The mid-air retrieval technology for returning of the reusable LV's boosters

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Abstract

Multianalysis of reusable launch vehicles (RLV) that authors have dissected for 8 years is empirically proved by Khrunichev Space Center activities in designing, producing and exploitation of aerospacecrafts. This multianalysis unambiguously shows that the mid-air retrieval (MAR) is the only technology for effective RLV production.

After the series of experiments together with M.L.Mil Moscow Helicopter Plant and "Parachute Design" Scientific Institute we managed to design the technology of LV's boosters reentry.

THE GENERAL RESULTS ARE FOLLOWING:

1. The project may be realized with minimal technical risk at the earliest possible date (2-3 years).
2. The project may be applied on the existing expendable LV (ELV) and may be easily adapted to different LVs.
3. The project may be demonstrated at minimal cost.
4. The project lets create the most economically effective RLVs (the savings equal about 30% and in the case the special exploitation technology is used the savings may reach 41.5%)

1. Realization

The MAR by airplanes or helicopters (Figure 1) is commonly used in the world – there were about 2 million MAR operations by today.

The technology is used to save:

- Containers of Earth satellites ("Discovery" and "Genesis", Figure 1a and 1b), geophysical rockets and spacecrafts;
- Remote controlled apparatus and airplane models;
- Cargoes and people from the ground and water surfaces, parachutist (Figure 1c), etc.

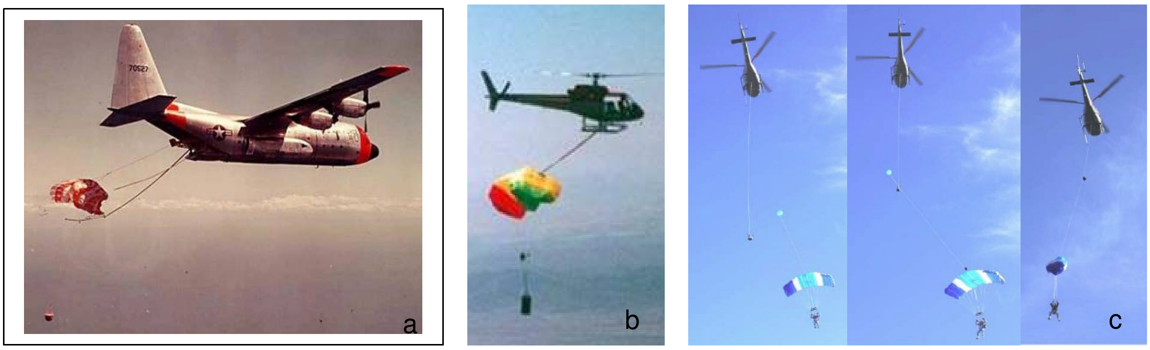


Figure 1: Examples of object MAR

The reliability of the first systems (1960-70-es) was 75-88%, but today it empirically approaching to the peak of 100%. The economic analysis will show that even the probability of 95% ensures the economic profits of the usage of the MAR technology.

The ability to MAR depends on the ability of the airplanes or helicopters to carry the mass of the capturing cargo and on the ability of parachute system to MAR the mass of the picked up cargo.

The helicopter is able to carry cargo with mass no more than 10 000 kg (Mi-26) without any modernization of helicopter and no more than 20 000 kg after modernization (according to M.L.Mil Moscow Helicopter Plant). The airplane can’t land with the cargo, carried outside. But existed until now parachutes are able to endure only 2 000 kg.

For heavy cargo with the purpose of decrease of weight of the main parachute and reduction of the sizes of an element for which pick-up implements - the parachute of pick-up is used. However, at increase of weight of cargo the area of the main parachute simultaneously increases. Increase of strength of the parachute of pick-up and its rope with the main parachute also is necessary. For removal of the parachute of pick-up from a vortex wake of the main parachute it is necessary to extend кщзу between them. For holding by the parachute of pick-up of such weight it is necessary to increase the area of the parachute of pick-up. For this reason at freights of 2000 kg and more the parachute of pick-up behaves astably or dies away.

In late 2002, Lockheed Martin Space Systems Company and Vertigo undertook a study to extend the concept of MAR to very heavy high-value payloads (10 000… 13 000 kg). It is supposed, that these development will be used for returning of an engine compartment of LV “Atlas-5”. Tests with the parachuter are shown in figure 1c.

But creation and operation of parafoil for large weights of freights very difficult and expensive task. Except for that it is necessary to control a parafoil that it did not move chaotically. Other problem, it not a universality of the solution.

