6. COST ENGINEERING EXAMPLES

6.1 Impact of Rocket Engine Options on System Development and Production Costs

The selection of the rocket propulsion system in terms of engine number and technology has a major impact on the total vehicle cost. The engine cost share can be as high as 50 % as shown in FIG. 6-01 for the production cost of selected launch vehicles. In case of development programs the minimum-cost solution is the use of existing engines; however, this may not be feasible in each case.

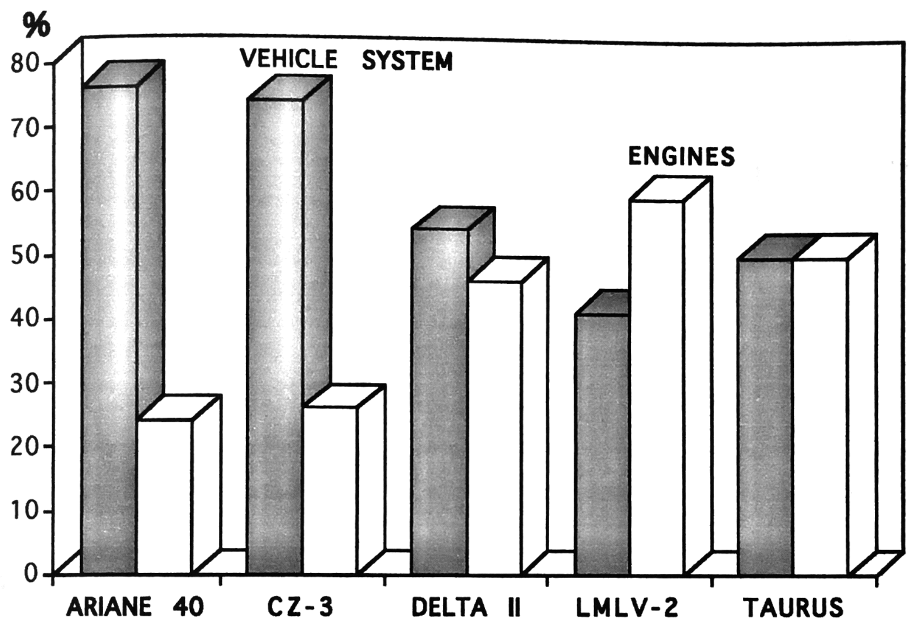


FIG. 6-01 : **Engine Cost Share vs. Vehicle System Production Cost for Launch Vehicles with Liquid Propellent and Solid-Propellant Engines**

6.11 Engine Number Impact on Cost

The number of engines for a vehicle or stage can be between 1 and 30 (N-1 First Stage) which has a great impact both on development and production cost. Large single engines require high development costs while a number of smaller engines increases the production cost but reduces development cost.

TABLE 6-I provides a survey about the engine options for a vehicle requiring a thrust level of 5000 kN. Pump-fed engines with cryogenic propellants are assumed. For the production cost the total number of engines required for 10 vehicles within 5 years are used. According to the engine mass and the total number of engines required the learning factor cost reduction is calculated. The resulting costs are shown on the next page.

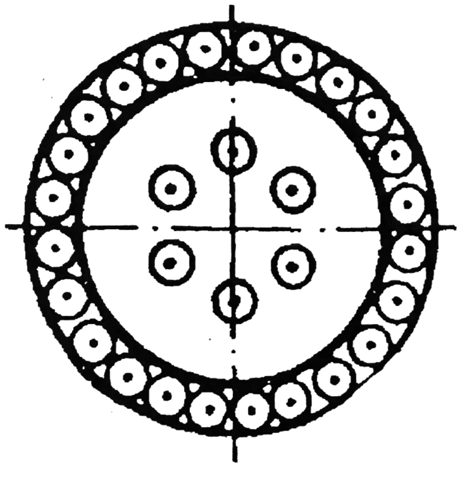
TABLE 6-I : **Number of Engines' Cost Impact**

No. of Engines		1	2	4	8	16
Engine Thrust Level	kN	5 000	2500	1250	625	312.5
Engine Mass	kg	6 060	3130	1615	830	430
Nom. Dev.Cost	MYr	19 900	13700	9400	6500	4500
Relative (%)		100	69	47	33	23
TFU Unit Cost	MYr	317	222	156	109	77
Total engines requ'd		10	20	40	80	160
Learning Factor p		1.0	0.97	0.925	0.875	0.83
Total Production Cost	MYr	3170	4000	4620	4550	4310

It is interesting to note that the 4-engine cluster in this case leads to the highest production cost. For a higher number of engines the learning effect is more effective than the number of engines. The result is of course influenced by the total number of engines required and the production number per year.

Adding up development and production costs results in a clear advantage of multi-engine systems, such as used for many vehicles. There remains the disadvantage of increased engine installation effort (fuel lines, valves), however, also the advantage of the potential „engine-out" capability if designed properly. The most ambitious system of this kind was conceived for the Russian N-1 Moon rocket first stage with no less than 30 engines (FIG. 6-02).

A modern multi-engine assembly with a central plug nozzle is shown in FIG. 6-03. In



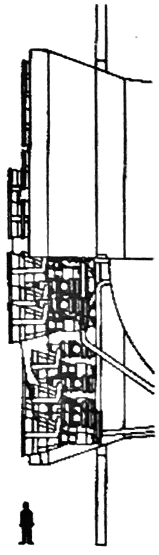


FIG. 6-02 : **Propulsion System of the N-1 Rocket First Stage (30-eng assembly)** this case high performance can be achieved with low-pressure engines due to the self- adaptive external exhaust gas expansion resulting in additional thrust.

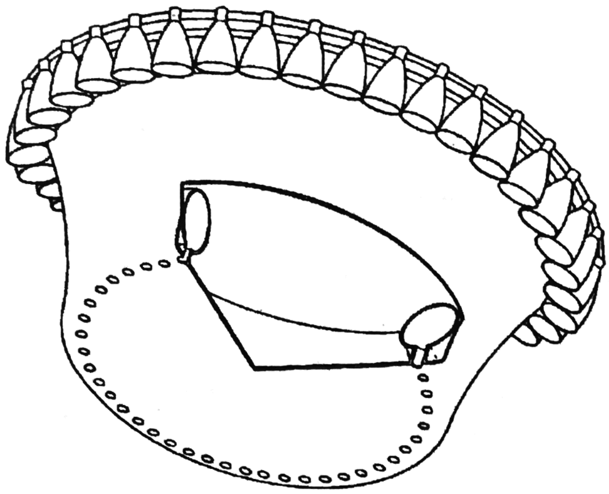


FIG. 6-03 : **High-performance Multi-engine Plug Nozzle Arrangement**

6.12 Engine Technology Impact on Cost

High-pressure rocket engines with extendible nozzles provide highest performance, decreasing vehicle propellant mass and size. However, this has a high price.

In the example of chapter 2.93 the development of the 1637 kN (SL) engines (8 units) with 150 bar staged combustion cycle at 1000 qualifications test runs (f_2 = 1.25) would require 16 550 MYr according to the *TRANSCOST*-CER (engine mass 3315 kg) which is equivalent to 3.6 Billion USD (2002). Engine performance at SL was 389 sec Isp with a short nozzle, and 345 sec for a long nozzle which provided 448 sec in space. This resulted in a required propellant mass of 794 Mg and a vehicle GLOW of 916 Mg.

