The 'Responsive Access' Concept (RAC) and Its Realisation in Russia

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ABSTRACT: With the advent of the Falcon, the capability of launch on demand will be an important asset of a Western commercial launcher for small satellites for the first time. While this capability is possessed by all military missiles, only those from the former Soviet Union were developed into small launchers which retained their responsive access characteristics unimpaired. Furthermore, quite large launchers, the Cyclone and Zenit 2 were produced with this ability.

In this paper the responsive access concept, its advantages and its implications for the launcher market are examined and assessed. Russian and Ukrainian launchers are examined and their suitability for meeting present day requirements for responsive access and their capabilities are compared with that of the Falcon. Possible developments in small satellite technology that may be stimulated by the general availability of a responsive access to space are described.

1. INTRODUCTION

The term 'responsive access' arose relatively recently. It covers a general concept which was recognized by its initiators, a range of specialists in U.S. space-concerned companies and organizations as the creation of a capability to launch various payloads into space with a minimum time of pre-launch preparation and for a minimum launch cost. By the opinion initially announced by the concept's developers, the realisation of this concept should give an opportunity to provide access into space for a range of spacecraft for various purposes while the spacecraft customers, developers and manufacturers would enjoy the opportunity to launch their spacecraft not only at cheap launch prices but also without the preliminary ordering of a launch which is usually no less than a year for small spacecraft and even a few years for heavy geostationary satellites. Instead, the 'responsive access' concept foresaw the launch of the contracted spacecraft within a few of weeks or even days of the request for the launch. This promised feature of the concept received its own appellation of 'quick response' or 'launch on request' while the 'responsive access' term meant a combination of this opportunity with the availability of these launchers at prices which would attract not only just the military or government users, but commercial users as well. Therefore, the realisation of the concept should provide access to space for a greater number of potential customers and also expand their variety.

Such new advanced launch vehicles as the 'Falcon' of the Space X company and the 'Sprite' of the Microcosm company are being developed taking into consideration the 'responsive access' concept. Although the 'Falcon' family project foresees the development of a few launch vehicles of various classes, the foregoing 'Falcon-1' which has carried out its maiden launch (true, an unsuccessful one) is a small class launch vehicle as is the 'Sprite', since it is evident that the concept could be realised for this class of launchers with less expenditure and effort. Besides, the small launch vehicles of this concept would be more in demand since both the military-purpose satellites to be urgently deployed and the civil spacecraft of 'poor' customers should be of the small class as well.

With the addition of this aspect, the current 'responsive access' concept is a direct evolution of that of 'Smaller, Faster and Cheaper' which the U.S. space industry was trying to realise during the nineties in regard to both spacecraft and launch vehicles. The realisation of this concept actually failed at that time (the U.S. specialists were even joking: 'You can choose any two goals from this slogan but not all three'). However, apparently, the experience which was gained during the attempt is being used now.

At the same time, this preceding attempt was not the first example of the implementation of a similar concept. Certain developments which were undertaken in the former Soviet Union (FSU) foresaw the realisation of actually the same principles which are laid down into the 'responsive access' concept. These developments were led up to the stage of operation or at least flight tests, in contrast with the significantly lower number of similar U.S. projects (for example, the 'Minuteman-IV' project which proposed the quick deployment of a constellation of orbital warheads with 'Minuteman'-type ballistic missiles actually used as small class launch vehicles for this purpose) that were not realised at all. Such launch vehicles which were created in the frame of FSU developments, i.e. the 'Cyclone' and 'Zenit', remain in operation up to the current time.

Besides this, those currently operated Russian small launch vehicles which were converted from ballistic missiles since the USSR collapse retain, completely or partially, certain capabilities for fulfilling the ‘responsive access’ concept which were inherited by them from their basic missiles.

It is necessary to note that a significant share of the above-mentioned developments were carried out in Ukraine, which was a part of the USSR at that time but is now an independent country. However, despite those launch vehicles in which the concept was realised, the ‘Cyclone’ and ‘Zenit’, now being Ukraine-built products, their production is provided with deliveries of certain main systems from Russia and their operation is being carried out with significant Russian participation. The single Ukrainian prime space company, the ‘Yuzhnoye’ NPO, developed a range of launch system projects which could be partially suitable for the ‘responsive access’ concept realisation (these projects were concerned with the use of converted ballistic missiles and their air launch), however, their realisation is impossible for political and other reasons. Therefore, it is possible to consider that Russia is now the only country of the USSR heirs which not only owns the concerned experience but is operating the corresponding launch vehicles and is developing new launch systems which should have the same capabilities with a high chance for these projects being realised. For this reason, this report discusses the FSU experience (including the experience which was gained in Ukraine) and the current Russian capabilities and potential in this field.

2. THE RESPONSIVE ACCESS CONCEPT (RAC)

Generalizing the requirements for any launch system, whether based on small class launch vehicles or on launch vehicles of heavier classes, that can be considered a ‘responsive access’ concept’s launch system, it is possible to formulate the following requirements which should be met by this system.

Requirement 1. The system has to be capable of providing the launch of small satellites, if only one satellite in a single launch, within a few days after a request.

Requirement 2. The system has to provide the launch of a few satellites with a minimum interval between their launches. This interval should not exceed the time of the launch vehicle pre-launch preparation after a request. The systems in which the launch vehicles are of classes heavier than the small class should provide the capability of multi-satellite launches.

Requirement 3. The cost of launch to be provided by the system should be at a minimum level, with the provision of a specific launch cost lower than the corresponding values which are being provided by current common launch vehicles of the same class.

These requirements are listed above in the order of their importance to the ‘responsive access’ conception. Indeed, if the first requirement of ‘quick response’ is not met, the system cannot be considered to be used for the supposed purpose at all. This requirement is mostly concerned with the launch vehicle which is a part of the system. A non-meeting of the second requirement means that the system would be suitable for the provision of a ‘quick response’ for individual satellites. A meeting of the third requirement is a desirable but not indispensable condition for the achievement of the concept’s primary goal. It has a greater importance for the achievement of a secondary goal i.e. the servicing of civil (commercial) launch customers.

As is remarked in the Introduction, there were repeated attempts to realise the ‘responsive access’ concept in the former Soviet Union (FSU). These attempts had been concerned with the primary goal of the concept. The developed systems which were inherited by Russia and Ukraine keep the corresponding capabilities and will be examined for the current concept realisation mostly for the achievement of the secondary goal. Besides, certain launch systems which are being currently developed in Russia would also provide the same capability to a greater or lesser degree.

3. THE FALCON AND THE RAC

The idea behind the ‘responsive access’ concept was clearly formed by the time the information on the FALCON (‘Force Application and Launch from CONUS’) U.S programme was published in November 2003[1] although the ‘responsive access’ term had been mentioned still earlier in the title of the RASCAL (‘Responsible Access, Small Cargo Affordable Launch’) conceptual study which was contracted by the U.S. DARPA in 2002[2]. A number of projects were developed in the United States in the frames of this concept realisation and two of them, the ‘Falcon-1’ and ‘Quick Reach-1’, have achieved the stage of real tests.

Although the FALCON and RASCAL’s requirements were different in regard of payload mass to be launched, 454 kg (1000 pounds) and 75 kg accordingly (true, into different orbit altitudes, 185 km and 500 km), both the programmes coincided in the requirement to provide a launch after a request within a very short time, 24-48 hours.

The same requirements were also repeated in the more recent European RLS (Rapid Launch System) conceptual project[3]. Therefore, it is possible to consider that the requirement to provide a launch during the period of 48 hours, with its following shortening down to 24 hours, is a main requirement for the 'responsive access' concept realisation in any concerned project.

Although the European RLS project did not foresee any future application as a carrier of strategic weapons, its goals are bound directly to the task of the urgent deployment of military-concerned spacecraft for a 'quick response' in a corresponding situation, while any application for civil mission servicing was not foreseen. This task can be considered to be at a strategic level for Europe since, in contrast with the United States, it has not any defined plans for the deployment of conceptually new strategic systems. This explains both the announced high launch price and the expected low annual rate of launches (2-3 per year[3]).

Another feature of interest which is distinctive for all the 'responsive access' systems that are being developed is that these systems are intended for the launch of small or even super-small payloads. This feature can be explained, of course, by the fact that those satellites which have to be launched by these launch systems should be as least expensive as possible and, therefore, should be attributed to the class of small spacecraft. Moreover, current technologies allow the building of small satellites for the same missions which were previously being fulfilled by satellites of significantly heavier classes (for example, in the field of ERS). However, it is interesting to compare the specific launch prices which were laid down into these systems to be created with the specific launch prices which were (and are) being provided by those expendable launch vehicles that are being used for the launches of heavier satellites for the same purposes. For example, the Russian 'Proton' heavy launch vehicle can provide the injection of a 24-ton payload mass into low-Earth orbit (LEO) with an altitude of 200 km at a launch cost of around US$ 30 mln. (This launch cost is not the launch price which is being offered for commercial launches but it is paid by Russian governmental bodies for launches in the frames of national missions.) Therefore, the achieved specific launch price for these specific missions, which are similar to the state-ordered missions to be carried out with a use of the 'responsive access' concept launch systems, is around US$ 1,250 per kilogram, which is more than 4 times less than the best value which is supposed for the RASCAL system (see above). Even in the worst example with a use of the U.S. 'Titan-2' with its 14-ton LEO payload capability at a commercial launch price of US$ 110 mln.[4], this value is slightly less than US$ 8,000 i.e. less than that which was required for the launch systems to be developed for the FALCON programme.

