions**" to take advantage of other reusable launcher operational capabilities.

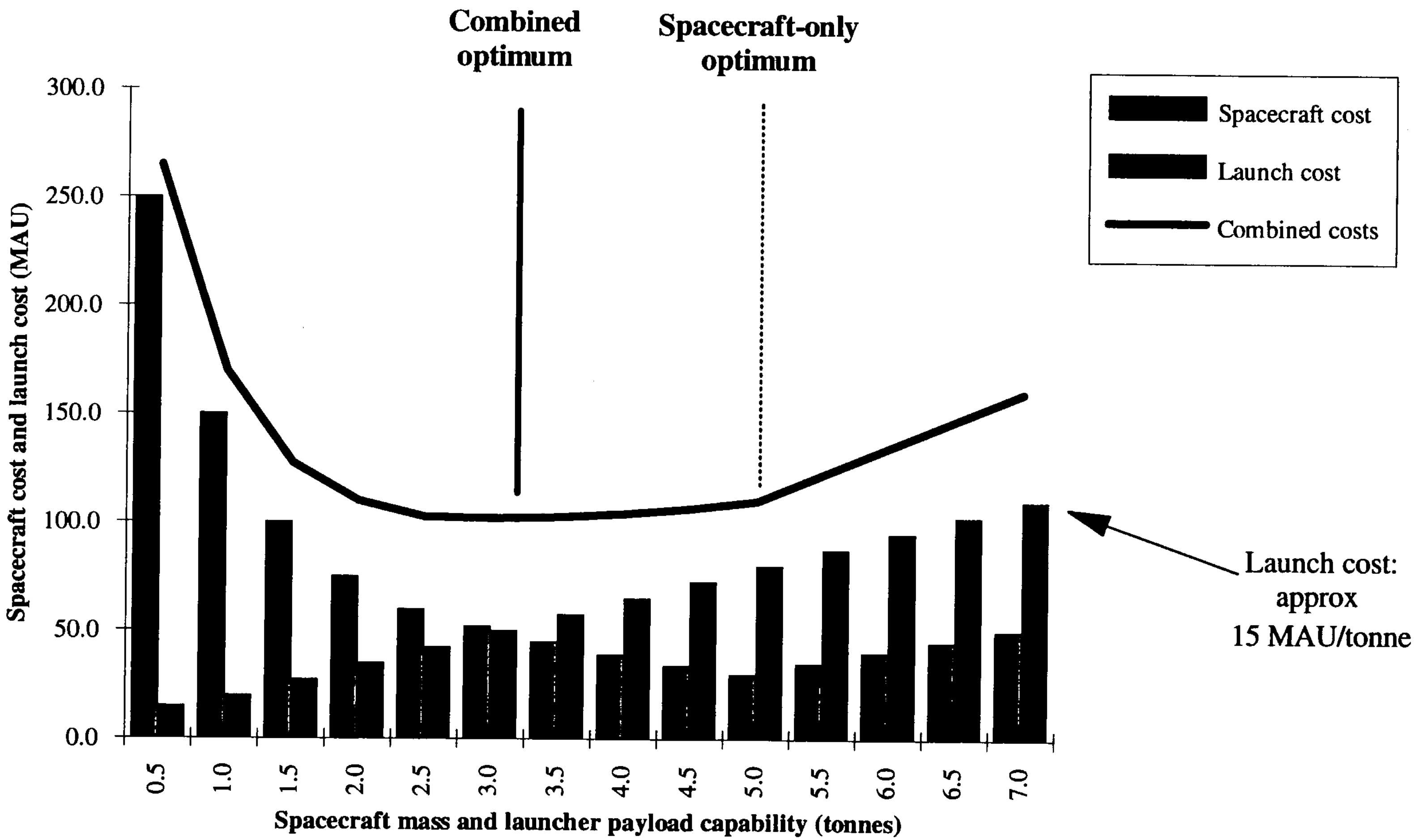
Generic Spacecraft Cost/Mass Relationship



Case 1: Impacts of Current Launch Costs into GTO



Case 1: Impacts of Current Launch Costs into LEO



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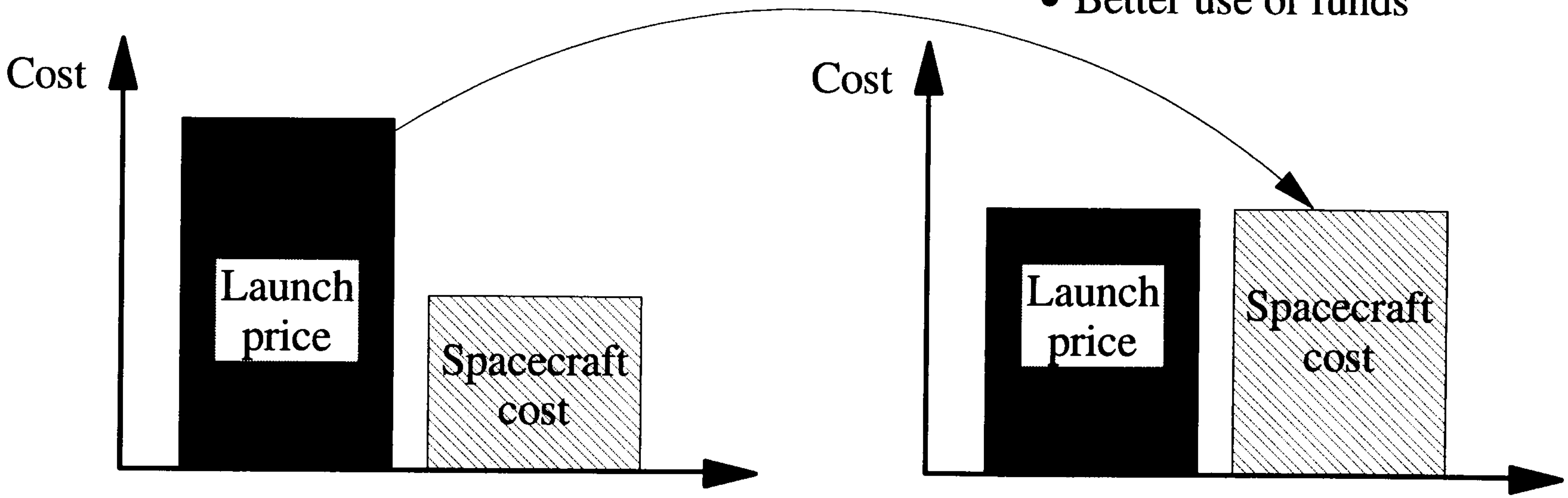
Can Spacecraft Cost Be Significantly Less Than Launch Prices?

Possible scenario
- Heavy, cheap spacecraft
- Expensive launch

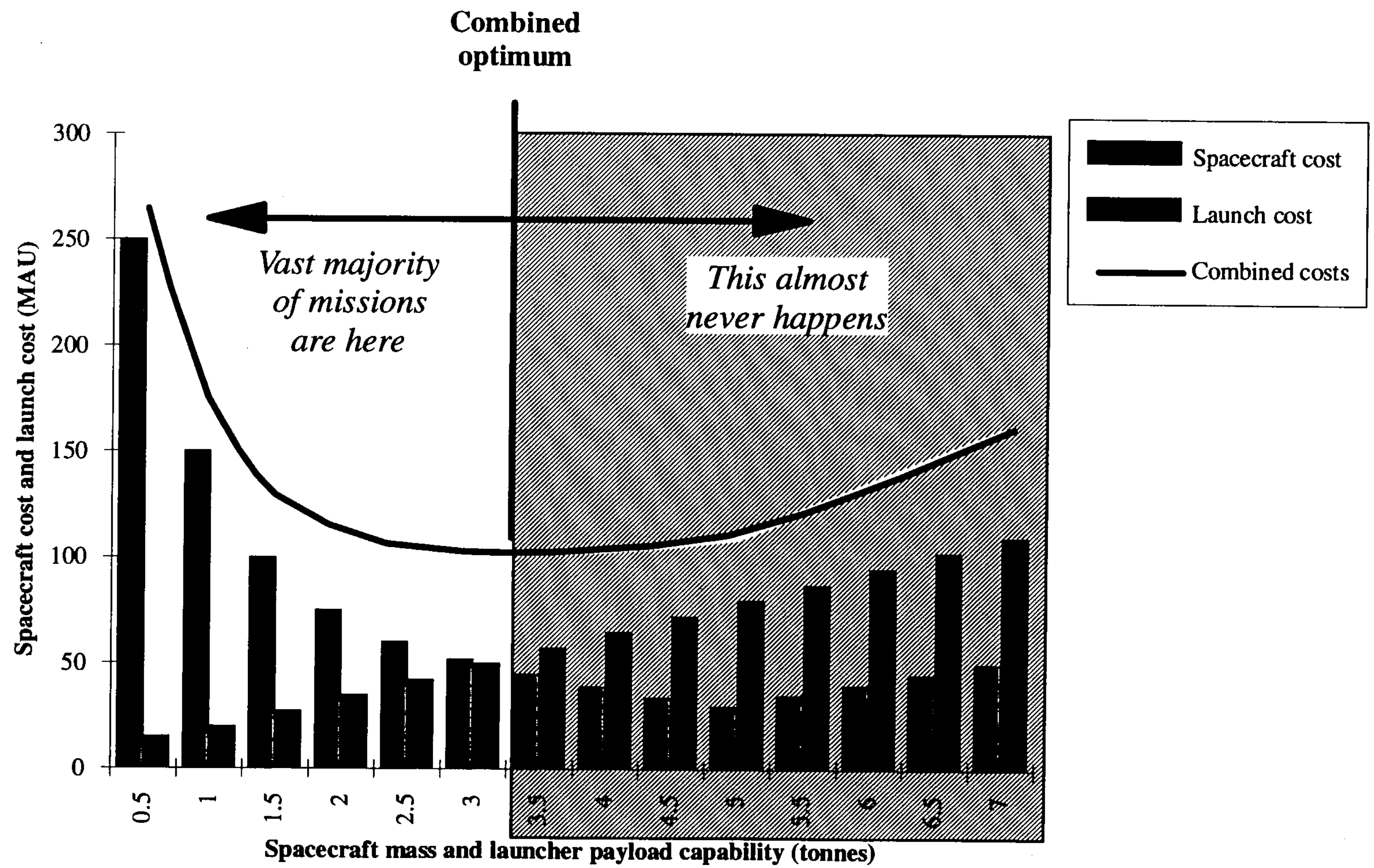
More likely scenario
- Same total cost approximately
- But, *improved* mission
- Better use of funds



➡ Tendancy to minimise transportation costs and maximise investment in space assets

➡ Exception: when there are no cheaper launchers available

Launch Costs are Very Rarely Greater Than Spacecraft Costs



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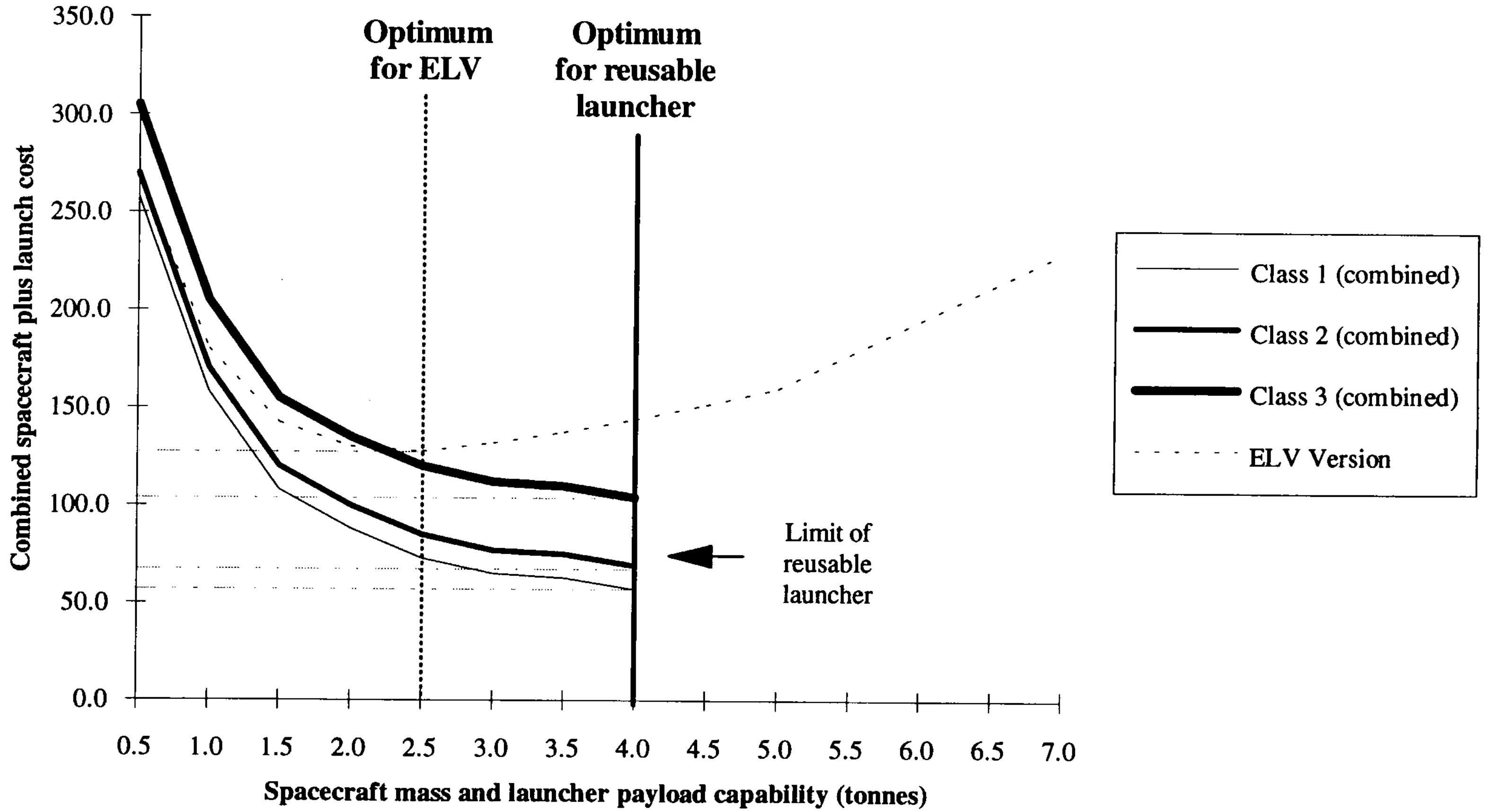
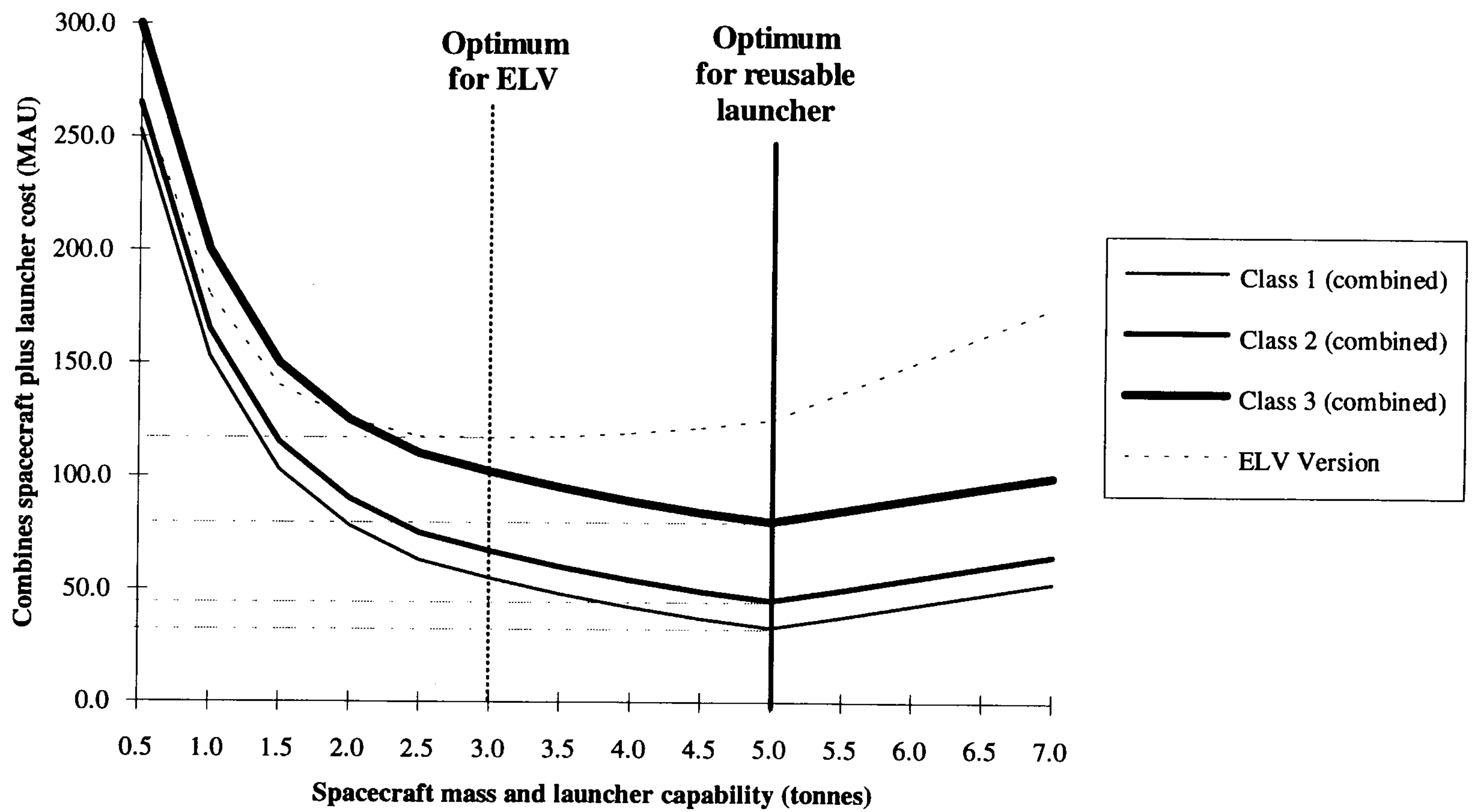
Case 1: Impacts of Reusable Launcher Costs into GTO

