4. GROUND AND FLIGHT OPERATIONS COSTS

4.1 Scope and Definitions

4.11 Major Criteria and Interrelations

Assessment and modelling of launch vehicles' operations cost is the most difficult task compared to development cost and recurring cost modelling. The reasons for this fact are

- -- the complex relationship between a large number of operational criteria , especially in case of reusable systems (see FIG. 4-01), and
- -- the scarce reliable reference data base, especially for reusable launch systems.

Aircraft operations experience can be used partially as background information but not applied directly to space launch systems because of differences in technology maturity. This is a major contributor through factors like reliability and margin, which manifests itself in the different flight rates and flight hours. FIG. 4-01 shows the central role of the launch rate : LpA = Launches per Annum. It strongly influences all parameters of ground operations. The term dependability is used to refer to a part failure on ground, as detected during checkout, by example.

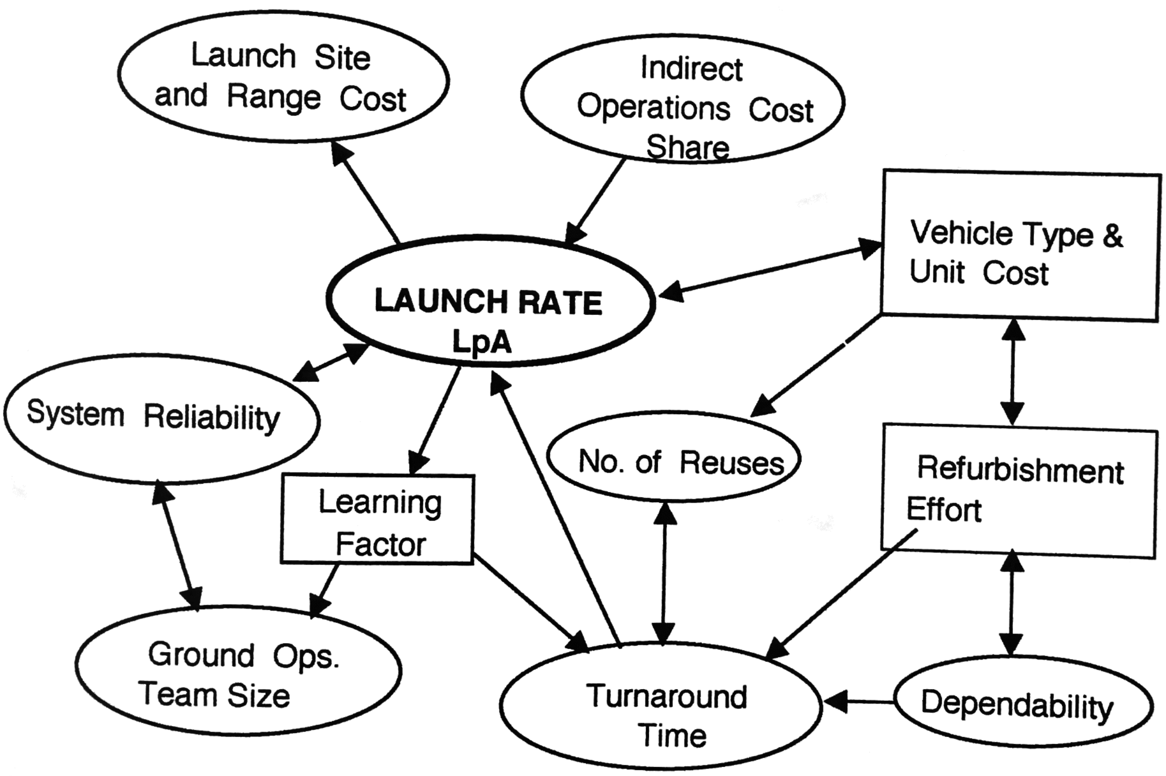

FIG. 4-01: **Interrelation of Major Operational Criteria (RLVs)**

4.12 *TRANSCOST* Operations Cost Submodel Structure

This Ground and Flight Operations Cost Submodel is the updated attempt to define a cost model for launch vehicle operations; it certainly needs further verification and improvement in the future.

The OPERATIONS COST as defined here are consisting of two major areas:

-- ***Direct Operations Cost (DOC)***
with all activities related directly to the ground preparations of a vehicle plus launch and mission operations,

and -- ***Indirect Operations Cost (IOC)***
comprising the cost items which are more or less independent from the individual launch operations, i.e. administration and management of the launch service provider, technical support and the general launch site and range cost.

In case of reusable launch systems additionally :

-- ***Refurbishment and Spares Cost (RSC)***
taking into account the system refurbishment and engines' exchange required for the „major overhaul" of vehicles after a certain number of flights.

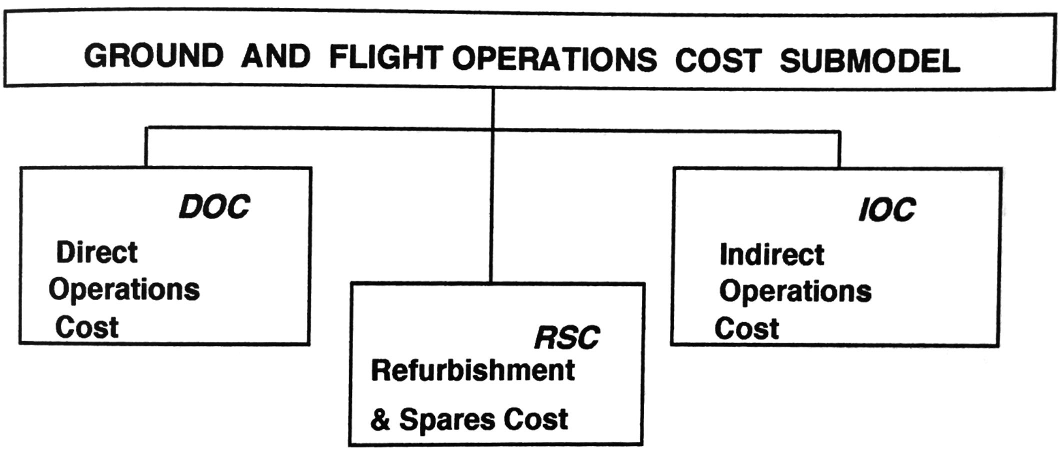

FIG. 4-02 : **Operations Cost Submodel Main Elements**

Excluded - by definition - are payload-related activities such as

-- payload preparation and checkout
-- mission specialists' training/ support
-- in-orbit payload and mission operations.

The Ground and Flight Operations Cost with actual launch rates of some 10 LpA represent 20 to 35 % of the total „Cost per Flight" (CpF) in case of Expendable Launch Vehicles (the rest are vehicle hardware costs), but 35 to 70 % in case of Reusable Launch Vehicles. The lower values apply to larger vehicles and/ or high launch rates while the higher values are valid for small vehicles and/or low launch rates. This is illustrated in FIG. 4-03, with 100 % being the total „Cost-per - Flight" as discussed in Chapter 5.1.

Experience from Space Shuttle and ARIANE 4 ground operations suggest that also in Operations Cost a cost reduction vs. time, resp. vs. the accounted number of flights can be taken into account, according to the Learning Factor ground rules as outlined in chapter 3.2.

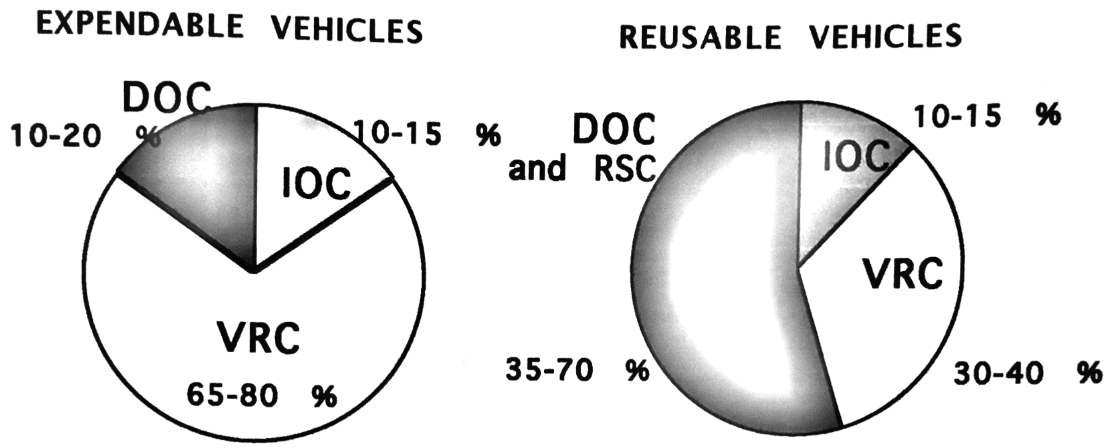

FIG. 4-03 : **The Operations Cost Shares of Expendable and Reusable Launch Vehicles are remarkably different**

In case of the US SPACE SHUTTLE the DOC and RSC reach an extraordinary share of 76 % of the total CpF. This is due to the very high refurbishment effort for the SRBs and the Orbiter. It must be (and can be) assumed that this will be much lower for future operational RLVs.

As an example for the *TRANSCOST* Operations Cost Submodel costing methodology the SHUTTLE Operations and Refurbishment Costs are summarized in TABLE 4-I. The data refer to the FY 98-Budget with 6 launches (ref. 81).

By a staff reduction between 1991 and 1997 the total SPACE SHUTTLE Operations Cost have been reduced by some 11 %. This fact suggests an 90 % Learning Factor cost reduction effect (cf. chapter 3.13).

It is evident from TABLE 4-I that some major cost items are missing in this case, especially the launch site-related IOC (Kennedy Space Center has its own Operations Budget) and any insurance costs and fees. Otherwise, the high Mission Operations Cost include the payload operations over 8 to 14 days in space which - by definition - do not belong to the space transportation cost proper. To arrive at the total CpF the cost of the ET (Expendable Tank) has to be added (with 285 MYr at 6 LpA, see FIG. 3-08), and normally also the vehicle and engines' recurring cost share. In the actual Shuttle Program, however, the fleet of 4 Orbiters

TABLE 4 - I : **Space Shuttle Operations Cost per Flight at 6 LpA**

DIRECT OPERATIONS COST (DOC)		**1160 MYr**
(1) Prelaunch Ground Operations[1]	690 MYr	
(2a) Propellants (LH_2 / LOX, OMS/RCS Props., etc.)	14 MYr	
(2b) Solid Propellants (SRMs)	75 MYr	
(3) Flight and Mission Operations	350 MYr	
(4) Transport and Recovery (SRBs)	31 MYr	
(5) Fees and Insurance	0 MYr	
REFURBISHMENT & SPARES COST (RSC)		**600 MYr**
(6) SRM /SRBs (2) , Refurbishment & Spares	362 MYr	
(7) Orbiter TPS Refurbishment & Spares	82 MYr	
(8) Other Orbiter Subsystems Ref.& Spares (est.)	56 MYr	
(9) SSMEs (3) Refurbishment & Spares	100 MYr	
INDIRECT OPERATIONS COST (IOC)		**230 MYr**
(10) System Management & Administration (Share)	158 MYr	
(10) Launch Site Support & Maintenance*	-- MYr	
(11) Technical System / Network Support	72 MYr	
TOTAL OPERATIONS COST per Flight at 6 LpA		**1990 MYr**

* part of the NASA KSC General Budget

has been accounted as part of the non-recurring cost (Total Shuttle Cost per Flight - CpF - see chapter 5.14).

4.2 Direct Operations Cost (DOC)

4.21 Cost Elements and Criteria

The organization and constituents of the Direct Operations Cost are shown in FIG. 4-04. There are five major areas including the fees and charges covering launch aborts and vehicles failures.

These activities require a certain ground staff size and a certain amount of time, called often the „turn-around-time" (minimum time period between two launches). The ground crew size and time period required are depending on the following factors:

[1] including Orbiter maintenance (about 50 % of total)

(1) the size and complexity of the vehicle, especially the number of stages and/ or auxiliary boost units,

(2) the fact whether it is a crewed or an automated vehicle,

(3) the assembly and mating and transportation mode (vertical or horizontal) and the transportation to the launch site (vertical or horizontal, on own wheels or on a special vehicle),

(4) the launch mode and type of facility (vertical launch from special pad / assembly structure, rigid or mobile, or horizontal launch from runway or special track),

(5) the number of launches per year (LpA).

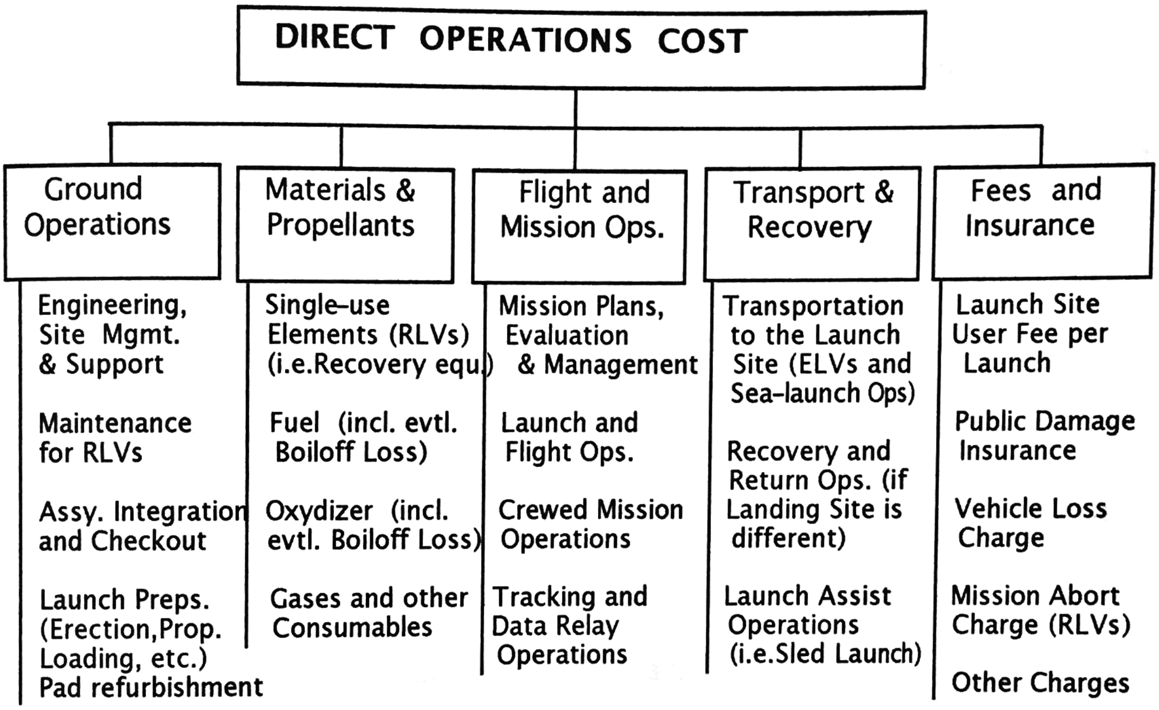

FIG. 4-04 : **Direct Operations Cost Elements**

The payload preparation as such, its integration and checkout before mating to the vehicle is *not* considered to be part of the vehicle ground operations (these cost must be accounted as part of the payload cost).