At the same time, current small class expendable launch vehicles have launch prices at the level of US$ 10-20 mln. for a ton of payload mass i.e. their specific launch prices are US$ 10,000-20,000 per kilogram.

Therefore, the financial aspect of the 'responsive access' concept is, actually, not the task to decrease the specific launch cost for military-purpose satellite injections in a comparison with the level which was achieved for the preceding heavier satellites by heavier classes of launch vehicles. The task is to approximate those specific launch prices to be provided by the new launch systems to the level achieved previously while an opportunity to decrease the masses of the satellites themselves, thanks to the applications of new advanced technologies would provide a decrease in the total launch prices for the missions to be fulfilled.

Of course, this decrease in the specific launch prices in comparison with the current level for the small class of launch vehicles must have a great importance for those potential civil launch customers who cannot use heavier launch vehicles for either reason (mostly due to the small sizes and masses of their spacecraft). The impact on the worldwide and U.S. domestic space market from the appearance of a certain U.S. low-cost small launch vehicle (SLV) to be developed in the frame of the 'responsive access' concept (the 'Falcon-1' was implied) was investigated in detail in a CST report[5]. However, as is shown above, this particular advantage of the 'responsive access' concept's launch systems is not a key factor in the achievement of the concept's main (primary) goal. The determinant factor is rather the task of providing the system's capability to provide an urgent launch after a request within a few days instead of the current duration of a few months (in the best case!) for the launch vehicle preparation. Due to this feature, the 'responsive access' concept is often being called the 'quick response' concept. Actually, this means that the choice in the selection of two terms from the 'Faster, Smaller and Cheaper' slogan which is mentioned in the Introduction above has been made in favour of 'Faster and Smaller'.

However, as was exposed in the CST report[5], a probable realisation of the 'quick response' reduced concept in a certain launch system does not provide the achievement of the 'responsive access' concept's primary goal i.e. the capability to urgently deploy a constellation (constellations) of small satellites or even of a few of these satellites after a sudden request. Two other conditions have to be met for this.

First, the duration of the pre-launch preparation for the satellite to be launched has to be not longer than for the launch system's pre-launch preparation after the request. This condition has to be met by the corresponding satellite developers proceeding from the known time of the launch system's pre-launch preparation (probably, on the basis of the 'plug, sense and play' concept application).

The second condition is that the launch system should have a permanently available stock of almost ready launch vehicles which has to be sufficient for the servicing of the most probable number of launches that could be requested simultaneously. The term 'almost ready' implies that the launch vehicle's further preparation after the request has to be carried out within the announced period of pre-launch preparation. This condition also includes the requirement that the system's launch site has to be prepared for the next launch during the period of the launch vehicle pre-launch preparation.

4. RUSSIAN CANDIDATES FOR FULFILLING THE RAC

Most of the Russian vehicles discussed had been developed in the previous regime, the USSR, and almost all of these launch systems were derived from basic ballistic missiles which, being weapon systems, had to provide a high readiness for their battle use on command.

Therefore, requirement 1 was actually met in the early sixties and the main problems with the realisation of that time's 'responsive access' (that was really required from time to time in order to replace a satellite which had failed in orbit) were concerned mostly with the existence of another satellite for the replacement and with a long time for its preparation and with the inter-launch preparation of the launch facility. However, these problems were being solved by the common FSU practice of that time by having a back-up spacecraft in a high degree of pre-launch readiness and to have a second launch facility for any type of launch vehicle. This allowed the launch of the back-up satellite within a few of days of a request. So, requirement 2 was met as well.

Nobody even thought about a meeting of the requirement 3 (a saving of funds) at that time.

However, since that time most of the missiles, during their conversion into commercial launchers have lost some if not all of their ability to fulfil RAC requirements. Therefore, the converted missiles of the Cyclone family as well as the Cosmos, Rockot, Strela, Dnepr, Start and Shtil will be examined to see what abilities they retain.

Then, a single FSU launch system which was not derived from a ballistic missile, the 'Zenit', will be discussed because of its potential ability to launch whole systems of small satellites at time according to the RAC.

Finally, three projects, Angara, Air Launch and Ishim will also be examined. Those launchers which can implement the RAC from all of those looked at will then be compared with the Falcon-1.

The Cyclone Family

The Cyclone is unique among FSU missile systems in that, even in its first 'FOBS' configuration, it was designed to what was then considered as the RAC. At the present the production of the top stages for the Cyclone-3 has stopped and there are a few Cyclone-2's remaining in stock. The production limes have been halted but not abandoned. Cyclone-4, a Brazilian-Ukrainian project would be GEO capable if developed and Cyclone-2K, relevant here, is a Russian-Ukrainian project.

The 'Cyclone-2K' project, which was described in detail in a CST report[6], foresees to equip the former 'Cyclone-2' with a third stage. This ADU-600 top (upper) stage should eliminate the 'Cyclone-2's' shortcoming which is expressed in the impossibility to launch those satellites which could not boost themselves at the final leg of the injection trajectory. Therefore, this improvement would expand the launcher's range of potential payloads, moreover, a capability to provide multi-satellite launches is, apparently, foreseen in the project as well. At the same time, the ADU-600 stage (it is shown in Figure 1) is an up-graded version of a Russian submarine-launched ballistic missile's (SLBM's) post-boost stage which keeps this post-boost stage's distinctive feature – this stage is fuelled with propellant in its manufacturing plant with a following 'ampoulization'[7]. Therefore, this stage will not complicate and prolong the process of the launcher preparation at the launch site. This means that the times of this preparation will remain the same as those which were provided by the basic 'Cyclone-2'.

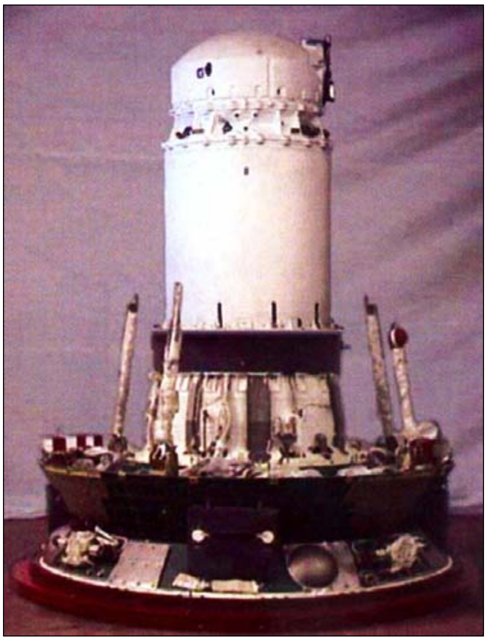

Fig. 1. The ADU-600 stage

At the same time, the 'Cyclone-2K' should use the 'Cyclone-2's' technical and launch sites in Baikonur with the launch site retaining those features which were providing the realised 'quick response' capability for the basic 'Cyclone-2'. Moreover, the technical site's capacity could be expanded in the case of demand by a moderate reconstruction of some other technical sites which are being in a laid-up condition in Baikonur (as was recently used for an expansion of the 'Proton' and 'Sojuz' commercial operation). Certain of these laid-up technical sites' facilities would also be used as storehouses for a provision of the 'responsive access' concept realisation (for civil purposes, of course) in the case of the corresponding demand appearing in the world's space market.

However, there are at least two serious obstacles which would, if not prevent, then significantly complicate the realisation of the 'responsive access' by the 'Cyclone-2K' launch system. First is the high payload capability of the 'Cyclone' launcher in all its options and, therefore, its high launch prices.

Even if the 'Cyclone-2K' would provide the same specific launch price which was announced in May 2002 of US$ 8,000 per kilogram for commercial launches[8], which is even better than the corresponding value for the U.S. FALCON/RASCAL programmes, the total launch price would be around US$ 15 mln. The 'Cyclone-2K' should launch up to 1.8-2.0 tons of payload into sun-synchronous orbits and its price would be found to be a quite unacceptable value for potential civil customers with their small spacecraft with masses which do not exceed one ton in the best case, while an overwhelming majority of these sort of potential customers would wish to launch satellites with masses of 300 kg and less.

Of course, the situation could be saved by a use of the cluster launch method. However, as experience has shown, to search for a number of various small satellites which would be launched simultaneously into near orbits is a complicated task by itself.

Nevertheless, if even this task will be solved for the 'Cyclone-2K', a second obstacle should arise in the process of meeting this supposed demand by a high rate of launches. As it is mentioned above, the serial production of the 'Cyclone' launch vehicle is currently absent although certain capabilities for its restoration are retained in the 'Yuzhnoye' NPO's 'Yuzhmash' Plant. These capabilities should be used for an establishment of the 'Cyclone-4' option's serial production in the case of the Ukrainian/Brazilian project's success. As it was shown in the CST report[6], this newly-established serial production would provide an expanded operation of the Russian/Ukrainian 'Cyclone-2K' as well. However, if the 'Cyclone-4' project fails, this production will not be restored especially for the 'Cyclone-2K' project, which foresees only the use of the available stocks of the 'Cyclone-2' launch vehicles that would be transformed into the 'Cyclone-2K' option).