The authors offer an "object capture methods", permitted to remove practically the restrictions on a captured object mass. In this case, the restrictions will be connected only with the possibilities of helicopter or airplane for capture (Patent No. RU 2242409 of "object capture methods", with priority on 21.08.2002. The USA patent application is now sent). Application of a rotor instead of the parachute of pick-up allows to leave from all last problems not resorting to a parafoil. It is possible to supply with the engine of a rotor necessary thrust. Besides it the gyroscopic properties of untwisted propeller stabilize its position.

On the basis of the invention the technology of MAR of boosters of LV has been developed (Figure 2).

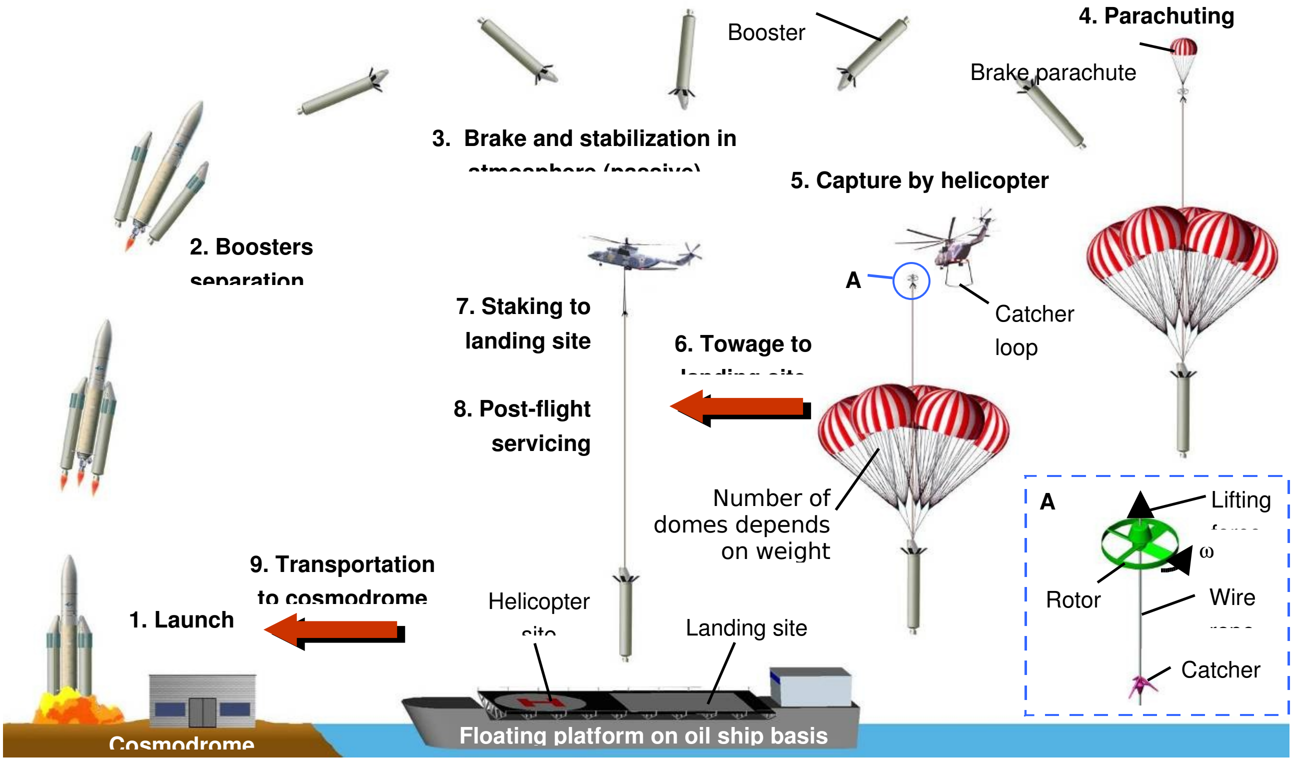


Figure 2: The scheme of functioning on an example of LV "Ariane-5"