(Includes upper stage costs)



Case 1: Impacts of Reusable Launcher Costs into LEO



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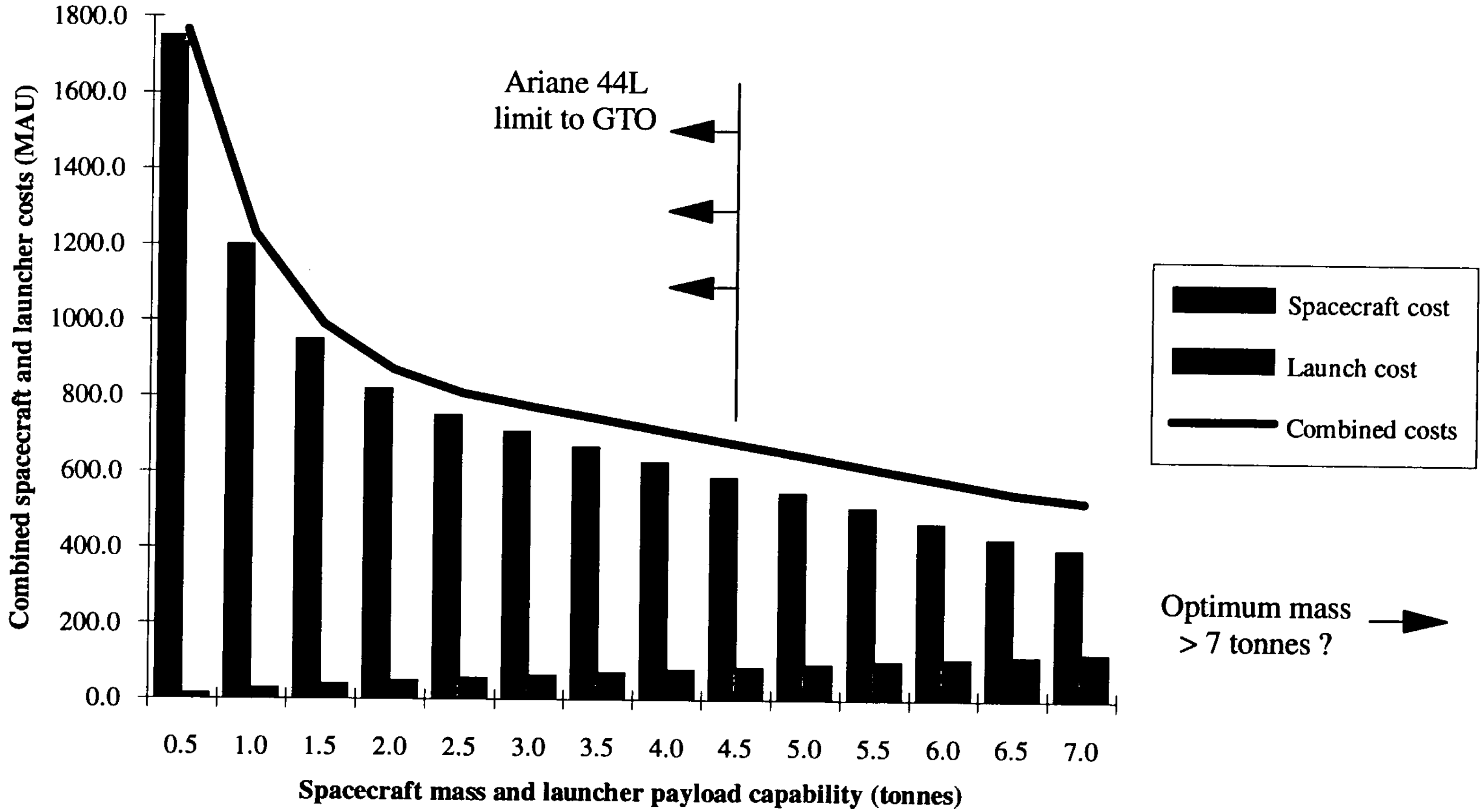
Conclusions for Case 1 Spacecraft

- Spacecraft costs vary as a function of mass.
- Optimum occurs where spacecraft cost is roughly equal to launch costs.
- Therefore, reusable launcher would lead to both launch and spacecraft cost savings.
- LEO savings less significant than GTO.

Case 2: Impacts of Current Launch Costs into GEO
(S/L = 5)



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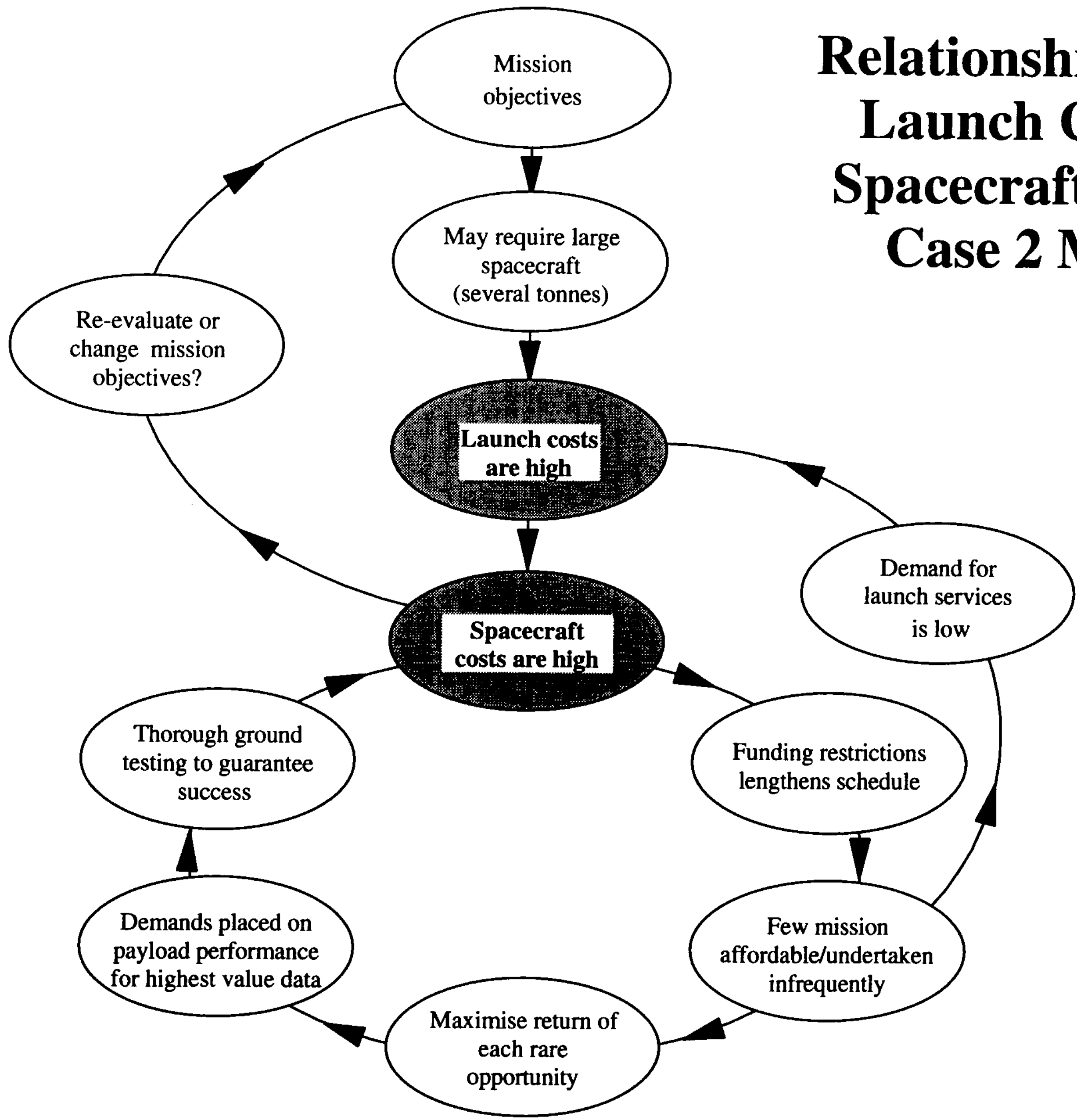
Relationship Between Launch Costs and Spacecraft Costs for Case 2 Missions



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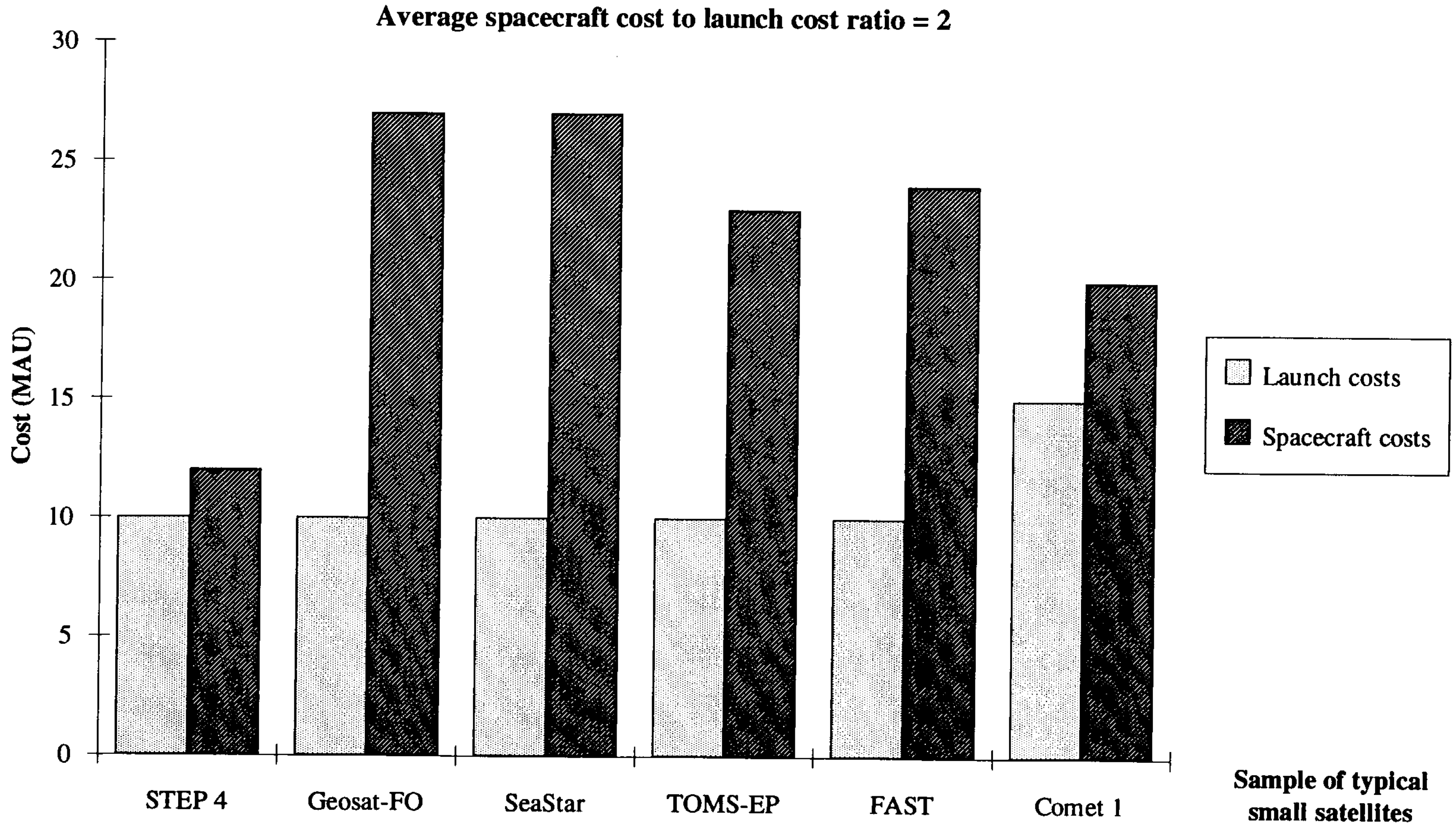
Conclusions for Case 2 Spacecraft

- Appears reusable launchers would make only a small impact on current designs.
- However, EO and science spacecraft tend to cost about 5 times launch cost.
- Therefore, if launch cost is 100 MAU, cheapest spacecraft is 500 MAU.
- Hence, reduced launch costs "**provides the opportunity**" to perform other lower-cost missions.

Providing the Opportunity:
The Small Satellite Precedent



Sample of typical small satellites

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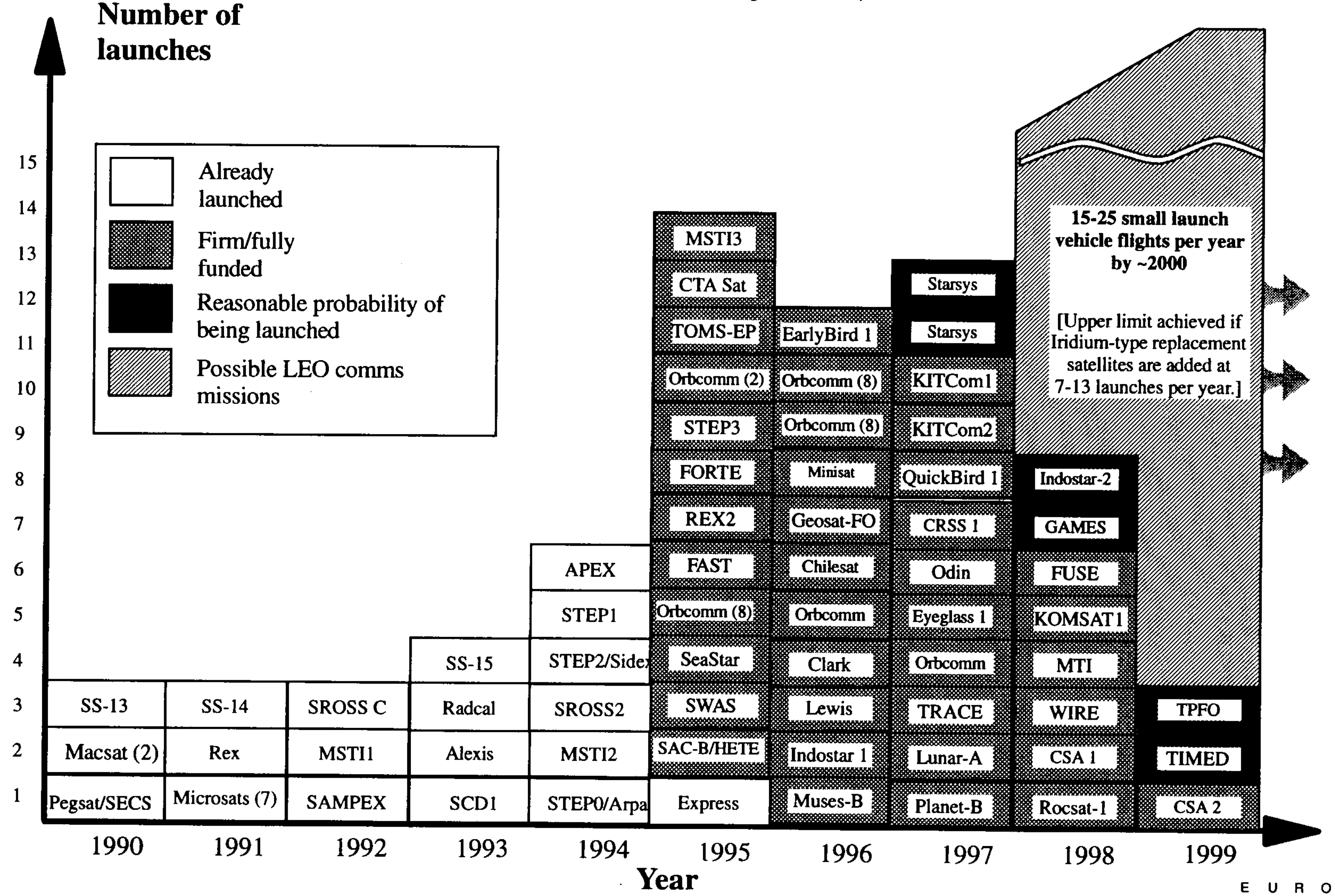
Small Launch Vehicle Events: 1990-1999

(Revised February 1995)



(**Note:** Does not include Russian and Chinese launches)

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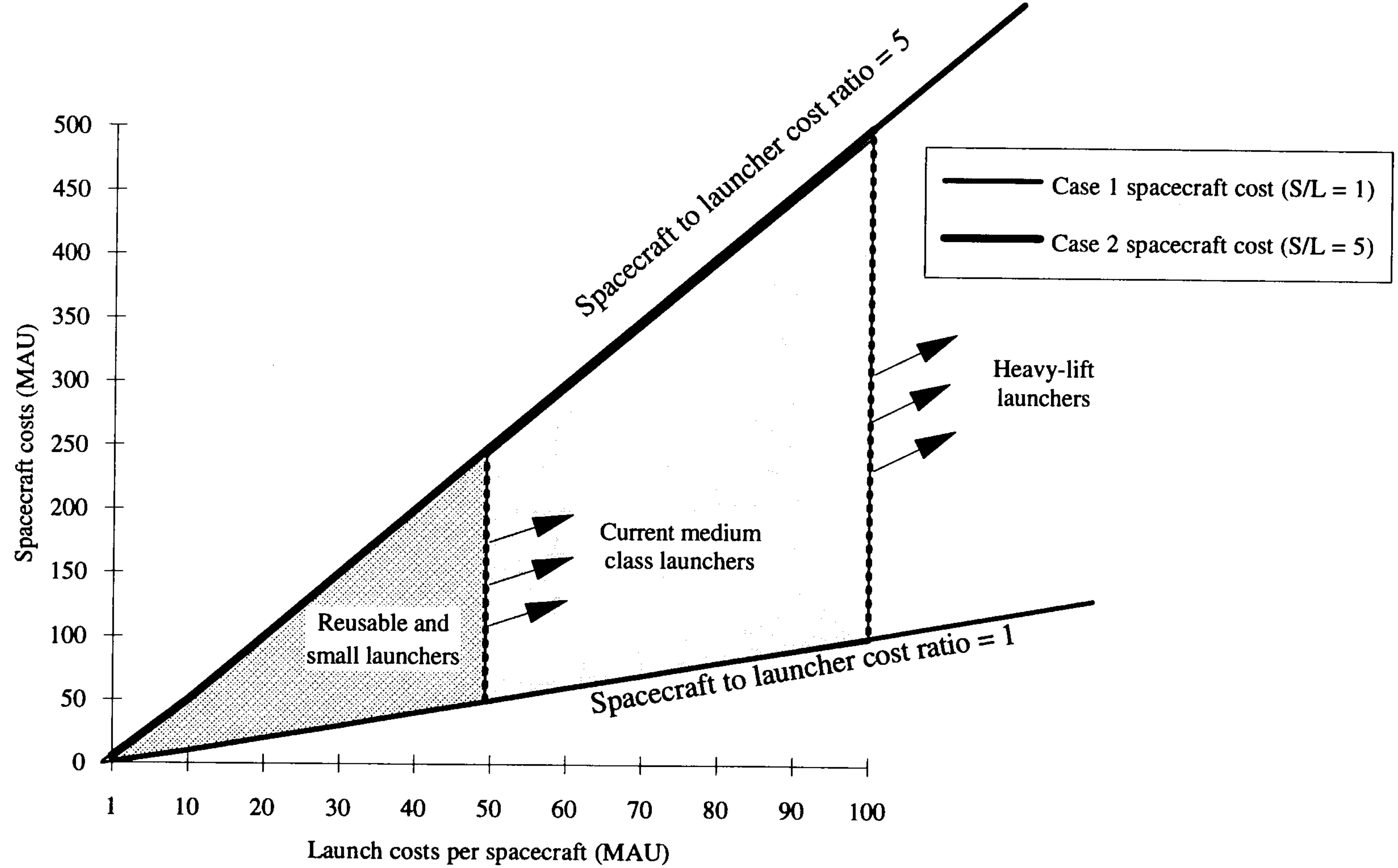
Spacecraft Cost Limitations



Conclusions for Providing the Opportunity Missions

- From cost perspective only, reusable launchers are same as small launchers

  → *Potential new market area.*

- However, payload mass 10 times and payload volume 50 times larger.
- Therefore, could either,

  1. Allow mass of small satellites to grow to reduce costs and do more
  2. Build cheaper, complementary cut-down versions of Case 2 mission

- In second case, take launch cost savings and re-invest them in 1 or more precursor or complementary technology demonstration missions.