This direct dependence of the expansion of the 'Cyclone-2K' future operation on either the success or failure of the 'Cyclone-4' project, for which itself the prospects are not so clear, aggravates still more the doubts about the potential suitability of the 'Cyclone-2K' launch system for a supposed realisation of the 'responsive access' concept.

For these considerations, the 'Cyclone' launch system in all of its options cannot be assessed as a potential competitor in Section 5 below. It remains an example of an FSU first launch system which was developed and even used partially, especially for the 'quick response' concept realisation, but cannot be currently used any more even for the same purpose, to say nothing about the 'responsive access' concept.

Cosmos

The usual operation of the 'Cosmos-3M' and its features were described in numerous sources. At the current time, the launch system's capability to provide a 'quick response' has been decreased since one of the Plesetsk's three launch facilities was reconstructed for launches of the 'Rockot' launch vehicle and another one was laid up. The arsenal in the Tambov Region does not have these launch vehicles any more and they are being delivered from the 'Polyot' PO's Plant in Omsk with a long duration for this delivery. The production of the launch vehicles is being provided at a low rate by the method of 'cannibalism' i.e. the use of certain suitable parts of those launchers for which the lifetimes are already expired in a combination with a number of newly manufactured parts (see references 8 and 9). Although information on the full-scale restoration of the 'Cosmos-3M' production at 'Polyot' is arising from time to time in the Russian mass-media, the probability of this is very low since this restoration would be done only with a replacement of all the Ukraine-built parts by products of Russian industry. The share of the Ukraine-built parts is more than 50% in the 'Cosmos-3M' launch vehicle and, therefore, it would be more reasonable to build another, more advanced launch vehicle instead of this obsolete launcher. However, the 'Polyot' can not find the corresponding funding since its financial state is not good.

For these reasons, the 'Cosmos-3M' can be considered at the current time as a launch system which actually has no capabilities to provide an urgent launch of any satellite on request. Due to this, the system is not assessed in Section 5 below as a probable competitor for a realisation of the 'responsive access' concept in the worldwide market of launch services. Instead, the 'Cosmos' family can be considered a first in the FSU example of a realised and operated launch system which, thanks to certain unpremeditated preconditions, received capabilities to provide 'responsive access' to a certain degree, but these capabilities were not demanded.

Rockot

As was shown in the preceding section, the realisation of the 'quick response' concept in the USSR which was carried out in the frame of the 'Cyclone-2/3' launch system development was concerned with military-purpose missions. However, these missions had to be fulfilled exclusively during the times which would precede any large-scale war conflicts.

Indeed, the 'Cyclone' launch system's on-ground infrastructure had a low protection against enemy air raids (this protection could be provided only by the country's anti-aircraft defence or its domestic detachments) to say nothing about attacks with a use of nuclear weapons and ballistic missiles. However, as was evident for the USSR military supreme command, a probable nuclear war conflict of any scale would include an enemy's attack against the USSR military-purpose satellite constellations.

Any damage or, worse, destruction of these constellations would deprive the USSR troops, including nuclear forces, of any space support (reconnaissance data in real time, communications, navigation service, etc.) and, therefore, would seriously complicate the battle actions of these troops.

Since the in-space defence of in-orbit satellites was as yet a prospect for the far future during the late seventies – early eighties, the problem could be solved by a replenishment of the damaged constellations with 'war-time' satellites, i.e. satellites which should have the same purposes and capabilities (probably, with a certain limitation in regard of lifetime duration, etc. in order to decrease the masses and complication of the satellites) but should be launched already in the process of the war.

It was evident that these 'war-time' satellites should be launched as urgently as possible (due to the supposed short time of the war conflict's escalation) from a standby condition of the launch vehicles. Besides, these launch vehicles with already mated satellites should be protected permanently (at least during the periods of arising of war threat) against a potential enemy's attacks of any sort, including attacks by ballistic missiles equipped with nuclear warheads.

It was also evident that these 'protected' launch vehicles would be created relatively simply on the basis of silo-based ICBMs. Moreover, a vast experience of space launch vehicle developments on a basis of ICBMs had already been gained in the USSR while certain USSR's silo-based ICBMs of that time could provide a sufficient payload capability thanks to their high power potential. Probably, the heavy ICBMs of the R-36M type (SS-18 by the Western designation) could be the best candidates for this role since their power potential was near to that which the 'Cyclone' had. Besides, this type of ICBM had a sufficiently powerful post-boost stage which could provide the deployment of a few of the 'war-time' satellites in a single launch.

However, these ICBMs were not so numerous as other types of less heavy ICBMs while the restrictions of the U.S./USSR acting Strategic Armament Reduction Treaty (START) did not allow to increase the number of launch sites for any type of ICBMs. (The space launch vehicles that were converted from the ICBMs which were included into Treaty frame of action were considered to remain in ICBM capacity from the Treaty's point of view). Therefore, a conversion of these SS-18 ICBMs share into the new launch vehicles for the launches of the 'war-time' satellites with a deployment of these launch vehicles in a corresponding number of the SS-18's launch sites should mean a shortening of the most effective part of the Soviet offensive nuclear force.

A choice was made in a favour of the less heavy (about 105 tons of lift-off mass against around 200 tons for the SS-18) but sufficiently powerful UR-100 NU ICBM (15A35 by its military designation or SS-19 by its Western designation). This ICBM had been developed by the Academician V. Chelomey – led Design Bureau which later received the 'Salyut' DB appellation (it is currently part of the Khrunichev Space Center).

This ICBM was deployed, beginning from 1975, in numerous launch silos which had a strong protection against near nuclear explosions. The ICBMs were stored in a fuelled conditions for a number of years in a standby state from which they could be launched within a few of minutes after receiving a command. The SS-19's power potential could provide the launch of a payload with a mass of 1-1.5 tons into LEO, but its post-boost stage which had to pull apart three warheads along different trajectories (in an accordance with the MIRV concept)[10] had too low power potential for the deployment of numerous payloads along orbits which would differ significantly in altitudes and inclinations.

The 'war-time' launch system which later received the 'Rockot' appellation (its real appellation of that time as well as its military designation remain classified to the present time) was developed on the basis of the UR-100NU by the mid-eighties at the level of an engineering project. The main difference with the basic missile was an introduction of the 'Breeze' especially developed upper stage instead of the removed post-boost stage. The missile's control/guidance system was also replaced with a new system of digital type which had an on-board computer.

The configuration of the first, silo-based 'Rockot' launch vehicle's version, is shown in Figure 2 together with its payload accommodation zone's configuration.

A brief description of the 'Rockot' launcher's design can be found in the book[11].

Despite the SS-19's launch site being suitable for this 'Rockot' launcher accommodation, the silo had to be up-graded in order to provide launches of this launch vehicle. This up-grading was concerned mostly with the replacement of the former SS-19's launch control equipment.

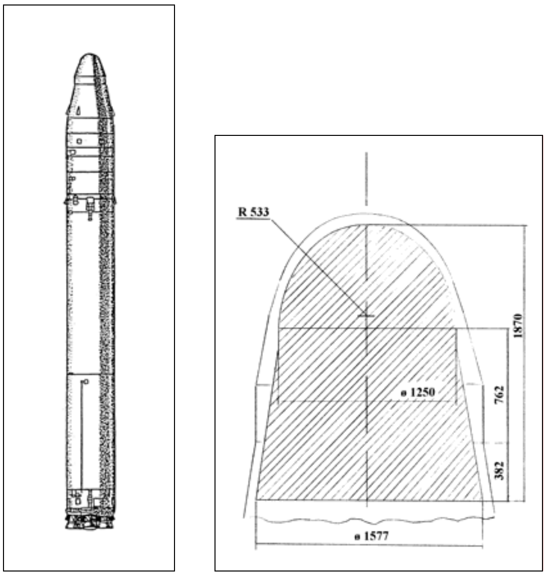

Fig. 2. The general configuration of the 'Rockot' launch vehicle's early silo-based version (left) and its payload accommodation zone (right)

Two test silo facilities for the SS-19s in Baikonur were begun to be up-graded. One of them was ready in 1990 and the first launch of the 'Rockot' was carried out from it at the end of that year along a sub-orbital trajectory. The second sub-orbital testing launch was carried out after a year, in December 1991. These launches were dedicated to the in-flight testing/verification of the new 'Breeze' upper stage and this task was successfully solved.

The first orbital mission was completed on December 26, 1994. The 'Radio-ROSTO' Russian radio-amateur small satellite was successfully launched.

However, before that time, the collapse of the USSR had occurred in 1991 and post-USSR Russia had no demand for 'war-time' launch systems for this sort of 'quick response' due to, mostly, a lack of funds. These funds would be required not only for a deployment of the 'Rockot' launch systems in a certain number of up-graded launch silos but also for the development of corresponding 'war-time' satellites which had not yet been begun.

So, the 'Rockot' system was 'granted' by the Russian government to the newly established Khrunichev Space Center (of which the 'Salyut' DB had become a part) for future commercial operation.

Initially, the Khrunichev's top management had an intention to use the existing launch silo in Baikonur for a provision of the 'Rockot's' commercial launches. There were also plans to put into operation the second launch silo in Baikonur and even to up-grade five SS-11 launch silos in the new

Russian Svobodny spaceport for the same purpose.