4.22 Ground Operations Cost

4.221 Scope of Prelaunch Activities (plus launch pad refurbishment after launch)

The preparation of the vehicle for launch comprises the following activities:

-- Ground facilities' preparation,
-- Vehicle elements (stages / boosters) functional checkout,
-- Mission and flight software update and loading,
-- Payload encapsulation (integraton with vehicle shroud),
-- Transportation to / erection on launch pad,
-- Payload container / shroud mating with vehicle,
-- Propellant loading,
-- Final interfaces' checkout,
-- Ground operations management and technical support.

In case of RLVs there are additional activities, such as

-- Post-flight vehicle inspection,
-- Vehicle maintenance, including exchange of single-use items, (cf. chapter 4.223)

Maintenance is an on-line activity. This is different to *REFURBISHMENT* acitivities which are performed *OFF -LINE* after a certain number of flights, comparable to the „major overhaul“ of aircraft. This is dealt with in the Refurbishment Chapter 4.3.

4.222 Vehicle Processing Options and Related Facilities

Different prelaunch operation procedures are being used:

(A) Vertical vehicle assembly on the launch pad, using a large launcher assembly and service tower which is moved away before the launch. This method is used for the ATLAS -II and DELTA-II launch vehicles and was used for the European ARIANE-1 launch vehicle. This requires a relatively long preparation effort and occupies the launch pad for about a month.

(B) More flexible launch preparations are feasible by remote vertical vehicle integration (TITAN IV , ATLAS V, ARIANE 5) and subsequent transportation of the complete vehicle assembly in vertical mode to the launch pad. This shortens the pad time to few days and allows the preparation of two vehicles in parallel.
In case of Solid-Propellant Boosters a separate intermediate assembly station is required for safety reasons. A staff of 200 to 500 people are required for the prelaunch ground operations of this type, depending on the size and complexity of the vehicle.

(C) The most efficient ground operations mode uses horizontal launch vehicle integration, transportation to the launch pad with an interconnect table, erection, propellant loading and launch. This mode is used by all Russian launch vehicles due to their originally military nature. The operations are higly automated and require only one or 2 days on the launch pad. This was demonstrated by three successful PROTON-launches within 12 days (July 1

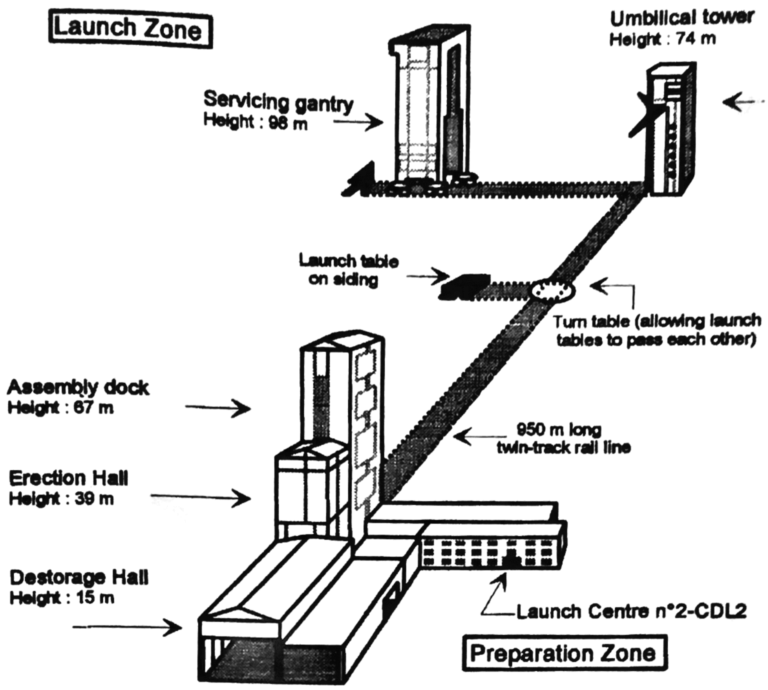

FIG. 4-05 : **Vehicle Preparation and Assembly Building, Mobile Launch Table Track, Launch Pad with Umbilical Tower** (ELA-2, Kourou)
(Initially also a Mobile Service Gantry was used as shown above which is no more required in modern concepts, i.e. ARIANE 5)

to July 12, 2000). Mode C has also been adopted for the DELTA IV-Launcher, reducing the pad time to 6-8 days compared to 24 days for DELTA II.

The type of ground operations and the necessary effort depends on the vehicle type, size and operational launch rate. For small vehicles and / or test vehicles the most simple ground operations concept can be employed with largely mobile

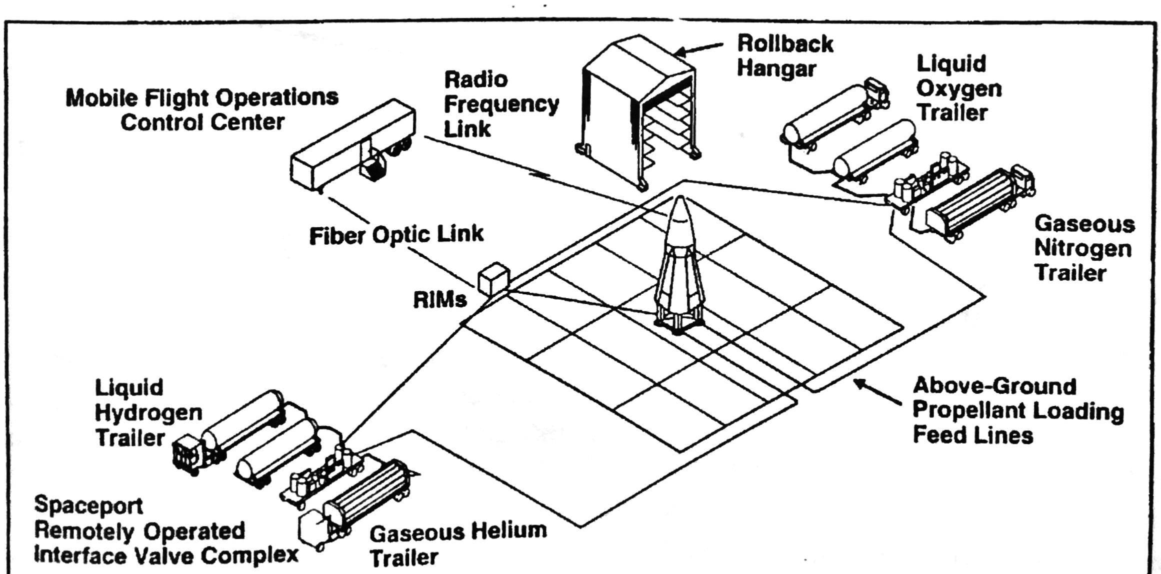

FIG. 4-06: **Mobile Ground Operations Facility for the DC-X Vehicle**(ref. 51)

installations, as shown in FIG. 4-06. Such field-type or military (mobile) operations with horizontal vehicle integration was also used for the THOR and JUPITER missiles and had been revived in 1993 for the Delta-Clipper (DC-X) experimental rocket vehicle. This concept can also be used for small launch vehicles with solid-propellant stages. FIG. 4-06 shows this ground operations mode as used for the DC-X and performed by a team of only some 20 people at the White Sands Missile Range (WSMR), N.M., USA. For a larger operational system with payload this number certainly needs to be higher.

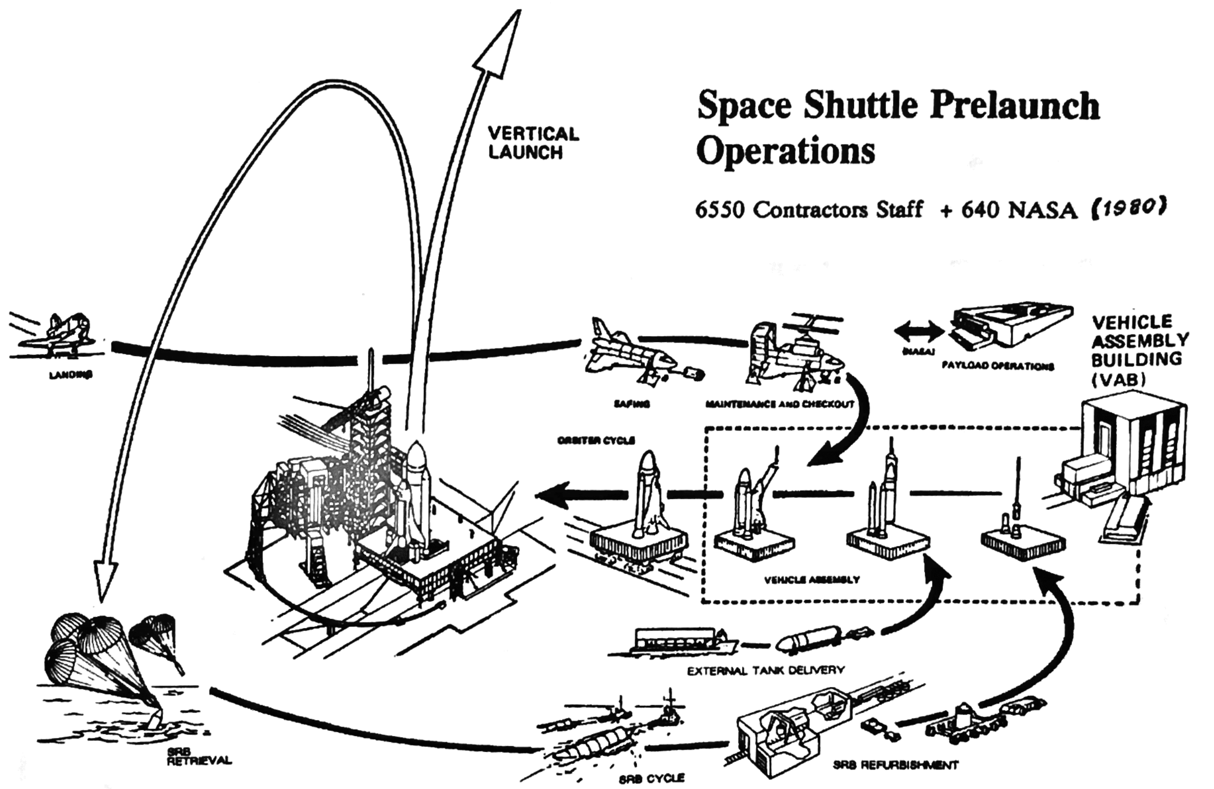

FIG. 4-07 : **SPACE SHUTTLE Ground Operations Schematic**

The most complex ground operations and facilities were conceived for the crewed US SPACE SHUTTLE with the reusable winged Orbiter Vehicle and the recoverable solid boost motors, representing the first stage of the vehicle. FIG. 4-07 illustrates the concept which in the year 2002 still required some 12 000 people for the Space Shuttle ground operations. It is the most complex version of ground systems option (B), plus the implications of a reusable and orbital vehicle requiring heavy maintenance and refurbishment after each flight. Originally the facilities were designed with the (unrealistic) assumption of up to 65 launches per year. In addition, the recovery and the refurbishment of the two boosters are adding to the complexity.

However, the Space Shuttle is far more than a standard cargo launch vehicle: it is a multipurpose system including crew transportation and an orbital laboratory with a mission period of up to two weeks in orbit. A large share of the total „Cost per Flight" are mission cost dedicated to payload operations on ground and in orbit (ca. 500 MYr) and must be deducted in a comparison to other cargo launch systems.

Regarding the ground operations activities and the TURNAROUND TIME of Reusable Launch Vehicles (RLVs) a Boeing Study (ref. 11) has outlined the ground operations schedule for three different RLV systems. Using the same groundrules, FIGs .4-08, -09 and -10 identify the required activities and estimated duration (hours).

(1) A Ballistic Single-Stage Vehicle (BSS) would require 90 hours (including 24 h maintenance) or a minimum 6-day-turn-around-period. This would allow a maximum of 42 flights per year, taking into account 1 day orbital operations and a 6-day refurbishment period after 25 days.

(2) A Two-stage Ballistic Vehicle (BTS) would require for the first stage 44 hours for recovery operations from the sea, plus 116 h for prelaunch operations of the first stage and the combined vehicle. The second stage is estimated to require 70 h. This results in an 11-day turn-around-period, assuming two shifts

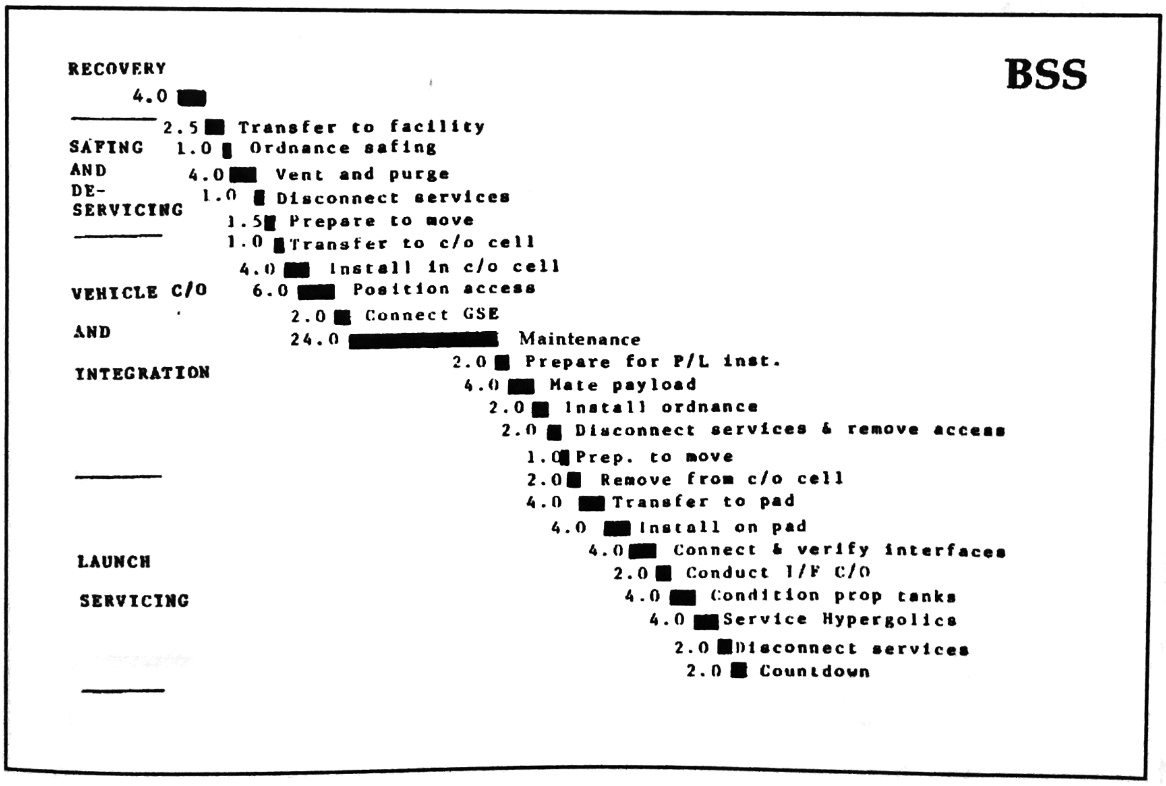

FIG. 4-08: **Ground Operations for a Ballistic SSTO-RLV** (Ref.11)

