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Specific Transportation Costs to GEO - Past, Present and Future

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SUMMARY:

The paper presents the analysis of space transportation cost development for the geosynchronous orbit (GEO). While the launch cost increased subtancially since 1963 - the launch year of the first GEO satellite - the satellite mass increased from 36 kg to more than 2800 kg in GEO (BoM). Thus the specific cost (launch cost per kg or per channel) have dramatically been reduced from 550 000 $/kg to only 36 000 $/kg in 2002. The reason, however, is almost only the „law of scale", i.e. the increased payload mass, but not improvement of the launch systems. An further cost reduction on the launch vehicle side is possible by the introduction of reusable launch systems (RLVs) by a factor 2 to 4, depending on the vehicle design concept.

1. INTRODUCTION

The largest share of space missions is going to the Geosynchronous Orbit (GEO) ; those missions are also of the highest economical importance.

The price for launching a GEO spacecraft in 1963 (Syncom II) was 2.6 M$, using the DELTA-TAD launcher. The satellite mass in the target orbit after apogee injection (BoM) was 36 kg. Nowadays the INTELSAT 9 series of satellites is launched with more than 2800 kg mass in GEO (BoM) for some 100 M$. This looks like a tremendous increase of launch cost. However, the contrary is true if we compare *specific* launch cost (per kg payload), normalized to the year 2002 economic conditions. In this case the launch cost in 1963 were 550 000 $/kg, and in 2002 only 36 000 $/kg.

The cost criteria and trends will be discussed in more detail in the following chapters.

2. LAUNCH COST AND PRICES

Commercial satellite launches are sold by launch service provider companies for a certain price. This price normally should be higher than the cost, the difference being profit and amortisation charges. However, it has happened in the recent years that launches have been sold for prices lower than cost. This was enforced by strong competition, and it may even be justified economically in order to maintain its launch crew or to avoid a vehicle production stop.

For the satellite owner the launch price is a program cost element. In addition to the vehicle and the launch operations he has to pay for insurance, another cost factor.

Launch prices (or better : Cost-per-Flight - CpF) depend on the launch vehicle complexity, the payload capability, the launch frequency (Launches per year - LpA) and the market situation. They are also subject to inflation, resp. the annual MYr-cost growth in the aerospace industry.

For comparison, *specific costs*, related to the payload mass or launch vehicle payload capability provide better evidence.

Pricing according to Payload Mass:

In case of dual (multiple) payload launches

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with one launch vehicle the pricing issue becomes more complex.

In principle, the dual launch strategy provides the great advantage that smaller payloads can be launched at the reduced costs of larger satellites, according to the law of scale. A generic cost reduction of 25 to 35 % is feasible which, however, is reduced by the negative effect of a lower launch rate (+ 10 to 15 %). Also other factors reduce the theoretical advantage:

First, the vehicle's maximum payload capability will be reduced by the required additional payload support structure. Secondly, the average utilization of the vehicle's payload capability will be lower than for single payload launches. It is already difficult to achieve an average payload utilization factor (actual payload mass flown vs. vehicle maximum payload capability) of 90 % with single payloads. For multiple payloads the utilization factor decreases further since it is difficult to find two satellites at the same time the combined mass of both filling exactly the maximum vehicle capability.

Launch operations are also hampered by the dual launch strategy since often one of the two satellites has a schedule problem or a technical problem so that the launch has be delayed.

3. SPECIFIC TRANSPORTATION COST (SpTC)

Specific Space Transportation Costs are the total Cost-per-Flight (CpF) divided by the payload mass to a specific orbit. This means that the mission orbit always has to be indicated (LEO, SSO, GTO or GEO).

The *theoretical* specific costs are the CpF divided by the launch vehicle's maximum payload capability. For the *realistic* specific costs the launch vehicle's payload utilization factor has to be taken into account. In average, the launch vehicles' payload capability is utilized only to 80-85 %. This means that the realistic SpTC are some 20 % higher than the theoretical or minimum SpTC related to the maximum launch vehicle payload capability which is mostly provided.