With advanced technology high-pressure engines of 244 bar chamber pressure with a two-position-nozzle delivering an Isp of 379 sec (SL) and 460 sec (vac) the vehicle size (GLOW) can be reduced to 703 Mg. This means also smaller engine size: 1180 kN thrust level and 2560 kg mass. However, the advanced high-pressure technology and the two-position nozzle is assumed to require some 1500 test firings (f_2 = 1.45) - in order to achieve the same reliability as the state-of-the-art engine - which would result in development cost of 22 900 MYr or 5.0 Billion USD (2002). This means about 1.4 Billion USD more which cannot be balanced by the cost saving due to the smaller vehicle size which is about 0.7 Billion USD.

The third option would be the use of (modified) existing engines. This case - if feasible - results in the lowest possible development cost.

6.2 Potential GTO Transportation Cost Reduction by RLVs

The largest share of space missions is going to the Geosynchronous Orbit (GEO); those missions are also of the highest economical importance. Insofar it is of great interest what cost reduction can be expected in the future from the introduction of RLVs for this type of launch service ?

As shown in FIG. 5-21 the specific transportation cost to GEO for a modern expendable launch vehicle with 4500 kg payload in GEO after apogee injection (= ca. 7500 to 8300 kg in GTO) are about 120 MYr/Mg. Beside the payload size the launch rate is very important. In this case 15 launches per year have been assumed.

In order to define the potential cost reduction for RLVs two different launcher concepts have been assumed, and both with an additional expendable or a reusable perigee stage for GTO injection :

CONCEPT A: A two-stage reusable launch system with 800 Mg GLOW comprising a Flyback-Booster or Winged First Stage (VTOHL) which is a preferred concept for manned space transportation. The Booster has 440 Mg propellant mass (LOX/LH_2) and a dry mass of 85 Mg. It uses 6 engines with 1680 kN thrust ea. The I_{sp} is 350 s (SL) and 442.5 s (vac). For the flyback operation to the launch site two kerosene turbojet engines are used. The winged Orbiter has a propellant mass of 200 Mg and a dry mass of 50 Mg. The engine I_{sp} is 463.5 sec.

CONCEPT B : A ballistic SSTO vehicle with 800 Mg GLOW, the minimum-cost concept for cargo transportation (ref.108). The propellant mass is 690 Mg and the dry mass 64 Mg . The net mass includes the propellants required for orbit maneuvers, return and landing and amounts to 78 Mg. The propulsion system comprises 12 + 1 engines with 850 kN thrust ea. aranged around a central plug nozzle (FIG. 6-03). The Isp ranges from 350 s at SL to 450 s in vacuum.

The EXPENDABLE Perigee Stage (EPS) using LOX/Hydrogen propellants has a mass of 10.5 tons with 7.7 tons propellant, using the VINCI rocket engine. Taking into account the cost reduction by series production it still would cost some 135 MYr including the VEB with guidance equipment. This represents 40 to 50 % of the total CpF which have been calculated to some 350 MYr/ flight for Concept A, and to 270 MYr/ flight for Concept B using the International „Cost-per-Flight" Definition (chapter 5.1), including 7 % profit. Compared to modern ELVs this is a cost reduction to some 78 MYr/ Mg or by 35 % in case of Concept A, and a cost reduction to some 60 MYr/ Mg or by 50 % in case of Concept B.

Since this cost reduction may not be sufficient to justify he development effort for a new RLV , especially for Concept A which requires development cost twice as high as for Concept B, one could consider a REUSABLE Perigee Stage (RPS). In this case the vehicle size increases to 18 tons, including 14 Mg propellants.

Assuming (only) 25 flights per vehicle which is brought back to Earth after each flight flight, the cost could be reduced to some 35 MYr per flight, including maintenance. This would reduce the total Cost-per-Flight to only 240 MYr/ flight for Concept A, and to only 163 MYr/ flight in case of Concept B, resulting in a transportation cost reduction by 56 % for Concept A and **by 70 %** for Concept B, compared to modern ELVs.

FIG. 6-04 shows the results: For the case of 4.5 Mg to GEO and 15 flights per year, RLVs can reduce transportation costs to GEO to 45 MYr/ Mg with EPS and to 36 MYr/ Mg with RPS, however, only in case of a cost-optimized cargo-RLV.

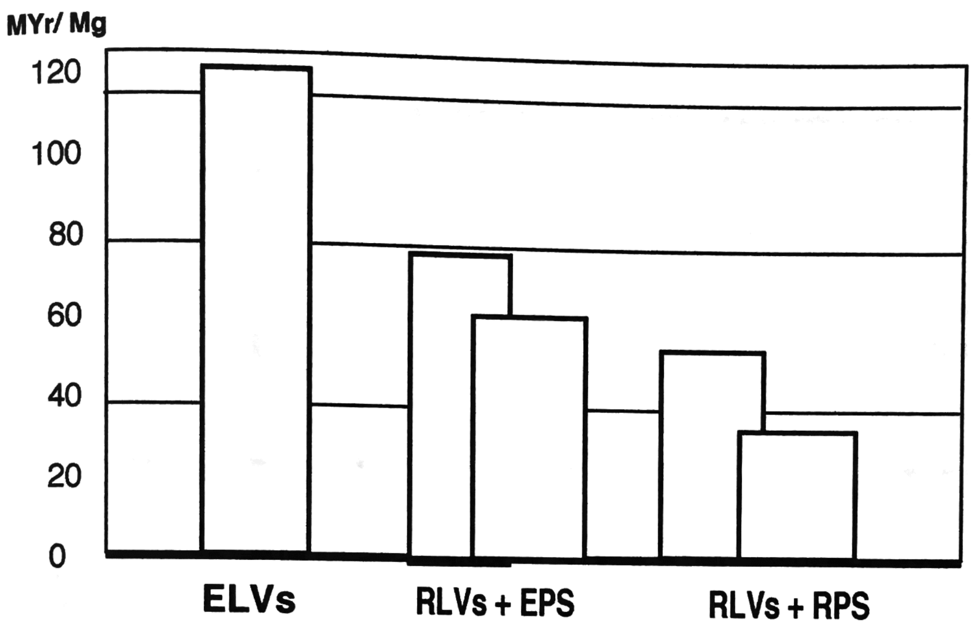


FIG. 6-04: **Potential Future Specific Transportation Cost Reduction by RLVs for GEO Missions**

6.3 Optimization of Launch Vehicle Payload Capability for Large-scale Cargo Transportation (SPS)

Specific transportation cost decrease with vehicle size, as well as with increasing launch frequency (LpA). Is a larger vehicle or a larger number of launches with a smaller vehicle more cost-effective? This question is of special importance in case of a given transportation demand per year, as it is the case, by example, for establishing a Space Power Station (SPS).

This project to place a number of solar power stations with a large total mass of several thousand tons into geosynchronous orbit is the most challenging space transportation task of the future (beside space tourism). The total payload mass to be placed into LEO is in the order of 5000 to 20 000 Mg per year. There are several methods of LEO-GEO transfer which influence the LEO mass as well as the assembly in LEO or GEO which is more demanding for smaller chunks of payload compared to larger pre-assembled units. The cost of transportation to GEO represents the largest share of the total program cost; consequently a careful transportation cost analysis and vehicle optimization is a must.

The *TRANSCOST* - Model provides the possibility to perform a trade-off for the different possible vehicle sizes and annual transportation mass requirements. In TABLE 6-II the main vehicle and cost data have been assembled, assuming commercial industrial development.

