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Possible Directions for a New Era of Space Activities

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POSSIBLE DIRECTIONS FOR A NEW ERA OF SPACE ACTIVITIES

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Abstract

With the end of the cold war, the justification for government expenditure on space activities has fallen sharply, and government-funded space programs in most countries are being reduced. Consequently, if new commercial markets are not found, the space industry is likely to shrink rather than expand in the future.

Reducing the cost of space activities substantially will be essential to increasing the participation of commercial companies. In order to achieve this, fully-reusable launch vehicles need to be developed. However, in order to justify the development of such vehicles it is necessary to identify new commercial markets with the potential to grow substantially. The paper reviews a range of possible future activities in space and the demand for space transportation which they might create, and considers how the development of reusable space transportation might be advanced.

Introduction - a New Era

With the recent collapse of the cold war regime, the environment of space development activities is changing rapidly. In addition, 1992 which was celebrated as "International Space Year" was the 35th year after the launch of the first artificial satellite, Sputnik. Thus the space industry's 36th year seems an appropriate time to be considering the basis of a future "new era" of space activities.

During the cold war era space activities, and particularly manned space activities which were not justified on a purely functional basis, showed a number of characteristic features.

National prestige and national security. An important reason for taxpayer funding of space activities was that they were popularly perceived as evidence of a nation's strength.

Leadership by dominant countries. The two super-powers' space budgets and capabilities were an order of magnitude greater than their allies', who followed their lead in establishing their own space objectives.

Government initiative. The great majority of space industry activities, and essentially all crewed activities, were carried out for governments.

With the end of the cold war, the justification for government expenditure on space activities has fallen sharply, and government-funded space programs in most countries are being reduced. Thus the pattern of space activities around the world is likely to change in the coming years. In particular we can expect that in future space activities will show a number of features different from those seen hitherto.

Internationalization / Globalization. Activities will increasingly be the product of genuine partnerships between organizations in different countries - in contrast to the earlier model of "follower" countries participating in "leader" countries' projects.

Civil / Economical. With the reduction in cold war funding, government space budgets will be smaller, projects will have to be justified according to their usefulness for civilian application, and they will be selected according to their cost-effectiveness.

Cooperative joint efforts. For all but the smallest projects, work will increasingly be performed jointly in several countries as occurs in business, as well as in other fields of technological and scientific research.

Earth / Space environment as key factor. Earth's environment and its relation with the surrounding environment of space will be a major theme of future space research.

In addition to geo-political changes, the global economic environment has changed in recent years. In particular, as more countries achieve rapid industrial development global commercial competition is stronger, and countries must be more active in continually restructuring their economies. As government budgets in most of the richer countries are under pressure, if the space community is to grow, it must find new directions for future space activities. In line with fundamental trends in the world economy, the space industry will increasingly depend on international cooperation (1).

Any future funding for space activities must come from either the private sector or the government sector. That is, income must be received from the general public either as willing customers buying goods and services from the space industry, or as taxpayers paying for projects chosen by politicians. (Military activities are not discussed in this paper.)

Overall, both private and government space activities will grow significantly only if their costs are reduced substantially. Furthermore, only fully-reusable launch vehicles can reduce costs low enough for space activities to become normal commercial activities with wide markets, like commercial aviation. However, like any vehicle, in order to develop a reusable launch vehicle, a specification is needed. And in order to decide the specification it is necessary to determine the market for the vehicle.

In addition, unless markets which have the potential to grow many times larger than existing launch markets can be identified, the development of a fully reusable launch vehicle is difficult to justify. Consequently in the following we look at some possible future markets for launch that may have the potential to grow many times larger than present launch demand.

In order to do this it is useful to clarify the distinction between "primary income" and "secondary income". "Primary income" is income for space activities that is received from Earth, that is payments by people and organisations on Earth in exchange for goods and services provided on Earth, such as the sale of a chemical product manufactured in space. "Secondary income" is income earned by services performed in space, such as provision of some equipment to the operator of a space station.

It should be noted that primary income is the net income of the space industry. Secondary income is redistribution of primary income within the industry, not an addition to the overall income, at least until space activities reach the stage of development where people are living and using their incomes in space. Primary income is therefore the necessary foundation to enable space activities to grow. Unless new sources of primary income are developed, the space industry cannot grow significantly.

Future space activities

It is not possible to predict the growth of future space markets precisely. Nevertheless it would seem to be a reasonable objective to try to achieve approximate agreement within the space industry about some of the potential markets that would open up as the price of launch fell, and in particular on their likely order of magnitude. Without some such agreed view of future possibilities it will be difficult for the space industry to justify investment in reusable launch vehicles.

Commercial activities

As consumers, the public currently purchase some services from the space industry - notably telecommunications, broadcasting and remote sensing services. Unfortunately the prospects for growth of these markets are rather poor.

Fixed-link telecommunications and broadcasting via satellite are not likely to grow very much due to the growing competition from optical-fiber cables. These provide a better service than satellites, because they are more secure, are interference-free, have high capacity, and suffer no time-lags.

For mobile communications, land-based cellular networks are generally more cost-effective than satellite systems because the investment required is much less than for satellite systems. Consequently it may be difficult for a system such as the proposed "Iridium" to become commercially profitable without government subsidy.

Navigation systems based on GPS are now reaching the consumer market, and sales of ground systems may well grow large. However, investment in a new space system would seem unlikely to be necessary.