Benefits of Other Reusable Launcher Capabilities

Benefits include:

1. Improved reliability and safe abort and payload recovery
2. High availability, on-demand and surge launch capabilities
3. In-orbit rendezvous and spacecraft return to Earth
4. Payload containerisation.

➡ All of the above would be demonstrated as part of an aircraft-like certification programme.

➡ Each has significant impacts independently and collectively on spacecraft design and missions.

Benefits of Improved Reliability on Insurance Premiums

- Premiums are a function of failure rate, launch frequency and investment
  - → 1.5 failures per year (last ten years)
  - → 200 MAU average write-off implies insurance capacity of 300 MAU
  - → 10 insured launch events per year implies a **premium of 15%**
- If failure rate for a Class 2 reusable launcher was the same as ELVs (1 in 20)
  - → This would lead to 2 or 3 catastrophic losses per year
  - → Clearly unacceptable give replacement cost of 1 BAU+
- One catastrophic loss every 3 or 4 years is much more realistic
  - → One reusable launcher failure every 150-200 flight is a factor of 4.5 better than ELVs
  - → 50% of ELV failures due to upper stage - assume the *same* for reusable launchers

- Hence, contribution to premium from reusable launcher 1.5%
- Hence, contribution to premium from upper stage 7.5%
- **Therefore, total premium for Class 2 vehicle + upper stage ~ 9 %**

[Similarly, Class 1 and 3 premiums are 7.75% and 15%, respectively.]

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Benefits of Higher Availability & On-demand Launch

Consider the example of Iridium-type constellation missions:

- Iridium requires 66 satellites in 11 orbital planes to be operational
- (Roughly 10 satellites must be replaced annually)
- With ELVs, low availability/delays means deployment will take 3-4 years
- GPS has taken 6 years to deploy 24 Navstar satellites
- Intermittent service will not attract many users
- Each year of delay will loose ~ 1 BAU in revenues
- Therefore, more rapid deployment leads to earlier revenues
- Iridium and similar ventures would benefit from reusable launchers

Regularly scheduled and frequent access to space is important to many missions, particularly those which are *transportation-intensive*.

Benefits of In-Orbit Rendezvous & Payload Return

Consider the example of on-orbit servicing:

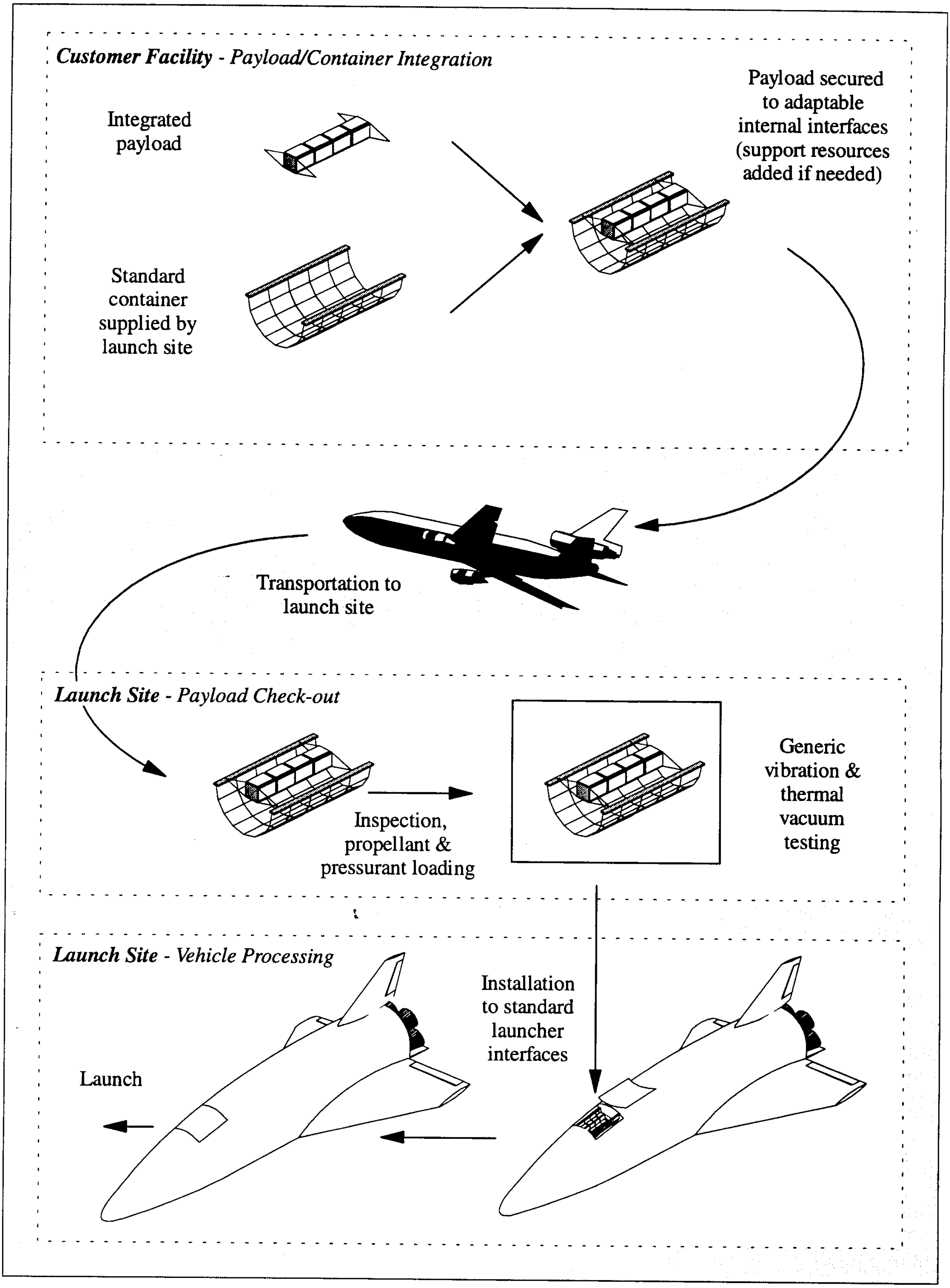
- Servicing holds the potential to save costs and benefit from space assets
- ENVISAT-1 cost ~ 1 BAU, but will be expended after 4 years (nominally)
- Numerous other spacecraft are potential servicing candidates
- Shuttle only vehicle available for servicing
- But, it is very expensive, has very low availability and often delayed
- Only Space Station and Hubble "justify" use of Shuttle
- Hence, reusable launchers expected to lead to cost benefits from servicing
- Can be demonstrated as part of certification programme

Servicing is an attractive proposition if the cost is significantly less than the replacement cost, if there are frequent opportunities to undertake such missions and if it is demonstrated

Benefits of Payload Containerisation

- Most launchers are tailored to a specific payload
- To minimise mass, standard interfaces are not used throughout
  - ➡ A new Shuttle harness is manufactured for each mission
- Payload delays can delay schedule for other customers
- For reusable vehicles to achieve low costs they must be used often
- Airliners, ships, trains and trucks employ standard containers to minimise turnaround
- Hence, benefit of reusable launcher containers are that:
  - ➡ They reduce spacecraft AI&T personnel needed at launch site
  - ➡ Spacecraft integration is decoupled from launcher integration

The use of payload containers is probably mandatory for reusable launchers to achieve very high flight rates - also a sign of a maturing capability



Customer Facility - Payload/Container Integration
Integrated payload
Payload secured to adaptable internal interfaces (support resources added if needed)
Standard container supplied by launch site
Transportation to launch site
Launch Site - Payload Check-out
Inspection, propellant & pressurant loading
Generic vibration & thermal vacuum testing
Launch Site - Vehicle Processing
Installation to standard launcher interfaces
Launch

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Main Aims of this Analysis

Three main objectives are to:

1. Assess how reusable launchers may impact the six current space mission types

2. Quantitatively estimate the changes in demand as a function of the three vehicle classes

3. Derive "stimulation factors" for each mission type

→ *Plug into elasticity of demand model (WP 3000)*

Structured Analysis Approach

Definition of Reusable Launch "Impacts":

Impact 1 →	Economic savings derived purely from a **lower cost launch** where spacecraft must be compatible with current launchers	*Same missions* (Impacts 1–3)
Impact 2 →	Economic benefits from **other operational capabilities** of reusable launchers (e.g., improved reliability, servicing, etc.)	
Impact 3 →	Economic benefits from **re-optimising the spacecraft design** for the reusable launch while maintaining the same mission	
Impact 4 →	Economic benefits from completely **re-optimising space missions** in order to achieve the user needs cost-effectively	*Different missions*

Each successive impact represents an increasingly strong response to the utilisation of the reusable launcher

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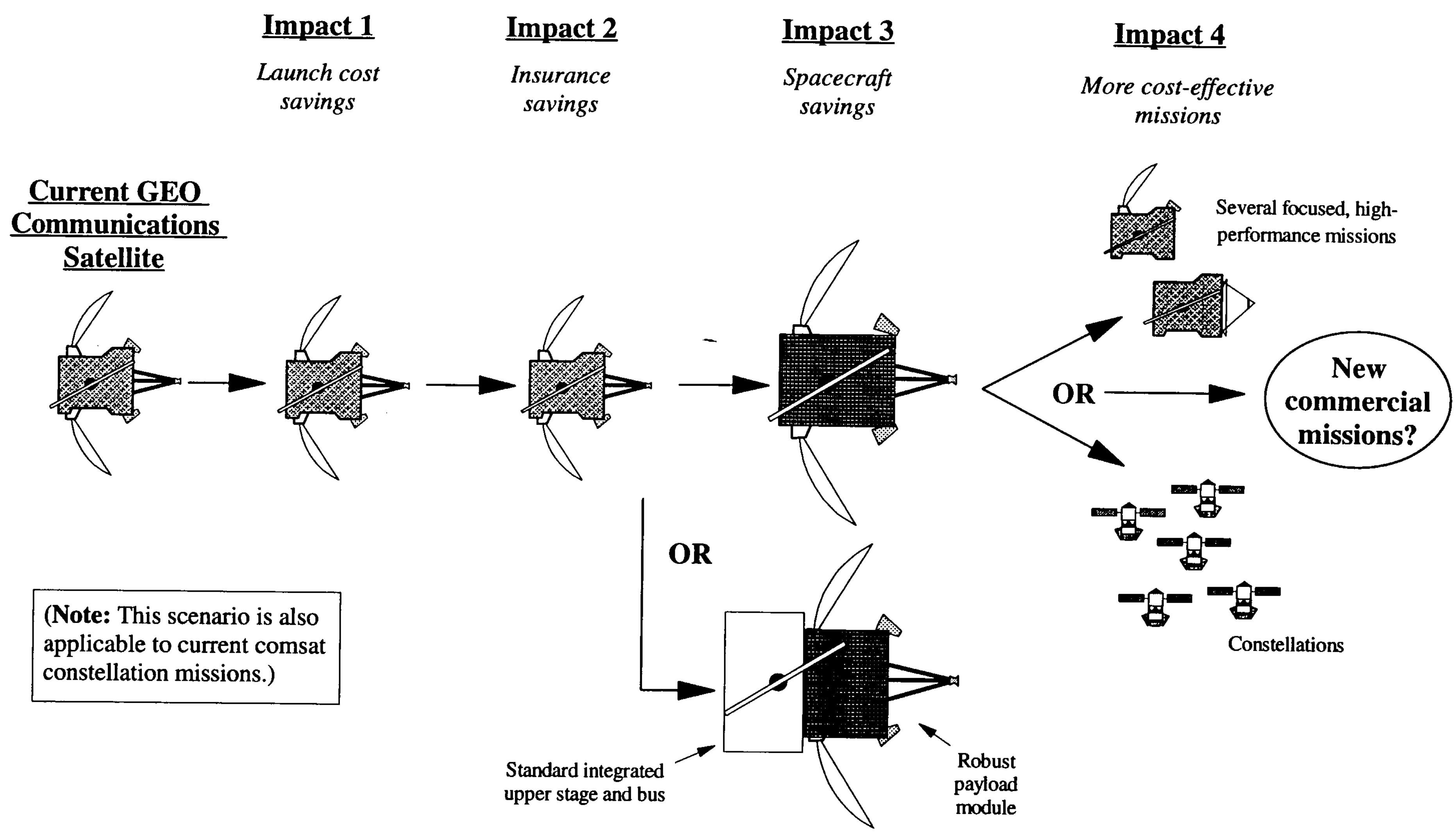
Future Launchers & Their Users

Communications Satellites



(**Note:** This scenario is also applicable to current comsat constellation missions.)

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Impact 1: *Launch Cost Savings*

Typical Current GEO Comsat Economics

Spacecraft cost	75 MAU
Launch cost	75 MAU
Launch insurance (@15%)	23 MAU
TOTAL	**173 MAU**

Impact 1 Economics

	Class 1 Launcher	Class 2 Launcher	Class 3 Launcher
Spacecraft cost	75 MAU	75 MAU	75 MAU
Upper stage cost	15 MAU	15 MAU	15 MAU
Launch cost	3 MAU	15 MAU	50 MAU
Launch insurance (@15%)	14 MAU	16 MAU	21 MAU
TOTAL	**107 MAU**	**121 MAU**	**161 MAU**
Savings	***66 MAU***	***52 MAU***	***12 MAU***

Impact 2: *Other Operational Benefits*

Typical Current GEO Comsat Economics

Spacecraft cost	75 MAU
Launch cost	75 MAU
Launch insurance (@15%)	23 MAU
TOTAL	**173 MAU**

Impact 2 Economics

	Class 1 Launcher	Class 2 Launcher	Class 3 Launcher
Spacecraft cost	75 MAU	75 MAU	75 MAU
Upper stage cost*	15 MAU	15 MAU	15 MAU
Launch cost	3 MAU	15 MAU	50 MAU
Launch insurance	7 MAU	9 MAU	21 MAU
TOTAL	**100 MAU**	**114 MAU**	**161 MAU**
Savings (cf. Table 3.1-1)	*73 MAU*	*59 MAU*	*12 MAU*

Impact 3: *Re-optimised Spacecraft Design*

Typical Current GEO Comsat Economics

Spacecraft cost	75 MAU
Launch cost	75 MAU
Launch insurance (@15%)	23 MAU
TOTAL	**173 MAU**

Impact 3 Economics

	Class 1 Launcher	Class 2 Launcher	Class 3 Launcher
Spacecraft cost	56 MAU*	56 MAU*	75 MAU
Upper stage cost	17 MAU	17 MAU	15 MAU
Launch cost	3 MAU	15 MAU	50 MAU
Launch insurance	6 MAU	8 MAU	21 MAU
TOTAL	**82 MAU**	**96 MAU**	**161 MAU**
Savings (cf. Table 3.1-1)	***91 MAU***	***77 MAU***	***12 MAU***

*Assumes 25% reduction by selectively allowing spacecraft mass and volume to grow.