TABLE 6-II : **RLV Sizing Data for an SPS Program**

LEO Payload	Mg	30	150	600
Vehicle GLOW	Mg	810	2 900	9 300
Dry Mass	Mg	61.6	200	536
Development Cost	MYr	18 600	29 300	42 300
= Billion US$(2001)		4	6.3	9.1
CpF	MYr	85-130	135-210	220-320
Specif.Transp.Cost	MY/Mg	2.8 to 4.3	0.9 to 1.4	0.37-0.53

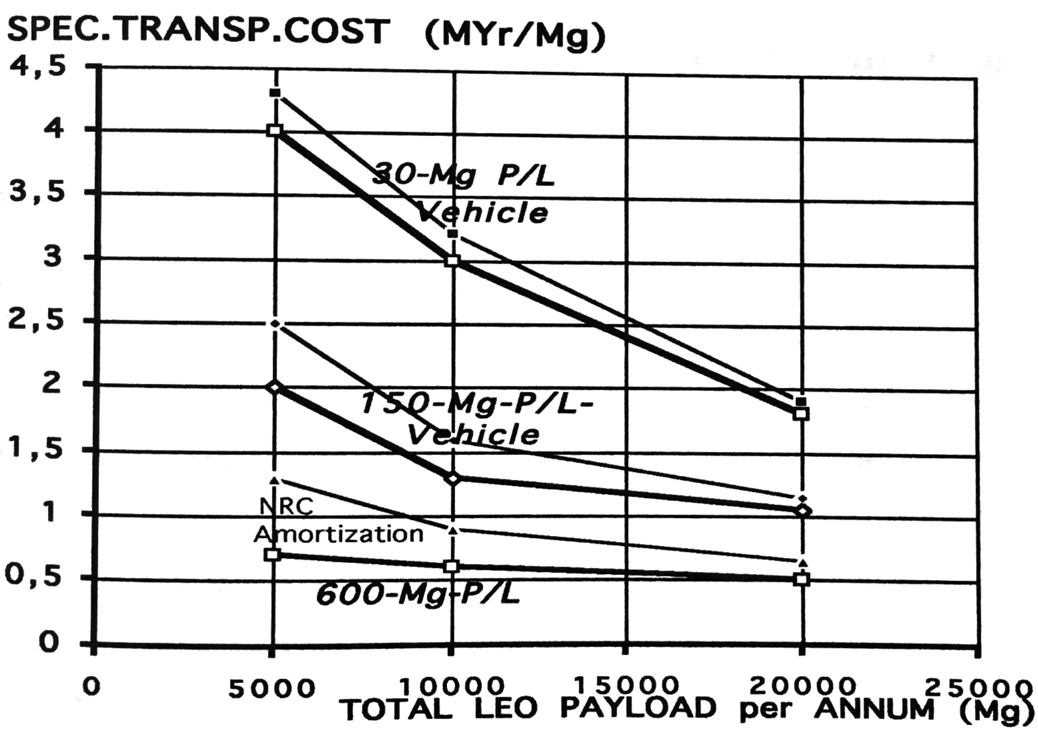


FIG. 6-05: **Specific Transportation Cost to LEO for three different-size Ballistic RLVs without and with NRC Amortization over 15 Years**

FIG. 6-05 shows the specific cost to LEO for three selected vehicle sizes vs. the annual total payload mass. The cost reduction trends both by vehicle size and by increased flight frequency (higher total mass per annum) are evident. In US $ of 2001 the specific costs are between 600 and 100 $/ kg to LEO. In addition, the cost of LEO- to-GEO-transfer have to be taken into account.

The results show the advantage of larger vehicles with respect to specific transportation cost. On the other hand the required development cost investment as well as the realistic payload unit mass and size will certainly limit the launch vehicle size. This means that the potential low specific transportation costs with a LARGE vehicle cannot be realized. The maximum practical RLV size will probably be in the 150 Mg-range (100 to 200 Mg).

This example with a relatively large cost range shows that a careful analysis and trade-off has to be performed (including the mode of development cost financing) in order to define the most cost-efficient transportation system with the optimum launch vehicle payload capability.

Another cost factor to be considered in case of an SPS construction is the assembly in orbit (LEO or GEO). The delivery of larger payload assemblies requires less effort for orbital integration than a larger number of smaller units. This will also be influenced by the transportation mode selected for the LEO-GEO transfer.

6.4 Economic Comparison of Alternative Launch Vehicle Concepts by Life Cycle Costing

For the selection of a launch vehicle concept COSTS should be the decisive factor. Frequently only the development effort is taken into account as the required upfront investment (this was the case for the Space Shuttle Project as well as for Ariane 5) but the economic criteria in reality are the Life-Cycle Cost, i.e. the combined cost of development and a projected number of launches. Although it is difficult to predict the total number of operational flights a new launch system will accumulate, some common-sense assumptions can be made.

The following example is the LCC comparison for a number of launch vehicle options with expendable and reusable stages, all designed for 15 Mg LEO payload capability (ref.10). Ten different two-stage concepts were conceived :

1 Two-stage vehicle, re-using an existing first stage, plus a new cryo upper stage
2 Cryo-core vehicle plus a number of small SRBs (Solid Boosters)
3 Cryo-core vehicle plus a number of liquid-propellant boosters
4 Cryo-core plus two large solid boosters as first stage
5 Two-stage cryo vehicle with recoverable and reusable first stage and expendable second stage

6 TSTO vehicle with both stages recoverable and reusable
7 TSTO vehicle with two equal-size stages, recoverable and reusable
8 Winged fly-back first stage with expendable second stage
9 Winged fly-back first stage with recoverable reusable second stage
10 TSTO with both stages winged and reusable (VTO-HL)

The launch mass (GLOW) of these vehicles was between 360 Mg (Concept 5) and 800 Mg (Concepts 3 and 10). TABLE 6-III provides some more detailed informations on the stage type and size (propellant mass) of the different vehicles (L.40 means Liquid-propellant stage with 40 Mg propellant mass). The major configurations are shown in FIG. 6-06. A total number of 150 launches

TABLE 6-III: **Launch Mass and Stage Characteristics of the Vehicle Configurations Investigated**

VEHICLE CONCEPT	1	2	3	4	5	6	7	8	9	10
TYPE		CRYO – CORE			TWO–STAGE BALLISTIC			WINGED 1st STAGE		
Booster	4 x L.40	4 x P 8	–	–	–	–	–	–	–	–
Stage 1	L. 200	H. 385	8 x L.40	2 x P.150	RH.250	RH.250	RH.180	WH.220	WH.310	WH.550
Stage 2	H. 60	–	RH.385	H.115	H. 40	RH.65	RH.180	H. 60	RH. 90	WH. 60
Launch Mass (Mg)	478	477	810	495	357	383	435	367	506	780

L = Liquid storable propellant stage
H = Cryogenic propellant stage
RH = Reusable cryogenic stage
WH = Winged cryogenic stage