However, these plans were finally declined by the late nineties in favour of a new surface launch site in Plesetsk. This construction (more exactly, a re-construction of one of the 'Cosmos-3M's' launch facilities) was carried out in the frame of the Khrunichev/German DASA company ('Astrium' at the current time) collaboration.

This collaboration was realised through the 'Eurockot' Joint Venture establishment as well as the 'Rockot' operation which was being provided by this JV. The most important fact which was concerned with this re-organization was that the 'Rockot' launch vehicle itself was slightly improved in order to be more suitable for commercial launches from the surface launch facility instead of the former launch silo.

So, the current 'Rockot' which is being operated from Plesetsk cannot provide a realisation of the 'quick response' concept to say nothing about the 'responsive access' concept.

However, the former realisation of the 'Rockot's' silo-based version remains to be the only-in-the world example of a 'quick response' concept's silo-based launch system which was adapted very well even for the conditions of nuclear war.

In contrast with the 'Cyclone', this version of the 'Rockot' could provide an urgent launch from a stand-by condition (the maintaining of which was also provided by the launch system) but could not provide an urgent repeated launch from the same silo (the required inter-launch repair of the silo had a duration of no less than two weeks). So, the launch system was really better adapted for the launches of required satellites during a war than for these launches during peaceful times.

Strela

The 'Strela' launch vehicle, the design of which is shown in Figure 3 is actually the UR-100NU (SS-19) ICBM in which the post-boost stage (it was called the 'Aggregate/Instrumental Unit' in the developer's advertising materials) was kept and used as the launcher's third (top) stage. Differences of the 'Strela' from the basic SS-19 are only in the new flight software, an introduction of a telemetry equipment compartment (it was being used with the missile's flight testing examples) and a new larger nose fairing under which an adapter for space payload mating is installed. With this nose fairing, the converted launch vehicle can not be covered with a launch silo's hardened lid and this lid was permanently opened when the 'Strela' was prepared for its first (and single as yet) test launch on December 5, 2003 (see Figure 4). This created certain inconveniences in the launcher's operation (for example, the silo with the installed launch vehicle should be protected by a special removable cover against rains and dusty winds), however, this was actually a 'payment' for the opportunity to use the SS-19's silo without any serious up-gradings.

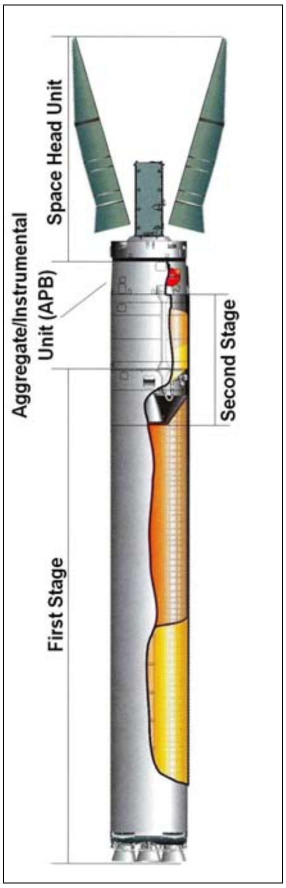

Fig. 3. The design of the 'Strela' launch vehicle

Fig. 4. The 'Strela' launch vehicle in its launch site before a test launch. The open hardened lid of the launch silo is well seen on the left

Not having a powerful upper stage, the 'Strela' can launch significantly less payload mass than its 'half-brother' 'Rockot'. Thus, it could inject around 1000 kg only into a circular orbit with an altitude of

1000 km (the 'Strela's' performance and description of design were given in reference 12) i.e. almost half that of the 'Rockot'. However, the 'Strela's' expected launch price would be significantly less as well: US$ 8.5 mln against around US$ 13 mln for the 'Rockot'[8].

The 'Strela' was tested successfully from a silo in Baikonur but its operation is foreseen from Svobodny where one of the former SS-11 silos which had been supposed to be used for the 'Rockot' (see above) has been almost completely re-constructed for the 'Strela'. The 'Strela' launch system's developer, the Research and Production Association for Machinebuilding (NPOM) have an intention to use later the remaining four launch sites in Svobodny. Besides, a large number of SS-19 launch silos would be available in missile bases since the former START Treaty's prohibition to launch spacecraft by converted launch vehicles from their basic missiles' bases is not in action anymore while the corresponding launch silos are gradually becoming free of their missiles due to the expiration of their lifetimes.

A combination of these circumstances makes the 'Strela' a serious candidate for a realisation of the 'responsive access' concept in Russia in the case of a corresponding demand appearing. This launch system's potential in this regard is assessed in Section 5 below.

Dnepr

The 'Dnepr' launch system which was converted from the RS-36M1 (SS-18) heavy ICBM and is being currently operated beginning from April 21, 1999 by the Russian/Ukrainian 'Kosmotras' join stock company from a single launch silo in Baikonur has its own features, both negative and positive ones in comparison with the 'Strela'. Thus, it has an almost twice the lift-off mass and its higher power potential allows it to inject more payload mass, up to more than 4 tons into LEOs, but this potential would not be realised completely without an introduction of an especially developed upper stage as in the 'Rockot'. Having the same capability as the 'Strela' to provide urgent launches from silos, the 'Dnepr' has to collect a group of small satellites for every commercial launch which is complicating the task of mission arrangement. The 'Dnepr's' developer, the Ukrainian 'Yuzhnoye' NPO intends to introduce this especially developed upper stage in the nearest future. This introduction will expand the launcher's capabilities in regard to various payloads deployment in space, but should increase the launch price.

Probably, the improved 'Dnepr' with this new upper stage would be most suitable for the urgent launches of satellite clusters in the frame of the 'responsive access' concept realisation. However, this concept, in its current understanding does not especially require these group launches.

If these group launches would not be demanded at all or will be very rare, the 'Dnepr' will lose the competition against less heavy launch vehicles with similar capabilities on 'quick response' provision. For this reason, the 'Dnepr' is not assessed in Section 5 below.

Start

The 'Start' family of small launch vehicles includes the 'Start-1' four-stage option and the 'Start' five-stage option (they are shown in Figure 5) which are derived from the Russian 'Topol' (SS-25) solid-propellant ICBM (a history of the 'Start' family development and operation can be found in reference 8 while its brief description and its performance were given in reference 13).

Although no intention to provide a 'quick-response' capability for Soviet missions was taken into consideration when the 'Start' project was begun to be developed in the late eighties, the resulting launch system inherited the specific features of the basic ICBM including that part which could promote the 'responsive access' concept realisation.

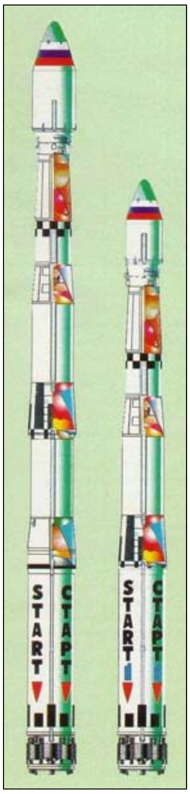

Fig. 5. The 'Start' (left) and 'Start-1' launch vehicles

Besides a high readiness for launch by command which was typical for modern ICBMs (the provision of this readiness for the 'Topol' was simplified with its solid-propellant propulsion units in all of its stages), the 'Topol' was a mobile ICBM that could be transported on its transportation/launch mobile device mounted on a heavy truck with all its supplementary on-ground facilities were mounted on similar trucks as well. A launch of the missile was provided from an erected launch canister by the so-called 'pop-up' method i.e. the missile was pushed out from this canister by a special solid-propellant gas-generator with an ignition of the first stage's engine at an altitude which guaranteed no damage to the transportation/launch device. Of course, the launch canister was damaged significantly but this canister was expendable and could be replaced with the new one (with the new missile inside) within a few hours. The missiles were being installed inside their canisters in the manufacturing plant and could be transported by special heavy trucks following the complex of the mobile transportation launch device and the mobile supplementary facilities which actually formed a 'mobile launch site'.

From the point of view of the 'responsive access' concept, this meant that the derived ''Start' launch system, mostly in the 'Start-1' option, can be delivered to any spot on the globe in order to provide a broad range of available orbit inclinations and an approximation to the launch customer's location. It does not require any stationary launch or technical sites (although it does not provide for the pre-launch preparation of satellite and their mating with the launch vehicles) and, which is important, provides not only a very urgent launch on request but could be quickly prepared for a following launch.

As was shown in reference 5, the 'Start' launch vehicles and, especially, the 'Start-1' have a payload capability which is near to the optimum for the servicing of those potential customers in the worldwide space market who would demand a realisation of the 'responsive access' concept.

The slightly heavier 'Start' option was launched only once from Plesetsk on March 28, 1995 and was not demanded after this as the launch was a failure. It is necessary to note that launches of both the 'Start-1' and 'Start' options from Plesetsk were being carried out from the so-called 'transportable' launch device which was an option of the mobile launch device which was demounted from the truck and installed onto fixed supports. Probably, the longer five-stage 'Start' could be launched from this fixed launch device only. However, this does not decrease the launch system's capabilities for the provision of 'responsive access'.