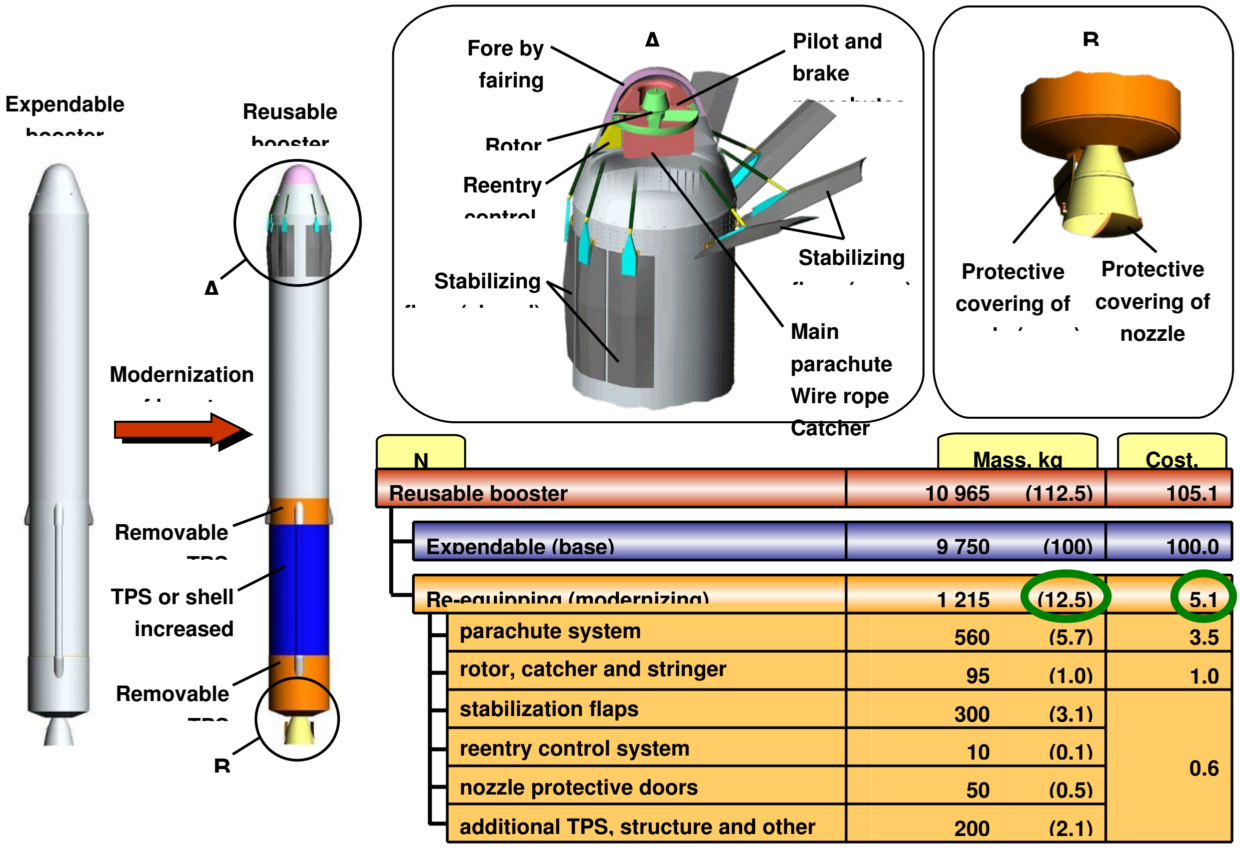
2. Universality and adaptability

The MAR technology may be adapted to achieve the ability to reenter LV's boosters of almost every type. In case the accelerator's mass exceeds the abilities of MAR, the accelerator may be parted. The most expensive part of the accelerator is engine, so only the tale part of accelerator may be saved.

In order to ensure the reentry of the accelerator (Figure 3) its front bay is supplied with MAR means. The parachute system that is offered is multicanopy modification of parachute system of accelerator "Ariane-5". The number of canopies depends on the mass of saving object.

In order to defense the accelerator from thermal action it should be supplied with additional surface insulation. The nozzle may be supplied with protective lids. As yet the more perfect decision of minimizing the engine overpatching are in process.

For reduction of fields of falling and loads on a booster can be set stabilizing flaps. Such a decision helps to eliminate the need of use reactive lowering control system (usually it is also poisonous) and start to use less comprehensive and expensive lowering control system.



N	Mass, kg		Cost,
Reusable booster	10 965	(112.5)	105.1
Expendable (base)	9 750	(100)	100.0
Re-equipping (modernizing)	1 215	(12.5)	5.1
parachute system	560	(5.7)	3.5
rotor, catcher and stringer	95	(1.0)	1.0
stabilization flaps	300	(3.1)	0.6
reentry control system	10	(0.1)	
nozzle protective doors	50	(0.5)	
additional TPS, structure and other	200	(2.1)	

Figure 3: Transformation of the expendable booster families LV “Angara” in reusable

All in all, the overpatching is local and has minimum influence on the design of LV, launching site and aircraft performance characteristics (ex. Table 1)