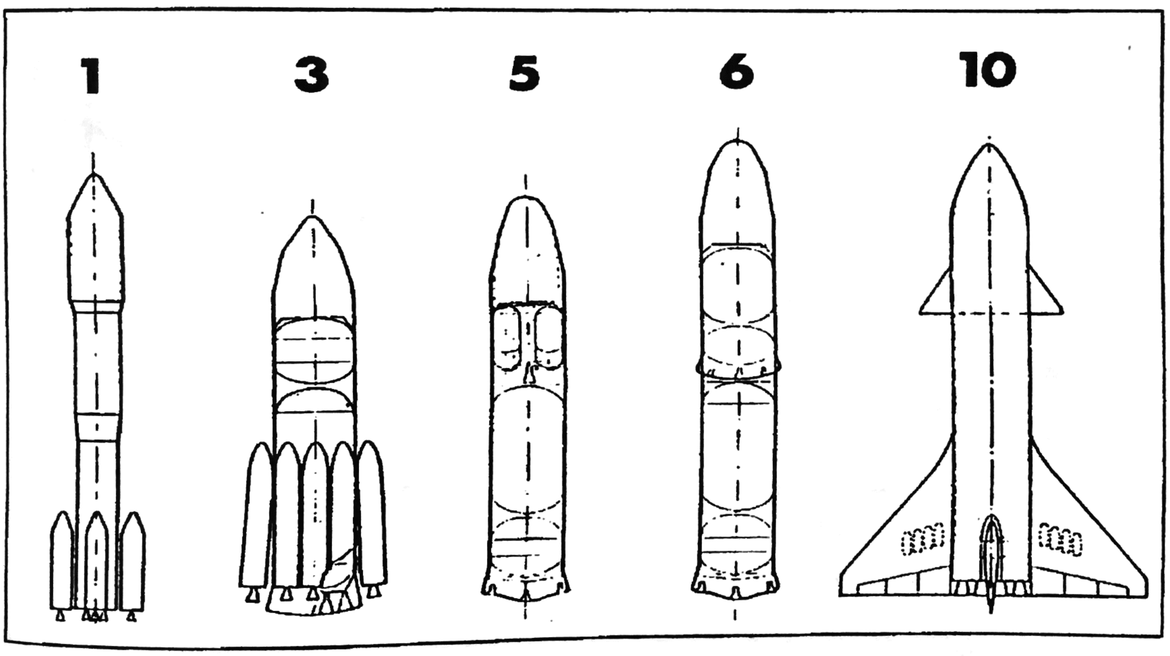


FIG. 6-06: **The Major Candidate Launch Vehicle Configurations**

has been used for the purpose of comparison in this study, representative for a 15-year European launch activity.

The results, as shown in FIG. 6-07, indicate a clear trend: the lower the development costs, the higher the Cost-per-Flight (CpF). This is exactly the same basic result as it has been presented in a study performed for NASA in 1971 for different Space Shuttle Concept options (ref. 64). Somebody called it „the high price for low cost" (of space transportation). The lowest CpF are valid for reusable fly-back vehicles but they require unfortunately the highest development cost. The higher the number of missions assumed in the cost comparison the more favourable are the results for fully reusable vehicles. In our example only the vehicle recurring cost for the 150 flights have been calculated, not the DOC and IOC, for the sake of simplicity, since it would not change the basic results.

The minimum total program cost solution is vehicle concept 7 which is a two-stage reusable vehicle with two equal-size stages. However, it requires relatively high development cost which represents a hurdle for decision-making. Most such decisions, unfortunately, are near-term oriented and not taking into account long-term economics.

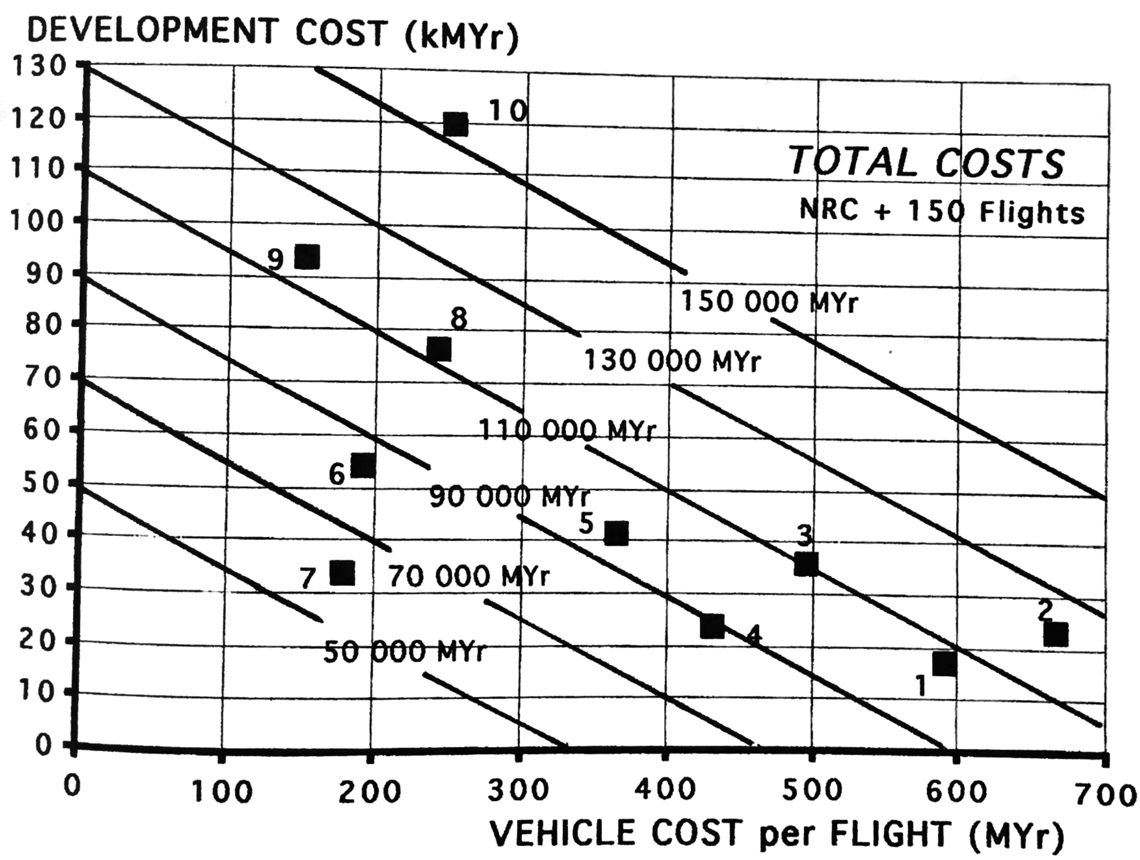


FIG. 6-07: **Development Cost and Vehicle Cost per Flight with LCC Levels for Development plus 150 Launches**

6.5 Economic Optimization of the Stage Separation Speed of HTOL Winged Launch Systems

Winged HTOL first stage vehicles with airbreathing propulsion and a rocket-propelled upper stage are one of the options studied as a future space transportation system. In Germany a large effort for the definition and technology assessment for such a system has been performed in the 1985 to 1993-period for the SÄNGER Concept (FIG. 6-08) in the National Hypersonics Technology Program (more than 300 M$ have been spent). In the year 2000 such a system was adopted as the reference project for the Japanese activities towards a reusable space transportation system.

In the USA the BETA II Concept has been studied by Boeing, in the UK the AN-225/Hotol combination, which was also analyzed in an ESA Study as WLC-2 Concept. The stage separation speeds in these project ranged from Mach 0.7 to Mach 3.3 (Boeing) to Mach 6.6 (Sänger) and even to Mach 12 in a NASA Langley Study.