Rather, any delays in the process of the system preparation for urgent launches would be concerned with the pre-launch preparations of the satellites to be launched since the 'Start-1's' 'mobile launch site' has not any mobile facilities for satellite separate preparation. However, both the Plesetsk and Svobodny spaceports have stationary facilities for this purpose while the technical site in Svobodny is especially adapted for the preparation of payloads for the 'Start' launch system[1].

True, there are plans to mothball the Svobodny spaceport as a whole[14]. However, this information is mostly concerned with the supposed withdrawal of Russian Space Troops military units which are currently servicing the 'Start-1' launches from this spaceport, while further launches of the 'Start' and 'Strela' (see above) would be serviced by their operators' launch crews.

Besides a technical capability to provide not only urgent launches on response (i.e. a meeting of the requirement 1 for the 'responsive access' concept realisation) and a technical capability for the provision of repeat launches within a short period of time, which is a partial meeting of the requirement 2, the 'Start' launch system has a good potential for a provision of the launchers in a necessary number for a complete meeting of this requirement 2, i.e. for these repeat launches. As much as 360 'Topol' ICBMs were deployed in Russia in 1996[10] and they are being gradually replaced with the improved 'Topol-M' ICBM while the decommissioned 'Topol' ICBMs would be converted into the 'Start-1' or 'Start' launch vehicles for their use in the 'Start' launch systems.

This opportunity enables the relatively low level of the 'Start's' launch prices, US$ 8 and 10 mln. for the 'Start-1' and 'Start' accordingly. With these launchers' payload capabilities of 600 and 900 kg, the specific launch prices of about US$ 11,000…12,000 per kilogram of payload are being provided which are comparable with the same value for the U.S. 'Falcon-1'.

Therefore, the 'Start' launch system meets all the requirements for the 'responsive access' concept realisation due to i) a successful combination of the inherited ICBM's capability for an urgent launch from a long-time stand-by condition, ii) operational flexibility provided by the inherited launch/supplementary devices' mobility and capability to be urgently prepared for a repeat launch and of significant reserves of ready basic hardware and iii) relatively low launch prices provided by an availability of these decommissioned reserves at low purchasing prices. The creation of this launch system can be considered an example of the Russian experience on the development of a real ‘responsive access’ concept launch system, although the system’s ‘responsive access’-concerned properties had not been premeditatedly laid down into this specific development.

The competitive potential of the ‘Start’ launch system in regard to meeting the supposed demand in the worldwide space markets is examined in Section 5 below.

Shtil

The ‘Shtil’ small launch vehicle family was developed on the basis of the Russian three-stage liquid-propellant RSM-54 submarine-launched ballistic missile (SLBM) in a few options. However, only the ‘Shtil-1’ and ‘Shtil 2.1’ submarine-launched small space launch vehicles have been realised so far.

The ‘Shtil-1’ is the simplest option which differs from the basic RSM-54 with a replacement of the flight software and with an accommodation of a space payload instead of the SLBM’s warheads (in a very limited zone of accommodation). This ‘Shtil-1’ is being launched from the Russian Navy’s nuclear submarines during the submarines’ training cruises and these launches, which are being serviced by these submarines’ crews, are being considered the RSM-54 SLBMs’ training missions as well.

Due to this ‘combined purpose‘ of the launches, the launch price for the customers is very low. Despite the ‘Shtil-1’s’ low payload capability of 160 kg this provides a good level of specific launch price but, at the moment, the inevitably required coincidence of the booked launch term with the schedule of the Russian Navy’s submarines’ training cruises makes the ‘Shtil-1’ almost completely unsuitable for a realisation of the ‘responsive access’ concept.

However, other options of the ‘Shtil’ family (all the options are shown in Figure 6 and were described in detail in reference 15) were developed with the clearly defined destination of being launched from a surface launch site in the Nenoksa test range which was used for the test launches of the RSM-54 SLBMs (Figure 7).

Any of the options being realised can provide the RAC. Indeed, the RSM-54 SLBM’s are being delivered from the manufacturing plant in a fuelled condition and, therefore, the SLBM’s launch vehicle derivatives require a short time for their pre-launch preparation. Unfortunately, the single test launch facility in Nenoksa cannot provide the urgent preparation of repeat launches even in its operational condition (this facility is currently in a condition which requires much repair).

Fig. 6. The ‘Shtil’ family of launch vehicles converted from the SS-N-23 (RSM-54) SLBM, from left to right: ‘Shtil-1’, ‘Shtil-2.1’, ‘Shtil-2’, ‘Shtil-3’

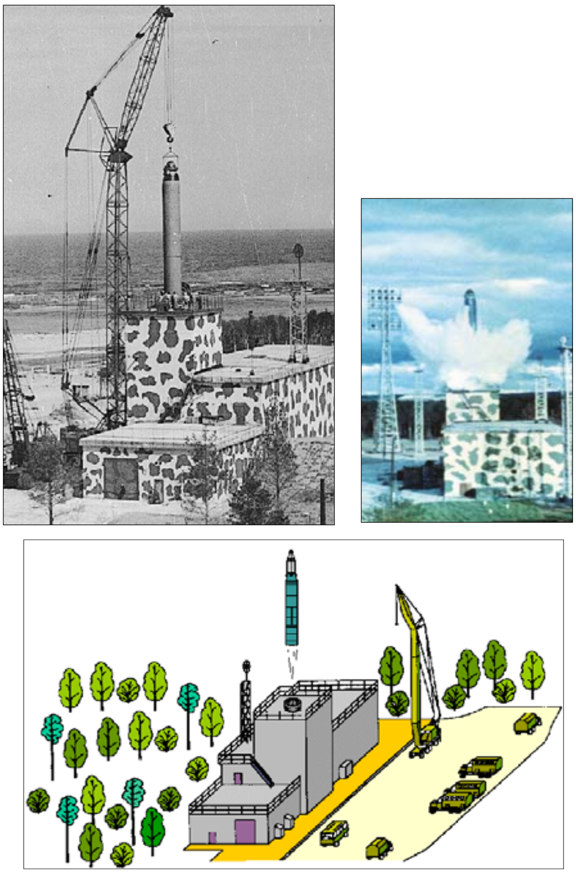

Fig. 7. Nenoksa test range - Ground-based launch complex in Nenoksa (NSK-37)

Shtil 2.1 began operation this year and CST is managing a launch of this variant for the South African government. The satellite is designated ZA-002 and the launch is scheduled for December 2006, albeit also from a submarine.

So, it is premature to estimate any competitiveness of the 'Shtil' surface-based options although they would have a certain potential in the investigated regard if they will be realised themselves and if the launch facility in Nenoksa will be restored, probably, with the introduction of a short inter-launch maintenance capability introduction.

The example of the 'Shtil-1'-concerned experience shows that the adoption of a ballistic missiles' capability to be urgently launched on command ('response') does not always lead to the possibility to use this capability for a realisation of the 'launch on response' concept for those launch systems which were developed on a basis of these missiles.

Zenit

The 'Zenit-2' two-stage launch vehicle development was begun in 1976 in the frame of the Soviet launch vehicle fleet renovation. Despite its first stage being the 'Energia' super-heavy launch vehicle's strap-on booster, the 'Zenit' is actually the first example of a USSR launch vehicle (excluding the preceding N1 super-heavy launch vehicle) which was especially developed for space purposes and not derived from a ballistic missile.

However, the creation of the 'Zenit-2' (the digit in the launcher's appellation shows the number of stages as in the 'Cyclone-3' appellation) pursued a military-concerned task nevertheless. This task was the same one which was solved earlier with the 'Cyclone' launch vehicles i.e. the realisation of the capability to deploy urgently a constellation of military-purpose satellites within a period of any serious international conflict or during a pre-war period. This meant that both the launch vehicle and, especially, its on-ground technical and launch sites had to provide an urgent preparation of the launch with a certain repetition of this launch within a short period of time.

The necessity to have a heavier launch vehicle than the 'Cyclone', which already provided the same capability, was stipulated by those payloads which required this 'urgent launch on request'. The first of them was the 'Tselina' elint satellite in a few different options. Although the 'Tselina' series' first satellite ('Tselina-O') was being launched by the 'Cyclone-3', its flight testing showed that the composition of the on-board equipment should be expanded and its instruments and units should be improved in order to meet the requirements for the provision of global electronic intelligence both on land and sea. The absence of an advanced electronic element base in the FSU led to an increase of the satellite mass and even the available 'Sojuz' launch vehicle with its payload capability of around 5-6 tons was not suitable for these launches, to say nothing about it not having the capability to be urgently launched on request.

The second supposed payload would be the 'Zarya' reusable manned spacecraft which was being developed in the Central Design Bureau for Experimental Machinebuilding (TsKBEM, Design Bureau of the 'Energia' RSC at the current time). This spacecraft which was intended mostly for servicing the FSU's manned orbital stations should provide rescue missions in the cases of necessity and, therefore, would be launched on response.

Currently, the 'Zenit-2' is being operated with a very low rate of launches from a single launch facility in Baikonur (the second launch facility was destroyed in the process of the 'Zenit's' flight tests). This sole launch facility as well as the remaining on-ground structure retain the capability to provide rather the 'quick response' than the 'responsive access' since the greater share of the 'Zenit' production in the 'Yuzhmash' Plant is being delivered for the provision of the 'Zenit-3SL' launcher's operation in the frame of the 'Sea Launch' international company's activity.