Impact 4: *Re-optimised Missions*

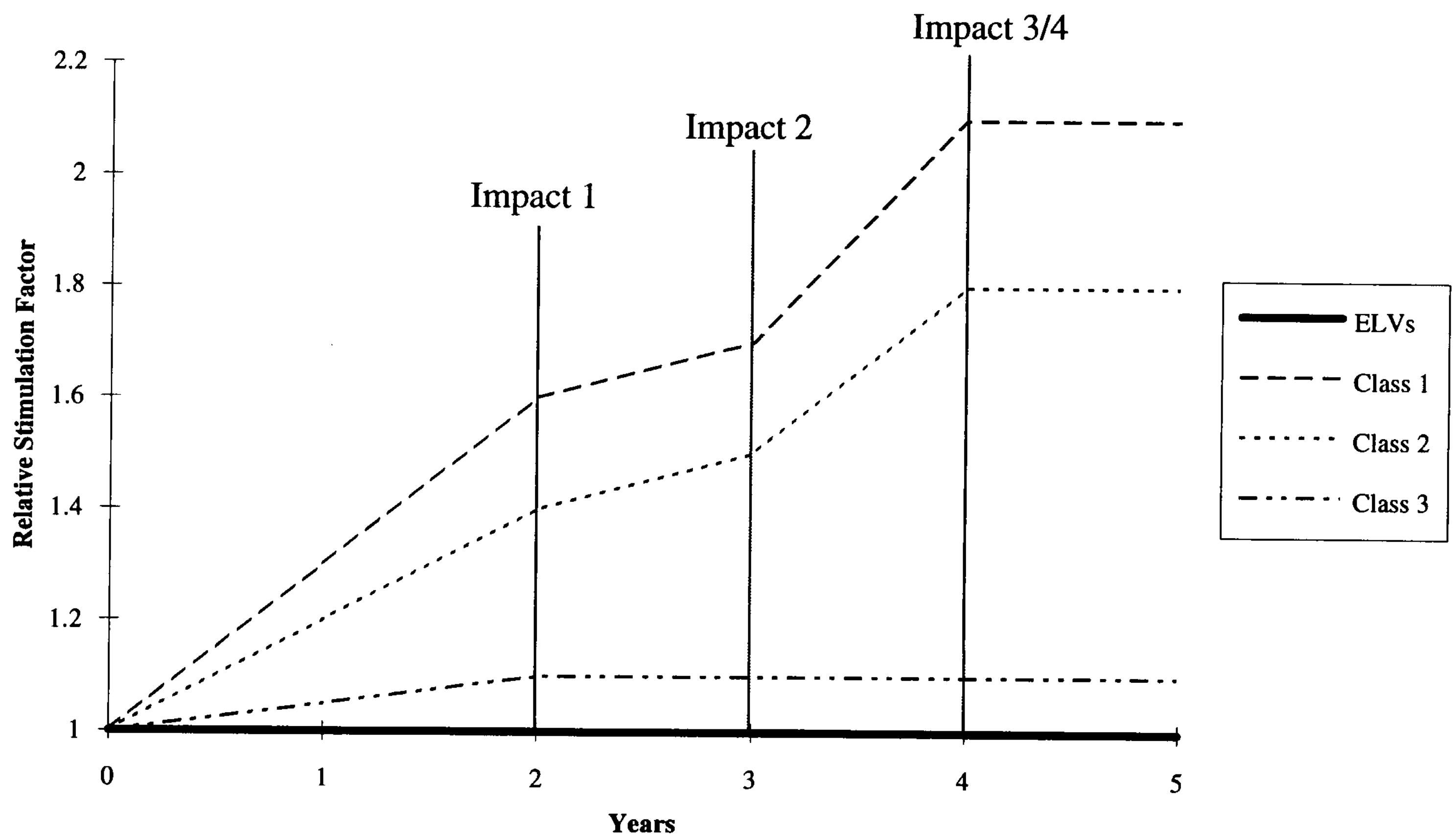
- Impact 3 for Class 1 and 2 vehicle gives S/L ~ 3 and 1.75, respectively
- Implies the example comsat is not "cost optimised" for reusable launcher
- Hence, theoretical optimum cost for *any* comsats would be:
  - → Class 1 vehicle ~ 20 MAU
  - → Class 2 vehicle ~ 30 MAU
- Further, consider two extremes alternatives for a Class 2 vehicle:

	Extreme 1 **e.g., 2 tonnes**	**Extreme 2** **e.g., 1 tonne**
Spacecraft cost	30 MAU	40 MAU
Upper stage cost	15 MAU	15 MAU
Launch cost	15 MAU	5 MAU
Launch insurance	5 MAU	5 MAU
TOTAL	**65 MAU**	**65 MAU**

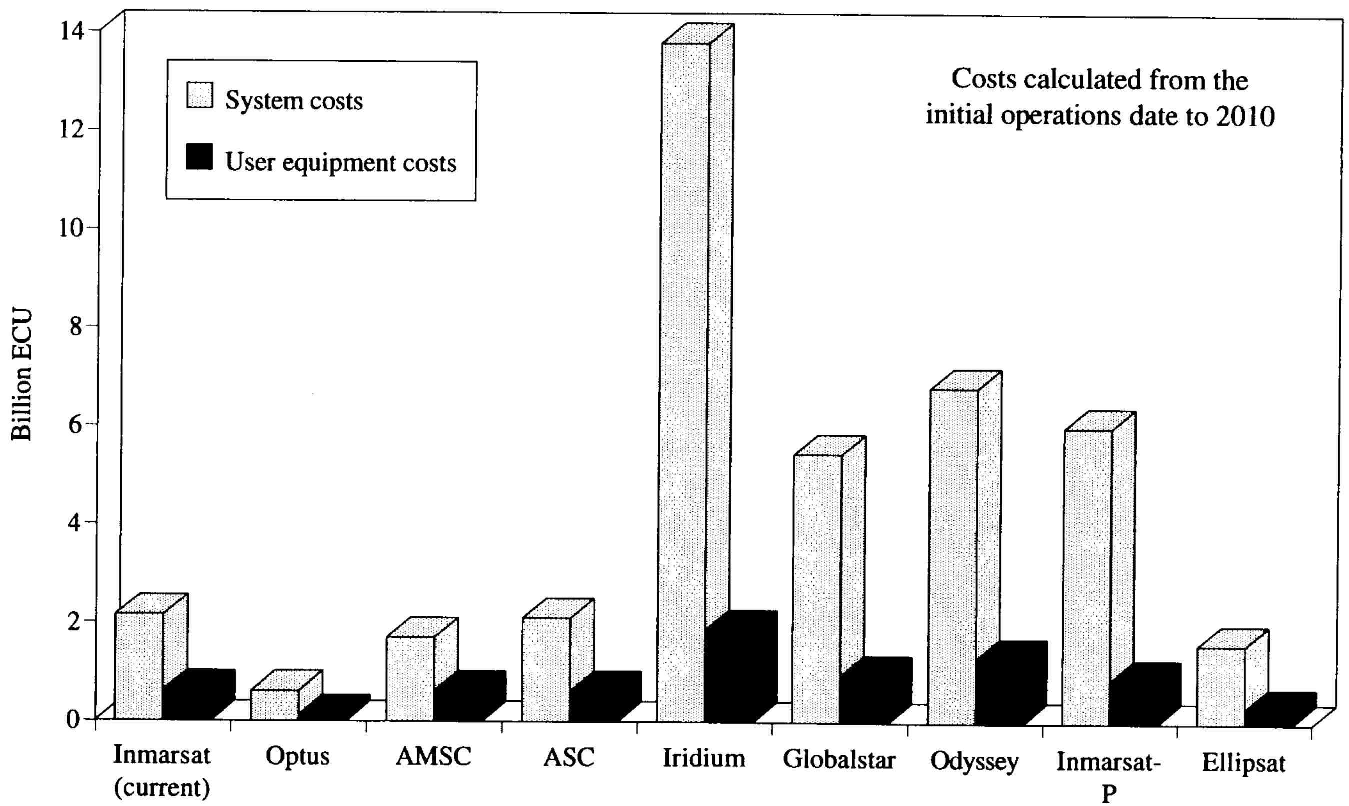
OK - cost optimised ***Not cost optimised (S/L~2)***

Low launch costs appear to drive comsats to smaller, cheaper and more focused satellite designs that are replaced frequently - i.e., **constellations**

Stimulation Factors: *GEO Commercial Communications Satellites*



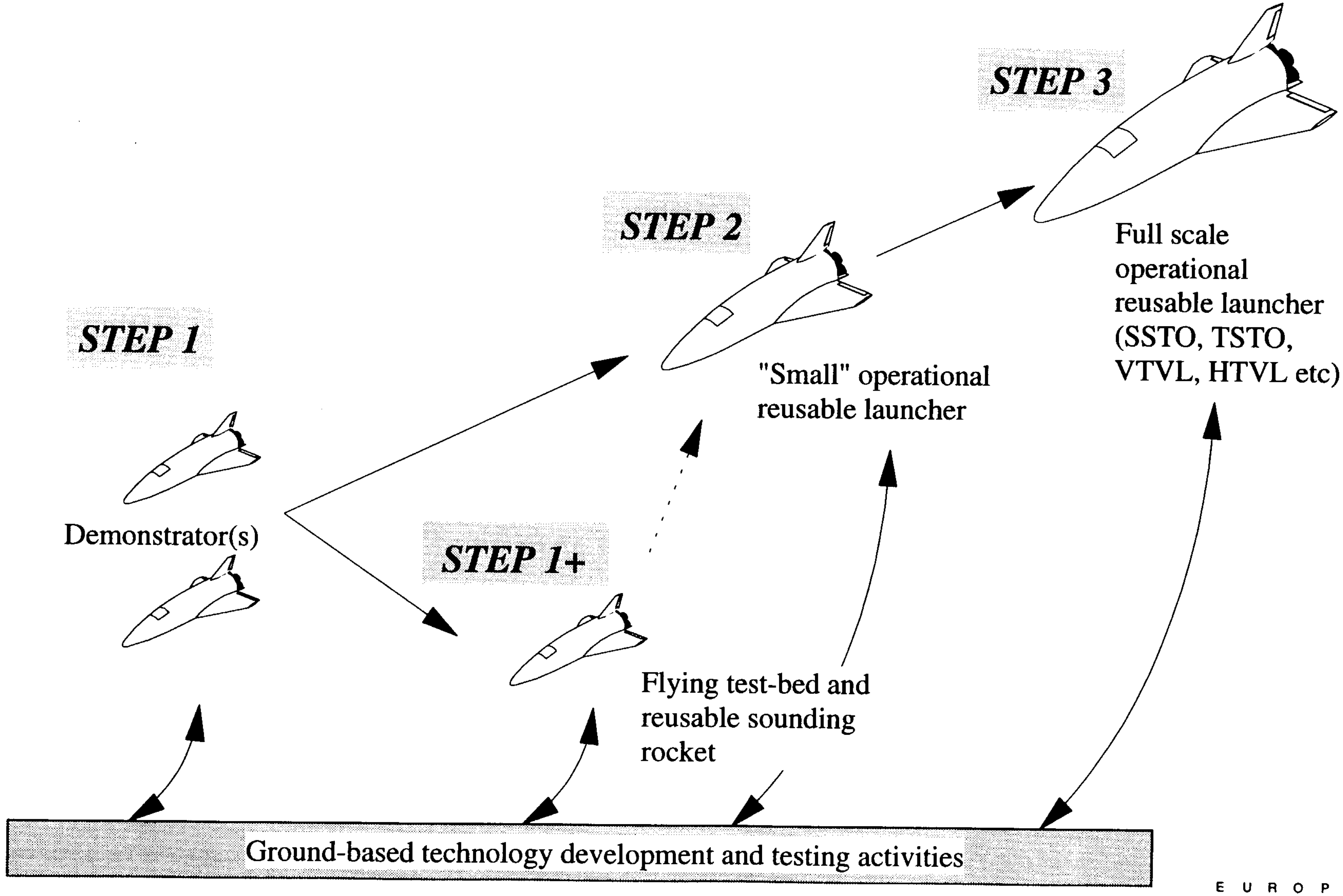
Mobile Satellite Systems



Launch costs account for 30-50% of the total system costs.

Thus, drastically lower launch costs will be of major benefit.

Possible Reusable Launcher Evolution



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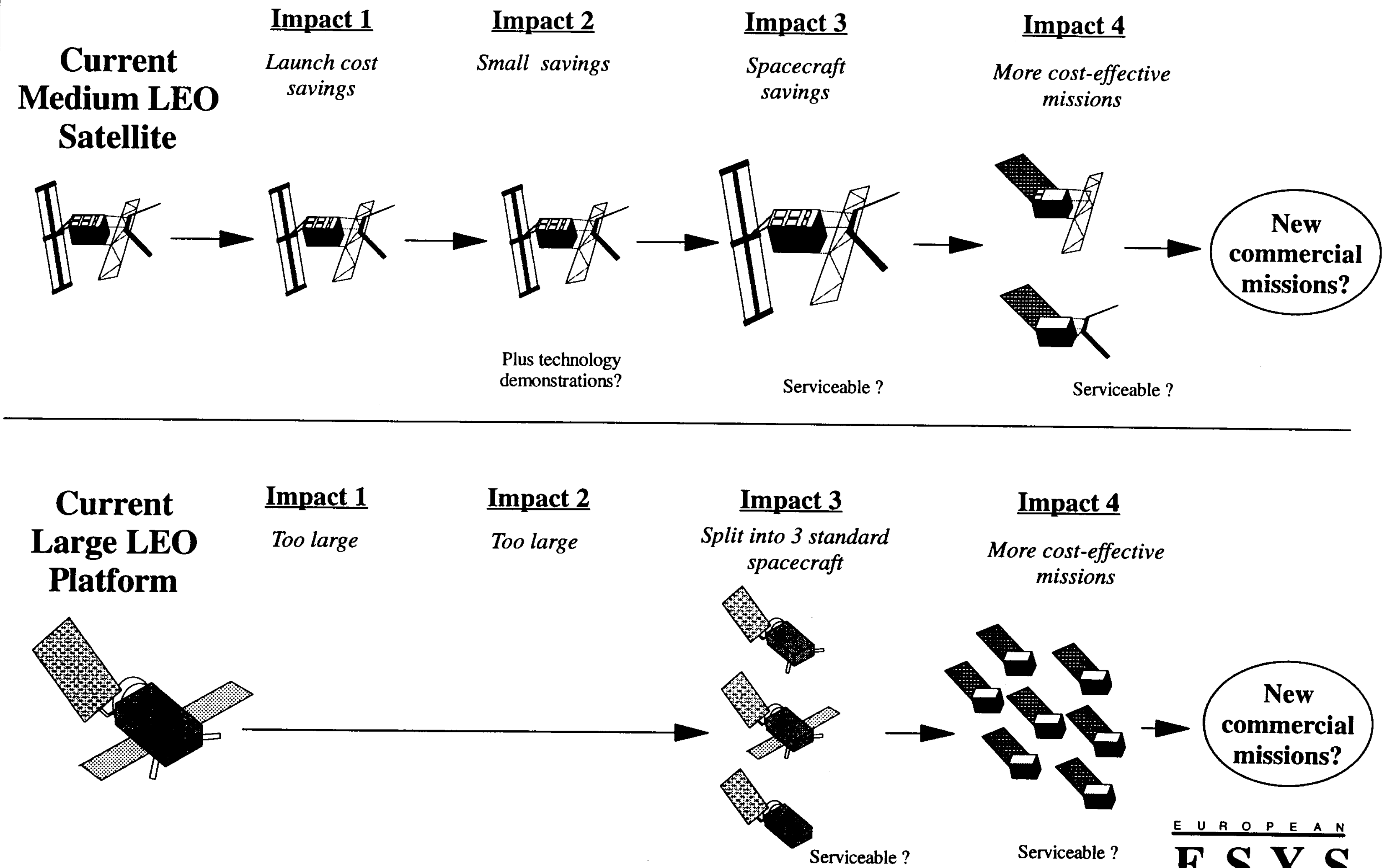

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Future Launchers & Their Users

Earth Observation

Current ENVISAT 1

C= Complementary, not necessarily same platform
D= Dependent, together on same platform

	MERIS	AATSR	ASAR	GOMOS	MIPAS	RA-2	SCIAMACHY	SCARAB	MWS	DORIS
MERIS		D	C				C	C		
AATSR	C									
ASAR	C	C				C				
GOMOS					C		C			
MIPAS				C			C			
RA-2	C	C	C						D	D
SCIAMACHY				C	C					
SCARAB	C	C								
MWS										
DORIS										

Payload mass: 1.8-2.0 tonnes
Spacecraft mass: 8 tonnes

Three Spacecraft Fulfil Same Mission Requirements

Mission 1:
MERIS
AATSR
SCARAB
RA-2
MWS
DORIS*
P/L:600 kg
S/C: 2,500 kg

Mission 2:
ASAR
P/L:700 kg
S/C: 3,000 kg

Mission 3:
SCIAMACHY
GOMOS
MIPAS
P/L: 500 kg
S/C: 2,000 kg

*Laser retroreflector also required

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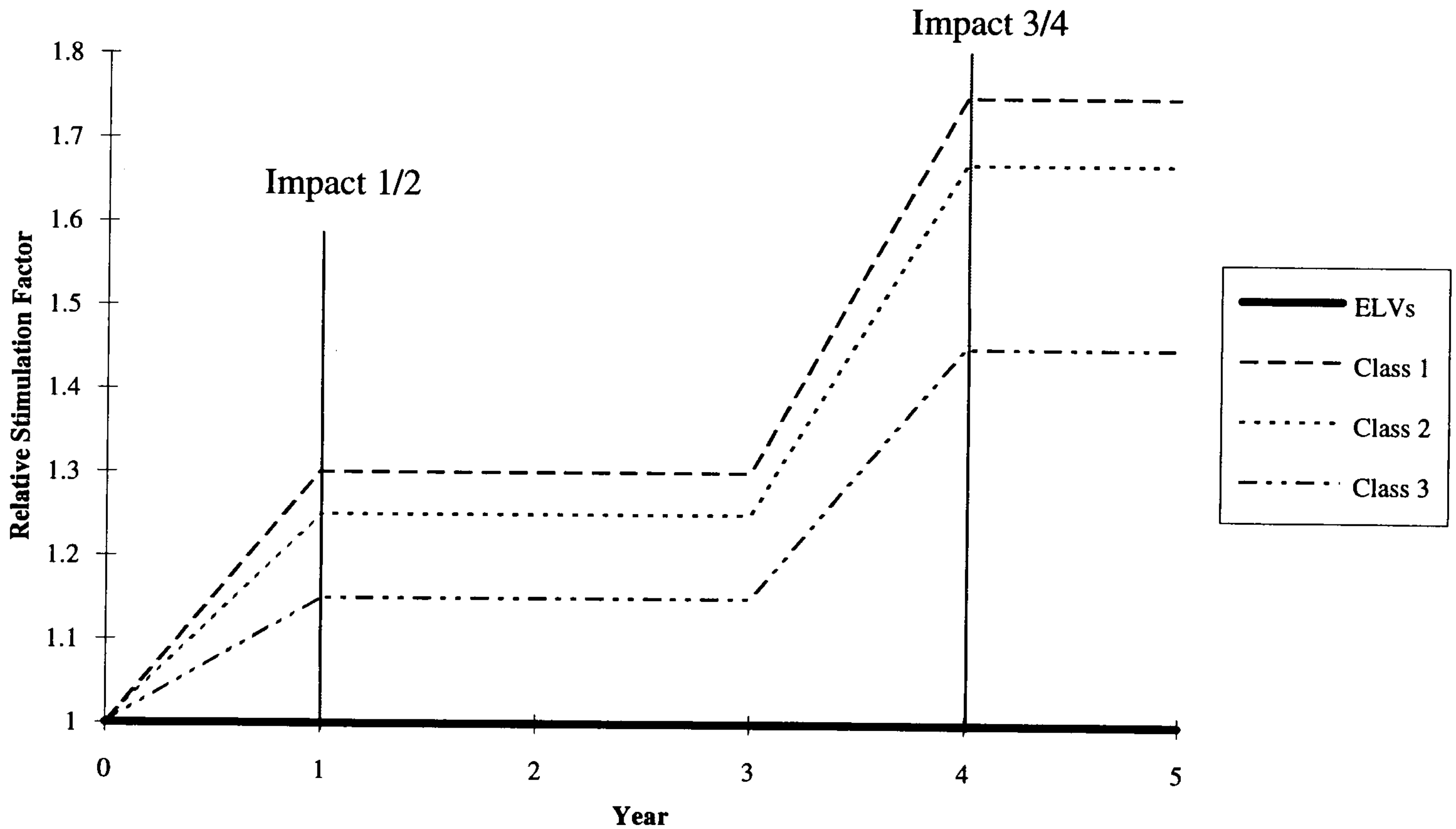
Stimulation Factors: *Medium LEO Earth Observation Missions*