The most evident impact of the separation speed on the overall vehicle system is the size, respectively the mass of the upper stage. FIG. 6-09 shows the upper stage mass as a function of the separation speed which is valid for vehicles sized for 7 to 10 Mg payload in LEO. The extreme case with separation at Mach 0.5 from a ground-based sled requires actually an SSTO vehicle with a launch mass of some 700 Mg or more. Up to Mach 4 the required upper stage mass is more than 200 Mg(Boeing BETA: 265 Mg). On the other hand, for separation speeds above Mach 7

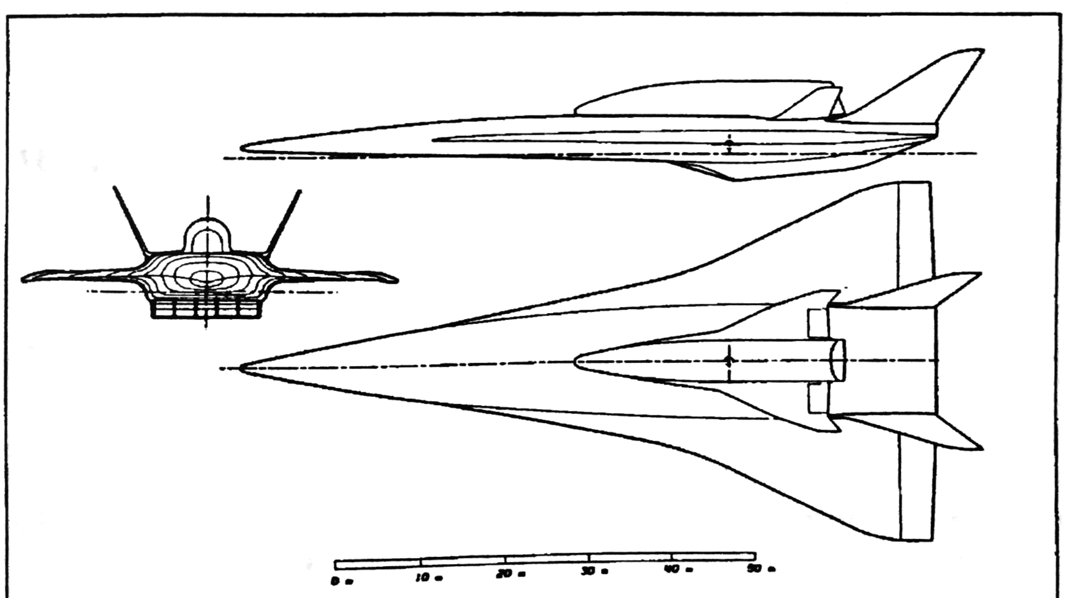


FIG. 6-08: **SÄNGER Advanced STS with LH_2-Turboramjet First Stage**
(Mach 6.6 Separation Speed, Mach 4.4 Cruise Speed)

TABLE 6-IV: **SÄNGER Launch System Data Summary** (ref. 137)

		Crewed Version	Cargo Version
TOTAL LAUNCH MASS (GLOW)			410 Mg
FIRST STAGE	Total Mass		295 Mg
	Vehicle Dry Mass (OWE)		167.5 Mg
	Maximum Propellant Mass (LH_2)		119 Mg
	Vehicle length/ wing span		82.5 / 45 m
SECOND STAGE	Total Mass incl. payload	115 Mg	115 Mg
	Vehicle Net Mass	28.9 Mg	24.9 Mg
	Vehicle Dry Mass	26.0 Mg	22.3 Mg
	Usable Propellant Mass (LOX/ LH_2)	83.1 Mg	82.4 Mg
	Vehicle length/ wing span		32.5/ 18 m
	PAYLOAD	3.0 Mg (450 km Orbit/ 28.5°)	7.7 Mg (200 km Orbit)

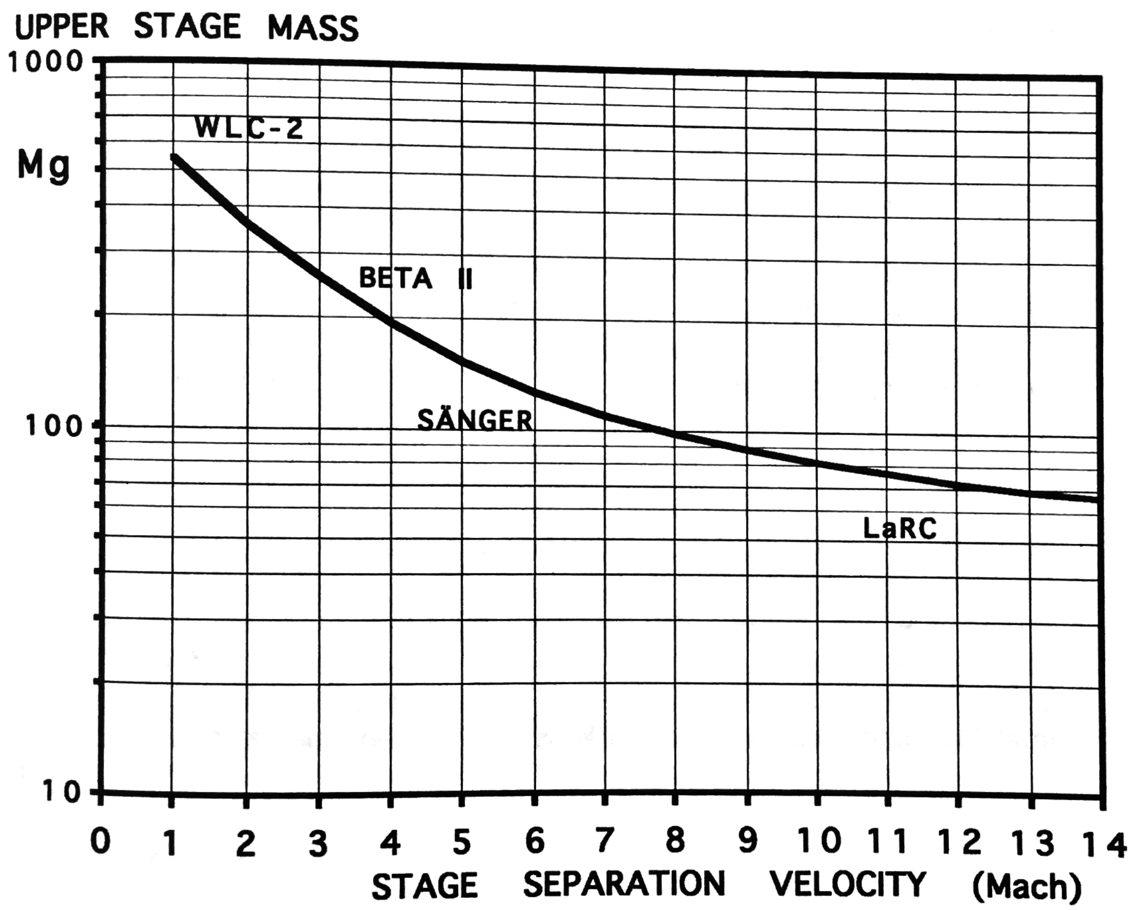


FIG. 6-09: **Upper Stage Mass vs.Separation Speed for HTOL-TSTO-Launch Systems, and Typical Upper Stage (Sänger-HORUS)**

the upper stage mass will be less than 100 Mg, but the size reduction is no more essential. Considering the practical case of a „standard" payload bay diameter of 15 ft = 4.6 m, the upper stage vehicle can only reduce in length but no more in scale. A typical vehicle of this type is shown in FIG. 6-10 (Sänger-HORUS-C). A reduction of tank and fuselage length only does not result in any major cost reduction; in the contrary: the shorter the vehicle, the larger the stability and control problems. For this reason an upper stage with 90 to 120 Mg total mass seems to be the minimum cost configuration

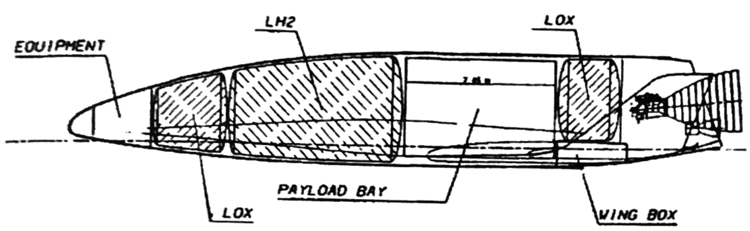


FIG. 6-10 : **Typical Winged Orbital Stage Vehicle (SÄNGER-Horus-C)**

FIRST STAGE SIZE: There are two contrary trends regarding the first stage vehicle size: with decreasing upper stage mass the first stage size reduces; however, it grows at the same time due to increasing speed requirement. These two factors result in an almost constant first stage size for the range of Mach 2 to 5, namely some 300 to 400 Mg. Beyond Mach 7 stage separation velocity, however, the first stage stage starts to increase for several reasons: the growing LH2 volume, the rapidly increasing external heating and the additionally required secondary rocket thruster system for attitude control at high altitudes. The inherent disadvantage of air-breathing first stages in comparison to rocket-propelled vehicles (with vertical launch) is the large vehicle dry mass, caused by the airbreathing engine mass´ (low thrust-to-weight ratio) with the complex air-intake and the large fuselage size, caused by the liquid hydrogen mass with its low density. Up to Mach 6.5 modern Titanium alloys can be used (for short-duration thermal loads), at higher speeds new exotic materials are required. Beyond Mach 11 even active cooling needs to be applied for critical areas.