Another, more recent 'Land Launch' project which is at an early stage of realisation at the present time would keep the 'Zenit-2's' capability of 'quick response' for its 'Zenit'-based launch vehicles which are foreseen in both two-stage and three-stage options. This project is based on a use of the 'Zenit-2's' launch site in Baikonur[16].

However, even in the case of the 'Land Launch' project realisation with a keeping of the 'Zenit-2's' capability for 'quick response' provision, this improved launch system will inherit the main shortcoming of the 'Zenit-2' in this regard. This shortcoming is the too high payload capability of the launch vehicle which is quite unsuitable even for the deployment of most constellations since a great number of small satellites should be collected together for one launch in order to economically justify this launch.

Therefore, the 'Zenit-s' launch system can be referenced as an example of the 'responsive access' realisation for the times when the satellites to be urgently launched were heavy ones and which has become unsuitable for this purpose when the satellites to be launched are small ones. However, the main concepts and technical solutions which were laid down into the ‘Zenit-2’s’ design and, especially, its launch site would be adopted for the developments of new, smaller launch systems for the ‘responsive access’ concept realisation, especially, for those which will use liquid-propellant (including cryogenic) propulsion.

Angara

The ‘Angara’ launch vehicle family which is being realised by the Khrunichev Space Center includes, beside the ‘Angara-5’ heavy option and the ‘Angara-3’ medium option, two options of the small class, the ‘Angara-1.1’ and ‘Angara-1.2’ (see Figure 8). While the heavier ‘Angara-3/5’ are being realised in the first turn, the smaller options would be realised nevertheless later, supposedly around 2010, since they will not require the construction of a separate launch site (all of the family’s launch vehicles should use a single launch facility which is being currently built in Plesetsk).

This launch site in Plesetsk was reconstructed from a former launch site for the ‘Zenit 2’ the construction of which had been begun even in USSR times. One of the requirements of the tender for the ‘Angara’ development was that the new launch vehicle would use the ‘Zenit’s’ launch site with minimum up-gradings[17].

This requirement gave a reason to suppose that the ‘Angara-1.1/1.2’ would become the ‘Zenit-2’s’ diminished derivatives which would have the same capabilities for the ‘responsive access’ realisation but with less payload capabilities and which would therefore mean their greater suitability for this concept realisation.

However, this supposition has not been confirmed. In the process of gradual mutual adaptation of the family’s main option, ‘Angara-5’ and the launch site which was being built for it, the launch site including its launch facility was changed significantly and certain features of the former ‘Zenit’s’ facility were lost. It is possible to consider now that the launch site in Plesetsk has only a bit of mutual similarity with the ‘Zenit’s’ launch site.

The technology of the ‘Angara-1.1’ pre-launch preparation will be somewhat similar to the preparation of the current ‘Rockot’, since both these launchers have the ‘Breeze-KM’ upper stage as their top stages This upper stage is prepared separately in a technical site and is mated separately with the payload to be launched. This technology does not provide for an urgent preparation of the launch system as a whole. The preparation process for the ‘Angara-1.2’ with its new URM-2 second stage is as yet unknown. However, it will be similar i.e. it will not provide urgent preparation either.

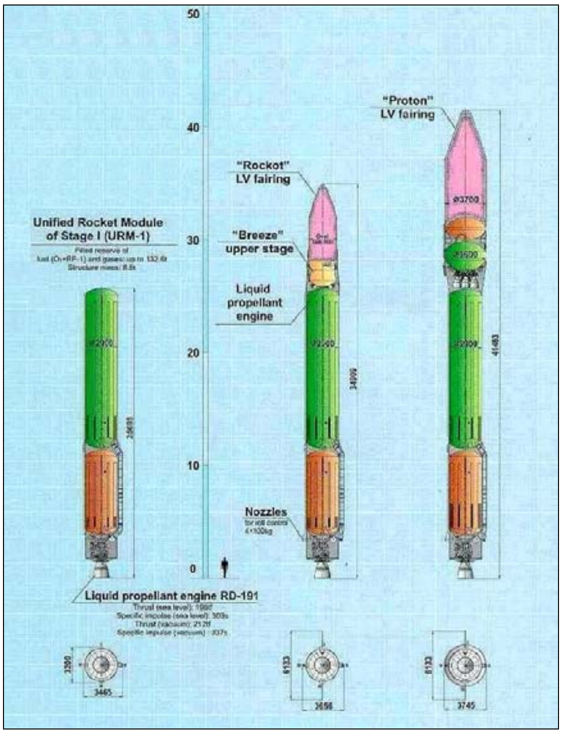

Fig. 8. Designs of the URM, ‘Angara-1.1’ and ‘Angara-1.2’(left to right)

Therefore, the adoption of the ‘Zenit’s’ experience for the ‘Angara’ development is one more example, besides the ‘Rockot’, of how the basic launch systems, which had been initially developed for a provision of the ‘responsive access’ capability have lost this capability in the process of their up-grading for normal commercial operation.

Air Launch

The ‘Air Launch’ project which is being currently developed by a consortium of Russian companies on a private basis beginning from 1997 and the ‘Ishim’ project which was begun to be developed at the same time but has received some real support in late 2005 are attributed to the launch systems that use an ‘air launch’ concept. This feature gives ground to suppose their suitability for the ‘responsive access’ concept realisation (the U.S. RASCAL programme is based on the use of the same concept as well, see Section 3).

Indeed, a carrier aircraft of an air-launch system could be prepared within a relatively short time for the flight in which the launch should be carried out while it would provide a broad range of launch azimuths, i.e. realised orbit inclinations due to the flexibility of its flight routes. However, the same cannot be said about the preparation of the used launch vehicle before its loading into the aircraft (or suspension under this airplane). Besides, the aircraft cannot take more than one launch vehicle and its return back to the airfield plus the time of its inter-flight maintenance would require tens of hours i.e. the system's readiness for the next launch cannot be less than this total time even if the next launch vehicle will wait for this carrier aircraft while this launch vehicle will have to be prepared in advance.

Therefore, a use of the 'air launch' concept does not guarantee by itself the suitability of a launch system for the 'responsive access' provision. The design of the launch vehicle and its process of preparation before loading into the carrier aircraft (but not the process of pre-launch preparation onboard the aircraft!) are important influential factors as well. The 'Air Launch' and 'Ishim' launch systems differ significantly not only in these two factors but even by the classes of carrier aircraft. The 'Air Launch' project including its evolution in the process of development was described in detail in reference 8. The final version which recently received an organizational (but not financial!) support from the Russian Federal Space Agency (Roscosmos) is based on the use of the An-124 'Ruslan' heavy cargo airplane as a carrier aircraft from which the especially designed 'Polyot' liquid-propellant launch vehicle should be pushed out in a launch container that should be braked and turned into a launch position by a parachute system.

This two-stage launch vehicle designed by the Makeev SRC should use cryogenic propellant (liquid oxygen/kerosene) in both of the stages. While this chosen design provoked a serious criticism for its doubtful suitability for long-time transportation by air in a fuelled condition and for its problematic capability to withstand g-loads during the pushing-out and the turn-around in the air (see reference 8), the launch vehicle would also have serious obstacles for its application to the 'responsive access' realisation.

One of these obstacles is that the system should have a sufficiently powerful on-ground facility for fuelling with liquid oxygen. This facility should have the capability for an urgent fuelling operation and, besides, should have the capability to provide the next fuelling of the following launch vehicle after a period of time which is defined by the time of the carrier aircraft's readiness for the next flight. In turn, the heavy An-124 cannot be prepared for this next time urgently, its interflight maintenance requires no less than one day, especially after a flight at maximum range with a complete consumption of on-board fuel stocks.

However, the main obstacle is the 'Polyot' launch vehicle's expected payload capability. This payload capability for LEO should be at the level of 3-4 tons which is comparable with the payload capability of the 'Cyclone'. This parameter makes the 'Cyclone' unacceptable for the provision of 'responsive access' in the current conditions when the too high payload capability is expected to be mostly unclaimed for even multi-satellite launches (due to the difficulty in collecting a number of small satellites for a single launch) to say nothing about dedicated launches of single small satellites by a launch vehicle with an excessive payload capability (the specific launch price would be too high in this case).

Ishim

The most recent 'Ishim' project is being currently developed on the order of Kazakhstan and will be the property of this country. However, the project is being developed by Russian companies on the basis of Russia-owned technologies and experience and the resulting launch systems will be operated, apparently, with Russian technical assistance. Moreover, this system could be repeated simply for Russian national needs or even for commercial use by Russian operators. For these considerations, the 'Ishim' project is included in this report as an evident example of the most recent Russian developments in the investigated field.

The 'Ishim' project is based on the earlier development of the MiG-31 heavy fighter-based launch system for an anti-satellite purpose which had been ready for tests before the USSR collapse. The 'civil' derivative of it is the 'Converted Contact'[8]. This 'Converted Contact' project was proposed by the MiG aviation company in 1998. The solid-propellant launch vehicle for this launch system had to be developed by the 'Vympel' Experimental Design Bureau (OKB) which was one of main developers of the FSU anti-aircraft missiles and had been, apparently, the developer of the anti-satellite missile for the project's most early version[18].