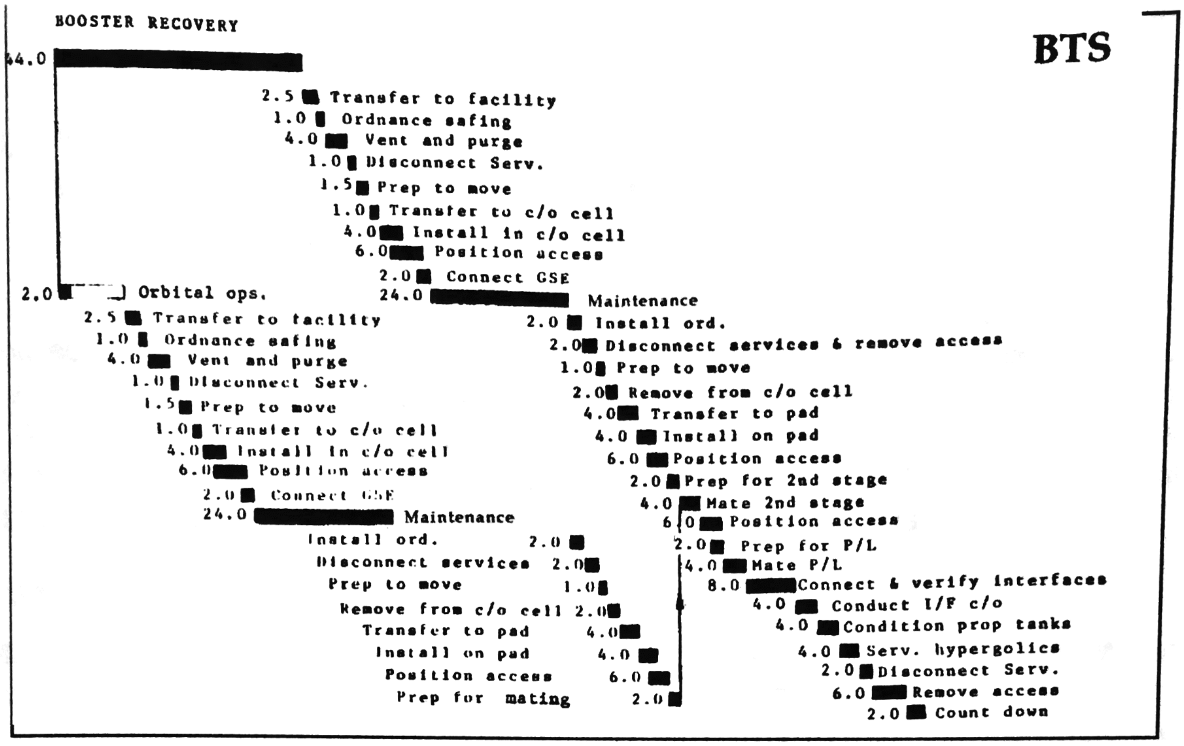

FIG. 4-09: **Ground Operations for a Ballistic TSTO-RLV** (Ref. 11)

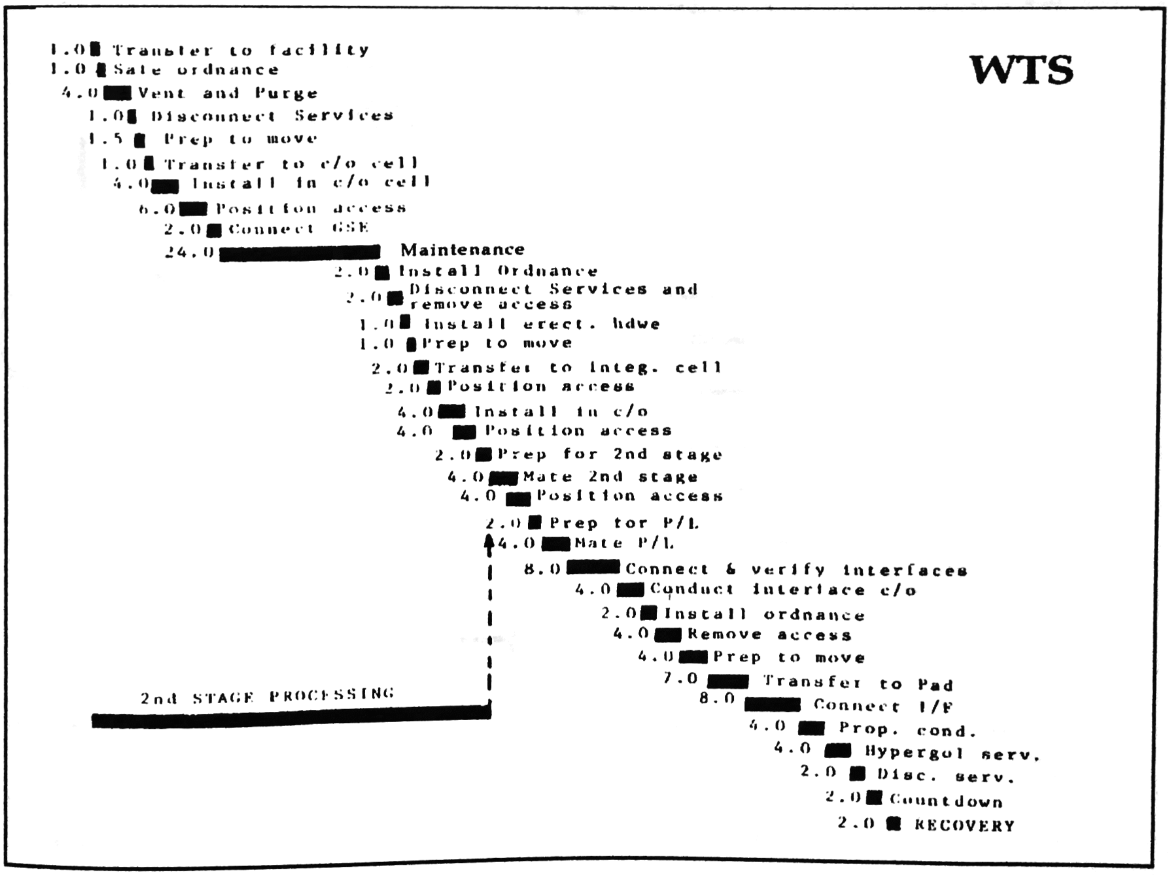

FIG. 4-10: **Ground Operations for a Winged TSTO-RLV** (Ref.11)

per day, plus a small reserve. With the same assumptions as above some 25 missions per year would be feasible as a maximum.

(3) A Winged Two-stage Vehicle (WTS) requires 130 hours on ground for the first stage and the combined vehicles plus 65 hours for the second stage. This results in a 9-day turn-around-period, and a maximum of 29 flights per year.

Although the specific activities and their duration may vary, the relativ differences between the three RLV configurations are remarkable because they have a direct impact on the ground operations costs. In addition, in case of a busy program making use of the minimum turnaround period, the fleet size, respectively the number of vehicles to be built, is influenced by the turnaround cycle: A larger number of vehicles is required for TSTO systems compared to SSTO vehicles.

4.223 Maintenance of RLVs and Reusable Rocket Engines

Maintenance activities are specific to reusable launch vehicles (RLVs). They replace partially the extensive assembly and checkout activities required for the present multistage expendable launch vehicles and comprise all activities to bring the vehicle back after landing to standard status. This excludes, however, hardware items which are required anew for each flight. They have to be accounted separately.

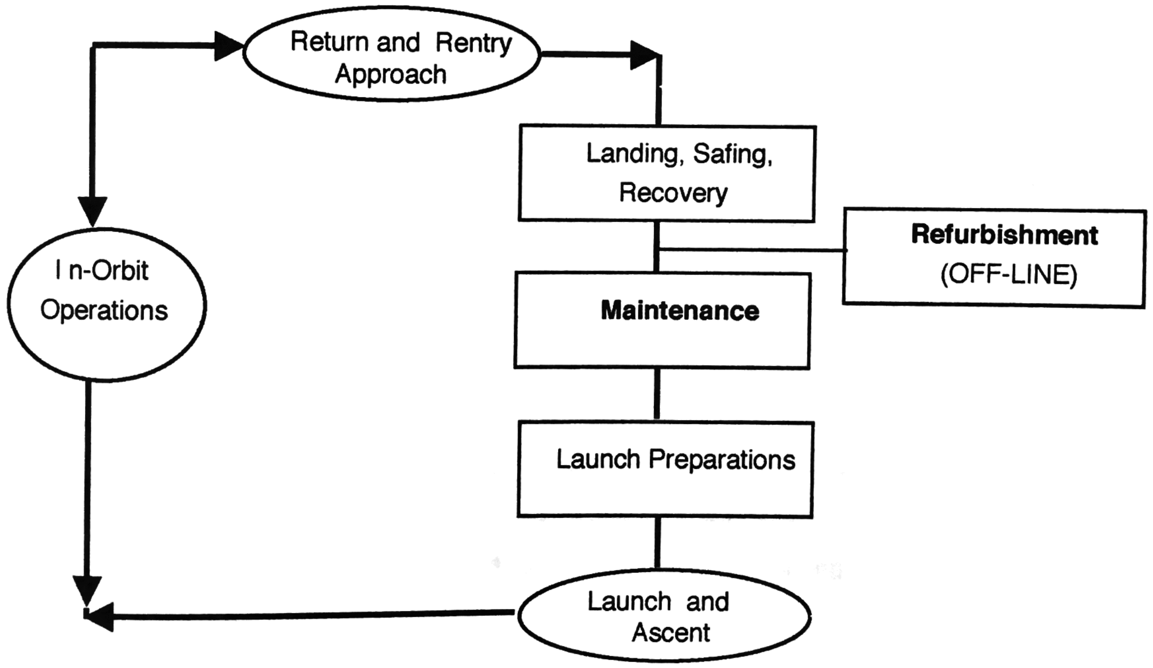

FIG. 4-11: **Ground and Flight Operations Cycle for Reusable Launch Vehicles**

As alread mentioned, „Maintenance“ by definition means the activities between two flights, or „on-line“. All activities „off-line“ are called „Refurbishment“. In contrast to maintenance, refurbishment activities are only performed after a certain number of flights when the vehicle is pulled out of service, undergoing detailed inspections - including structure and tanks - and replacement of units before wear-out (example: rocket engines). This is comparable to the „major overhaul“ of aircraft; see chapter 4.3. The Space Shuttle in this respect must be considered as a special case: The Shuttle requires „heavy maintenance“ after each flight which is comparable to refurbishment operations. Nevertheless, additional major refurbishment activities are performed after two years in service. This means that normally only three Orbiter vehicles have been at the launch site KSC and one vehicle at the refurbishment facility in Palmdale, CA. (The Orbiter „Atlantis“ refurbishment and upgrade in 1997/98 did cost some 70 M$[2]). Thereafter the refurbishment activities have been moved to KSC for reasons of cost reduction.

For an economic operational reusable launch vehicle the maintenance effort needs to be reduced to less than 5 % of the SHUTTLE Orbiter maintenance cost. This appears feasible considering aircraft-type operations and the technical progress in TPS and engine systems made since the Orbiter design in the early 70ies. For future RLVs the incorporation of a self-diagnosis system is considered a standard feature.

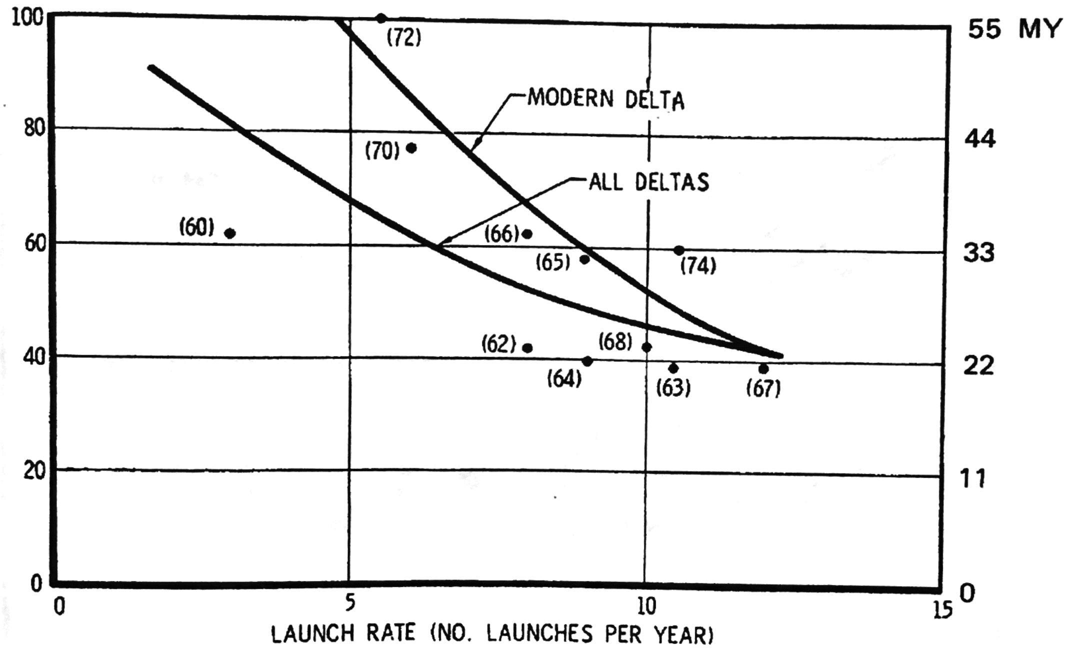

FIG. 4-12: **DELTA Vehicle Gound Operations: Manpower Requirement vs. Launch Rate**

Rocket Engines' Maintenance :

The incorporation of a self-diagnosis system applies also to future rocket engines for RLVs where Aerojet estimates a maintenance effort of 20 manhours per engine and mission for an RLV engine based on the RD-0120 design (ref. 88).

[2]International Space Industry Report (ISIR), Sep.28,1998

For the Shuttle SRBs (Solid Rocket Boosters) the average maintenance and refurbishment effort is some 270 MYr, plus the propellant cost of 74 MYr, plus recovery cost of about 26 MYr per flight. This adds up to 370 MYr for the two Boosters which is about equivalent to the cost of two new expendable boosters, taking into account the cost reduction by series production (learning factor) and the unnessessary recovery equipment.

4.224 Ground Operations Cost Estimation Data Base

From other launch vehicles there are only few reliable data available on the required manpower effort for prelaunch operations. One of the few examples is the DELTA chart as shown in FIG. 4-12 (ref. 5). The diagram shows not only the number of Mh per launch but also the important impact of the launch rate. The decreasing number of man-hours per launch is logical since a certain minimum launch team size is required. The chart shows a range of 42 to 21 MYr for 6 to 12 LpA, reflecting a team size of some 200 people (assuming some overtime, as usual in this business)[3] .