Table 1: Family of LV “Angara” with MAR boosters of the first stage

Name of LV	Angara-1.2	Angara-A3	Angara-A5
PL into LEO (Plesetck)	3 500 kg	14 000 kg	23 750 kg
Decrease of mass of injected PL	5.4%	4.1%	3.1%
Decrease of launch net cost	21%	38%	30.4%

Besides applying to boosters, the MAR technology can be used in landing manned spacecrafts (for ex. the spacecrafts of Soyuz type). The MAR technology would ensure comfortable accelerative forces and operational delivery. Otherwise the spacecraft would land by “soft landing”. Supplying the spacecraft with MAR systems would not lead to worsening of mass characteristics, because it would let reduce demands to engines of soft landing which in this case become reserving.

3. Demonstration and testing

The MAR technology may be demonstrated at the earliest possible date at minimal cost at the example of MAR of freight of 5 000 kg. We use parachute platform P-7 (costs approximately $100, with resource of 15 times), supplied with block with all means necessary for MAR instead of basic parachutes. All conditions are closed to real.
Such a modification in future may be added to regular exploitation and be used for freight delivery.

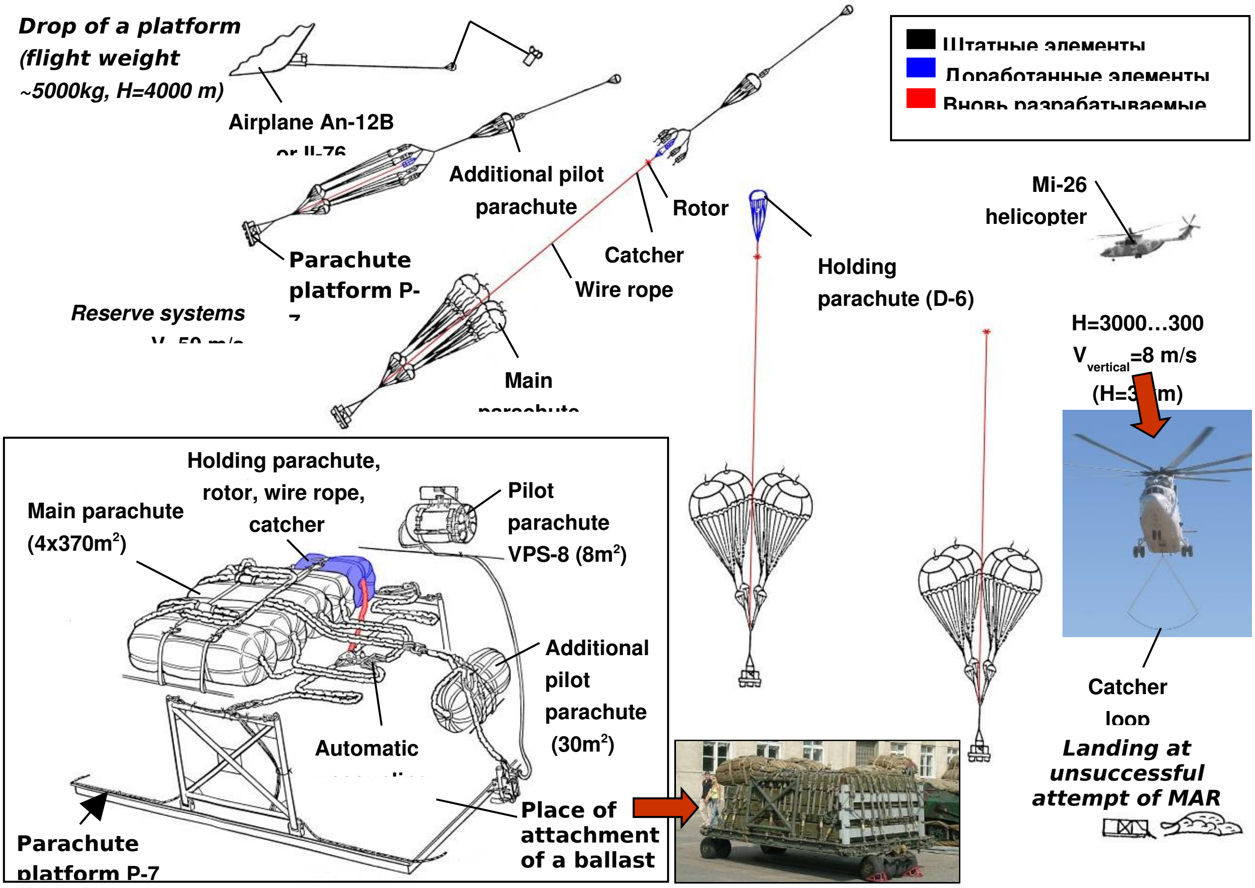


Figure 4: Application of parachute platform P-7 for demonstration of technology of MAR

4. Economic effectiveness

4.1. Existed technologies problems

Let's try to select and to analyze the existed reentry technologies problems. Let's review the diagram, shown in Fig. 5 and prepared by the authors on the Khrunichev official data basis. The first column in the left side shows the specific cost price of payload injection by the heavy expendable LV like "Angara-A5" (Khrunichev project). This cost price is accepted like basis for the further comparison (i.e. 100%).