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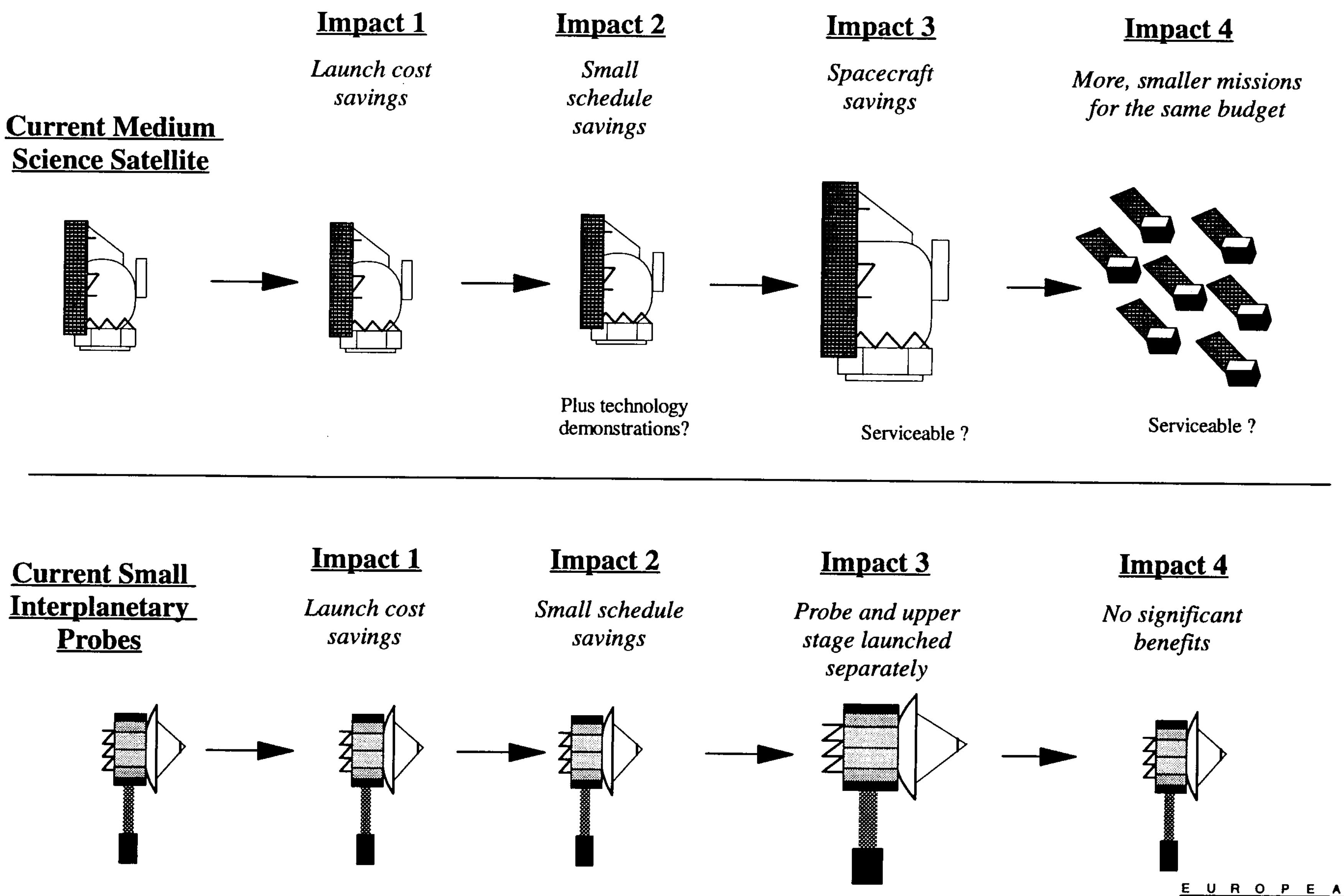

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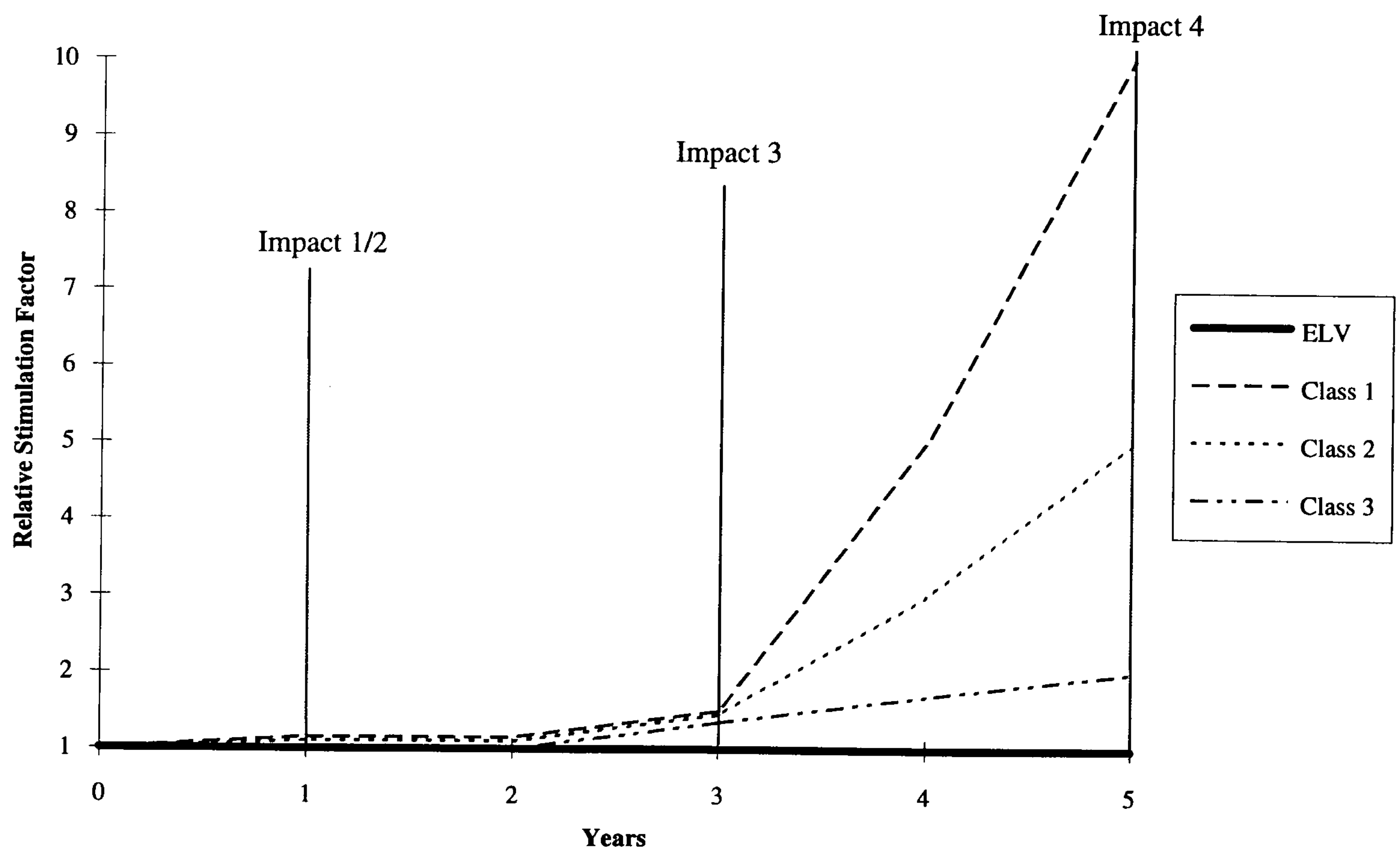
Stimulation Factors: *Medium Space Science Missions*



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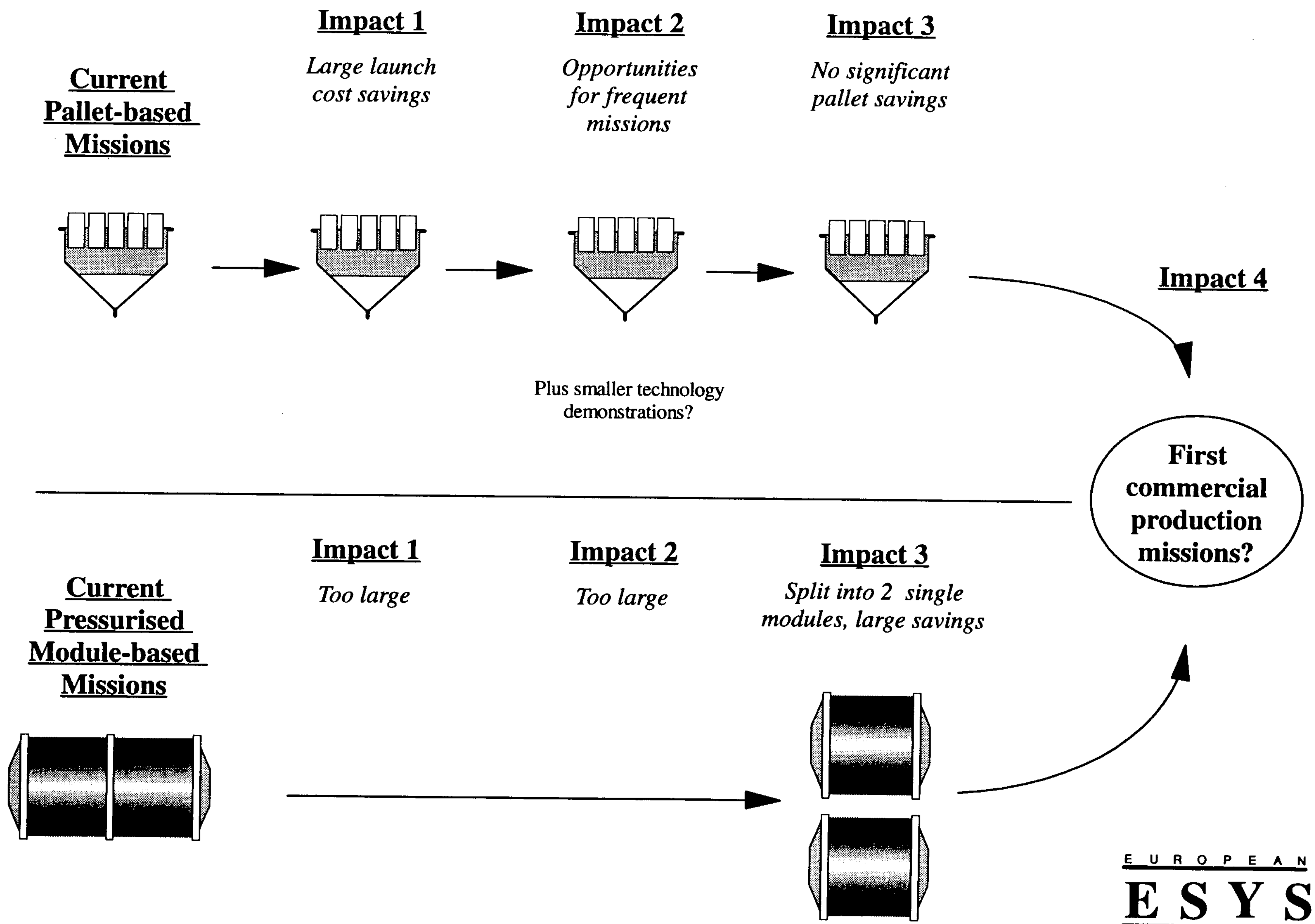

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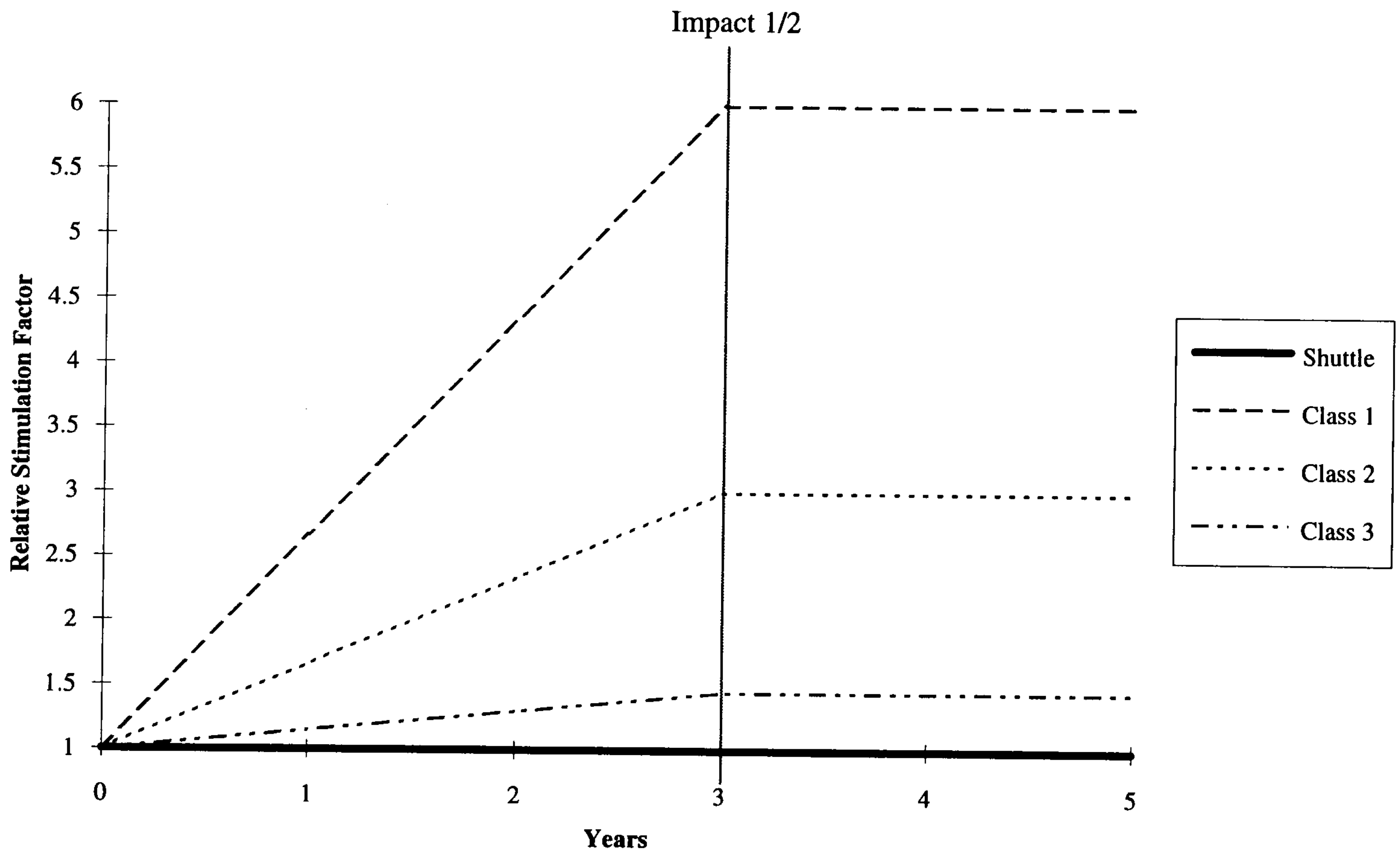
Commercial Materials Production

• Specific Shuttle transportation cost	15 KAU/kg (actual)
• Fraction of platform mass that is production payload	25%
• Fraction of payload that is the final product	10%
• Spacecraft to launcher cost ratio	>1
→ Hence, effective payload cost (value of payload)	60 KAU/kg
→ Hence, effective product cost	**1200 KAU/kg**

Most high value/low mass products worth around 10-50 KAU/kg

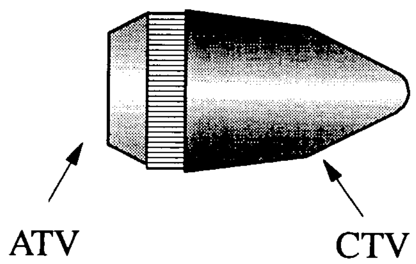
- Class 1 reusable launcher would reduce this to about **140 KAU/kg**
- Further reductions require better mass fractions and shared launches

Stimulation Factors: *Pallet-based Microgravity Missions*



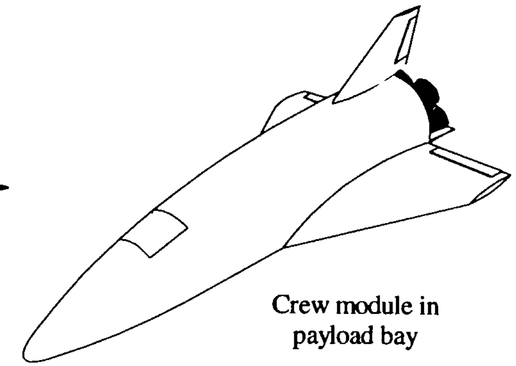
Future Launchers & Their Users

Proposed Crew Transfer Vehicle Mission

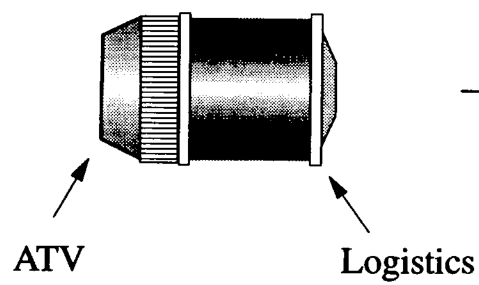


Impacts

Very large savings, safer, more frequent, etc.