For the determination of the final launch cost (or better: Cost-per-Flight) in case of commercial launches the insurance fee has to be considered (5 to 15 % of the launch cost plus the payload cost !). Therefore, compared to theoretical L/V-related SpTC costs, the actual total costs will be 25 to 35 % higher .

Further the specific costs can be related to the GTO mass (Transfer Orbit), or the satellite mass in GEO (after apogee impulse). There is a difference of 1.65 for launches from Kourou and 1.85 for launches from Cape Canaveral due to the different geographical latitude. In order to avoid the impact of the launch site location the best is, therefore, to use the satellite mass in GEO after injection at mission start (BoM).

However, the costs of the satellite apogee propulsion system (or the share of a unified propulsion system of the spacecraft) are not considered. They would increase the values shown in FIGs.1 and 3 by 5 to 7 %. The costs are shown in MYr/Mg which eliminates the inflationary effects, as well as the continuous changes in currency conversion factors. The MY/ Mg-value can easily converted into actual-year US-Dollars

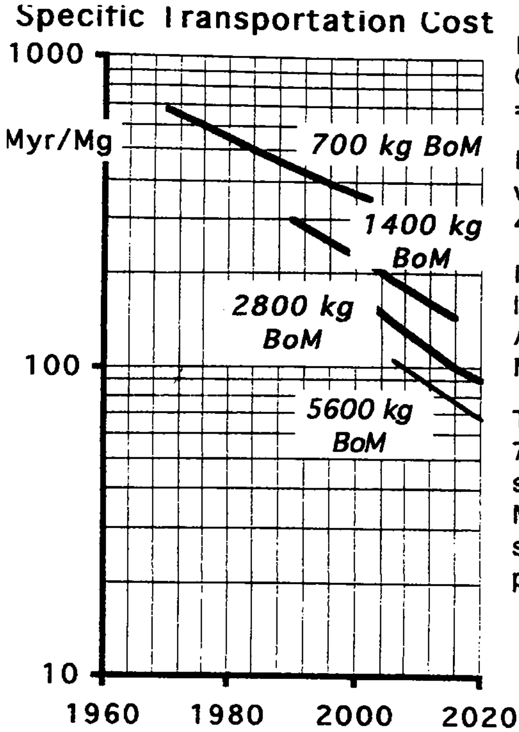


FIG.1: **Historic Trend of Specific Transportation Cost to GEO**

or Euros or Yen by using the actual MYr-costs:

1 MYr (2002) = 221 000 USD, or
= 200 100 Euro, or
= 24.4 Mio Yen

(MYr = Man-Year, see ref.1)
(Mg = Mega-Gram = metric ton)

4. COST HISTORY (SpSTC to GEO)

The historical evolution of the SpTC to GEO is shown in FIG.1. For a correct historic cost evaluation a 700-kg-satellite has been used for reference in order to define the actual cost reduction vs.time:

In 1972 the launch with an ATLAS-CENTAUR (SLV-3C/ D-1) did cost 20 M$ = 650 MYr/Mg.

In 1989 the same satellite could be launched with a DELTA-6925 vehicle for 50 M$ = 480 MYr/Mg.

In 1999 the 700-kg spacecraft could be launched as part of a dual payload on ARIANE 42P for 47.5 M.Euro = 365 MYr/Mg.