The column on the diagram consists of several parts, showed the various articles of the costs: the lower part is LV and PL adaptation, upper part is the cost for the launch maintenance and realization and above it is a cost for the LV manufacture. For the further analysis, the cost for manufacture is divided into the cost price of the LV first stage and its remaining part.

Let's allow, that we shall transform this expendable LV into reusable one with the first stage reusable boosters (RB). Let these boosters for reentry ensuring are made with using the Fly-Back technology, which is a most popular now (for example, booster "Baikal").

If all costs are the same, then, for example, at 100 multiple use, the RB cost price for each specific launch will be 1/100 from their full cost price and 0.5% accordingly from the total launch cost price. Thus, we shall save money equal to 48.5% (i.e. almost in 2 times) in comparison with the ELV. This result is shown in the second column of the diagram. It will be nice, if it is in practice, but it is an "ideal" one.

Now, let's sequentially take into account the main reasons, which increase the cost price of the RLV in comparison with the ideal one. The reasons of rise in price are problems, which solution degree for each concept or project determines a level of coming to the stated ideal.

At first, let's take into account a problem, connected with the significant rise in price of the RB in comparison with the expendable one. This rise in price is about 5 times, i.e. the cost share for each launch will be 2.5 % instead of 0.5%. Also it is necessary to take into account the cost increasing for the launch ensuring (due to additional operations), which will add 1.8% as per the most optimistic evaluations.

Secondly, let's take into account a problem, connected with the RB reentry probability. So, if we accept the reentry probability equal to 0.98 as per the available experience of the LV operation, the average expected multiplicity of the boosters use, designed as per a known procedure N=Px(1-Pn)/(1-P) (N – mathematically expected multiplity of use; n – element resource; P - reliability), will be only 42 times instead of 100 (i.e. more than in 2 times less). Let the reentry probability corresponds to the perspective parameters of 0.99, then the average expected multiplicity of use will be 63 times.