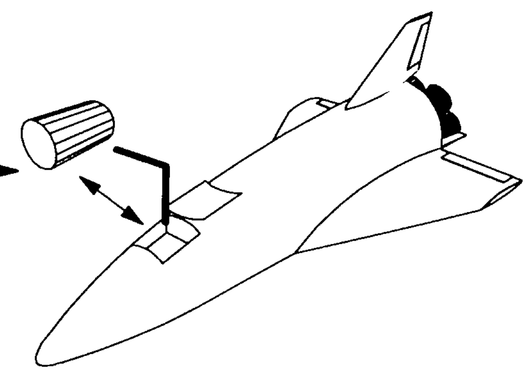


Proposed Automated Transfer Vehicle Mission



Impacts

Large savings, more frequent, etc.



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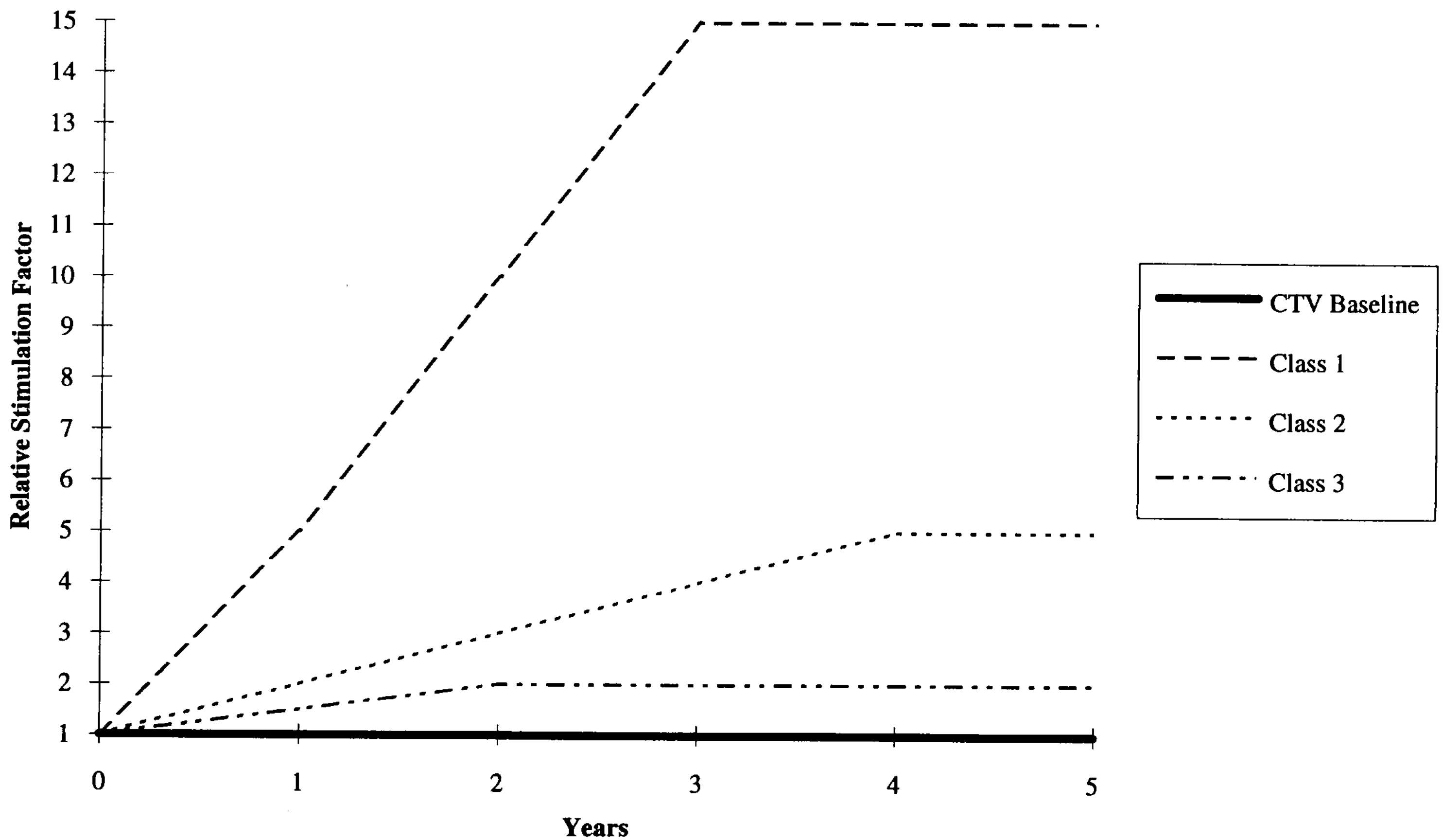
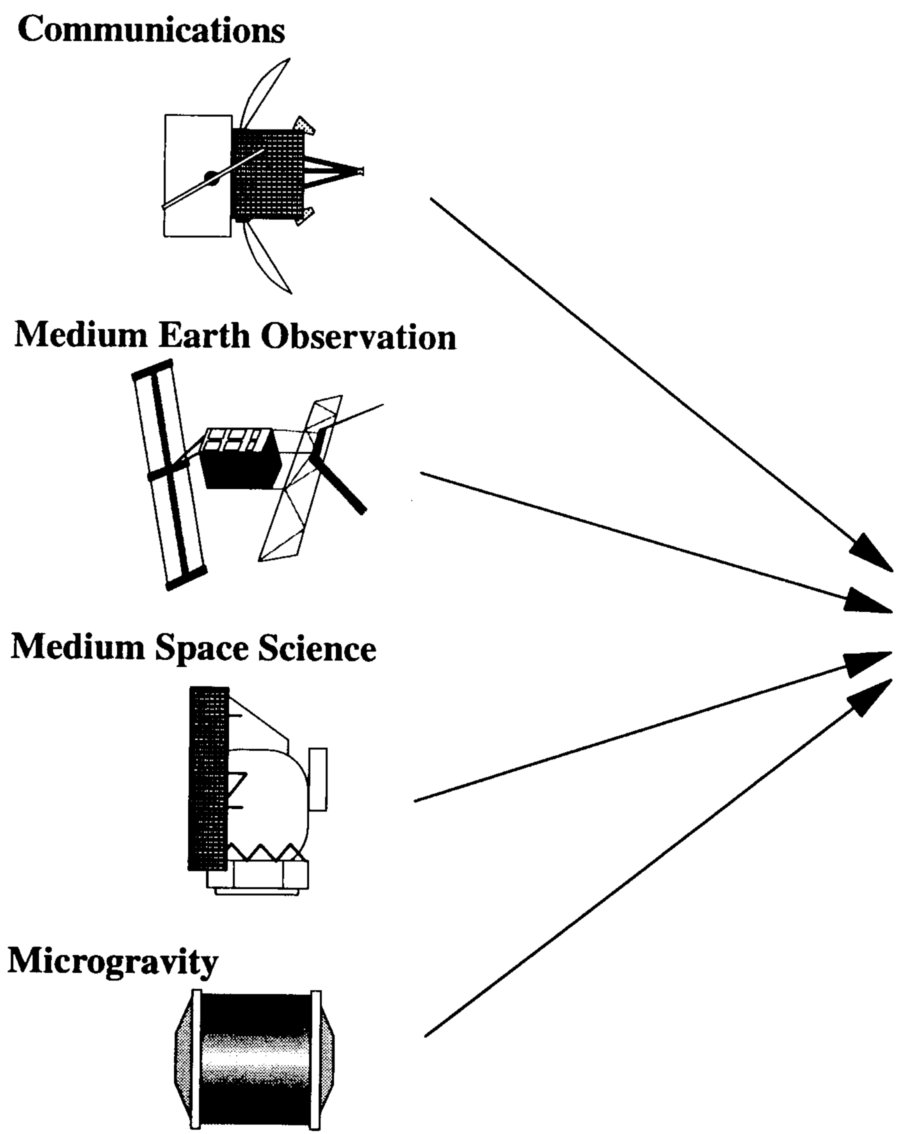
Stimulation Factors: *CTV-type Crewed Missions*



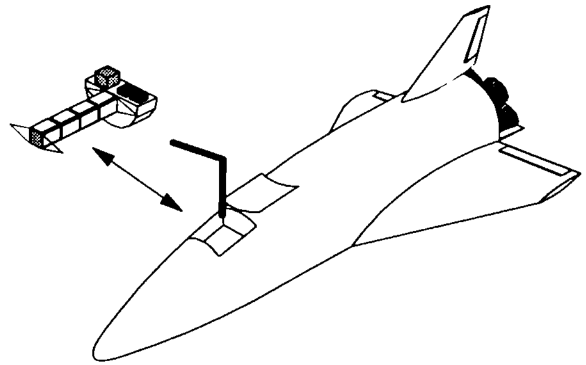
Future Launchers & Their Users

Technology Demonstrations



Technology Demonstrations

10% of Impact 3 level savings used for funding



- Regularly scheduled
- Responsive to demand
- Dedicated missions
- Low total cost per experiment
- Standard experiment interfaces
- Standard experiment testing

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Maximum Stimulation Factors

	Class 1	Class 2	Class 3	Trend/Evolution ?
Communications				*Small satellite-type missions*
GEO	2.1	1.8	1.1	
LEO	2.1	1.8	1.1	
Earth Observation				*Small satellite-type missions, more commercial*
Large LEO	5	3	2	
Medium LEO	1.8	1.7	1.5	
GEO	1.8	1.5	1.1	
Space Science and Probes				*Small satellite-type missions*
Medium Science	10	5	2	
Small Probes	1.5	1.25	1	
Microgravity				*Regularly-scheduled research*
Pallet-based	6	3	1.5	
Module-based	1.5	1.2	1	
Space Infrastructure				*Cheaper, more frequent and safer*
CTV-type	15	5	2	
ATV-type	15	8	4	

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Presentation Overview

Introduction & assumptions

Reusable launcher flight rate requirements

Interaction method of assessing payload demand

Relationship between payload costs and launch costs

Mission concepts for reusable launchers

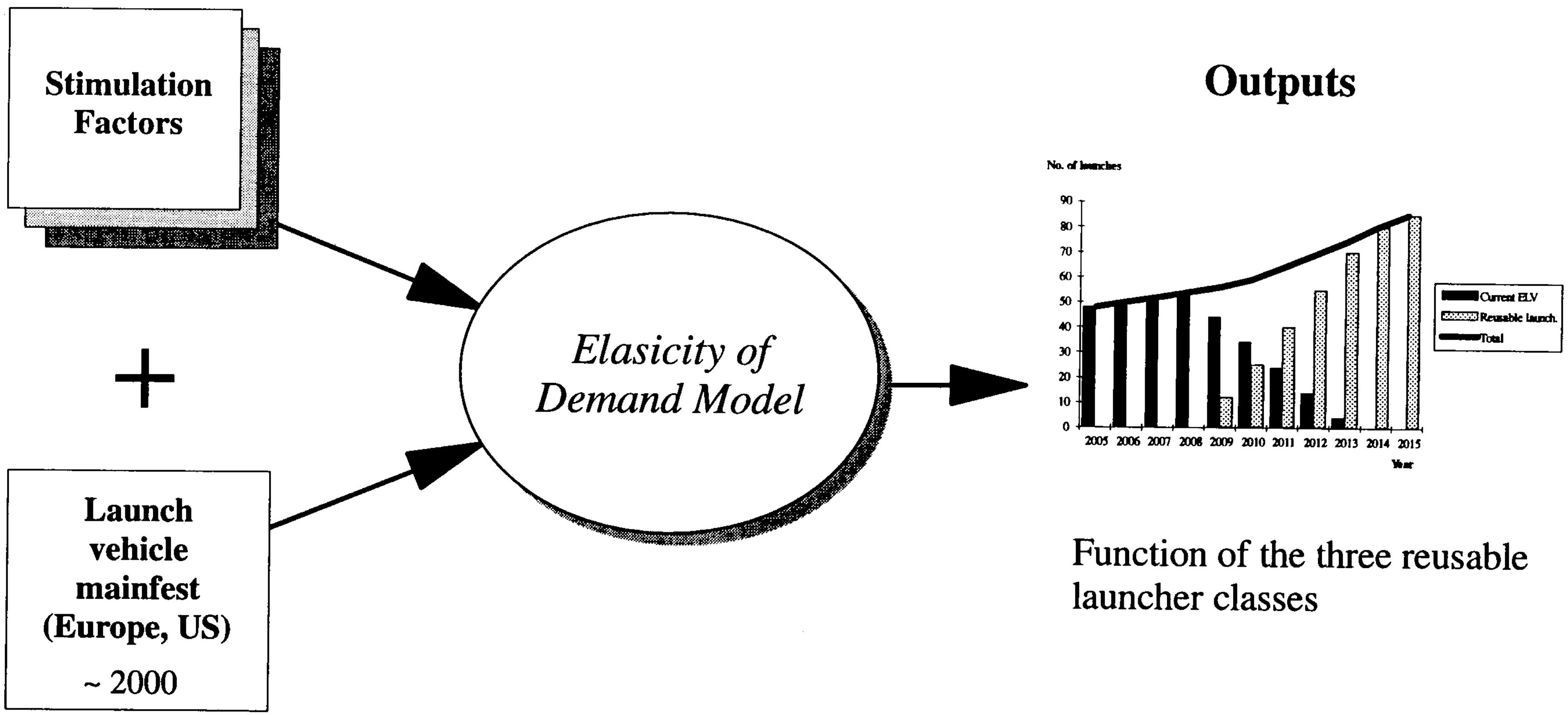
Estimation of space transportation demand elasticity

Conclusions & recommendations

Elasticity of Demand Modelling (WP 3000)

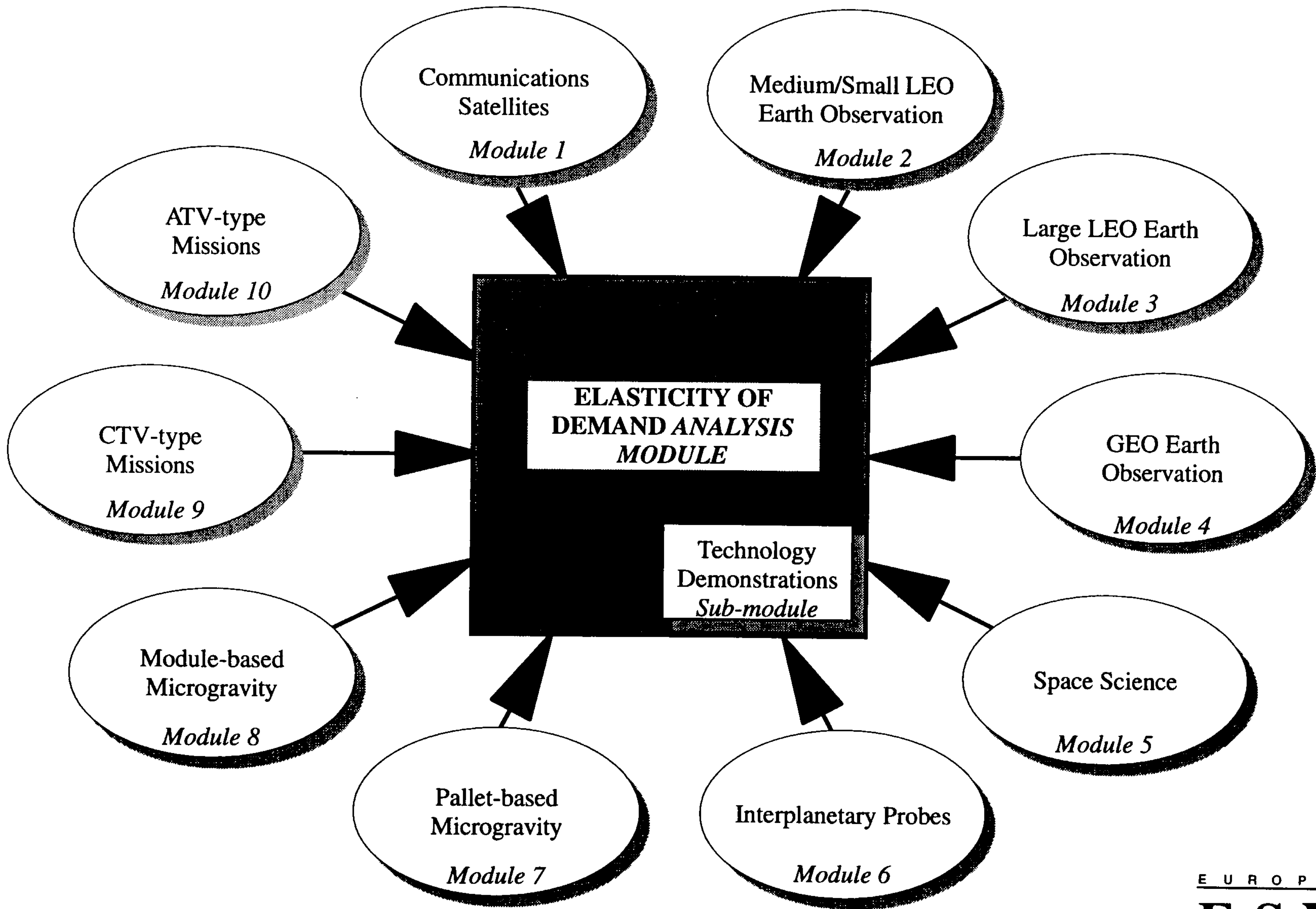
Inputs

Outputs



Function of the three reusable launcher classes

Future Launchers & Their Users



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Accessible Market to the first Reusable Launcher

A radical improvement in space launch capabilities would mean the first reusable launcher would have access to more than just the payloads of the countries involved in the project.