However, this project found neither state support, nor commercial customers at that time. The project has been changed in recent times by a replacement of the 'Vympel's' two-stage launch vehicle with another solid-propellant launcher to be developed by the Moscow Institute for Thermal Technology (MIT) which had been the developer of the 'Topol' ICBM and 'Start' launch vehicle family. The MIT also became the prime developer of the project.

The project was presented to Prime Minister of the Kazakhstan Republic on March 2005. Kazakhstan was searching for potential directions for the country's future space activity, this aspiration was grounded, besides certain practical considerations, with the location of the Baikonur spaceport in Kazakhstan's territory which has provided the country with the nominal status of a 'space state' and this status had to be kept, proceeding from considerations of the country's international image. Besides an order for their own 'KazSat' communication satellite and the establishment of the Russian/Kazakhstan 'Baiterek' project (a deployment of the operation of the 'Angara-5' heavy launch vehicle's option from Baikonur), the Kazakhstan's government considered that a certain simpler launch system for the launches of small satellites would be useful for a quick transformation of their country into a real 'space power'.

The MIT/MiG project promised this opportunity and a contract for this project development/realisation was signed by the Kazakhstan's government with the MIT in late 2005[19].

An additional argument for this contract signing was that Kazakhstan had inherited two MiG-31D aircraft after the collapse of the Soviet Union. These aircraft were especially up-graded for the role of carrier aircraft for the above-mentioned anti-satellite missile. (Both of these aircraft were, apparently, at the Sary-Shagan test range in Kazakhstan where they had been prepared for the beginning of the anti-satellite system's flight testing).

The contracted project received the 'Ishim' appellation ('Ishim' is the name of one of the rivers in Kazakhstan). The total cost of the contract was about US$ 144 mln. Flight tests of the 'Ishim' launch system should be begun in 2007, apparently from the Sary-Shagan test range where the system would be based for its operation after the testing completion[20].

The MiG-31D should be up-graded into the MiG-31I option, a model of which with a suspended launch vehicle was shown in February 2006 at the 'Asian Aerospace 2006' Airshow in Singapore (this model is shown in Figure 9). Besides this air-launch component, the 'Ishim' launch system should include the on-ground facilities for the preparation of the launch vehicles and their payloads and a flying command/tracking station-aircraft to be developed on the basis of the IL-76MD cargo airplane[20]. (This concept of a 'flying command/tracking station' had been already proposed in the 'Diana-Burlak' project where it was adopted from the practice of cruise missile flight-testing.)

The three-stage solid-propellant launch vehicle which is being developed by the MIT on the basis of the 'Start' launcher's technologies should have a launch mass of 10.3 tons, a total length of 10.76 m, a diameter of 1.34 m and the following dimensions of the payload accommodation zone: a length of 1.4 m and diameter of 0.94 m. Being launched from the MiG-31I at an altitude of 15-18 km with a speed of 2120-2230 km/h, this launch vehicle would inject a payload with a mass of 160 kg into a circular LEO with an altitude of 300 km and inclination of 46º (or 120 kg into an orbit with an altitude of 600 km). The take-off mass of the MiG-31I with the suspended launch vehicle has to be 50 tons, its range to the launch point has to be 600 km[20].

Fig. 9. A model of the 'Ishim' launch system's MiG-31I carrier aircraft with a suspended launch vehicle

The 'Ishim' launch system would provide a broad range of orbit inclinations including polar and equatorial planes for orbits, especially, if the system will be based at the territories of foreign countries (common airfields of first class will be suitable for this purpose)[20].

Due to the use of a solid-propellant launch vehicle which will not require a long time for its on-ground preparation and which would be stored in a number of almost ready examples near to the used airfield (the Sary-Shagan test range has both a suitable airfield and corresponding storehouses) as well as, thanks to the use of the carrier aircraft on the basis of fighter (for which a short-time for inter-flight maintenance is a typical feature), the 'Ishim' launch system would provide a meeting of the first two requirements for the 'responsive access' realisation (see Section 2 above).

Regarding the third requirement, which is concerned with the provision of minimum specific launch prices, it is possible to make a supposition only since the values of launch prices for the 'Ishim' have not been yet announced.

It is supposed in numerous sources, see for example reference 18, that the maximum specific launch price which can be paid by 'civil' launch customers is around US$ 10,000 per kilogram of payload. In this case, the total price for an 'Ishim' launch would be no more than US$ 2 mln which seems to be too low for the especially developed launch system with its significant expenditures for development. It is possible to suppose that this launch price would be rather at the level of US$ 3-4 mln. This means that the specific launch price would be around US$ 20,000…25,000 per kilogram which exceeds the values which were recognized as acceptable for a realisation of the RAC. However, with this specific launch price level, the launch system would be found to be uncompetitive in the worldwide market of launch services even for the provision of common launch missions. Therefore, Kazakhstan's owners-operators of the system will be forced to lower this specific price down to the above-mentioned level of US$ 10,000 per kilogram, at least, even at the expense of their profit, especially taking into consideration Kazakhstan's aspiration to enter this market independently from any other countries.

Hence, this specific launch price of US$ 10,000 per kilogram can be assumed as the value which would be offered for launches in the frame of 'responsive access' concept realisation. This value, although exceeding the supposed level of specific launch price which was laid down in the RASCAL programme is less than the value which would be offered by the 'Falcon-1' small launch vehicle.

It is possible to see one more advantage of the 'Ishim' launch system in regard of the 'responsive access' provision. The system's low payload capability makes it most suitable for the dedicated launches of small satellites with masses which do not exceed 150 kg, while the small satellites of this class are being assumed as the most probable candidates to be launched in the frame of the concept realisation[21]. At the same time, these satellites would be launched for this purpose mostly one at a time i.e. in dedicated launches.

The above-given considerations, together with the high probability of the 'Ishim' launch system project realisation (the corresponding items of expenditures were already laid down in the Kazakhstan state budget for 2005-2007[20]) create a ground for the further examination of the system as a potential competitor in the case of the arising of a demand for the 'responsive access' provision in the worldwide market of launch services.

5. THE COMPETITIVE POTENTIAL OF RUSSIAN LAUNCH SYSTEMS

It would seem that three Russia-developed launch systems, 'Strela', 'Start-1' and 'Ishim' are potential competitors in the world's market of launch services in the case of a demand arising for the realisation of the 'responsive access' concept on a commercial, or at least civil, basis.

Cases of the concept realisation for the deployments of military-purpose satellites in the interests of the country-launch system developer or on the order of that countries-allies are beyond the frame of this report. Therefore, those foreign launch systems which are being developed for the 'responsive access' realisation for military purposes only, such as the U.S. RASCAL programme's ones and French RLS, or those systems which are being already in operation but cannot be used for commercial launches, for example, the U.S. 'Minotaur' are not assessed as foreign competitors for the chosen Russian launch systems. Actually, only the U.S. 'Falcon-1' can be currently assessed in this capacity. However, it can be even more important to estimate the competitiveness of the chosen Russian systems between themselves as well as with the Falcon-1.

The chosen launch systems present three different methods of launch: the silo-launched 'Strela', the 'Start-1' which is being launched from a mobile launch device, and the air-launched 'Ishim'. Each of these methods have their own advantages and shortcomings in regard to the 'responsive access' realisation.

Thus, the silo-launch method can provide a 'quick response' i.e. a very urgent launch on response, however, it cannot provide the next (repeat) launch from the same silo. The task of numerous launches on request with certain intervals but not the simultaneous launch of a few satellites in a cluster launch would be solved for this launch method by the use of a few silos with ready launchers which are already installed in these silos. This method cannot be used for launches from a foreign customer's territory. The range of realised orbit inclinations is also limited (it is defined by the location of the silo).

The method of using a mobile launch device can provide a 'responsive response' in all the regards including launches from a customer's territory. However, the range of realised orbit inclinations is limited as well although to a lesser degree than for the launches from silos since the point of launch is a fixed one for each of the ordered launches (these points in the customers' territories would not provide launches into desired orbit inclinations in certain cases).

The air-launch method expands this range significantly (in limits which are defined by the available range of carrier aircraft) while the time for the next launch provision, which is defined by the duration of the carrier aircraft's back flight and the aircraft's inter-flight maintenance and not only the readiness of the next launcher for suspension under the aircraft plus the duration of the aircraft flight to a launch spot would be more than for the method of launch from a mobile launch device.

Lastly, the method of launch from a stationary surface launch facility which is used for the U.S.

‘Falcon-1’ launch system is somewhat intermediate between the silo-launch method and a launch from a mobile launch device. Launches are from a fixed location as for the silo launches but the process of next launch preparation requires significantly less time, however, this process duration is longer than for the ‘Start-1’ mobile launch system in which a launch container that has been used for a preceding launch could be urgently replaced with a new launch container with the installed launch vehicle. Perhaps, the duration of this process for the ‘Falcon-1’ can be comparable with the duration of the next launch preparation for the air-launched ‘Ishim’. The existence of a fast-mounted launch facility for the ‘Falcon-1’ (the same type of launch facility was developed for the U.S. ‘Taurus’ small launch vehicle) would provide athe capability of launches from foreign customers’ territories and expand the range of realised orbit inclinations. However, the mobile ‘Start-1’ and, moreover, the air-launched ‘Ishim’ will have evident preferences in this regard.