These effects on the first stage mass are summarized in FIG. 6-11: extending the separation speed beyond Mach 7 increases the first stage mass more than the possible reduction of the upper stage vehicle mass. The reasons are that a ram-scram propulsion system is required with lower efficiency than an optimized ramjet in the Mach 3.5 to 6.5 range, growing structure mass and the addition of a secondary reaction control system with some 20 rocket thrusters. The latter is required because for separation speeds above Mach 6.5 the first stage reaches flight altitudes above 40 km where aerodynamic controls are no longer effective.

The development cost of Winged Orbital Vehicles are about 40 % higher than those of advanced aircraft, as the development cost CERs shown in FIGs. 2-41 and

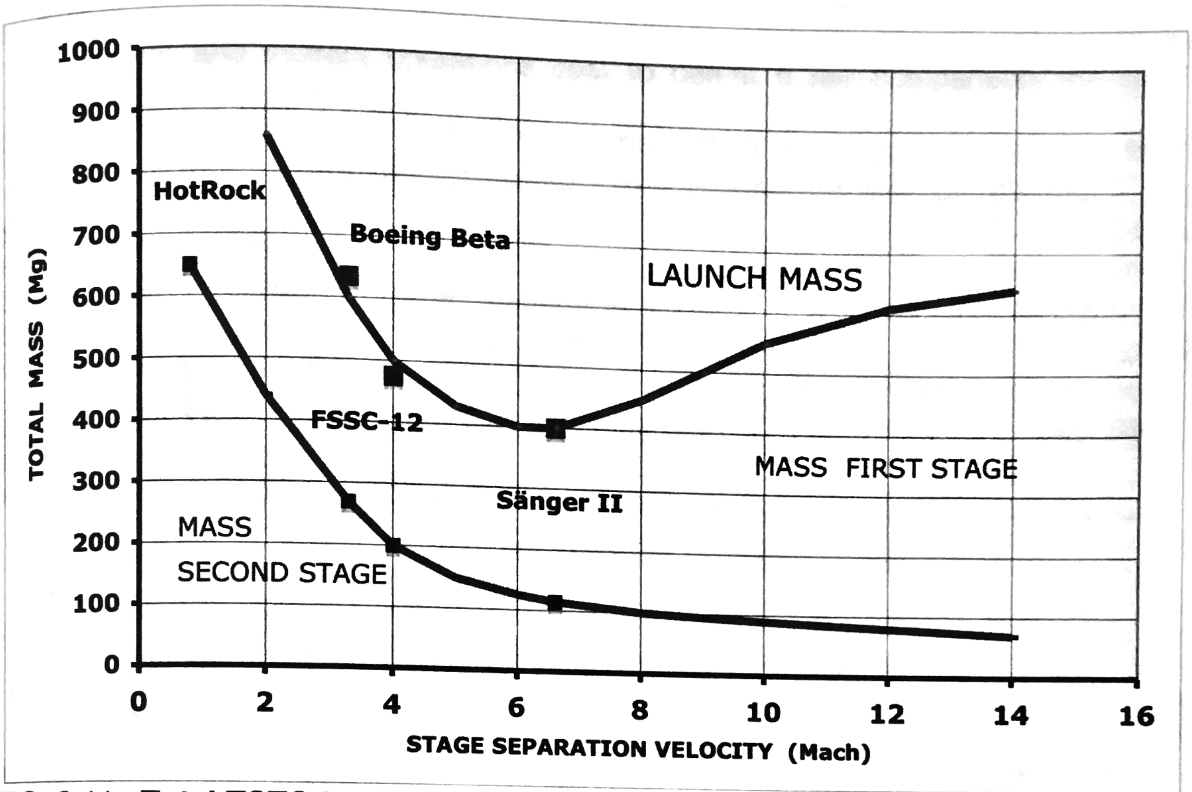


FIG. 6-11: **Total TSTO Launch Mass vs. Stage Separation Velocity**

2-46 indicate. Therefore, large orbital vehicles are expensive to develop, but require also high amortization and refurbishment cost. This makes a small upper stage higly desirable, also with respect to the geometrical integration of the two vehicles which is of growing importance for higher separation speeds.

6.6 CpF-Economics of an Aerospace Plane
(Orbital SSTO-Vehicle with Combined Airbreathing and Rocket Propulsion)

The winged HTOL vehicle with scramjet propulsion (NASP-type) is the most demanding space transportation system presently conceived. It requires a tremendous effort to develop new propulsion system combinations with scramjet engines and advanced structures technology (including active cooling systems) in order to make this system feasible at all.

The key question, however, is whether it is worthwile to make this large effort. Does it result in reduced space transportation cost, by example in comparison to a more conventional two-stage winged system ? The important decision criteria in this case is the „Cost- per -Flight" (CpF). While in case of rocket-propelled VTO vehicles the SSTO system provides the lowest CpF to LEO, the situation for airbreathing vehicles is different. The *TRANSCOST*- Model provides the tool for a comprehensive CpF estimate which must include vehicle amortization, refurbishment and indirect operations cost to permit a fair comparison.

The vehicle configurations which are compared here costwise have both been designed by MBB/ BAe according to an ESA-requirement of placing 7 Mg payload into a 28.5° - 450 km orbit. The TSTO system is a SÄNGER-type vehicle with 410 Mg launch mass, including the 115 Mg rocket-propelled winged upper stage (not piloted). The first stage vehicle is a hypersonic aircraft with 119 Mg propellants (LH_2) and 167.5 Mg dry mass (OWE). It has turbo-ramjet propulsion and a cruise capability of some 2000 km. The main data are shown in TABLE 6-IV. FIG. 6-12 shows the configuration of the TSTO and the SSTO systems.