For example, today's precedents:

- Ariane launches ~60-70% of the payloads accessible to it (not just European)
- The Shuttle launches European payloads requiring recovery
- US small launchers are used to loft international payloads.

Therefore, it is assumed that the first reusable launcher fleet will have access to:

1. All commercial payloads world-wide on a competitive basis, and
2. "Appropriate" government payloads of Europe, the US and Japan

This assumes that the first reusable launcher is operated "commercially" with Europe leading or involved.

Expected Payload Manifests Around the Year 2000

Communication satellites

- ➡ GEO — 18 per year
- ➡ LEO/ICO clusters — 3 per year
- ➡ Replacement rate — 10 per year

Earth Observation

- ➡ Small/medium LEO — 5 per year
- ➡ Large LEO — 1 every 2 years
- ➡ GEO Metsats — 1 per year

Space Science & Interplanetary Probes

- ➡ Space science — 5 per year
- ➡ Probes — 1 per year

Microgravity Research

- ➡ Pallet-based — 4 per year
- ➡ Pressurised modules — 4 per year

Space Infrastructure

- ➡ ATV missions — 1 per year
- ➡ CTV missions — 1 per year

Only major assumptions are that:

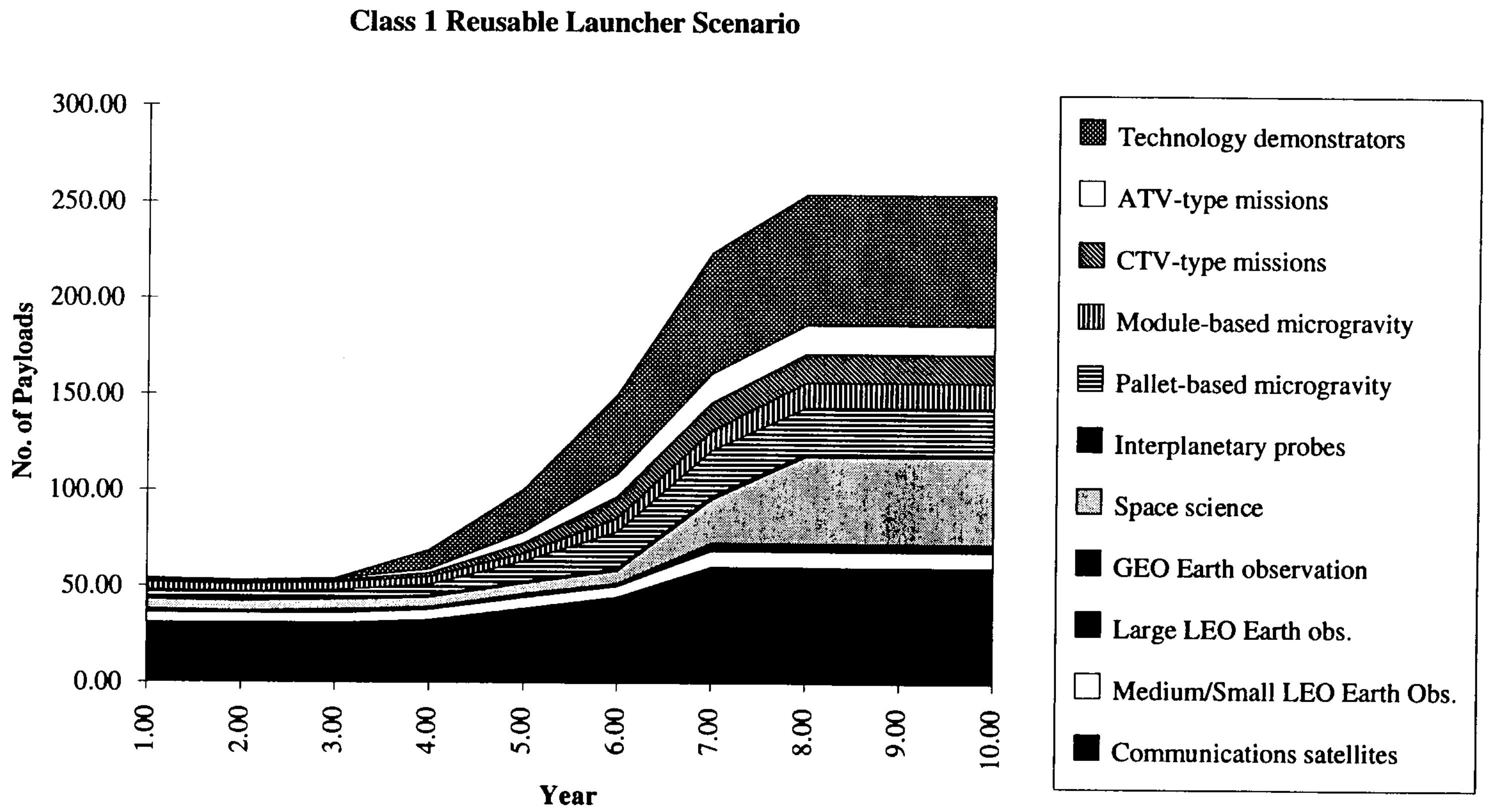
(1) Iridium (or similar) will be deployed (50% funded)
(2) CTV and ATV will be funded
(3) GNSS2 and military missions have not be included

Interpreting the Results

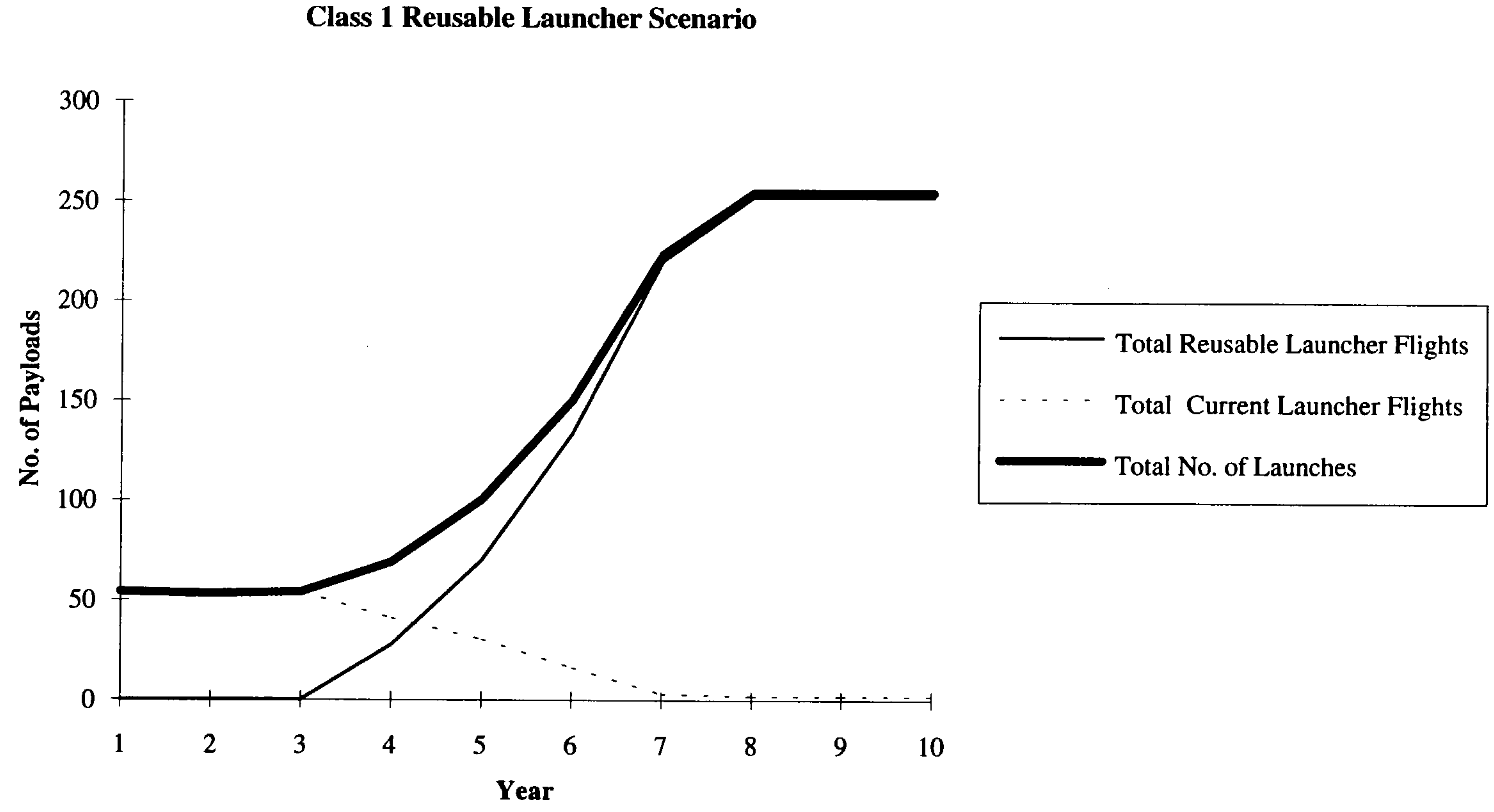
- **Year one** represents a point 3 years before reusable launcher introduction
- **The first 3 years** represent a static situation (no growth in current payloads)
- **By the fourth year** the reusable launcher is phased in (gradually)
- **By the eighth year** the reusable launcher is fully phased in and maximum growth factors are in effect

The static launch rate at both ends of the graph ensures that roughly the same total expenditure is spent each year.

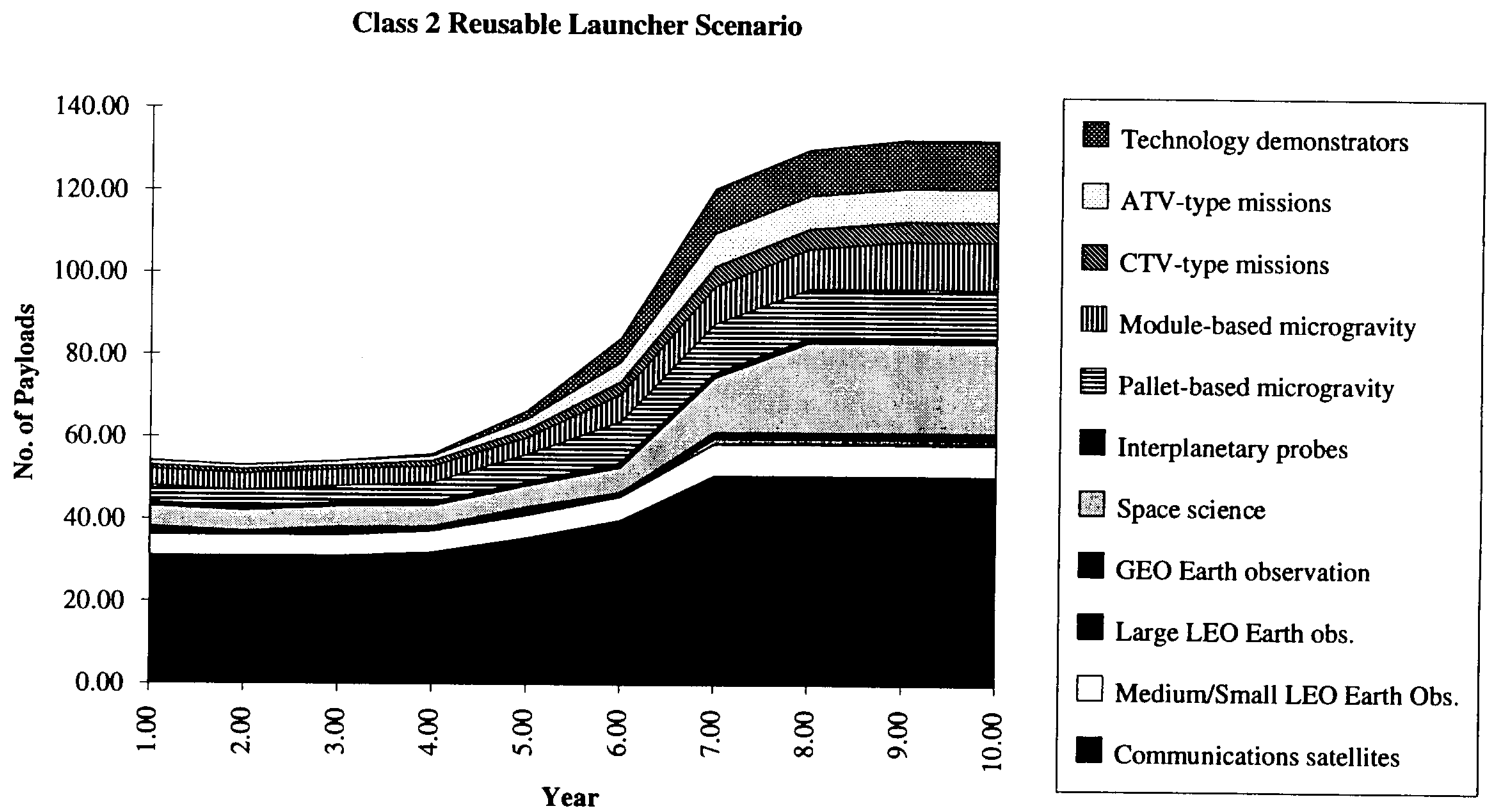
Class 1 Reusable Launcher Mission Breakdown



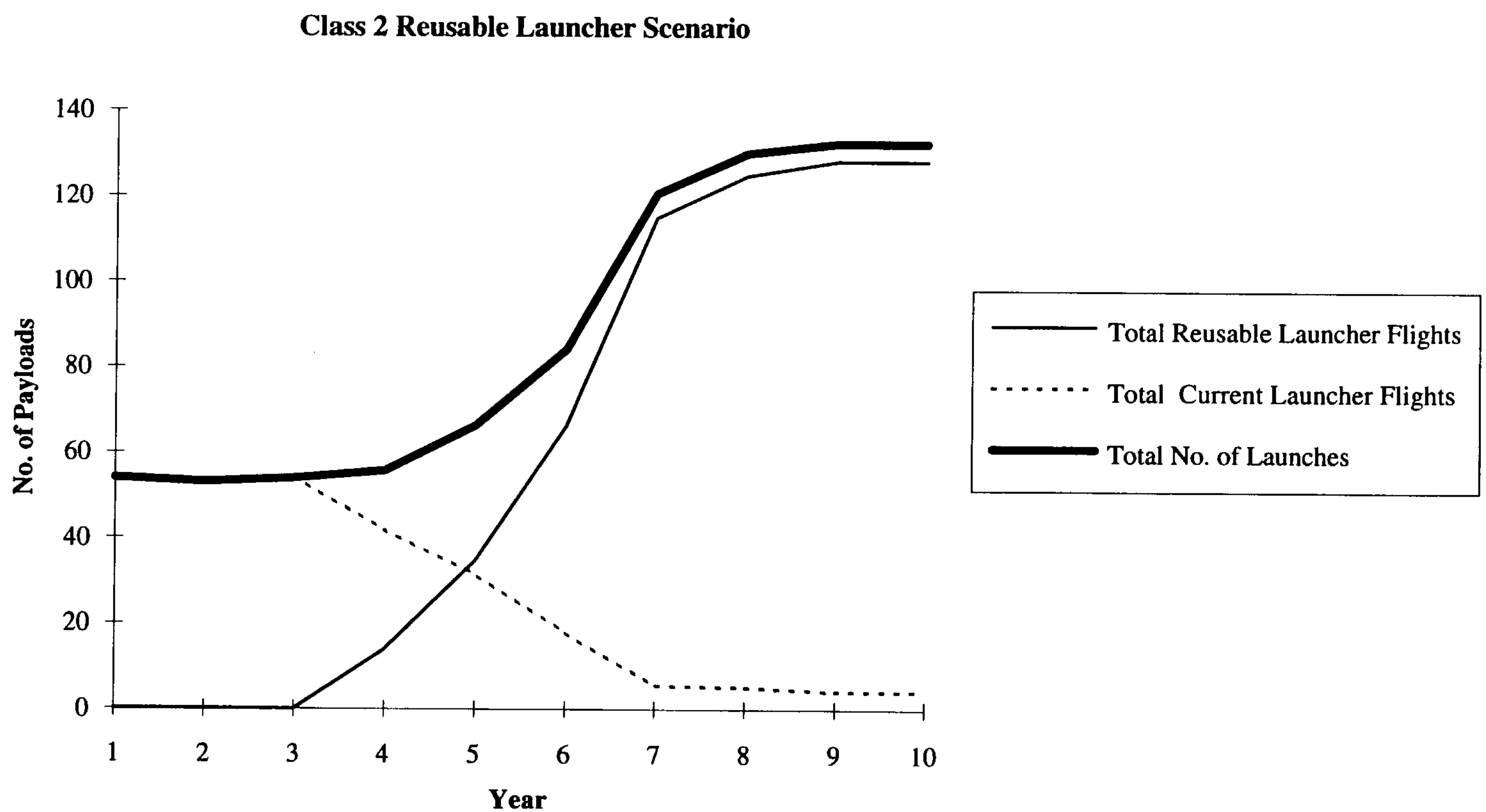
<u>Class 1</u> Reusable Launcher Transition Characteristics