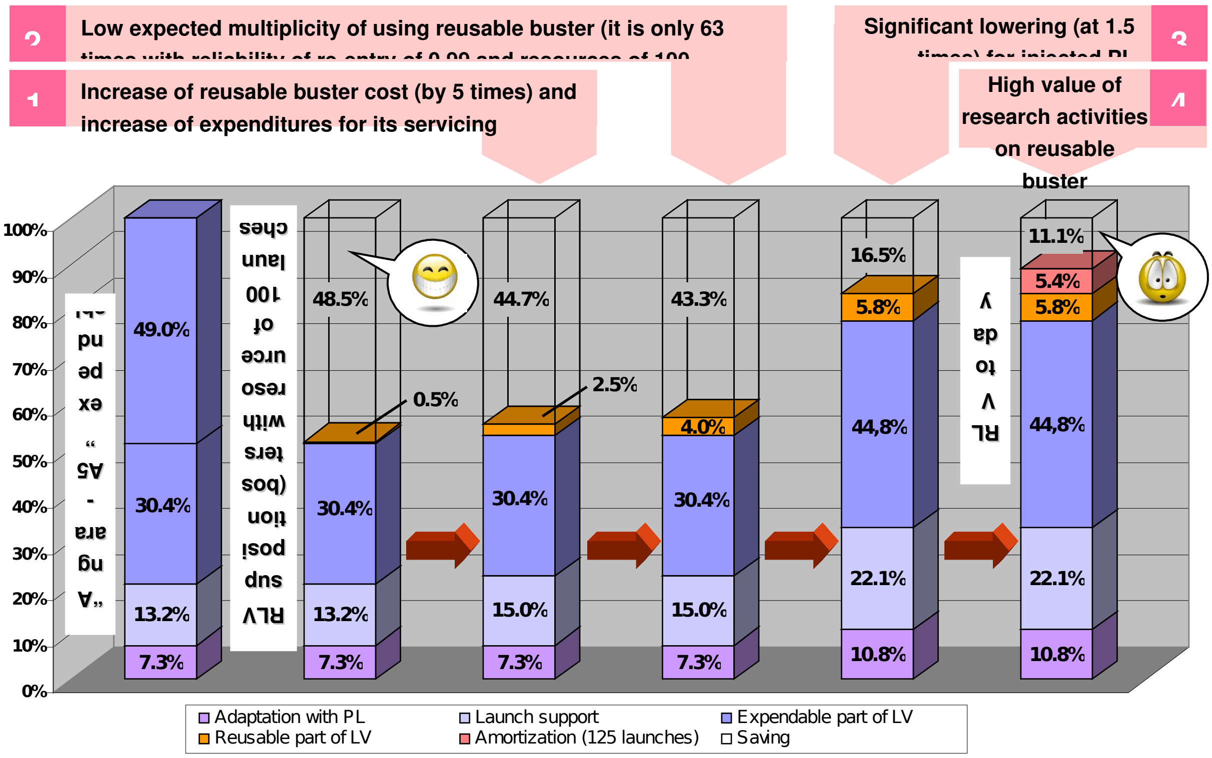


Figure 5: Existed projects problems RLV (on example of payload injection specific cost)

Thirdly, let's take into account a problem, connected with significant mass decreasing of payload to be injected. A "dry" mass increasing for RB, made as per the Fly-Back technology, in comparison with the expendable analogs, will be in about 2 times (jet engine, propellant and tanks for it, wing, unusual loads on LV, chassis etc. will appear). As a result, the payload decreasing will be in 1.5 times for the LV reviewed class. For ensuring the same cargo traffic, it is necessary to make launches in 1.5 times more that will bring to increasing in 1.5 times of all costs for launch!

And at last, ***in - fourth***, let's take into account a problem, connected with necessity to amortize the costs for the research and development work of the RB, which are 675% (from taken basis) as per the Khrunichev official data. In total, if amortization is done for 125 launches, the safe of money will decrease at 5.4%.

Finally, the save of money will be only 11.1% in comparison with the initial one, which is 48.5% (it is ideal one), that at 37.4% worse than for the ideal one. The saving for LV of more light type would be much lesser and even may become negative.

The similar analysis may be done on other reusable technologies, but for brief we shall give only the experts opinion.

As per evaluations of the American consulting company, Teal Group Corporation, now there are no commercial RLV and economically profitable projects of a similar type. In this case, it is necessary to point out that more than tens programs of the RLV development have stopped due to a high risk, stipulated by a new complicated technologies use.
As to reusable stages with hypersonic parallel flow jet engine (HPFJE), their first flight is expected to be not earlier than in 2015. In this case, as per the experts opinion, they never can put a large mass payload into orbit and make a competitiveness to the systems with rocket engines. Most likely, a payload mass will be about 9 t and cost price of $4250 per 1 kg of payload (in comparison with $6250 per 1 kg for the initial ELV). More than $4.000 mln. were spent for investigations in hypersonic area within last 40 years in the USA.
Thus, even the most perspective projects do not allow to expect the economically expedient RLV development (and payload injection cost price decreasing accordingly) in nearest 15-th years. Moreover, even through 15-th years it is not possible to expect the qualitative cost price decreasing for launches.

4.2. Conceptual ways of coupling with problems

The analysis of reentry systems, conducted by the authors, has shown that all these systems have the common features, which are the first reasons for consideration of above problems. These features may be generalized by the following concept:

onboard equipment of reentry system plays a main role,
while the external one plays a auxiliary role in main.

As is not surprising, this concept covers not only a Fly-Back technology, but also all systems, which ensure a descent on the parachute and landing on inflatable sacks or using the "soft" landing engines.
As the example, it is possible to show the K-1 LV project, made by “Kistler” company (Fig. 6). Though, a parachute system use for descent and air sacks for landing gives potentially a possibility to have the less mass and cost price for the stages reentry in comparison with a Fly-Back technology use, however a necessity to solve a landing problem by extremely onboard equipment has brought to needs in the special conditions for it realization.
The stages are compelled to land on deserted territories with an appropriate relief near the launch pad. From the above, a partition on stages and injection trajectory are not optimum. Moreover, there is a necessity to send a return impulse into stages for reentry to the launch point. As a result, the additional equipment mass and manufacture and service cost will increase, but the reliability decreases. As it is visible, all indications and problems of the above concept are clearly looked through.
As it is visible, the above problems are peculiar to all projects without exclusion, which are within the framework of this concept and do not dependent on how the reentry is realized (Fly-Back technology, parachute and air sacks or something else). So the unique method of cost decreasing is these problems solution "directly", i.e. the qualitative new technologies development for ensuring the following:

- structure and devices mass decreasing;
- reliability increasing;
- manufacture and service cost price decreasing.