On the basis of this brief analysis, it is possible to make a preliminary conclusion that, of these four compared launch systems, the ‘Start-1’ and ‘Strela’ would meet the requirement 1 for the ‘responsive access’ concept realisation in the best manner i.e. they would launch the ordered satellites within the shortest time after a request for its launch (this time will be defined by the time to be required for the pre-launch preparation of the satellite itself and does not require any additional time even for the launch vehicle fuelling). The ‘Ishim’ is at the third position since, although its launch vehicle could be prepared during the same time as the ‘Start-1’, the carrier aircraft should spend an additional time for this launch vehicle delivery to a launch spot. The ‘Falcon-1’ is at the last position since its fuelling can be carried out only after the payload mating while the technology of urgent fuelling (for example, as in the ‘Cyclone’ and ‘Zenit’) is not used in its launch site.

In regard to this requirement’s additional assumed statement i.e. to provide as wide as possible range of realised orbit inclinations (in order to provide a broad suitability of the launch system for the various missions to be demanded) and to provide the capability of launches from customer territories, the ‘Ishim’ has an evident preference, the ‘Start-1’ is inferior to it but has a significant preference over the ‘Falcon-1’ (in the case of a quickly erected launch facility and use). The ‘Strela’ is at a last position since it can provide only that range of inclinations which is defined by the location of its fixed launch suite.

A meeting of the requirement 2 i.e. the provision of a capability to carry out the next launch (launches) within a short time after a preceding launch completion (this is actually the condition which defines a ‘quick-response’ launch system to be a system for ‘responsive access’) can be fulfilled by the investigated launch systems in the following consequence of occupied positions which depend on the durations of times to be required for the next launch preparation: the ‘Start-1’ at the first position, the ‘Falcon-1’ and ‘Ishim’ would share the second-third positions while the ‘Strela’ is at the worst position since it would meet this requirement in a certain volume only by the existence of a few loaded launch sites.

Besides the investigated launch systems’ features which are defined by the launch method used and on the basis of which the estimation of the launch systems’ ranking is made above, there is also one more technical parameter that is concerned indirectly with a meeting of the requirement 3 (the provision of a minimum specific launch price) for each of the systems. This parameter is a payload capability.

Indeed, even if a launch system provides a low specific launch price but its payload capability is significantly higher than that value which can be forecasted as an optimum one for the supposed market’s demand, this low specific price would never be realised in the corresponding missions since the launch vehicle will be used with an incomplete payload while the launch price will be fixed in any case.

As shown in reference 5, this optimum payload capability would be at the level of around 500 kg for a standard orbit with an altitude of 200 km and with an inclination of 28º. This value is in correspondence with the ‘Falcon-1’ payload capability while the same parameter for the ‘Start-1’ is also approximately the same. Therefore, both of these launch systems would be suitable for a complete use of their payload capabilities in the case of ‘responsive access’ missions and their specific launch prices which are calculated on a basis of their maximum payload capabilities can be used for a comparison of these launch systems capability to meet the requirement 3.

The ‘Ishim’ should have half this optimum payload capability. This means that this launch system would miss a share of the available payloads which will be intended for launches in the frame of the supposed ‘responsive access’ concept realisation but will be heavier than the top limit of the

Table 1. Comparison of the investigated launch systems by requirements, parameters and features which are concerned with the systems probable use for the RAC realisation

Requirement or parameter, feature	Launch systems (ranking position by every the item)				Notes
	'Strela'	*'Start-1'*	*'Ishim'*	*'Falcon-1'*	
1. Capability to provide an urgent launch on response	Within no more than 1 hour (1-2)	Within no more than 1 hour (1-2)	Within no more than 2-3 hours (3)	Within no more than 3-5 hours (4)	-
2. Capability to provide the launches from customers' territories	Absent (4)	Provides with low expenditures (2)	Provides with minimum expenditures (1)	Can provide with certain expenditures* (3)	*In the case of quickly-mounted launch facility use
3. Range of realised orbit inclinations	Fixed, defined by the launch silo location (4)	Broad (2)	Most broad (1)	Broad* (3)	*In the case of quickly-mounted launch facility use
4. Capability to urgently provide the next launch (launches)	Low, within a week* (4)	Very high, within a few hours (1)	Sufficiently high, within a day (2-3)	Sufficiently high, within a day (2-3)	*Would be enhanced by a use of a few launch silos
5. Payload capability's correspondence to optimum (most probable) value	Oversized by three times (4)	Corresponds (1-2)	Less by two times* (3)	Corresponds (1-2)	*Nevertheless, corresponds to the expected mass of certain number of satellites to be launched
6. Specific launch price (US$ per a kilogram)	18,000* (3)	12,000-16,000 (2)	10,000-15,000** (1)	18,000-20,000 (4)	*Calculated for the payload mass of 500 kg **Supposed value
Total ranking position	***3***	***1***	***2***	***4***	**-**

'Ishim's' payload capability. However, all of the 'Ishim' launches which would be carried out in the frame of the concept realisation can be considered to be completely loaded and the launch system's assumed specific launch price can be used for a comparison as well.

In contrast with the 'Ishim', the 'Strela' has its maximum payload capability of three times more than the optimum value. This gives grounds for a supposition that this launch system could be used for all the 'responsive access' missions, but its specific launch price for a majority of these missions can be considered to be three times more than the value which is calculated proceeding from the launch vehicle's maximum payload capability. At the same time, it is possible to take into consideration a small additional preference of the 'Strela' system that it, the only one among the investigated systems, could be used for the simultaneous injections of a few 'responsive access' concept's small satellites with masses of up to 500 kg each in a cluster launch.

So, the 'Start-1' and 'Falcon-1' can be compared with regard to meeting requirement 3 by their calculated specific launch prices, the 'Ishim' can be compared by its supposed specific launch price, while the 'Strela's' calculated value should be multiplied by three for this comparison. The resulting values per kilogram are US$ 12,000-16,000 for the 'Start-1', US$ 10,000-15,000 for the

'Ishim', US$ 18,000-20,000 for the 'Falcon-1' and US$ 18,000 for the 'Strela'.

A comparison of these values shows that the 'Ishim' would exceed other launch systems in regard to a lower offered specific launch price. However, this system's value is rather assumed than calculated (see above). Among the other systems, the 'Start-1' has a certain preference while the 'Strela' is at approximately the same level as the 'Falcon-1' despite the value for the 'Strela' being calculated with a taking into consideration of the correction for its high (non-optimum) payload capability (see above).

All the advantages and shortcomings for the investigated launch systems are summarized in Table 1 below in order to make a final comparison.

This comparison Table shows that the Russia-developed launch systems would have a significant preference over the U.S. 'Falcon-1'. This preference is stipulated by their readiness for a launch on response which is provided by an adoption of their basic prototypes (ballistic missiles) corresponding capabilities, with their lower specific launch prices which are provided by the opportunity to use decommissioned military hardware, and by a smaller size of launch vehicle (for the 'Ishim') or with more flexibility in the change of launch sites (for the 'Start-1' and 'Ishim'). Besides, the 'Start' was shown to be in almost complete accordance with the optimum value of payload capability which was defined for the supposed demand for the 'responsive access' concept realisation.

The above-made conclusion about the high competitiveness of the Russian launch systems has no regard to the main purpose of the 'responsive access' concept which is concerned with military satellite missions (although the analysis as performed would be useful for the assessment of the Russian potential for using these launch systems for certain of its own 'responsive access' military-purpose space systems). However, this conclusion shows that evidently the current Russian launch systems which were and are developed on the basis of missiles technologies are found to be suitable for a realisation of the 'responsive access' concept despite their present developments not pursuing this goal.

At the same time it should be noted that the preceding FSU experience on the development of those launch systems which were directly specialized for the provision of actually the same concept has not been used in the Russian launch systems which are found to be suitable for the concept realisation in the current conditions. However, this experience would be used for those launch systems, both Russian and foreign ones, that would be especially developed for this purpose, especially if these systems will use liquid-propellant launch vehicles. An example of this experience's supposed application would be an improvement of the current 'Falcon-1' launch system in order to enhance its competitiveness against the 'Start-1' and 'Ishim'.

6. CONCLUSIONS

1. A few launch systems to be intended for a realisation of the basic principles of the current 'responsive access' concept were developed in the former Soviet Union (FSU) and the gained experience is at the disposal of Russian space companies.

2. The developed launch systems, 'Cyclone', 'Zenit' and 'Rockot' could realise the laid-down principles but cannot be used any more for a realisation of the concept in its current definition due to either an oversized payload capability (the 'Cyclone' and 'Zenit'), or a transfer to the use of another type of launch site and changing the technologies of pre-launch preparation (the 'Rockot').

3. Three current Russian launch systems, all of which are based on missiles technologies, are found to be suitable for the concept realisation in the current conditions. There are the operational 'Start-1', the 'Strela' which has begun its flight testing and the 'Ishim', a project which is being developed by Russian companies on Kazakhstan's order. The 'Start-1' and 'Ishim' would become serious competitors against foreign launch systems that either are already developed (for example, the U.S. 'Falcon-1'), or would be developed especially for the 'responsive access' concept realisation.

4. A certain share of the experience which was gained in the FSU in the field of liquid-propellant launch systems for the 'responsive access' provision could be adopted by foreign developers of the same type of launch systems, for example, for an improvement of the 'Falcon-1' launch system in order to enhance its competitiveness.

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