With additional data from other VTO launch systems a survey can be prepared such as shown in FIG. 4-13 for conventional US launch vehicle ground operations with launch rates of 3 to 12 LpA. Also shown in FIG. 4-13 is ARIANE-1 which fits well into the US launch operations picture, while in case of

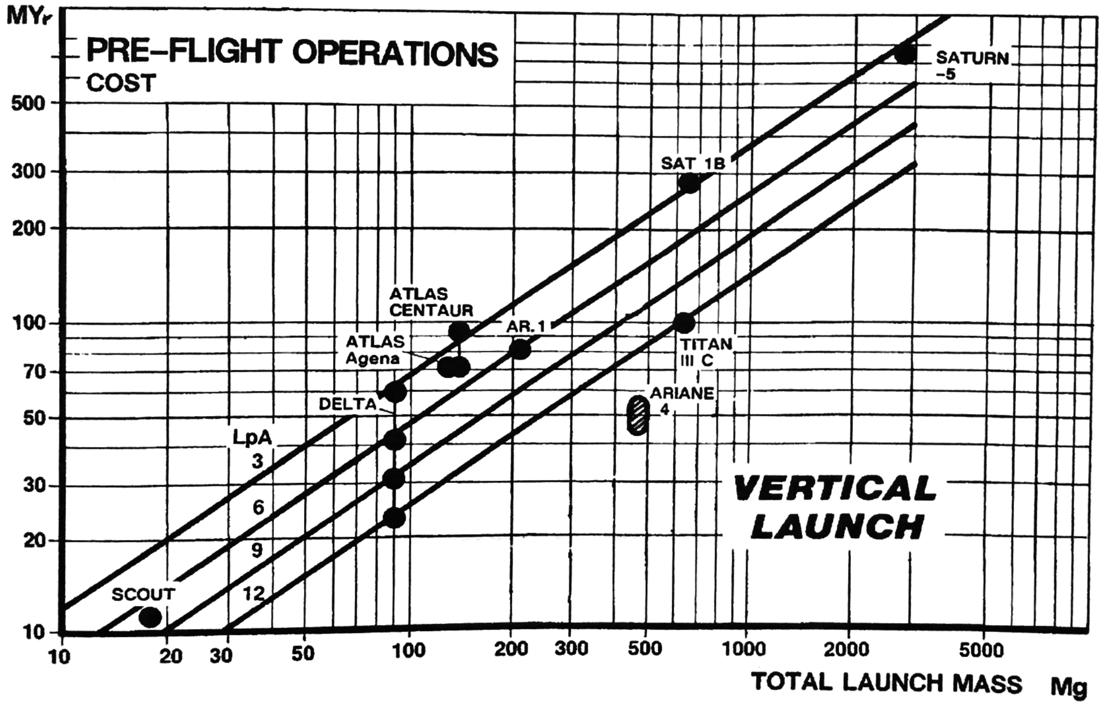

FIG. 4-13: **Survey of the MYr Effort for Pre-Flight Ground Operations vs. vs. Vehicle Size (GLOW) and Launch Frequency (LpA)**

[3] confirmed by a McDonnel Douglas Press Release, dated Feb.1987

ARIANE 4 the manpower was stepwise reduced to some 50 MYr at a launch rate of 11 LpA. Also the „turn-around-time" or time between two launches was reduced from initially 35 to 29, then to 22 and finally to only 18 working days. Also in case of the new ATLAS V vehicle the launch preparation time was reduced to 18 days by the Vertical Integration Facility (VIF) and the Mobile Launcher Platform (MLP), compared to 28 to 30 days for the pevious ATLAS II vehicles.

Russian launch vehicles do have an even lower manpower and time demand due to the highly automated and simple operations conceived originally for military operations : the ZENIT vehicle reqires only one day (5 h) on the launch pad, compared to some 6 days for ARIANE 4 and 90 days for the TITAN IV-Centaur launch vehicle.

Essential reductions of ground operation efforts and complexity are reported for the EELV generation of ATLAS V and DELTA IV[4] . Instead of 17 different ground facilities at the Cape required for processing the older ATLAS ELV this has been consolidated to only three facilities. This was expected to allow the reduction of the original launch team of 300-350 people by some 25 %.

The DELTA II and III vehicles even used 43 separate facilities for the pre-flight ground operations which now have been reduced to three primary sites for DELTA IV. In addition, horizontal integration has been introduced, with the capability of processing 3 to 6 DELTA IVs in the new Horizontal Integration Facility (HIF) simultaneously.

The older DELTA vehicles required 3 to 4 weeks in the Cape's DELTA Mission Checkout Facility while the processing time at the new HIF is only 2 weeks. This approach reduces the pad labor by some 58 %. The pad time will be only 8-10 days compared to 22 days fo r the older vehicles.

4.225 CER Definition for Ground Operations Cost

Based on the experience from the SPACE SHUTTLE, the DELTA Launcher with the data from FIG. 4-12, and even a small experimental vehicle like the DC-X with a team of 20 people and a turnaround period of one day, the following provisional CER has been established:

$$\boxed{C_{PLO} = 8 \cdot M_0^{0.67} \cdot L^{-0.9} \cdot N^{0.7} \cdot f_V \cdot f_C \cdot f_4 \cdot f_8} \qquad \text{(MYr)}$$

M_0 <u>is the launch mass</u> (GLOW) in Mg (metric tons), the exponent represents the vehicle size impact on the prelaunch operations effort which is derived from the

[4] Aviation Week 10 Dec.2001

trend shown in FIG. 4-13. However, this does not mean that the launch mass is the major determinant of the ground operations cost. Other factors such as discussed in the following are more influencial:

The factor **L** (Launch rate) determines the required launch team size vs. number of launches per year (LpA). The exponent of L defines the team size growth with launch rate: the exponent -1, by example, would mean a constant launch team size, independent from the launch rate. This could be valid for say 6 to 12 LpA, but is not realistic for higher LpA numbers.

The exponent of **N** (number of stages or major vehicle elements) being 0.7 says that a two-stage vehicle requires a 62 % higher effort, and a three-stage vehicle a 115 % higher effort than a Single-Stage (SSTO) Vehicle. A small kick stage or small attached boosters count as a half element while two large segmented solid boosters which have to be assembled on the launch site count as two elements.

The factor **fv** describes the impact of the launch vehicle type :

Expendable multistage vehicles
--- liquid-propellant vehicles, cryogenic props. $f_V = 1.0$
--- liquid-propellant vehicles, storable props. $f_V = 0.8$
--- solid-propellant vehicles $f_V = 0.3$

Reusable launch systems (with integrated health control system)
--- automated cargo vehicles (Cryo-SSTO) $f_V = 0.7$
--- crewed / piloted vehicles (Shuttle-type) $f_V = 1.8$

For vehicles with different type stages an average value is to be used, derived from the individual stage values.

The factor $\mathbf{f_c}$ indicates the impact of the assembly and integration mode:

Vertical assembly and checkout on the launch pad (Mode A) $f_c = 1.0$
Vertical assembly and checkout, then transport to launch pad $f_c = 0.7$
Horizontal assembly and checkout, transport to pad, erection $f_c = 0.5$

f_4 is the learning cost reduction factor (cf. chapter 3.2). The cost reduction vs.time, resp. with growing number of launches, is well confirmed by experience: In case of the PEGASUS vehicle the launch preparation period was reduced from initially 45 days to 30 days after 20 launches. In case of the ARIANE 4 a reduction to 27 days was achieved after some 50 launches compared to initially 35 days. The X-15 turnaround time was reduced from 34 to 27 days after some 40 flights. Also the Space Shuttle Operations showed a time and cost reduction of 7 % in 6 years. This all leads to a Learning Factor of 0.85 to 0.95 (or 85 to 95 %) depending on the vehicle size and launch frequency. The learning effect, however, applies only in case of continuous launch operation activities over several years with at least 6 LpA.

FIG. 4-14 provides a survey about the results of the CER for the Prelaunch Ground Operations Effort vs. number of launches per year which is the most influencial parameter. Major launch vehicle examples are indicated. The solid reference line illustrates what can be expected for a single-stage RLV (800 Mg GLOW) with an integrated health control system, depending on the launch frequency.

The experimental DC-X vehicle did have pre-launch operations cost of 525 000 $ (ref.121) = 3 MYr per flight. The application of the CER results in 2.5 MYr per flight, to which propellant cost etc. have to be added.

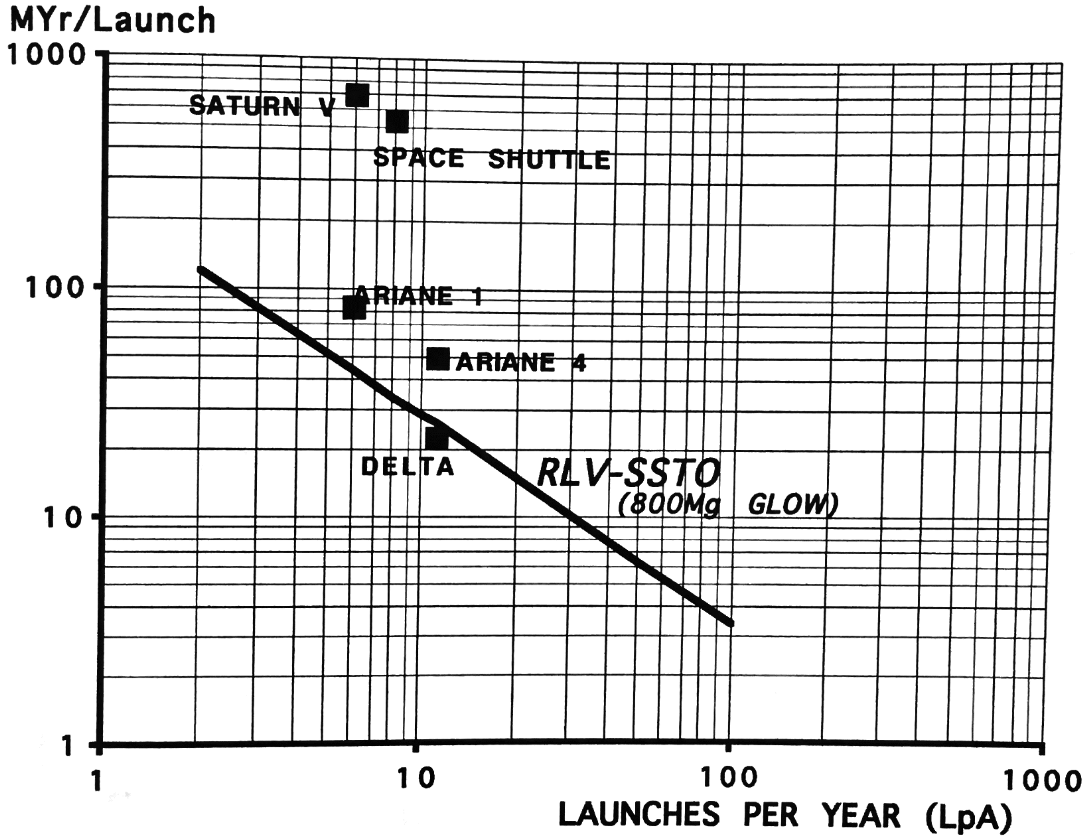

FIG. 4-14 : **Prelaunch Ground Operations Effort vs. Launch Rate (LpA) with Vehicle Launch Mass as Parameter** (with 95% Learning)
(SHUTTLE: 95th flight, 6 and 8 LpA, DELTA: 12 LpA, 67th vehicle according to FIG.4-12, SATURN V: 10th flight, 4 LpA, ARIANE I: 20th flight, 6 LpA, ARIANE 4: 100th flight, 11 LpA)

4.23 Costs of Propellants and Gases

4.231 General

Propellants cost represent only a small fraction of the total Cost-per-Flight, even though prices per kg can be high in some cases. The actual propellant cost are strongly dependent on the production source capacity, resp. the annual quantity demand. The most expensive liquid propellant is MMH (Monomethtylhydrazine) with almost 100 $/kg. Liquid Hydrogen in comparison is relatively cheap with 2 to 6 $ /kg. Lowest in cost is probably Liquid Oxygen with 0.1 to 0.15 $ /kg.

4.232 Liquid Hydrogen / Oxygen

Liquid Hydrogen is one of the most important propellants for launch vehicles. Hydrogen production in Europe is almost twice as expensive as in the USA due to the higher cost of electrical energy required for the LH_2-production.

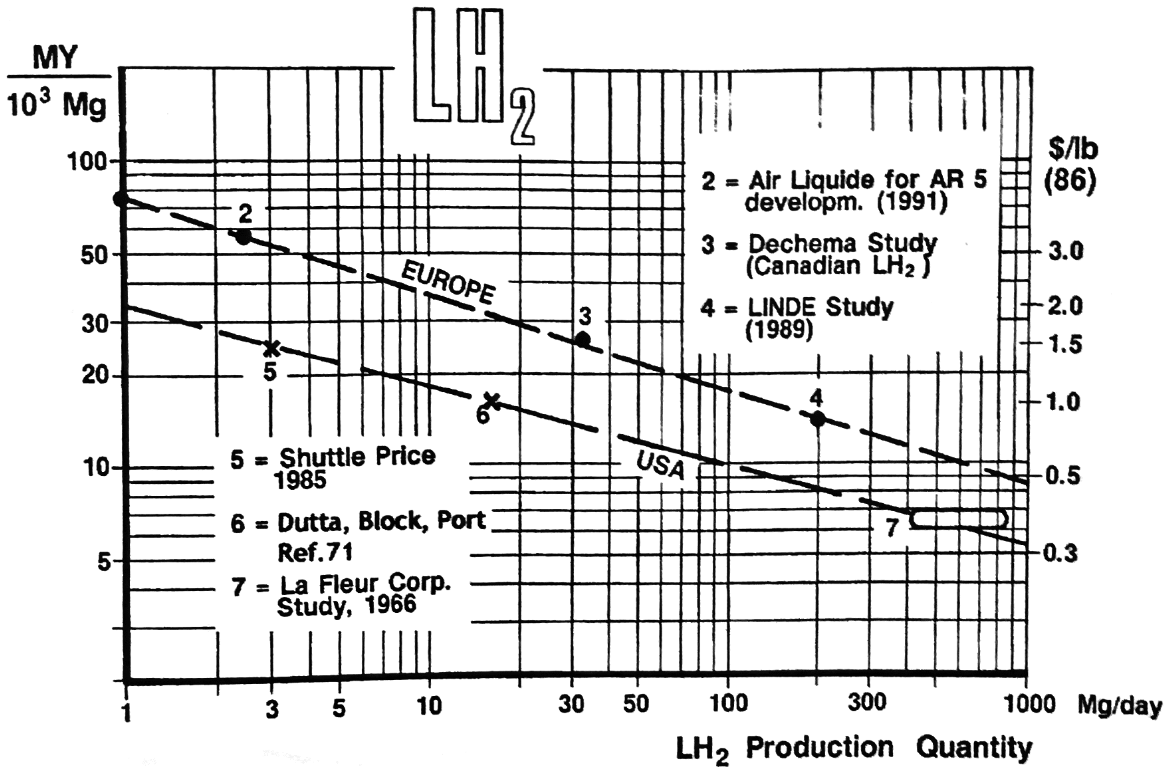

FIG. 4-15: **Liquid Hydrogen Cost vs. Production Quantity per Day**

Alternative production methods are under investigation. FIG. 4-15 shows cost data from different production companies quoted at different times for different production quantities, resulting in a good fit of cost vs. quantity. In order to calculate the required propellant mass for launch vehicles the unavoidable boil-off losses at transfer and ground storage have to be taken into account. This additional propellant requirement can be as much as 50 to 70 % for LOX, and

75 to 95 % for LH_2, compared to the actual vehicle propellant load. Another cost factor is the location of the production plant related to the launch site.