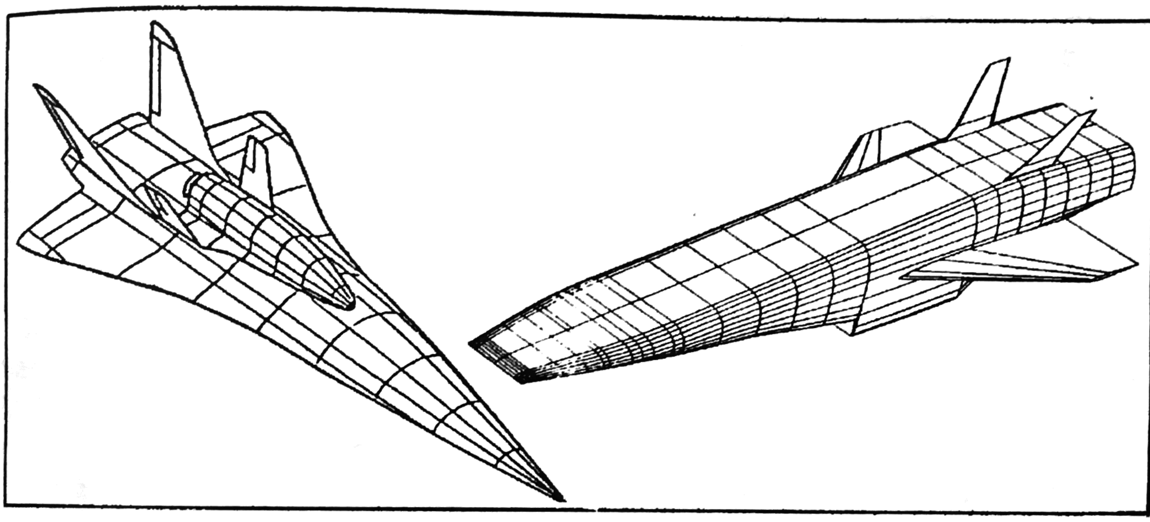


FIG. 6-12: **Winged HTOL Two-Stage vs. Single-Stage Vehicle Concepts**

The SSTO is similar to the NASP vehicle, but designed for operational use. It uses integrated air-ejector-rocket + scramjet + rocket propulsion and has a realistic launch mass of 500 to 700 Mg. The reason for the relatively high GLOW is the weight of the propulsion system (including large highly variable air-intakes) and the large volume required for the liquid hydrogen fuel - leading to a large vehicle size - as well as the wings and aerodynamic control surfaces with the related power supply system.

The results of the cost analysis are presented in TABLE 6-IV. In this case not only the nominal cost values are shown but in addition the potential range of costs due to uncertainties and the possible variation of assumptions, such as the number of flights per vehicle. For orbital vehicles these can be assumed , by example, to be between 80 and 200. In our comparison the nominal case for the SSTO is 120 flights (80 and 140). The same number of 120 applies for the TSTO upper stage nominal case but here with a larger variation of 60 and

200. 500 flights is the nominal figure for the TSTO first stage (range: 400 to 1000 flights). In addition, the number of rocket engine re-uses has been varied between 20 and 50. Both orbital vehicles are not piloted but a crew module can be placed into the cargo bay.

TABLE 6-V: **CpF Comparison of Winged SSTO and TSTO Launch Vehicles at 12 LpA** (excluding development cost amortization)

	TSTO Reference (Range)	SSTO Reference (Range)
1. VEHICLE AMORTIZATION	28.5 (17 - 41)	78.8 (56 - 139)
2. REFURBISHMENT COST	14.4 (10 - 20)	47.3 (33 - 66)
3. DIRECT OPERATIONS COST	36.5 (29 - 49)	26.3 (20 - 35)
4. INDIRECT OPERATIONS COST	22.2 (15 - 40)	22.2 (15 - 40)
Cost per Flight (CpF)	**102 (71- 150)**	**175 (124- 280)**
equivalent to	24.8 Mio.$ (2006)	42.5 Mio.$ (2006)

It is evident from the data in TABLE 6-V that the vehicle AMORTIZATION COST play a major role. The reason for the high SSTO cost is the large dry mass of 80 to 120 Mg which has to be placed into orbit - compared to only 23 Mg for the TSTO second stage.

For REFURBISHMENT COST the situation is similar since these are derived from the vehicle TFU production cost. But there are also good technical reasons to expect high refurbishment cost : the actively cooled structure elements of the SSTO, the huge air-intake going through re-entry conditions, and the complex integrated propulsion system.

The DIRECT OPERATIONS COST (DOC) are lower for an SSTO compared to a two-stage system which is logical since two systems have to be maintained and operated.

The INDIRECT OPERATIONS COST (IOC) are by definition the same since these (primarily administrative cost) are independent from the technical vehicle concept.

Alltogether, TABLE 6-IV shows that the SSTO vehicle will require most probably about 70% higher CpF than the TSTO system, not considering development cost amortization or Life-Cycle Cost. In this case the cost difference would be even larger.

Conclusion:
The winged SSTO vehicle with combined propulsion is NOT an option for cost reduction in space transportation, compared to other vehicle options. With respect to the extraordinary high development cost is is questionable to invest in the technologies required for a winged SSTO vehicle with combined propulsion.

6.7 Space Tourism Ticket Cost Assessment

Launch Vehicle Passenger Capacity, Cost per Seat and Market Size

The number of passengers per flight is a major economical factor since it determines the revenue per mission. The larger the number of passengers per flight the lower are the operations cost per seat. The total cost per flight are increasing with vehicle size and passenger capacity., but much less than the number of passengers would suggest.

TABLE 6-V shows the main parameters of three vehicles conceived for 50, 110 and 170 passengers in order to get more detailed information of the vehicle size/ performance impact on the cost-per-seat in case of space tourism missions (ref.106). The launch vehicle concept is used here is the Ballistic SSTO-RLV, as shown in FIG.2-27 which is best suited for tourists' accomodation according to chapter 5.44.

TABLE 6-VI: **Space Tourism Vehicle Sizing**

Launch Vehicle Options		A	B	C
No. of Passengers		50	110	170
Launch Mass (GLOW)	Mg	575	800	1030
Vehicle Net Mass	Mg	58.5	77.7	95.4
Vehicle Dry Mass	Mg	46.8	62.2	76.3
Propellant Mass	Mg	503	700	900
Crew (Pilots + Attendants)		2+2	2+3	2+4

Assuming a commercial development plan the vehicles production costs (TFU = Theoretical First Unit) have been estimated with the TRANSCOST-CERs as shown in TABLE 6-VII. There is a relatively small cost increase with growing vehicle size / capacity as discussed in chapter 2 („Law of Scale"). In addition to the TFU vehicle cost the hardware cost eduction by quantity production is indicated in TABLE 6-VII for two program options or market examples. This is required in order to desfine the number of required vehicles, as well as for the calculation of the complete „Cost-per-Flight"

(CpF). The following two cases are considered:

(a) 75 000 passengers per year = 0.75 Million passengers in 10 years, and

(b) 750 000 passengers per year = 7.5 Million passengers in 10 years.

As further assumptions 120 flights per vehicle and 40 flights per engine have been used. Refurbishment costs per flight are taken into account with 0.1 % of the vehicle recurring cost.

The high production numbers especially in case of Vehicle A reduces the hardware cost such that the VRC (Vehicle Recurring Cost) are only 44.5 % of the Vehicle C cost. The cost reduction effect, however, is not large enough to balance the basic size advantage of vehicles B and C. It must be mentioned in this case that the learning cost reduction can only be realized if the long-term full-scale production is authorized at program start. For limited production orders the learning effect may be greatly reduced.

The negative impact on costs of small launch vehicles with large production and launch numbers is the fact that a large number of launch sites/ launch pads has to be built and operated which balances part of the vehicle production cost advantages.

With these assumptions and the vehicle data of TABLE 6-V the Cost-per-Flight values can be calculated according to chapter 5.1. The results are shown in FIG. 6-13 for the three launch vehicle options as function of the annual launch rate. The essential cost reduction with increasing launch rate is caused by two factors:

(1) The vehicle hardware cost reduction for larger production quantities (the learning factor impact), and

TABLE 6-VII : **Launch Vehicle Unit Cost Reduction by Quantity Production (Learning Effect)**

Launch Vehicle Option :		A	B	C
TFU Cost (First Unit) MYr		2150	2550	2870
= M$(2002)		480	570	640
	=	100 %	100 %	100 %
PROGRAM (a)				
Total No.of Units required		125	57	37
Relative Cost per Unit		68 %	75 %	81 %
PROGRAM (b)				
Total No.of Units required		1250	570	370
Relative Cost per Unit		26 %	36 %	43 %

(2) the reduction of the Indirect Operations Cost (IOC) share per flight. IOC are defined as the overall administrative and engineering support cost of the launch operator company, fees, profit, etc.