The historic cost trend for the launch of a 700-kg-satellite from 1970 to 2000 (FIG.1) shows a reduction from 685 to 360 MYr/Mg, or 150 000 $/ kg to 80 000 $/ kg - some 47 % within 30 years, or only 2 % per year. This reduction can be accounted

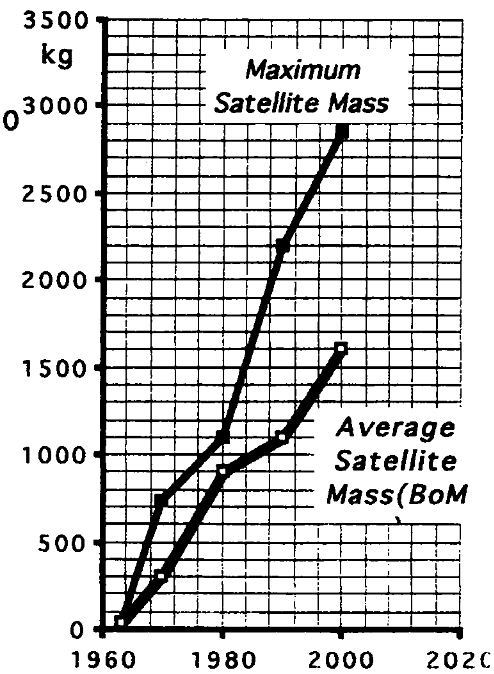


FIG. 2 : **Historic Growth of the GEO Satellite Mass** (BoM = Begin of Mission)

to the increased launch rate and the learning factor in launch operations, however, there is no effect which can be related to technical progress in the ELV area.

Fortunately the „law of scale" did help. The dramatic increase in payload mass and launch vehicle capability did indeed result in a great decrease of specific launch costs. FIG. 2 shows the growth of the maximum and average satellite mass values in GEO. Accordingly the *average* mass of all satellites in GEO has grown from 300 kg in 1970 to 1600 kg in the year 2000.

5. SPECIFIC COST vs. LAUNCHER PAYLOAD CAPABILITY

FIG.1 shows how much the satellite size or the launcher payload capability - which developed in parallel - influence the specific transportation cost. For the year 2000 this looks as follows:

700 kg S/C = 0.35 MYr/ kg = 77 000 US$/ kg
1400 kg S/C = 0.23 MYr/ kg = 50 000 US$/ kg
2800 kg S/C = 0.17 MYr/Mg = 37500 US$/ kg.