A close-by production is more cost-efficient than ground transportation over a longer distance, provided such a dedicated plant at the launch site is justified by a continuous and large enough Hydrogen demand. This was the case in Kourou, the European Launch Site with the introduction of the ARIANE 5 vehicle. A production plant with a capacity of 2.4 Mg Hydrogen per day was implemented there for more than 30 M$ by the French Company „Air Liquide".

FIG. 4-15 also indicates that an increased Hydrogen demand in the future would reduce the specific cost to one third or less compared to the present level of some 55 MYr / 10^3 Mg (Europe) or 15 to 25 MYr / 10^3 Mg (USA).

4.233 Solid Propellants

The cost of solid propellants are included in the development and fabrication cost CER's for solid-propellant motors in the *TRANSCOST* - Model. In some cases, however, it is useful to have the propellant cost available. In FIG. 4-16 the cost are shown for different European and US motors. A great difference is evident: while the propellant cost in Europe were strongly dependent on the motor size (and production quantity per year) the propellant cost in the US are almost constant since the small motors are using apparently propellants from the large-scale production established for the Space Shuttle and Titan IV Boosters. With the AR.5-Booster

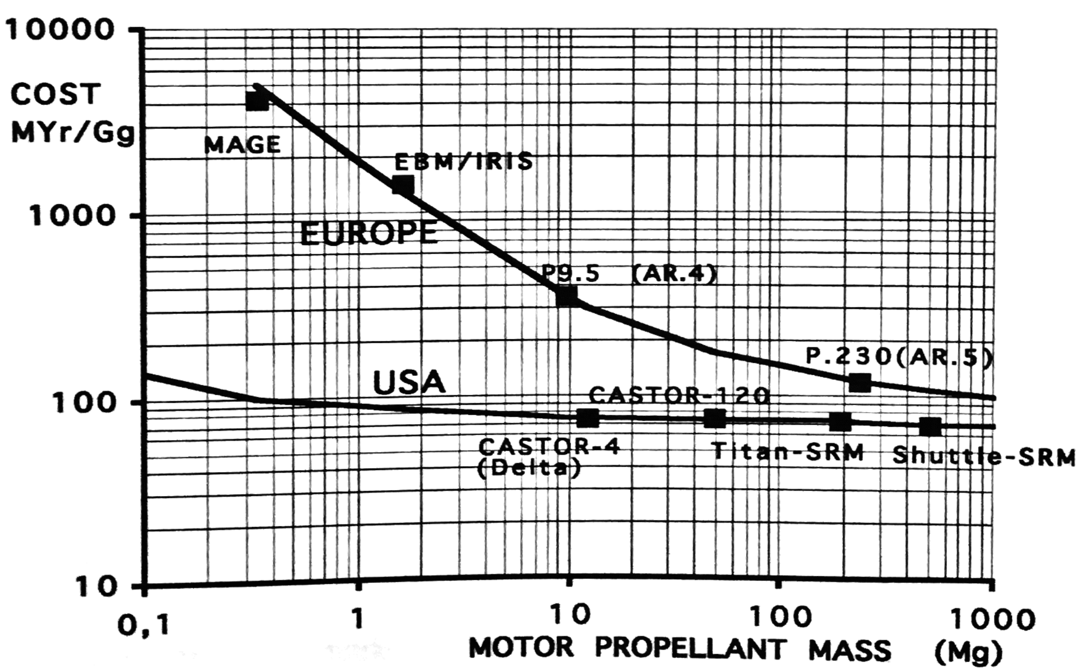

FIG. 4-16 : **Solid Propellant Costs for US- and European Motors**

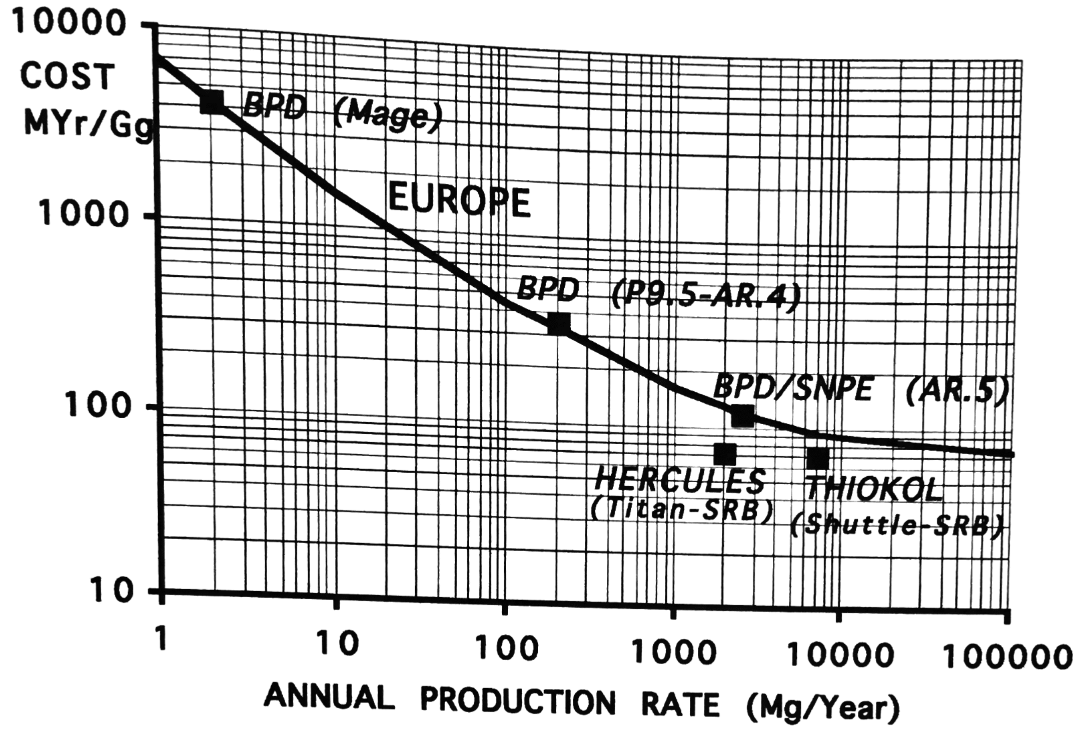

FIG. 4-17 : **Solid Propellant Cost vs. Production Capacity in USA and in Europe**

propellant production capability in Kourou this may change also in Europe to a certain extent.

It has been tried to derive from FIG. 4-16 the cost trend vs. Annual Production Rate which is shown as FIG. 4-17 for large-scale and small dedicated production facilities in Europe. Cost and Prices in the USA are somewhat lower. The great impact of the production quantity becomes evident from FIG. 4-17 : For small motors with low production numbers and the related production facility the specific propellant cost can be as high as 4000 MYr per Gg (Gigagramm = 10^9 g = 10^3 Mg) = 750 Euro / kg, 1999), while for large production activities the price can reduce to some 70 MYr / Gg (= 13 Euro / kg). With the large production facilities at ATK-Thiokol (Shuttle-Booster) and Hercules Aerospace (Poseidon, Trident) in the USA even specific costs of 9 $ /kg ('99) are feasible.

4.234 Price List of Liquid Propellants and Gases

The costs, respectively the market prices of LOX/LH_2 and other propellants as valid in the USA in 1998/ 99 are shown in the following TABLE 4-II :

TABLE 4-II : **Prices of Propellants and Gases**

LH2 Liquid Hydrogen		2.8 to 5 $ / kg	15 - 25 MYr / Gg
LOX Liquid Oxygen		0.11- 0.15 $ / kg	0.55- 0.75 MYr / Gg
Kerosene - RP-1		0.77 $ / kg	3.9 MYr / Gg
Kerosene - JP-5	(ref.72)	0.26 $ / kg	1.3 MYr / Gg
Kerosene - JP-7	(ref.72)	0.18 $ / kg	0.9 MYr / Gg
N_2O_4 - Nitrogen Tetroxyde		7,6 $ / kg*	38 MYr / Gg
N_2H_4 - Hydrazine		40-55 $ / kg*	200 - 275 MYr / Gg
MMH - Monomethyhydrazine		100-130 $ / kg*	500 - 650 MYr / Gg
H_2O_2 - Hydrogen-Peroxyde (85 %)		5,5 $ / kg*	27,5 MYr / Gg
Helium-Gas		18 $ / kg	90 MYr / Gg
Nitrogen-Gas		0.11 $ / kg	0.55 MYr / Gg

*) according to Space news, 17.8.98

4.24 Launch, Flight and Mission Operations Cost

4.241 Launch, Ascent and Descent Flight Control

The effort in this area is composed of

(a) Mission planning and preparation, incl. software update,
(b) Launch and ascent flight control until payload separation,
(c) Orbital and return flight operations in case of reusable, launch systems (excluding crew operations),
(d) Flight safety control and tracking.

NOT included - by definition - are in-orbit experiment - and mission-related activities since these do not belong to the space transportation task as such.

For ELVs (Expendable Launch Vehicles) the mission planning, launch and flight operations effort is relatively small. The flight time is less than 15 min for ascent to LEO, and some 30 min for GTO injection.

For RLVs (Reusable Launch Vehicles) the task becomes more demanding due to the much longer mission period of several hours or days including orbital operations, global data transmission and the return flight phase. The required effort for these activities depends on the launch system complexity, i.e. number of stages, expendable, recoverable or reusable, and the mission profile (type and duration).

In addition, the number of launches per year (LpA) is very important since a more or less constant team has to be employed and the cost per flight increase for a decreasing number of launches. In addition, the launch number is important in order to take into accounting the learning effect.

Only few reference data exist for the mission control cost. For the Wallops Island launch site and ATHENA-type small vehicles the cost for safety and range activities (provided by NASA) have been quoted to be 300 000 US$[5] per launch (at 4 to 5 LpA). With mission planning and preparations the total mission cost may be 500 000 to 700 000 US$ = 2.5 to 3.5 MYr.

With the major cost drivers discussed above a preliminary CER for unmanned launch and mission operations has been conceived as follows:

$$\boxed{C_m = 20\,(\Sigma\, Q_N)\, L^{-0.65}\; .\; f_4\; .\; f_8} \qquad \text{MYr per flight}$$

with L = launch rate (LpA), f_4 = Learning Factor cost reduction, and Q = specific value depending on the vehicle complexity, i.e. the number and type of stages:

--- Small Solid Motor Stages	Q = 0.15 ea.
--- Expendable Liquid-Prop. Stages or Large Boosters	Q = 0.4 ea.
--- Recoverable or Fly-back Systems	Q = 1.0 ea.
--- Unmanned Reusable Orbital Systems	Q = 2.0 ea.
--- Crewed Orbital Vehicles	Q = 3.0 ea.

The application of this CER for the above-mentioned ATHENA-Vehicle on its 10th flight (90% learning) and 4 to 5 launches at Wallops Island results in 2.4 MYr mission operations cost per flight. Assuming mature operations (50^{th} flight) at 90 % Learning and 8 flights per year this Model-CER results in 2.3 MYr for a two-stage expendable vehicle, and 5.7 MYr for a single-stage reusable vehicle. For the Space Shuttle configuration the result is 15 MYr per flight (excluding crew operations).

For crewed vehicles in general the mission operations phase - by definition - applies only to the ascent and descent phases and not to eventual orbital stay times (except for phasing operations). In case of future crewed vehicles for Space Station Operations Support and crew exchange the transportation task ends with vehicle docking to the space station, but applies also to the return flight.

4.242 Crewed Vehicles' Mission Cost (Model)

Crewed vehicle operations represent a high-cost item. The cost include not only the on-orbit activities - depending on the crew number and the mission time in orbit,

[5] Space News, 21.9.98

but also the cost of the crew staff itself, its ground support and training. Training, however, only regarding vehicle operations, not the specific payload and experiment operations. Those - by definition - do not belong to the transportation mission and cost. Another related cost item is the global voice communication system and staff over the full mission period.

In order to cover the additional crew-related mission effort for crewed and hybrid vehicles such as the SHUTTLE Orbiter, the late European HERMES Project, or a manned version of the Japanese HOPE vehicle, the following CER has been conceived to quantify the cost of crewed vehicle operations :

$$\boxed{C_{ma} = 75\ T_m^{\,0.5} \cdot N_a^{0.5} \cdot L^{-0.8} \cdot f_4 \cdot f_8} \quad \text{MYr per flight}$$

T = mission duration in orbit (days), Na = number of crew members,
L = Launch Rate (LpA), f_4 = Learning cost reduction factor.

Since the learning effect is clearly existing in this activity, the mission number and the total number of missions considered is important. The factor f_4 can be based normally on a Learning Factor of 90%.

The CER model results in some 68 MYr additional mission cost for a crewed vehicle with two pilots, 2 days mission period, 2 LpA, for flight no.10. An extension of the mission period to 10 days would increase the cost to some 150 MYr.

For an early SHUTTLE Orbiter mission (flight 10, 4 LpA) with 14 days in orbit and up to 10 crew members the resulting crew mission effort is 235 MYr. For mature operations (flight 95, 6 LpA), the crew mission cost would reduce to 122 MYr.

4.243 Shuttle Mission Cost Verification

For the actual SPACE SHUTTLE flight and mission operations cost it is mentioned in ref. 52 that these have been reduced from initially 1.2 million hours per flight (= 540 MYr) to less than 0.7 million hours in 1993, and to 0.6 million hours (ca. 270 MYr) by 1999. This illustrates the learning effect.

The level indicated, however, is much higher than derived by the two TRANSCOST mission CERs (i.e. 140 MYr for Shuttle mission operations in 1998, compared to the actual number of 300 MYr, cf. TABLE 4-I). The difference is due to the payload and experiment operations (Spacelab, Spacehab, EVA activities, etc.) which are not considered to be part of the transportation business. The conclusion is that in average 130 to 160 MYr (= 26 to 32 M$ 1998/ 99), or 6 to 7 % of the total Shuttle Cost-per-Flight have to be deducted for comparison of the specific transportation cost with other launch vehicles.

4.25 Ground Transportation and Recovery Costs

4.251 Transportation of Vehicle (Elements) to the Launch Site

This cost area comprises the following cases:

(1) Vehicle elements' transportation from the fabrication site(s) to the launch area, by road, ship or aircraft. Either commercial transport services can be used, or - for larger units - dedicated transport vehicles.

(2) Reusable vehicles' transportation from a remote landing site to the launch area (i.e. the Shuttle Orbiter ferry by a B-747 transport from Edwards AFB in California to KSC in Florida, did cost 2.8 M$ in 1991 [6)] .

(3) Transportation of sea-launch facilities from the home harbour to the launch location and return trip (complete cycle of sea operations, excluding the launch preparations phase on sea).

These transportation cost cannot be generalized or covered by a CER since the cases are very different and specific for each program.