But, it is easy to see that the above directions are in a rigid inconsistency one to another.
For example, for reliability increasing, it is necessary to rise the margins for loads, to implement a duplication, to rise the requirements to manufacture and monitoring etc. In total, it is possible to expect a significant rise in price and boosters mass increasing. The same concerns the rest directions.
As per the reusable systems projects preparation experience, it is possible to show that attempt to break this "vicious circle", staying within the framework of the same concept, does not hive a result. As it was shown, to expect the technologies, permitted to loosen this inconsistency, is possible not earlier than in 2015.
Whether there is another concept, which was already used in practice and has allowed to solve a similar situation? Yes, it is!

Let’s remember a history of distant aircraft development. When in 1954, there was a necessity of the non-stop flight on large distances, it was possible to hope on the new technologies development, which qualitatively improved the flight technical parameters. But, by a modern technologies level, the distant aircraft would not be today. Another thing was made – a problem of flight at the large distances was divided between a carrier airplane and tanker airplane. As a result, the distant aircraft in such way is successfully used up to day.
This experience may be formulated like the following concept with reference to the reentry systems:

optimum separation of reentry problem between ground and onboard equipment (hereinafter is simple optimum separation).

As per the author and scientific chief opinion, just within the framework of this concept, it is necessary to realize a search of design solutions, permitted to decrease really the payload injection cost price.
As an example, which may be referred to this concept, let’s show the project of “Space Launcher Systems Analysis” (SART) by DLR of German Space Agency (DLR-SART).
It is offered (see Figure 6) to capture the RB, glided in atmosphere (after separation from LV), by airplane and to tow it to the cosmodrome airdrome. At flying up to the airdrome, the booster is separated and lands.

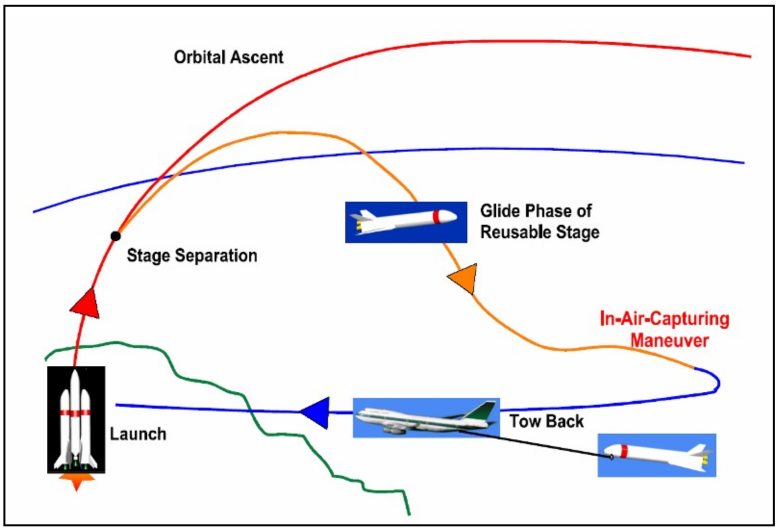


Figure 6: DLR-SART project

As it is visible from figure, the booster configuration is very similar to the configuration of boosters, made as per Fly-Back technology. However, it is not a Fly-Back technology, as the booster flies to cosmodrome not by itself. The attempt is seen how to divide a reentry problem optimally between onboard and ground equipment (i.e. concept, offered by the author). Due to this, the necessity of using the jet engines, additional propellant and tanks for it falls away.
As a result, increasing of the payload mass to be injected into GTO in comparison with the Fly-Back classical technology will be up to 25%!
Let's remark, that this essential result is not connected with use of composite materials or super progressive technologies. It is result of another concept use.
However, the wing and chassis use is not good combined with the LV arrangement and problems. The wing and chassis are not used at injection and at reentry the wing brings to essential transversal loads. As a result, a "dry" mass increasing does not allow show fully the optimal separation concept advantages. The return is lesser in the case of the wing appliance and is much greater in the case of parachute appliance, because in the last case the mass and cost of all systems necessary for retrieval is much lesser.