With the standardized complete CpF (Cost-per-Flight) as described in chapter 5.1 the cost-per-seat for space tourism launch services can be derived for the different vehicle options and market sizes.

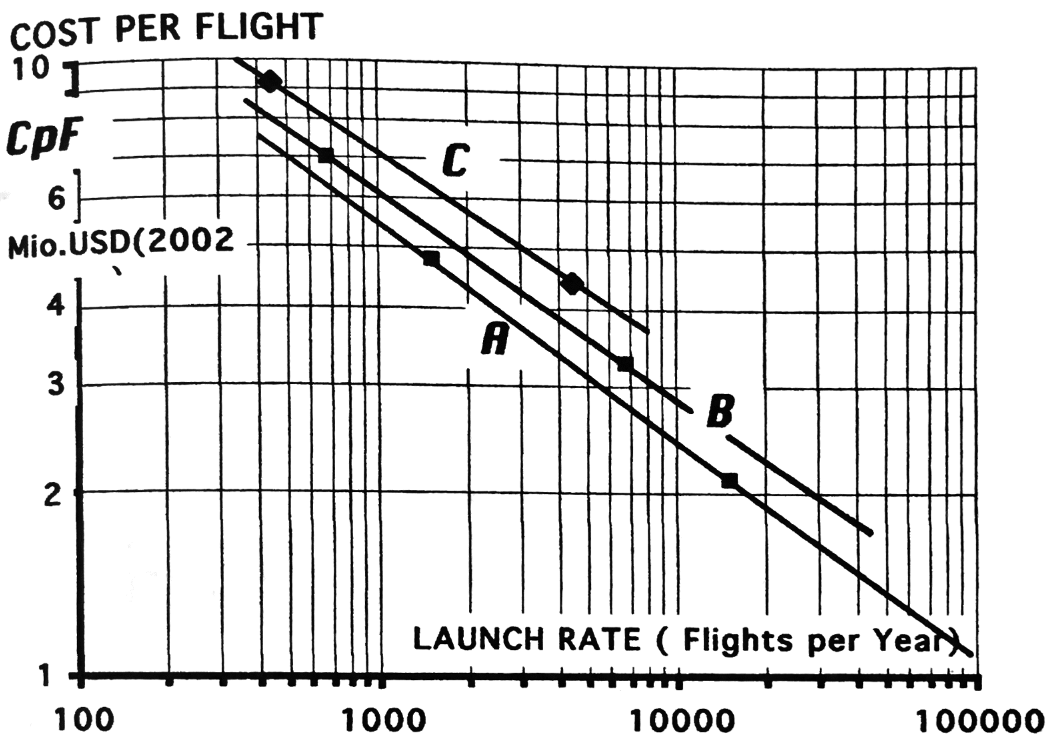


FIG. 6-13: **Cost-per-Flight (CpF) vs. Launch Rate for Vehicle Options A, B and C**

The results - as shown in TABLE 6-VIIÍ and depicted in FIG. 6-14 - are revealing an important fact regarding the vehicle size (A, B, C) : As expected, the larger capacity vehicles are more cost-efficient, but more important is the fact that for seat costs in the range of 50 000 USD (which is often quoted as an upper limit for larger-scale operations) some 450 000 passengers are required per year in case of the smaller A-Vehicle, but only 150 000, respectively 95 000 passengers for the larger B- and C-Vehicles in order to cover the annual flight operations cost.

Although the smaller vehicle A would be sufficient in the build-up phase, the larger ones are required for a profitable long-term operation. The small vehicle would represent a business risk since large passenger numbers are required to cover the high operations cost with 25 launches a day requiring many launch sites and pads.

TABLE 6-VIII: **Cost-per-Seat vs. Vehicle Passenger Capacity and Market Size**

VEHICLE SIZE **Passenger Capacity**	A **50**	B **110**	C **170**
(a) 75 000 passengers per year / 10-Year-Program			
Number of flights per year	1 500	682	442
Cost-per-Seat (USD/ 2002)	97 000	64 000	54 500
(b) 750 000 passengers per year / 10-Year-Program			
Number of flights per year	15 000	6820	4420
Cost-per-Seat (USD/ 2002)	42 000	30 000	26 000

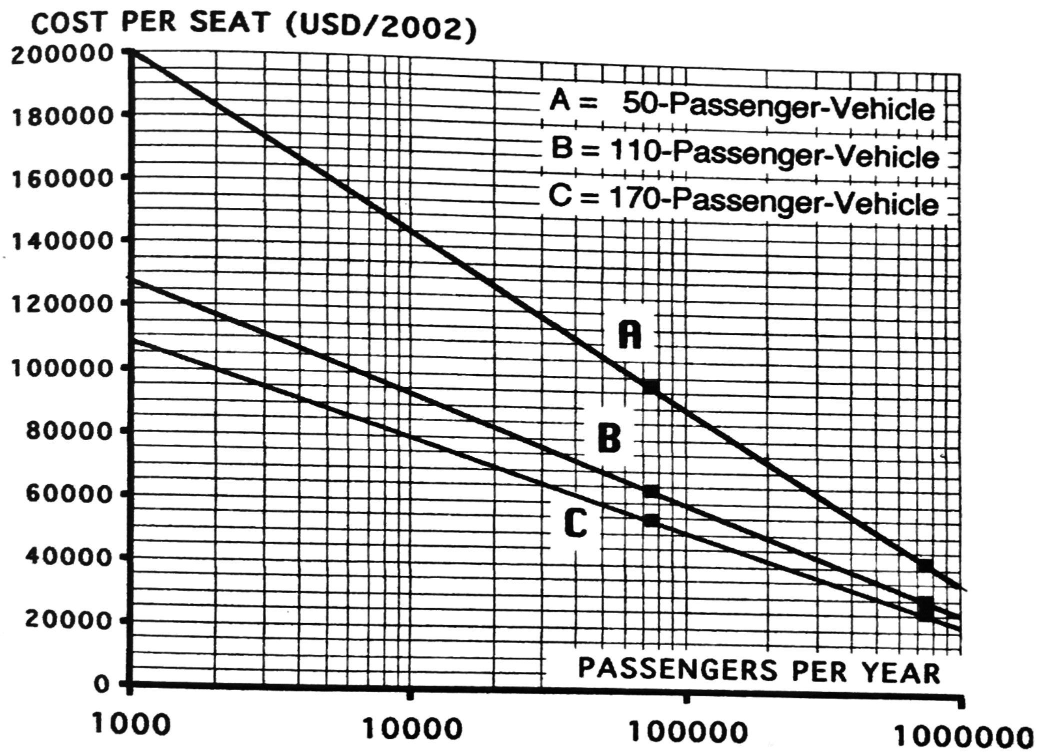


FIG. 6-14: **Cost-per-Seat vs. Passenger Numbers per Year for three Different Launch Vehicle Sizes**

Its should be mentioned again that the vehicle operations cost or cost-per-seat are only part of the total ticket cost : The full tour ticket will comprise in addition the cost of passenger training and preparation before launch, vehicle development cost amortization, infrastructure cost and capital cost for financing the commercial venture. The vehicle operations cost per seat, however, are the major factor and the conclusion can be drawn from this example that a future space tourism launch vehicle should be designed for at least 100 passengers in order to allow for economic operations.