4.252 Recovery Operations

Vehicles' or vehicle elements' recovery, such as the Space Shuttle SRBs (Solid Rocket Boosters) are specific means of potential cost reduction. However, it must be taken into account that recovery operations are expensive - especially at low launch rates.

Adding the cost of the required recovery equipment on board of the vehicle (elements), plus the necessary refurbishment cost, makes recovery economically questionable. By example, the Shuttle SRB recovery (ref. 24) did not result in the expected 30% cost reduction. Experience has shown that there is no real cost saving, compared to new expendable boosters without the additional recovery equipment. The cost of the recovery operations for each SRB unit are about 3 M$(98) = 15.5 MYr at 6 LpA.

A study performed in Europe by the experienced sea-recovery company HARMS in Hamburg for ESA/CNES regarding the recovery of an ARIANE-1 first stage (M = 13.8 Mg) resulted in cost of 1 Mio DM(82) per retrieval at a frequency of 6 operations per year. This is equivalent to some 8 MYr.

Recovery costs for stages or boosters from sea were already addressed by the

Douglas Company in the ROMBUS Studies 1963 (ref. 54).

Based on these reference cases a preliminary CER has been conceived for

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[6] according to AW, 22.7.91

recovery cost:

$$\boxed{C_{Rec} = 1.5 / L \; (7 \, L^{0.7} + M^{0.83}) \, . \, f_8} \quad \text{MYr}$$

with L = Launch rate and M = Recovery Mass in Mg.

The CER considers that a certain team size plus equipment is required for recovery operations, so that the specific cost per recovery decrease with the launch rate, respectively the number of recovery operations per year.

4.26 Fees and Insurance Costs

4.261 Launch Site User Fee

The usually government-controlled and financed launch sites require from commercial launch operators usually a user fee per launch. In case of US launch sites the US Department of Transportation (DOT) charges a fee of 2.50 $ per lb of maximum LEO payload. For a DELTA II vehicle with 11 000 lb payload this means a fee of 27 500 $ per launch. In Europe, the commercial Launch Operations Company ARIANESPACE had to pay for the use of the ESA/ CNES Kourou facilities 1 M.Euro per ARIANE-4 launch (in addition to a fixed annual fee of 4 M.Euro.

The Direct Operations Cost (DOC) consider only the fee charged per launch. There may be an additional fixed general cost contribution per year, but these cost are part of the Indirect Operations Cost (IOC), dealt with in the next chapter.

4.262 Public Damage Insurance (Third Party Liability)

There is normaly a governmental requirement for a launch service provider to take an insurance against public damage, i.e. damage caused by parts of a launch vehicle falling to the ground. For a 100 Million $ coverage the in surance cost are typically in the 100 000 $ range. Governmental and military launches are exempted from this requirement. In the early 80ies a 100 Million $ third-party insurance was required in the USA. CNES adopted the same requirement for ARIANE launches (400 MFF). With the Commercial Space Launch Act of 1984 the amount was raised to 500 Million $ for US launches, with damage up to 1.5 Billion $ taken by the US Government. For PROTON launches in Khasakstan a minimum coverage of 300 M$ is required (plus40 M$ for potential damage to the launch facility) which does cost in Russia some 200 000 $. For SOYUZ and ZENIT launches the coverage required is 200 M$ (+ 25 M$ for launch facilities) and for the smaller Russian launch vehicles 150 M$ (+5 M$ for launch facilities)[7].

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7) Space news, 21.Feb.2000

4.263 Launch Vehicle Insurance

For EXPENDABLE launch vehicles the insurance for a launch failure and payload loss normally has to be payed by the customer separately to an insurance company. Details see chapters 5.21 and 5.22.

In case of REUSABLE launch vehicles (RLVs) the situation is different. The launch provider is the owner of the vehicle and must insure the lifetime, resp. the achievement of the planned total number of flights because the recurring costs of RLVs are normally amortized by a DOC charge according to the number of planned operational flights. There is a small chance that a catastrophic failure leads to a premature vehicle loss (i .e. before it has reached the planned number of flights), and this risk must be covered either by an insurance or by a reserve fund contribution (self-insurance).

The „catastrophic failure rate" (vehicle loss) of RLVs can be reduced substantially in comparison to ELVs : the reasons are increased redundancy, higher safety margins, multiengine failure capability, integrated health control system and the inherent landing capability in case of emergency. In addition there exists the possibility of flight testing for RLVs before their operational use - in contrast to the present single-launch expendable launch vehicles.

The goal for RLVs is an improvement of reliability by one and later two orders of magnitude, i.a. to 1 failure out of 1000 flights (2nd generation) and 1 failure out

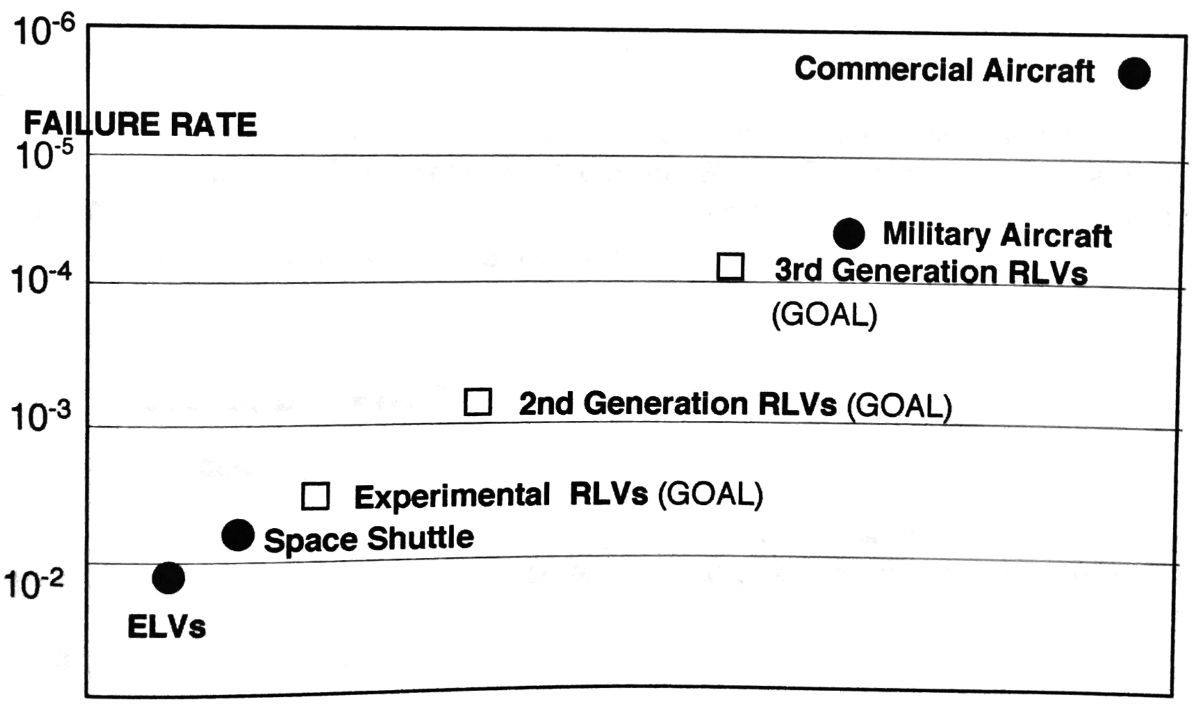

FIG. 4-18 : **Catastrophic Failure Rates (Crew Loss) for ELVs and Aircraft with Goals for RLVs (2nd and 3rd Generation)** of 10 000 flights for the 3rd generation. It will not be possible to reach the reliability of military or commercial aircraft as shown in FIG. 4-18. This will be especially true for multistage vehicles where the loss rate will be higher due to the use of two or three different systems plus the inherent stage separation maneuver(s).

For the US Space Shuttle as a semi-reusable launch vehicle a catastrophic failure rate (crew loss) of 1/245 has been calculated. This could be improved to 1/430 by better subsystems and replacement of the SRBs by LFBs.

4.264 Surcharge for Mission Abort

Reusable launch vehicles are able by definition to return to the launch site or at least to perform an emergency landing. This failure to deliver the payload (to be followed by a free re-launch) is connected with cost which have to be covered by the launch service provider. He can take an insurance for this or create his own reserve fund.

The experience with aircraft flight abort cases is as follows:

-- Civil aircraft	(with 4 engines):	1 of 2000 flights[8]
	(with 2 engines):	1 of 4000 flights
-- Military aircraft:		1 of 100 flights

The complete cost of an aborted flight can be higher than of a regular mission (up to a factor 2 or 3), due to the necessary investigations and consequences.

The potential abort rate of a future reusable launch system is difficult to assess and will depend on the vehicle system concept as well as on the operational maturity. For SSTO launch vehicles the assumed factors are 1 out of 30 to 50 flights, for TSTO vehicles 1 out of 20 to 30 flights. The actual flight reliability of a future vehicle will be much influenced by the upfront effort as to how much is put towards achieving an operational targeted reliability.

4.3 Refurbishment and Spares' Cost (RSC)

4.31 Cost Structure and Definitions

Reusable vehicles after a number of flights have to be taken out of the regular service to undergo a detailed inspection and exchange of components and elements before wear-out. These OFF-LINE activities are comparable to the „Major Overhaul" of aircraft performed every few years.

By definition, the term „Refurbishment" is used here only for the off-line activities. Everything that has to be done ON-LINE between two consecutive flights is called

„Maintenance", including the eventual refurbishment of parachutes and airbags, small repairs and replacement of single-use items. All maintenance is part of the Pre-launch Ground Operations.

The Space Shuttle ORBITER as the first reusable space transportation vehicle is an exception since it requires refurbishment („heavy maintenance") in the order of 10 M$ = 55 MYr after each flight. This is due to the vehicles design and the technologies employed (1970 status). Future reusable systems are expected to fly many times before a refurbishment activity is required. Mature sytem operations may have refurbishment combined with the rocket engines' exchange after some 30 to 60 flights.

The total refurbishment cost (including spares) over a vehicle's lifetime are distributed over the total number of vehicle flights as percentage of the average vehicle production cost. Due to the separate CERs for vehicle systems and engines the refurbishment effort is also defined separately.

The major refurbishment activities can be subdivided into four tasks:

(1) Detailed vehicle system inspection (especially structure, tanks and thermal protection),
(2) Exchange of critical (hot) structure elements, such as TPS panels,
(3) Replacement of the complete main rocket engines, and
(4) Exchange of critical components of the pressurization and feed system (i.e. valves, regulators), the power and hydroelectric system, etc.

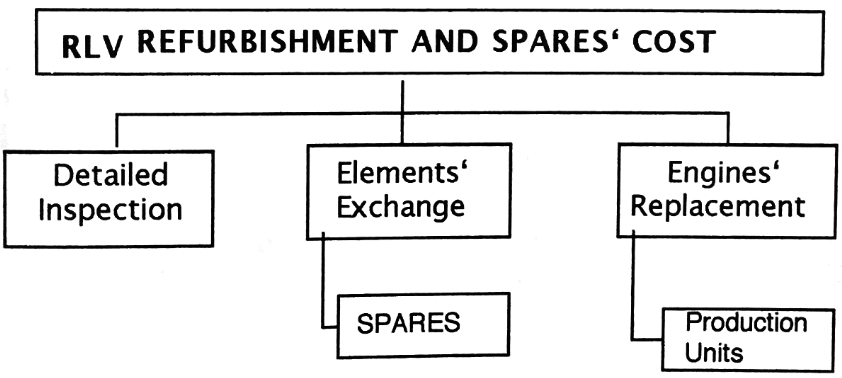

FIG. 4-19 : **Refurbishment Cost Elements**

According to aircraft experience some 75 to 87 % of the total refurbishment cost are spares' cost and 13 to 25 % is manpower for the detailed inspection and components' exchange.

4.32 Vehicle System Refurbishment Cost

Only few historical data exist for space launch systems' refurbishment cost. The X-

15 rocket plane and the Space Shuttle Orbiter can only be considered as experimental and prototype vehicles with technologies of the 60ies and 70ies. The Shuttle Orbiter refurbishment (OMM Cycle) performed every 4.5 years or after 6 flights required 18 month at 235 jobs. It includes the complete teardown of the vehicle for inspection and modifications. This activity has been performed for 20 years at the former Rockwell, now Boeing Palmdale, CA facility before it was moved to KSC in 2002 in order to save 30 M$ per cycle and to avoid the Orbiter in-flight transportation on a B.747[9).

Further refurbishment experience is available from aircraft operations but this is the other extreme of large-scale mature operations. This is illustrated in FIG. 4-20. The

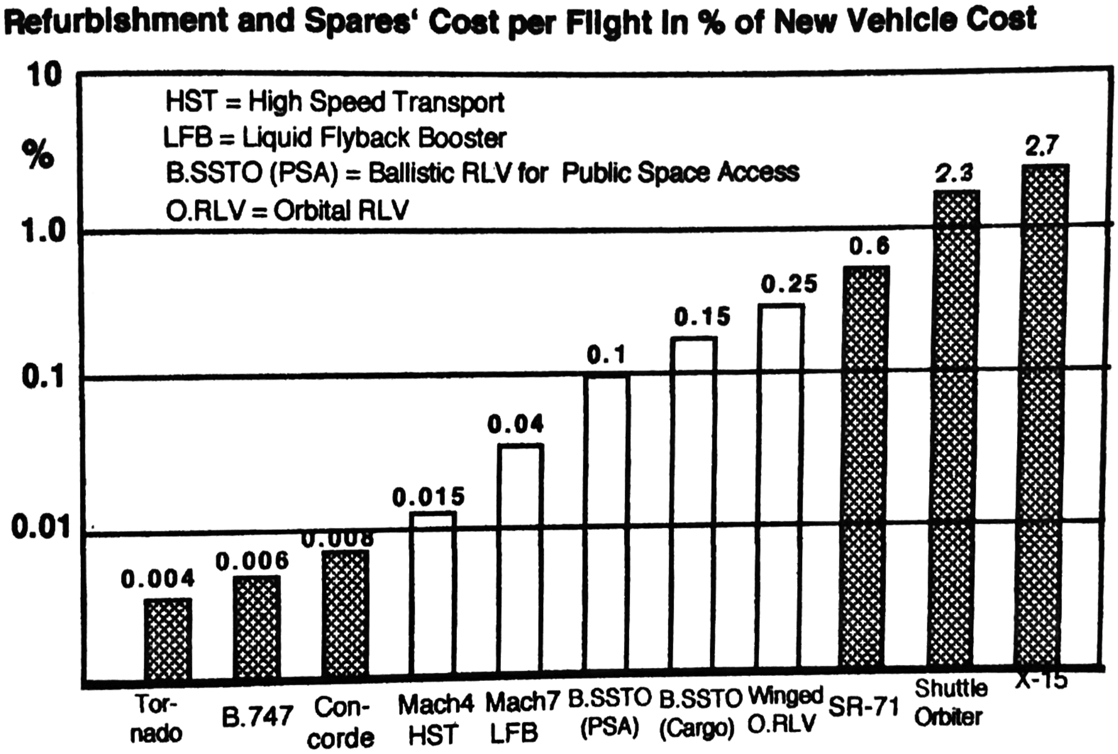

FIG. 4-20 : **Refurbishment Cost Factors of Aircraft and Experimental Space Vehicles plus Expected Data for Future RLVs**

values shown indicate the effort per flight for inspection, spares and exchange activities as percentage of the original vehicle production cost. Future operational reusable launch vehicle refurbishment certainly will be higher than for aircraft but lower than those of experimental vehicles. Therefore, as a first approach to the problem an assessment has been made of the refurbishment factors to be expected for future RLVs by interpolation as shown in FIG. 4-20. The actual values will depend much on the selected vehicle design and the technology employed. It must also be expected that the total number of flights during vehicle lifetime and the refurbishment effort will not be independent: The relative

9) Aviation Week, 11.Feb.2002

refurbishment effort is expected to reach higher levels with an increasing number of lifetime flights due to the larger number of elements to be exchanged. Resulting from this trend may be an optimum number of vehicles reflights - beyond of which it will be more cost-effective to introduce a new vehicle (cf. chapter 5.23).