The future large launch systems such as the improved ARIANE 5-ECB and the DELTA

Specific Transportation Cost to GEO

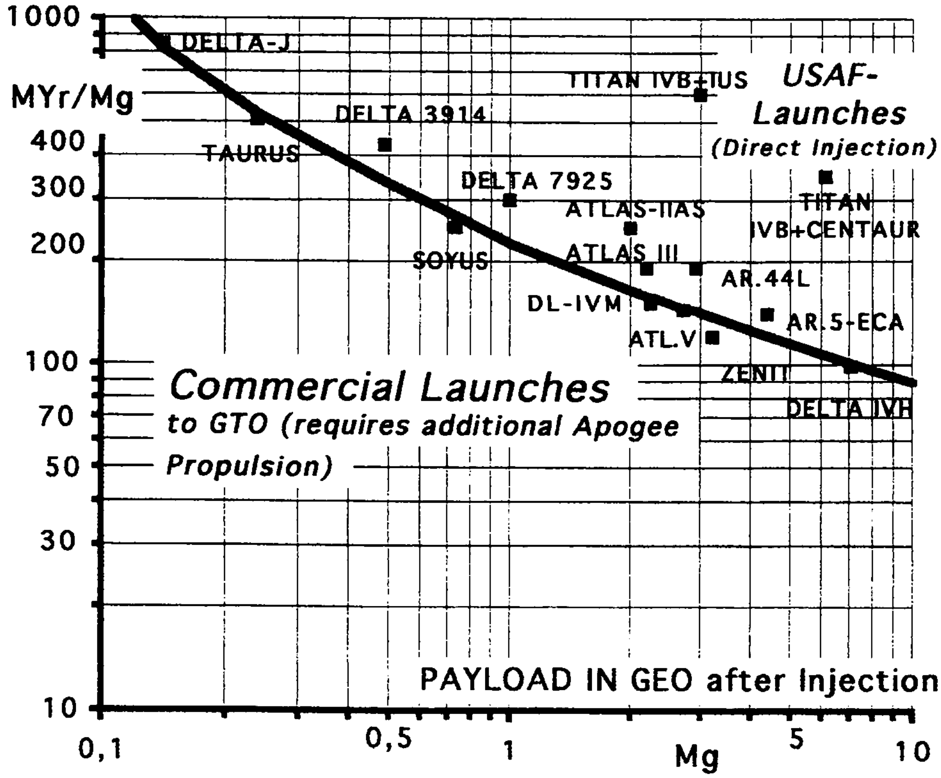


FIG.3 : **Specific Transportation Costs to GEO vs. Launch Vehicles' maximum Payload Capability**

IVH will be able to launch satellites with more than 6000 kg. This reduces the specific costs to a new level of some 0.13 MYr/ Mg = 28 500 $/ kg (2002).

FIG. 3 provides a survey about the theoretical specific transportation cost to GEO of all major launch vehicles. The cost values shown in FIG.3 are related to the maximum vehicle payload capability and do not include the apogee propulsion system cost (or the cost share in case of a unified satellite propulsion system).

For a fair comparison with the direct GEO injection mode by the last stage of the launch vehicle the appropriate cost of the apogee propulsion system must be added. This would increase the specific cost shown in FIG. 3 by 5 to 7 %.

There seems to be a major cost difference between injection via GTO with subsequent apogee injection by the onboard satellite propulsion system, and the ELV injection into GEO by a re-ignitable transfer stage (TRANSTAGE or CENTAUR). This is not generally true; here it is related to the TITAN IVB vehicle which is more than twice as expensive as other vehicles. This was the reason to replace it by the new EELVs ATLAS V and DELTA IV.

6. ACTUAL PRICES FOR GTO/GEO LAUNCHES

The actual status of CpF (Cost-per-Flight) and the resulting theoretical (minimum) specific transportation costs (SpTC) are summarized in TABLE I. A price range is provided in each case since the prices are negotiable and they depend on the special services and equipment requested such as payload fairing and adapter size.

With a reduced number of satellites and increasing competition the prices have decreased in 2001. Only three major launch providers have been left: Arianespace, Boeing (ILS, Sealaunch) and Lockheed Martin. In addition, China and Japan offer their Long March, resp. H-IIA Launch Vehicles.

7. FUTURE COST REDUCTION POTENTIAL

As shown before no further cost reduction can be expected with expendable launch systems (ELVs). There needs to be implemented a new generation of Reusable Launch Vehicles RLVs).

The degree of cost reduction, however, will depend very much on the RLV system concept selected. There are great differences in development cost and CpF as shown in ref. 4. In the USA the primary RLV-requirement is the replacement of the Space Shuttle as a manned transportation system for the ISS supply - with docking capability.

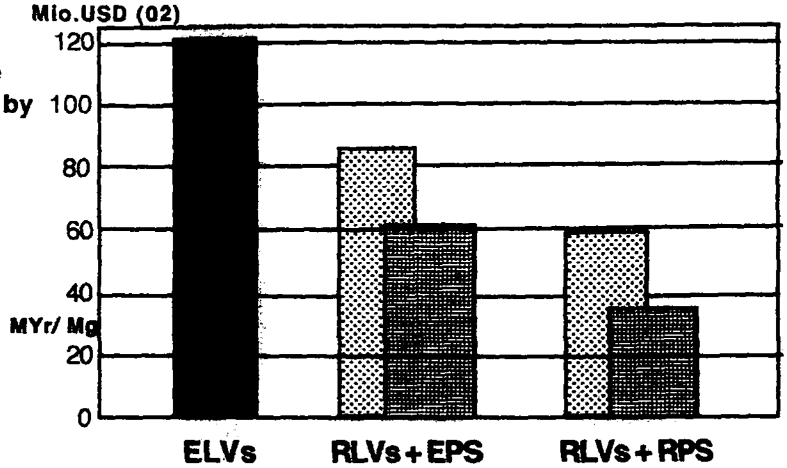
A cargo-only RLV can be developed much cheaper and is resulting in lower transportation cost. A preliminary cost analysis of two-stage RLV concepts with 7.5 tons payload in GTO (4.5 t in GEO from CSG Kourou) was performed. The assumed launch rate was 15 LpA.