4.3. Economic effectiveness of MAR technologies

Let's analyze, how we solved the problems of existing technologies of reentry due to the offered technologies use. For these purposes, let's carry out the analysis as per the scheme, which is similar to the described one earlier.
So, let's consider the diagram in Figure 5. For the further analysis (Figure 7), the manufacture costs are divided into the cost price of the LV first stage (49%), second stage (12.3%) and remaining part (18.2%).
Let's allow, that we transform, as well as earlier, this ELV into reusable one with multiply used boosters of first stage. However, for transformation, we use the technologies and technical solutions, offered by the author. Step-by-step we shall take into account an influence of all solutions (see Fig. 36).
As it is visible from diagram, at using the offered technology of reentry, the economies is 30% (!!) that only at 8.8 % less than for an ideal one.

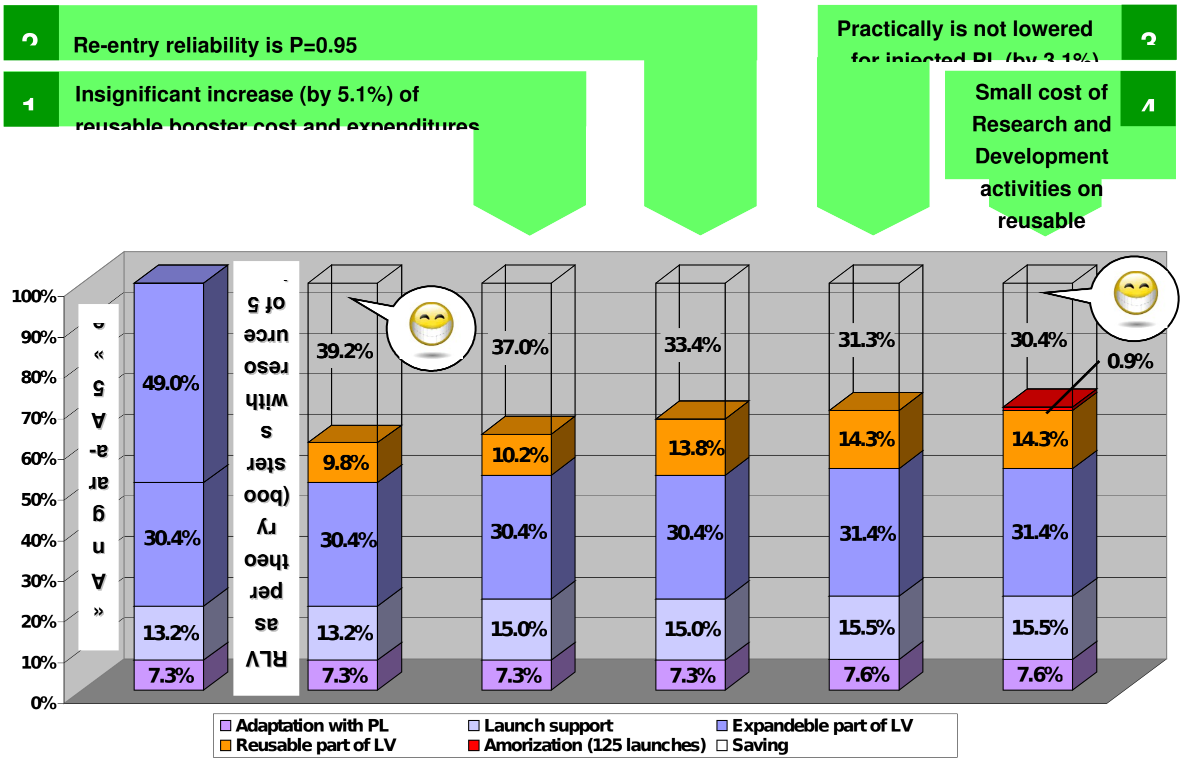


Figure 7: Advantages of offered technology of reentry on "Angara-A5" transformed LV example

Conclusion

The MAR technology is the only technology that offers the decision of creation the economically effective RLV already today. All other technologies put off this decision by indefinite future. This happens for several decades and only different combinations of the same old solutions are looking at (usually it is Fly-Back technology). However everyone comes to conclusion that the new materials and technologies are necessary and probably they would be invented (?). Most researchers are psychologically inhabited to the opinion that the most effective flying mean is airplane and so they limit the area of their research. At the same time they pose a problem to reduce the cost of PL launch by 100 and than by 1000 times (at the same time it is incorrect to compare the cost of air and space deliveries – the mechanical work and capacity that LV has is 10 times greater than the abilities of the plane).

It is necessary to start the creation of RLV based on the MAR technology today, because it can ensure its abilities applying present technical methods and materials. And new technologies and materials, if they are invented, would help to make the applying of MAR more profitable.

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