The lifetime in terms of number of flights is different for the various subsystems and elements of an RLV. The actual expectations are shown in TABLE 4-III.

TABLE 4- III : **Number of Flights Assumed for Different Vehicle Elements**

	Suborbital Vehicles	Orbital Vehicles
Airframe, Cold Structure (= vehicle lifetime)	200-600	100-300
TPS and Hot Structures	100-150	20-40
Air Intakes, Ramp Elements	150-200	----
Landing Gear	100-120	100-120
Avionics	150-200	100-150
Fuel Tanks (LH2)	100-150	60-120
Oxidizer Tanks(LOX)	150-200	80-150
Press.& Propellant Feed System Elements	100-200	80-120
Hydroelectric & Power System Elements	100-200	80-120

4.33 Rocket Engines' Refurbishment Cost

The main propulsion engines are considered in the *TRANSCOST*-Model as self-standing elements, not as subsystem units. For this reason also the refurbishment effort is dealt with separately. Historic experience exists only from the first rocket engine designed for 55 reflights - the Rocketdyne SSME for the Shuttle Orbiter: however, the design experience and technology of the 70ies did not allow to fulfil the requirement. The engines were too complicated and sensitive, especially when used with 107 % of the design power. As a result, refurbishment was required after each flight. The lifetime of the high-pressure fuel and oxydizer pumps was only 11 to 13 flights, while other engine elements fulfilled the design requirement as shown in FIG. 4-21.

The total refurbishment cost per flight (including spares) for the SSME amounted to some 11 % of the production cost , before the new P&W turbopump units with higher lifetime were introduced. Rocket engine designs with a much reduced number of parts and a more rugged construction can reduce the refurbishment effort to few percent per flight.

The RD-0120 engine - although designed originally as an expendable engine - was qualified by Aerojet for 20 flights on the Kistler K-1 vehicle, with refurbishment after

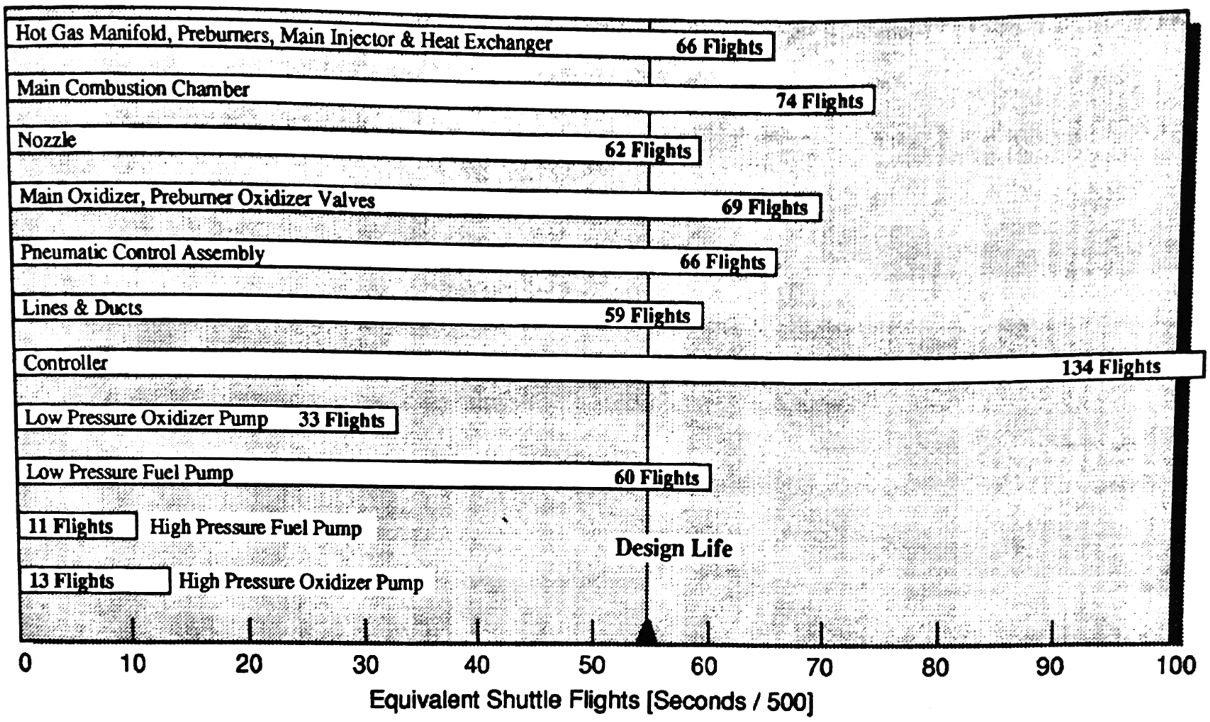

FIG. 4-21 : **Engine Component Lifetime of the SSME** (according to Paper AIAA-89-209 SSME Update)

10 flights. For an improved RD-0120 engine (Version AD-1) refurbishment wasconsidered only after 25 flights as MTBO (= Mean Time Between Overhaul) with two overhauls per lifetime (ref. 88).

The large impact of the engine thrust level utilization is shown in FIG. 4-22 by the RD-0120 example: If the operational thrust level is limited to 80 % of the design thrust level (chamber pressure) then initially refurbishment is required only after some 35 flights, and later in the lifetime after some 20 flights. In case of 100 % thrust level utilization refurbishment would be required after each 7th, respectively 3rd flight. As mentioned before, the Shuttle SSME was used at 107 % thrust level, resulting in a refurbishment required after each flight.

Future engines for RLVs will also feature a self-diagnosis system to reduce the inspection effort and to indicate maintenance requirements. With such features the refurbishment effort for rocket engines can be expected to reduce to less than 0.5 % per flight, with refurbishment after 20 to 25 flights, by example (total number of flights per engine = 40 to 80). Rocketdyne has estimated the refurbishment effort per engine to some 240 Mh every 20 flights plus 10 % spares.

The engine lifetime is influenced by the pressure levels involved : very high pressure engines will have lower lifetime and require a higher refurbishment effort. It is also effective with respect to lifetime to overdesign the engine and to use only some 90 % of the design thrust level (cf. chapter 2.32).

For high-speed turbojet engines a total number of 600 to 800 flights can be assumed, based on the experience with the J58 engines of the SR-71 which have been exchanged after 600 hours operation time.

For Solid-Propellant Motors/Boosters as used for the Space Shuttle recovery and refurbishment has been implemented with the goal of some 50% cost reduction (ref. 24) based on the assumption of 12 fligts per unit. Experience, however, has shown that the SRM cases can only be reused few times due to the higher damage at sea impact than expected. In addition, the required recovery equipment onboard of the SRBs and the recovery operations are expensive. With the actual refurbishment effort for two SRBs of 362 + 31 + 75 = 468 MYr (cf. TABLE 4-I) the cost are higher than a pair of new SRBs would cost - without recovery equipment, and taking into account the learning cost reduction for series production.

4.34 Refurbishment Cost vs. Number of Flights (Orbital Vehicles)

The refurbishment cost are not only dependent on the vehicle design and technology but also on the number of flights envisaged for a reusable vehicle. The refurbishment effort is growing with a higher number of lifetime flights as shown in FIG. 4-22 for an SSTO vehicle or a TSTO second stage.

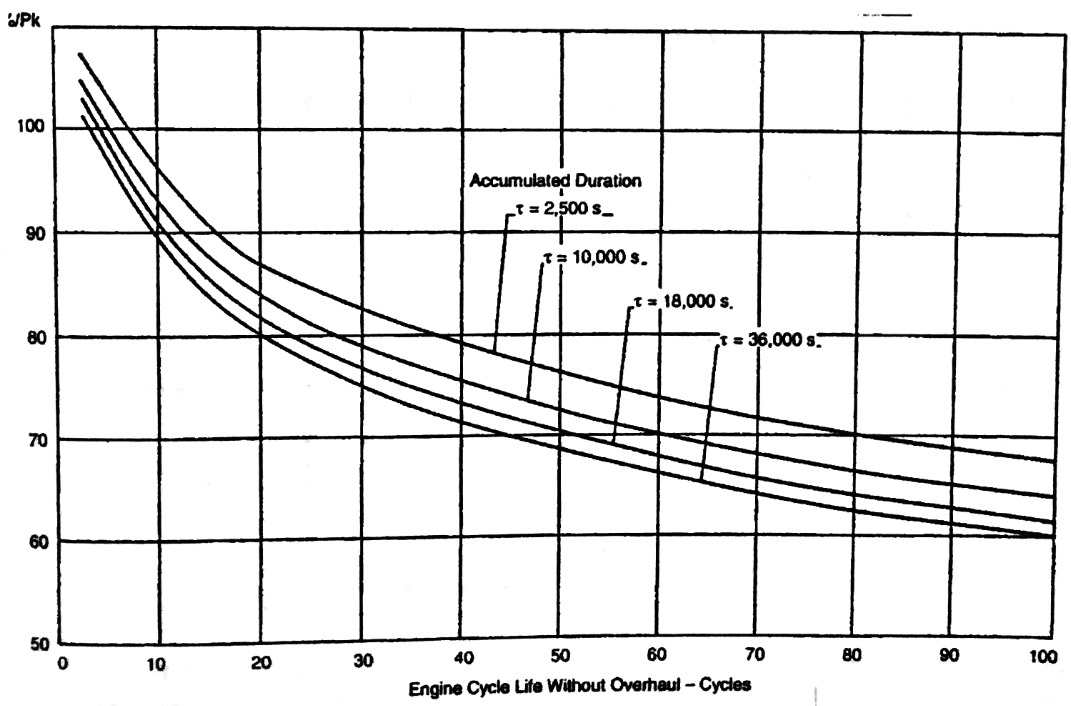

FIG. 4-22: **Engine Refurbishment Requirements vs. Operational Thrust Level (%) for the RD-0120 Engine**

The curves in FIG. 4-23 have been generated by simulation of an operational refurbishment program, using the subsystem lifetimes of TABLE 4-III. The refurbishment effort in total MYrs continues to grow steeply with the number of flights, however, the increasing number of flights has the effect of limiting the *specific*

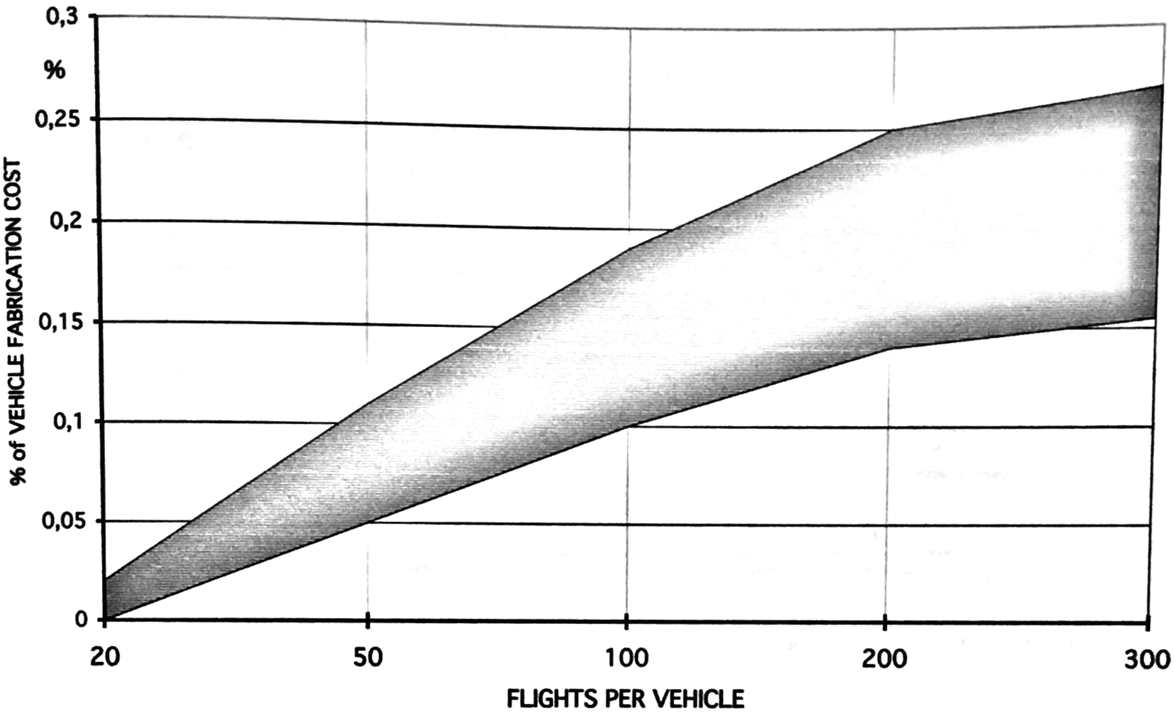

FIG. 4-23 : **Specific Refurbishment Effort vs. Number of Lifetime Flights**

effort (MYr per flight). FIG. 4-23 applies to launch rates of 10 to 30 per year. For essentially larger launch rates (> 100) the refurbishment cost are expected to be somewhat lower.

Another example for refurbishment cost estimation is shown in FIG. 4-24: It is taken from the MBB-Space Tug Study (ELDO/NASA, 1971), a reusable cryogenic orbital transfer vehicle for LEO-GEO transfer. The assessment of potential refurbishment after the 6th, 11th, 16th and 21st mission resulted in the following specific refurbishment cost (relatively pessimistic values at that time):

1.3 % per flight up to 10 missions,
4.0 % per flight up to 20 missions, and
5.3 % per flight up to 30 missions.

The refurbishment cost factor (as percent of vehicle production cost per flight) has an impact on the optimum vehicle lifetime: The higher the refurbishment factor, the lower is the number of lifetime flights in a cost-optimized program. This is shown in chapter 5.13.