CONCEPT A: A two-stage system with 800 Mg GLOW comprising a Flyback-Booster or Winged First Stage (VTOHL) as a preferred concept for manned space transportation. With an expendable Perigee Stage the CpF have been estimated to some 85 M$ or 19 k$/ kg. This is only a

TABLE I : **SURVEY OF LAUNCH SERVICE COSTS (PRICES) to GTO/GEO**

VEHICLE	LAUNCH PROVIDER	PAYLOAD (kg) GTO	PAYLOAD (kg) GEO	PRICE CpF M.$	Specific Cost k$/kg (GEO)
ARIANE 44L	Arianespace	4800	2900	108 -113	37 - 39
ARIANE 5	Arianespace	6640	4000	115 -125	28 - 31
ARIANE 5-ECB	Arianespace	12000	7250	125 -135	16 -19
ATLAS III	Lockheed Martin	4500	2400	75 - 85	31 - 35
ATLAS V-401	Lockheed Martin	5000	2700	75 - 85	28 - 32
ATLAS V-551	Lockheed Martin	8200	4400	95 - 105	22 - 24
DELTA II - 7925	Boeing	1870	1000	50 - 60	50 - 60
DELTA III	Boeing	3800	2000	75 - 90	37 - 45
DELTA IV M	Boeing	4200	2250	75 - 85	33 - 38
DELTA IV H	Boeing	13100	7000	140 - 170	16 - 18
H IIA - 202	Rocket System Company	4100	2100	65 - 70	31 - 33
LONG MARCH-3B	China Great Wall Industry	5200	2600	60 - 70	23 - 27
PROTON-M	ILS (Intern. Launch Services)	6000	2800	100 - 110	36 - 40
ZENIT 3SL	SeaLaunch	5250	3100	80 - 95	26 - 31

FIG.4 :
Potential Future Cost Reduction by RLVs for GEO Missions
(7.5 tons GTO,
4.5 t GEO,
15 LpA)



small reduction compared to near-term ELVs, but the high price is due to the expendable perigee stage which costs about 30 M$, including the VEB (equipment bay with guidance, attitude control and power supply).

CONCEPT B : A 1.5-stage ballistic cargo-optimzed vehicle with 800 Mg GLOW and the same payload of 7.5 t to GTO can do the job for probably 61 M$ per flight, or 13.5 k$/ kg. This is a cost reduction of about 50 % compared to modern ELVs. The expendable Perigee Stage plus VEB also required some 30 M$ or 50 % of the total cost. The stage has a mass of 10.5 tons with 7.7 tons propellant, using the VINCI rocket engine.

As a further step one could consider a REUSABLE Perigee Stage (RPS). Assuming (only) 25 flights per vehicle which is brought back to Earth after each flight, the cost could be reduced to some 4 M$ per flight, including maintenance. This would reduce the total Cost-per-Flight to only 35 M$, resulting in specific cost of · 7.8 k$/ kg or only 25 % of modern ELVs. The RPS size increases in this case from 10.5 to 25.5 tons. FIG.4 shows the results: RLVs can reduce the transportation costs to GEO to 50 or even 25 % of the ELV cost, however, only in case of a cost-optimized cargo-RLV.

The Cost-per-Flight have been calculated according to the International Standard (ref.1) including Indirect Operations Cost and profit.

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