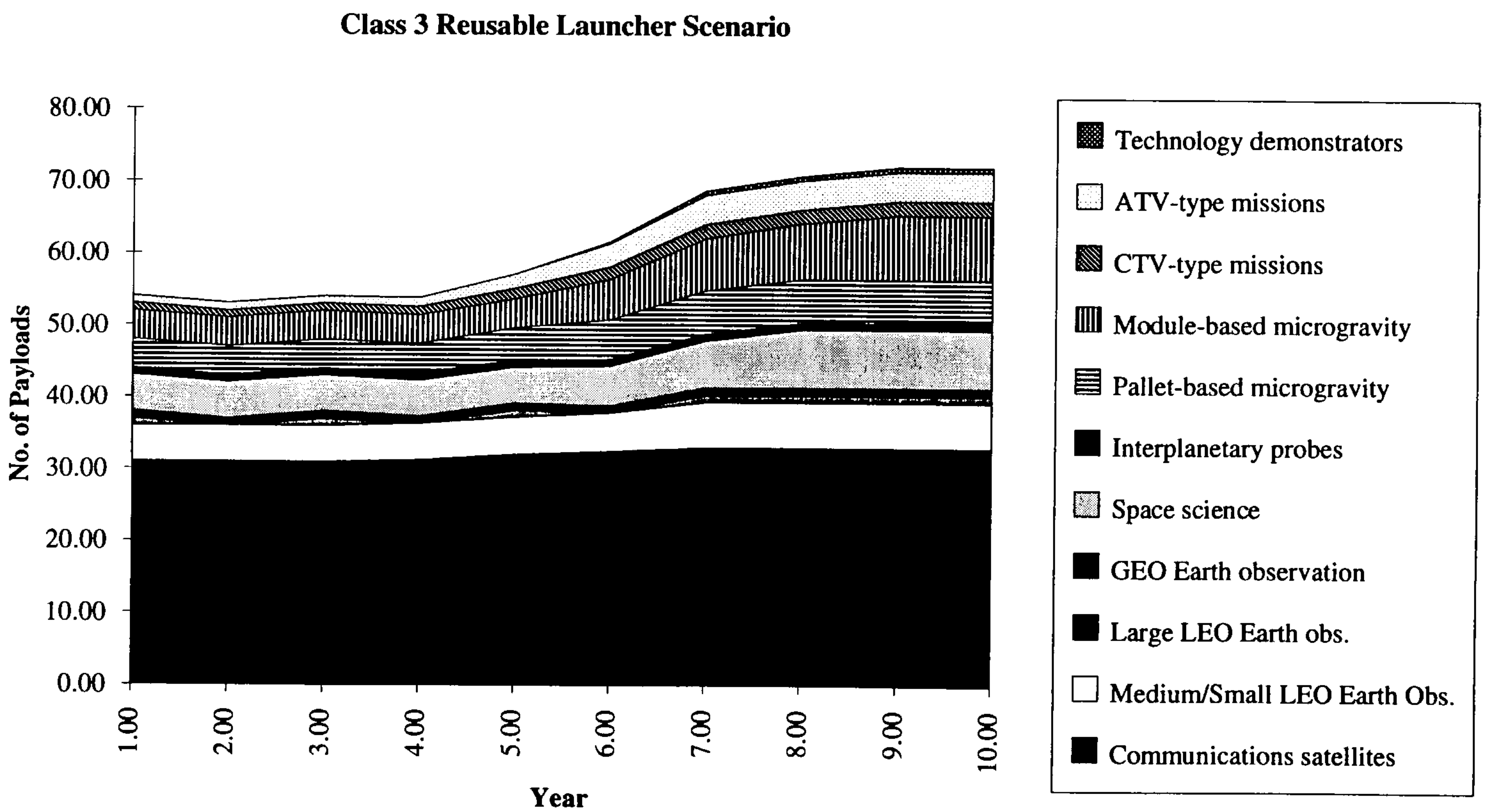
Class 2 Reusable Launcher Mission Breakdown



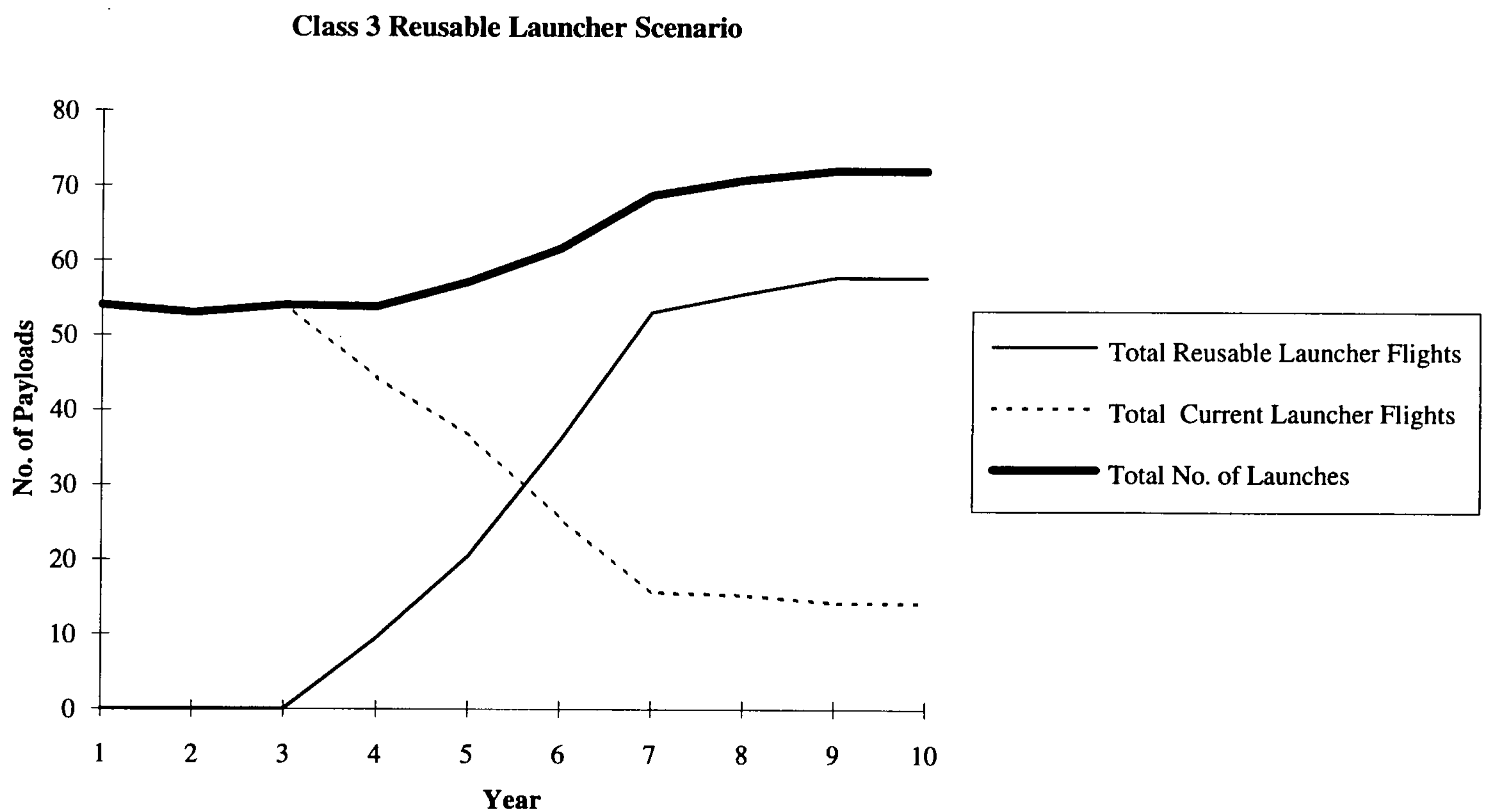
Class 2 Reusable Launcher Transition Characteristics



Class 3 Reusable Launcher Mission Breakdown



<u>Class 3</u> Reusable Launcher Transition Characteristics



Results: Flight Rate Requirement versus Number of Payloads *(no growth)*

	Class 1 Reusable Launcher (1-5 MAU)		*Class 2 Reusable Launcher* (10-20 MAU)		*Class 3 Reusable Launcher* (50 MAU)	
	Full cost recovery	Ops cost recovery only	Full cost recovery	Ops cost recovery only	Full cost recovery	Ops cost recovery only
Flight rate requirements	200-350+	100-200+	70-120	35-70	20-35	10-20
No. of payloads estimated	~250		~130		~57	

Number of payloads correlates well with the required launch rate

Growth Scenarios (1 of 2)

Current Launchers

- Groundrule of study: *keep roughly within current funding levels*
- However, a key reason why current budgets are flat is due to high launch costs
- For example, one 3 tonne science satellite costs ~500 MAU
- Thus, a large funding increment is required for each new mission added.

Reusable Launchers

- Radically lower launch costs mean cheaper payloads
- For a Class 1 vehicle, cheapest science mission is ~15 MAU
- For a Class 2 vehicle, cheapest science mission is ~75 MAU
- Thus, much smaller funding increments are needed for each new mission

An increase in the number of reusable launcher payloads may not necessarily imply a proportional increase in funding.

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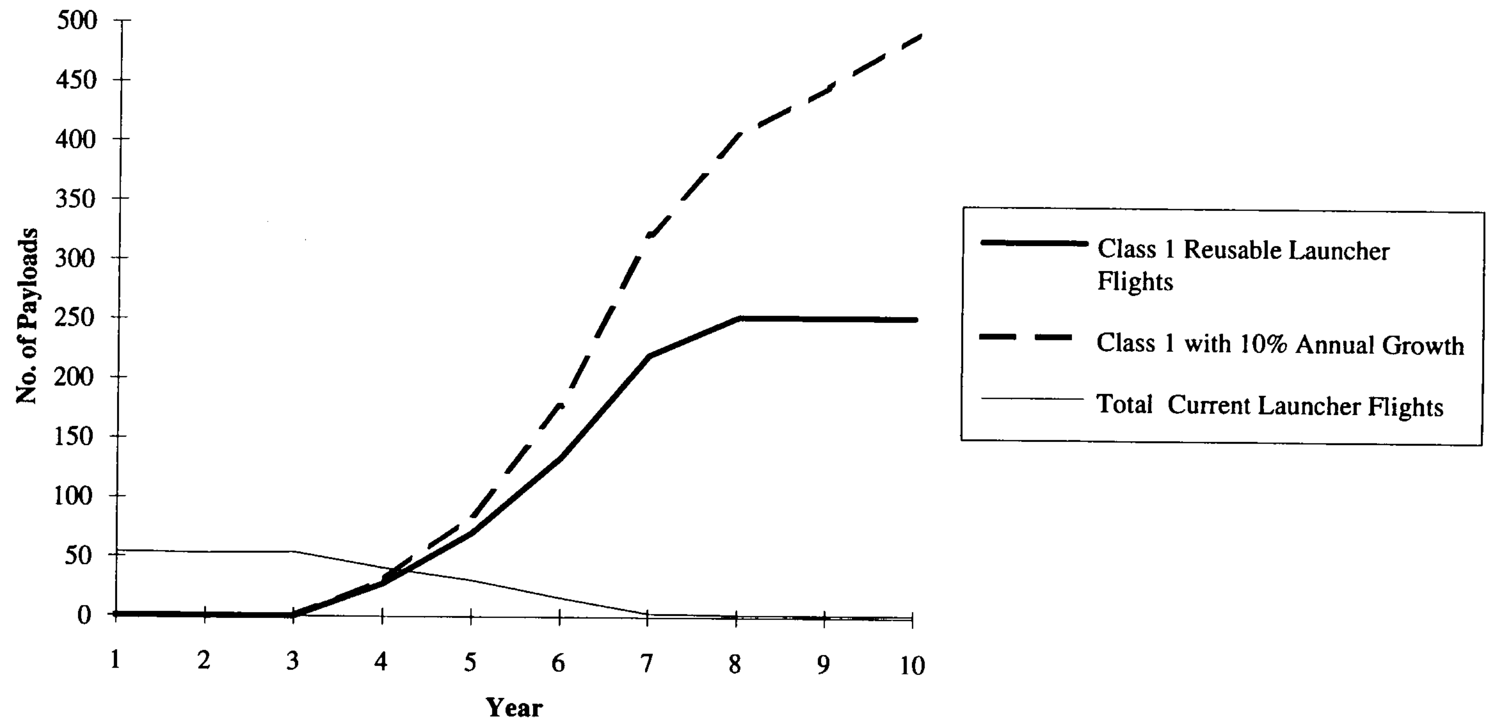
Growth Scenarios (2 of 2)

The following arbitrary growth factors were applied:

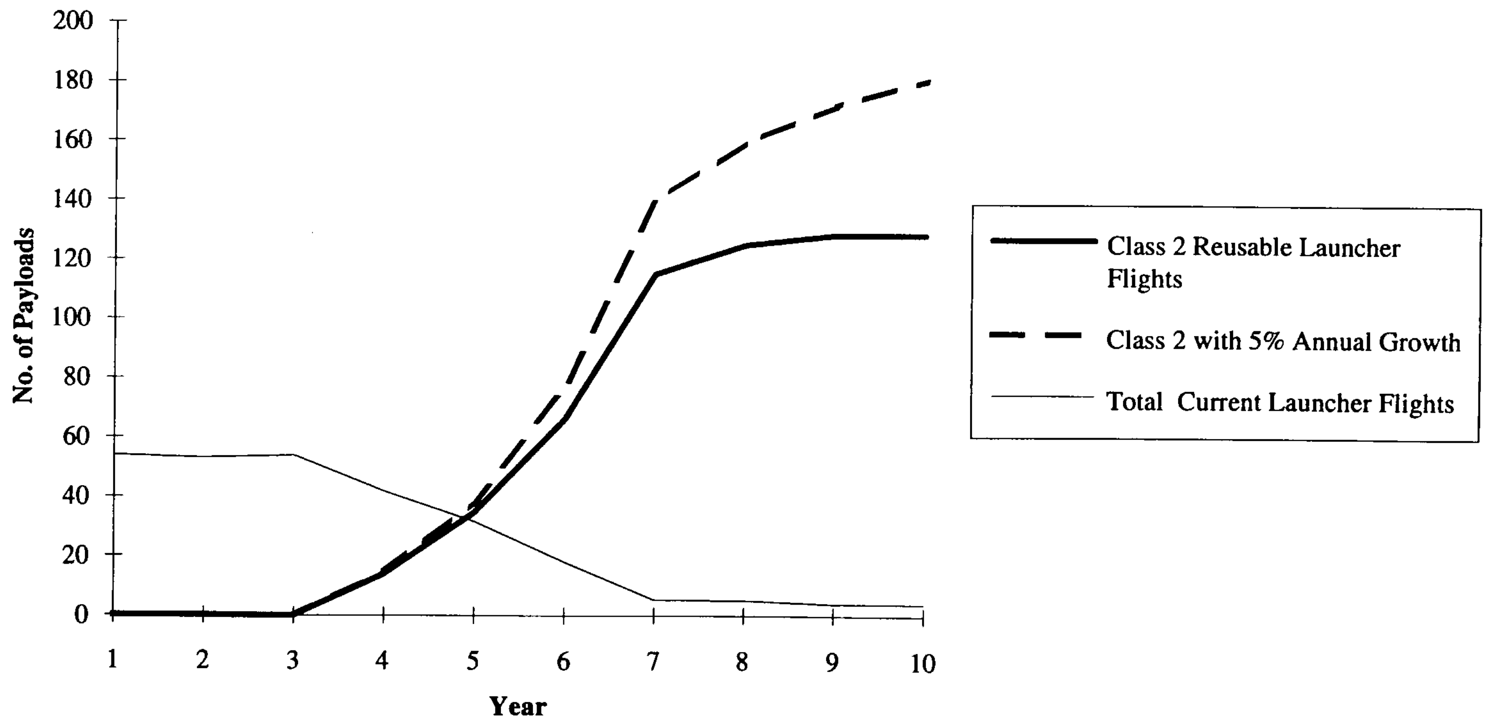
Class 1 vehicle	10% annual growth
Class 2 vehicle	5% annual growth
Class 3 vehicle	0% annual growth

Growth rates applied to only the reusable launcher payloads, while current launchers remain constant as before.

Comparing Growth/Non-Growth Scenarios for a Class 1 Reusable Launcher



Comparing Growth/Non-Growth Scenarios for a Class 2 Reusable Launcher



Results: Flight Rate Requirement versus Number of Payloads *(with growth)*

	Class 1 Reusable Launcher (1-5 MAU)		*Class 2 Reusable Launcher* (10-20 MAU)		*Class 3 Reusable Launcher* (50 MAU)	
	Full cost recovery	Ops cost recovery only	Full cost recovery	Ops cost recovery only	Full cost recovery	Ops cost recovery only
Flight rate requirements	200-350+	100-200+	70-120	35-70	20-35	10-20
No. of payloads estimated	~500		~180		~57	

Number of payloads is very significantly above the required launch rate

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Discussion: Future Launcher Pricing Policy

- Results are highly dependent on the assumptions used
- They suggest current market is sufficiently elastic to support each reusable launcher class
- Class 1 vehicle is expected to lead to many new missions due to low price
- However, the "daily" launch rate of the Class 1 vehicle is perhaps unrealistic for a first generation fleet
- Likewise, the price of a Class 3 vehicle may be too high to stimulate enough additional demand to further reduce prices
- Therefore, need to set launch price low enough to stimulate "slower growth" rate, and high enough to allow life-cycle cost recovery at lower flight rates.

A launch price in the region of about 25 MAU would be a reasonable target for the first generation fleet

Conclusions

- Class 1 and Class 2 reusable launchers will need to be flown at **high launch rates** to achieve life-cycle cost recovery
- Satellite costs are **very rarely less than the launch price** because of the need to optimise overall funding
- Reusable launchers **provide the opportunity** for less expensive science and EO missions as their cost is about 5 times the launch price
- A four-step **interaction method** allows stimulation factors to be developed which keep total annual funding roughly constant
- Reusable launchers appear to drive missions toward the **small satellite-type approach** but with larger mass and volume
- A **high degree of correlation** was found between the resulting number of payloads and the required launch rate (derived independently)
- Prudent launch pricing is essential for the first generation reusable launcher fleet.

Recommendations

Follow-on and future studies should address:

1. Required launch rates to achieve economic self-sufficiency
2. Relative impacts of launch price and other reusable launcher capabilities
3. Extent to which users would re-invest or save funding
4. Investment in new missions (static funding or growth)
5. Choice of either "fat-sats" or "small-sats"
6. Accessible market to a reusable launcher
7. Requirements for a dedicated small reusable launcher
8. US working meeting to exchange study results
9. Short briefing note and concise presentation pack