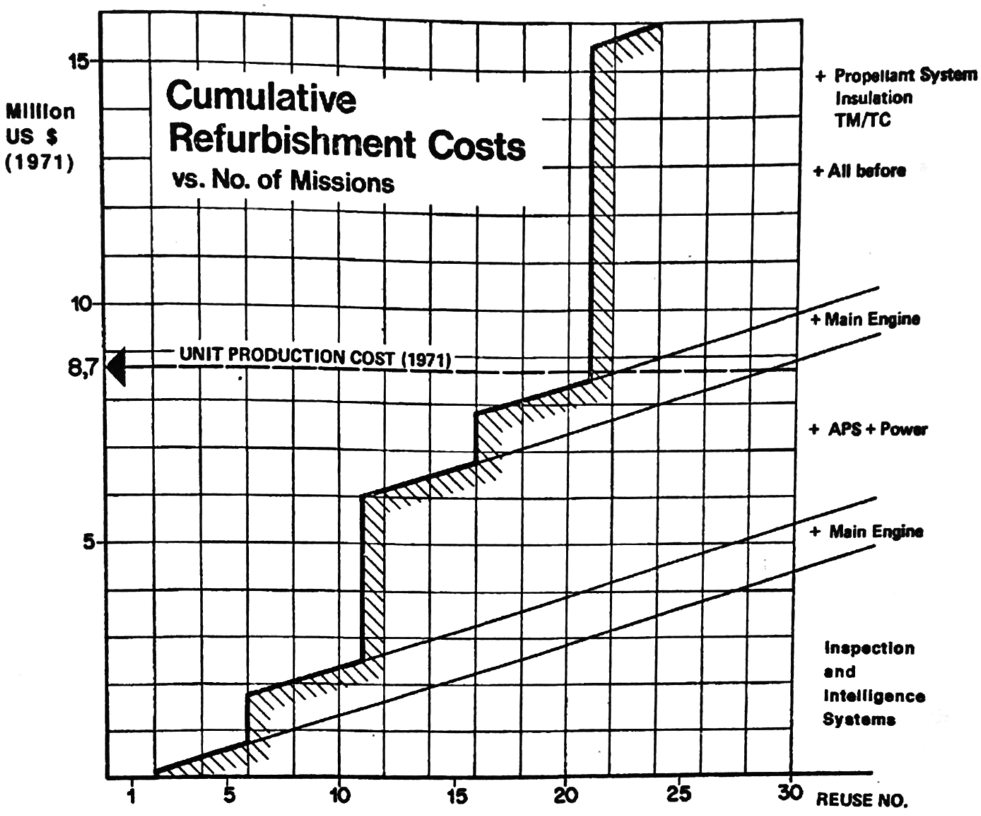

FIG. 4-24 : **Estimate of Refurbishment Cost vs.Vehicle Lifetime** (Example)

4.4 Indirect Operations Cost (IOC)

4.41 Cost Elements and Definitions

The Indirect Operations Cost (IOC) comprise all those costs which represent a constant value per year, almost independent from the launch vehicle size and the launch and flight activity. These are program administration and management, marketing and customer relations, general fees and taxes, technical support activities, pilot training (in case of piloted vehicles). Also the cost of technical activities like failure analysis, technical changes or improvements during the launch system operational period have to be taken into account.

The IOC are often neglected in the „Cost per Flight" estimates for future space transportation systems but this is not correct, especially if compared to present launch vehicle costs where the IOC represent a sizeable share (10 to 20 %).

As shown in FIG. 4-25 the IOC are subdivided into three areas:

(a) Launch system operations company administration and management, plus fees, profit and insurance charges

(b) Technical Support Activities
(including spare parts management in case of reusable vehicles and crew cost, if applicable)

(c) Launch Site and Range Cost
If a governmental or commercial launch site is used, then user fees for commercial customers will apply. In case of own property depreciation and maintenance cost apply.

The total annual IOC divided by the number of vehicle launches is the charge which is part of the complete Cost -per -Flight (CpF), cf. chapter 5.12.

INDIRECT OPERATIONS COST

Program Administr. & System Mgmt.	Technical System Support	Launch Site Support & Maint.
Program Administr. and System Mgmt.	Technical Support & Vehicle Improvem.	Annual User Fee or Actual Cost
Marketing and Contracts	Spares ' Center Administration	Launch Facilities' Maintenance
Fees and Charges, Financing	Crew Cost (if appl.)	Services and Supplies

FIG. 4-25: **Indirect Operations Cost Elements**

4.42 Program Administration, System Management and Marketing

4.421 Program Administration and System Management

A space launch system operator, either as a dedicated company such as „Arianespace" in Europe, Space System Corp. (RSC) in Japan, or as a division of a larger company needs a certain staff for administration and management.

The only way of cost assessment is the assumption of a certain number of staff required for this task. In addition to the direct and indirect personnel cost, all general overhead cost have to be added such as rental charges, equipment cost, power supply, travel cost, etc.

4.422 Marketing and Contracts

The staff has to cover the following tasks:

--- Marketing and customer relations
--- Vehicle procurement and industrial relations
--- Contracts handling
--- Accounting and Controlling, etc.

The related overhead cost for office rental, office equipment incl. computers, power and communications as well as travel cost are included, plus special cost like exhibits, publications, workshops, etc.

4.223 Fees and Charges

In this area also all expenditures for governmental fees, taxes, a reserve fund and/ or insurance fees have to be monitored. Also eventual financing cost (interest payments) have to be considered here.

4.43 Technical System Support

A launch operations organization needs a certain technical support capability even if not being involved in development activities. The tasks comprise:

(a) Supervision of the technical standard and performance of the vehicle, User's Manual Updates
(b) Technical supervision of industrial contracts for vehicle procurement,
(c) Failure analysis and implementation of technical changes/ improvements when required
(d) Spares storage and administration (excluding the cost of the spare parts which belong to the refurbishment cost)
(e) In case of piloted vehicles also pilots' training and support (cost depending on the number of pilots required: a function of fleet size and launch rate)

The cost for these activities have to be estimated in accordance with the number of personnel required. In addition, there may be required a budget for industrial support.

4.44 Launch Site Support and Maintenance

Launch sites in the past have been established and operated by governmental organizations (such as NASA, USAF, ESA/ CNES, NASDA, etc.) under a special budget. Launches of national spacecraft are, therefore, not charged with any site and range cost.

The situation is different, however, for commercial launches. The present situation is such that commercial launch service companies have to pay a certain fixed fee per month or year for use of the infrastructure. Additional fees per launch are accounted for in this Model as part of the Direct Operations Cost (DOC).

The ARIANE 4/ 5 operations at the CSG Kourou Launch Site required in 2004 an average total staff of some 1300 people, coming from 23 nations (plus some 25 payload specialists from the payload provider for each payload preparation and checkout). About 500 people - as required for the *VEHICLE LAUNCH PREPARATIONS* - are covered by the Direct Operations Cost (ca. 50 MY/ launch at 11 LpA), while a staff of about 800 from CNES, Arianespace and the industrial contractors is required for the *LAUNCH SITE OPERATIONS*, i.e. for

- (a) Administration and Management
- (b) Security / safety provisions
- (c) Facilities maintenance, incl. post-launch refurbishment
- (d) General support and supplies (power, water, food)
- (e) Range stations operational cost.

The total annual operations cost for CSG Kourou reached a maximum of some 190 M.Euros in 1999 and have been reduced since to 177 M.Euros for 2001. They have been covered with 54 % by CNES and 46 % by the other ESA countries. Investments for new facilities and the related personnel are in addition to the above-mentioned figures. As shown in FIG. 4-26[10] a substantial launch cost share has been covered in addition by ARIANESPACE, a commercial launch service provider, for ARIANE-4 launches. In order to create a level playing field with

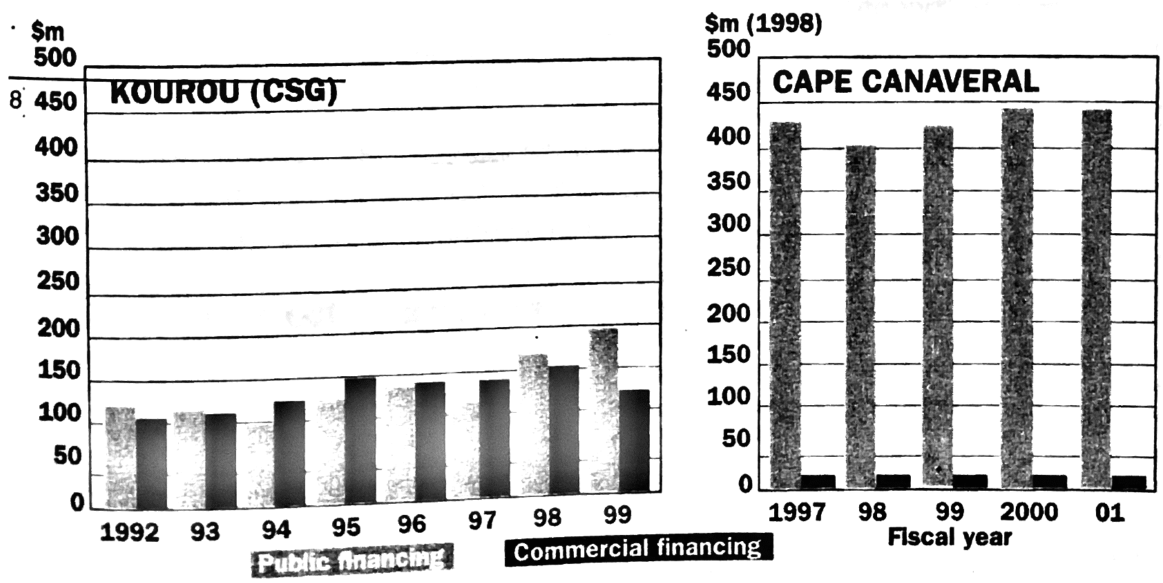

FIG. 4-26 : **Launch Infrastructure Financing for CSG Kourou and NASA KSC** comparable conditions the ESA Council decided in 2001 to reduce the financial burden for ARIANESPACE in case of ARIANE 5 launches. The CSG Kourou Budget for 2006 was 212 M.Euros, with 126 M.€ payed by CNES.

In comparison, the costs for NASA's Kennedy Space Center (KSC) in Florida are covered by the US Government. The NASA budget for the KSC was 440 M.$ for FY 2001, includig a total number of 1850 NASA civil servants there. A budget of 492 M$ has been approved in FY 2000 for the USAF Eastern Test Range at Cape Canaveral and the Western Test Range Vandenberg, CA[11]

Accordingly, the total US Government funding for the launch sites, range and safety operations are more than 900 M$ per year which is equivalent to more than 25 M.$ per launch (at 37 LpA). Several initiatives have been started now to reduce these cost essentially.

The basic cost of the Baikonur Launch Site in Russia are not known, but the Russian Aerospace Agency has to pay 115 M$ annually to the State of Kazakhstan for the use of the launch area.

The annual budgets for the traditional launch complexes show that the complete cost coverage of this type of launch site operations would not be feasible for commercial operations. The situation can be described as „subsidized" operation but this is precisely the same in the USA as in Europe, or elsewhere.

For future low-cost commercial launch services with reusable vehicles it remains a challenge to reduce the actual launch site cost to an acceptable level.

For the use of commercial launch sites like the „Virginia Spaceport" launch providers have to pay 900 000 USD per launch (600 k$ operating cost and 300 k$ for range support and safety which will be provided by NASA on a reimbursable basis[10] .

For the „Commercial Florida Spaceport" a value of 250 000 USD per month was quoted in the press[11] for the use of the basic infrastructure. This was the case, by example, for the ATHENA II launch from Pad SLC-46.

4.45 Total Indirect Operations Cost Assessment

The Indirect Operations Cost normally are adding up to a fixed cost budet per year. These total cost have to be subdivided by the number of launches per year, representing part of the „Total Cost per Flight" (CpF), as defined in chapter 5.1.

Normally, i.e. for launch numbers of 6 to 12 per year, the IOC are in the order of 8 to 15 % of the CpF, however, for a small number of launches the cost share of

10) Space News, 21.9.2000 11) Aviation Week 12.1.1998

the IOC can be substantial. It is not possible to establish a CER for the Indirect Operations Cost since the cost are very much depending on the local situation and conditions at the launch site.

The total cost estimate has to be based on

(a) the staff size required for Program Administration and System Management
plus general cost (overhead) for this team,

(b) the team size required for technical system support, plus general cost, and

(c) the fees charged for the use of the launch site infrastructure.

As an example, ARIANESPACE as a typical and worldwide first launch services company, had a staff of some 360 people in 2002[12] (including some 40 at the launch site CSG Kourou) for management of the ARIANE-4 and AR-5 vehicle production and launch services. This number decreased to some 300 after completion of the ARIANE-4 Program and shall be reduced to some 250 for the ARIANE-5 Program with the lower launch rate by 2004[13].

The STARSEM Russian-French company for marketing the SOYUS launch vehicle comprises some 50 people (6 LpA in 1999 for one customer). SEALAUNCH Co. has a staff of 310 people for up to 6 LpA of the ZENIT launch vehicle[14] (for direct and indirect operations activities).

The fees to be paid for use of the launch site are different in each case; ARIANESPACE, by example, had to pay for ARIANE 4 launches from Kourou a fixed contribution of 4 M.Euro per year plus a fee per launch (which are part of the DOC, by definition).

4.5 Operations Cost Uncertainties and Risks

Operations Cost generally and by nature comprise large uncertainties and risks and cannot be calculated with great accuracy.

4.51 *TRANSCOST* Operations Cost Model Estimation Accuracy

The *TRANSCOST* Operations Cost Submodel is one of the first efforts to establish a complete scope of operations cost, including the indirect cost. The results depend primarily on the conditions assumed and assumptions made for the vehicle operations. For a given case the Direct Operations Cost (DOC) can be determined with good accuracy.
It is recommended to perform a cost analysis with a certain bandwidth of assumptions, depending on the potential conditions

12) Aviation Week, 14.Oct. 2002 13) AW, 17.3.03 14) Aviation Week, 9 April 2001

.4.52 Uncertainty of Conditions and Assumptions

A number of assumptions have to be made for the vehicle flight operations which normally are some 10 years or more in the future. The market conditions are difficult to predict over that long time.

(1) The most important criterion is the DURATION of the operational phase, and the total NUMBER OF FLIGHTS. This determines the total number of vehicles to be built. The time period can range between 10 and 50 years which influences the results substantially, especially in case of a life-cycle cost (LCC) analysis.

(2) Also of prime importance is the ANNUAL LAUNCH RATE (LpA). The expected number of flights per yer can vary according to the market situation.

(3) The other uncertainty for a new launch vehicle project normally are the launch site conditions. What are the direct and indirect costs related to the use of the launch site and facilities in say 10 years?

(4) The fourth area are the required size (staff) and the fixed annual cost of the launch provider organisation.

4.53 The Major Cost Risks

4.531 Technical and Schedule Risks

Technical problems during the development and test period may delay the start of the operational flights. This can cause financing problems. Technical problems during the operational phase have several cost impacts:

(a) the failure investigation and implementation/ qualification of the technical modifications required,
(b) the interuption of the flight operations for a certain period (standby, no revenues), and,
(c) eventually a free re-launch, resp. repetition of the mission.

Another cost risk is the MAINTENANCE AND REFURBISHMENT EFFORT required in case of Reusable Launch Vehicles (RLVs). There is not yet sufficient experience available to define the scope of required spare parts and manpowe r effort.

4.532 Reduced Launch Rate

If the actual launch rate (flights per year) drops below the planned number this has an impact on

(a) the vehicle production rate in case of ELVs, and
(b) the direct and indirect operations cost. Both will increase.

A minimum launch operations team size must be maintained even in case of a greatly reduced number of flights.