Earth observation services are a growing market, but a specialized one and do not seem likely to grow into a significant consumer market.

Solar power satellites.

The world electricity market is very large, with annual revenues of some 50 trillion Yen. If economic growth leads to the present average electricity supply in advanced countries of 1 kilowatt of capacity per person becoming the norm around the world, some 10,000 Gigawatts of electric power generating capacity will be required in the 21st century.

Solving this "energy problem" is unquestionably the outstanding challenge facing humankind today, since no source of energy used today has the potential to provide electric power on such a large scale. In addition, the "energy problem" is inextricably mixed with the "environment problem" and the "population problem" which must also be solved if we are to achieve environmentally sustainable economic growth for the whole world population (2).

Whether SPS can contribute a significant share of this energy is of course a controversial subject, with figures as eminent as Ruppe claiming that it is unrealistic (3). However, until further research is carried out we cannot know whether this is correct. SPS work in Japan, including particularly the "SPS 2000" pilot plant project promises to produce very useful data on this (4). In addition, the recent promotion of SPS research in Japan to become a "Ka-ken-hi", or national research project of the Ministry of Education (5), shows recognition of the long-term potential of SPS.

It should also be noted that the successful development of SPS would generate a very large and growing primary commercial income for the space industry, which would finance the development of extensive space manufacturing infrastructure. It would thereby definitively open the space frontier, and enable human economic activities to expand indefinitely with less environmental stress on planet Earth. It could also lead to the exploitation of extra-terrestrial mineral resources, funded not by government but by commercial revenues earned from large-scale electricity sales on Earth.

However, the space industry has not been effective to date in promoting this idea. Proposed as long ago as 1968, delivery of electricity from space has still not been demonstrated; SPS 2000 seems likely to be the first case. Furthermore, space industry researchers have not been very successful in achieving agreement on future scenarios. For example, a scenario including development of SPS based on the assumption that launch costs fall to $100 per kg is described in (6). However, the figures quoted are inconsistent with current electricity supply and cost figures, and the estimate of the market is too small by an order of magnitude. By contrast O'Neill quotes figures for global electricity supply that are also incorrect by an order or magnitude but in the opposite direction (7). If the space industry is to be considered as a serious candidate for electricity supply, it must clearly do better than this.

The development of SPS for supply of electricity to Earth would certainly lead to a very high demand for commercial space transportation. However, this will not arise within the near future, and its potential is therefore not yet sufficiently clear to develop a detailed launch vehicle specification.

Tourism.

In April 1993 the Japanese Rocket Society started a formal study of space tourism, that is of the prospects for a commercial business offering short flights to orbit for fare-paying passengers (8). This is the first such study to be performed. The attraction of space tourism is that it appears to have the potential to grow to create a large demand for launch, of the order of a million passengers per year or more. This would dwarf the demand for launch from any other source, and would dominate the design of reusable launch vehicles. The commercial demand for space flight will of course be dependent on the price, and the study will therefore particularly consider the potential for reducing costs at high rates of launch.

Space tourism is also considered in (6), but the figures used again differ from other published estimates by an order of magnitude. It should be possible for the space industry to achieve something nearer consensus than this about the potential of this market. As a first step in this direction, market research has begun to be performed in Japan (9), which suggests that demand may be considerably higher than previously estimated (10). By using such demand data and making assumptions about launch vehicle operating costs it will be possible also to estimate the level of development cost for a fully reusable passenger-carrying vehicle that might be commercially justifiable.

Micro-gravity manufacturing.
In micro-gravity the behaviour of many materials is different from that in a one-gravity environment, and considerable research in different fields of science, including biology and materials science has already been carried out in order to understand these phenomena. This work includes experiments performed in drop towers, in aircraft performing parabolic flights, and in orbit, both in uncrewed spacecraft and in crewed vehicles and space stations.

To date this research has not fulfilled the hope that it might lead to major manufacturing "break-throughs". Thus it is not yet clear whether there will be discoveries of major commercial value, and particularly ones that could generate primary income. However there is clearly a possibility of this, and so such research should continue.

However, in order for such research to have the best commercial prospects, a substantial portion of it should be carried out by private sector companies. In order for this to be possible, a number of features of the present situation need to change. In particular, researchers need to have frequent, regular, assured access to secure micro-gravity research facilities - analogous to their access to corporate research laboratories on Earth. This has not been possible to date; access is very infrequent, very expensive and research data produced is not confidential. The best possibility for obtaining these conditions would be for companies to operate their own orbital laboratories. This will clearly require much lower launch costs than exist today.

Government activities.

Despite recent cuts in government funding, it seems that, as taxpayers, the public have considerable interest in space activities. However, recent pressure on government budgets, including space budgets, suggests that the level of popular interest in space activities depends on their cost, and on their relevance to people's daily lives. Consequently future taxpayer-funded space activities will receive popular support only to the extent that their cost is considered acceptable.

Space science.
Research can be expected to continue, on a scale roughly proportional to the level of continuing popular interest in the subject. Such research will include subjects of particular concern to the public, such as damage to the global environment. However, at lower launch costs the possibilities that could be funded within a given budget will be much wider - including more advanced projects that the public find interesting. If launch costs fall sufficiently low, private industry would also surely become interested in operating their own laboratories in orbit.

Earth / Space environment research.
At lower launch costs a number of new projects may become feasible.

Orbital debris removal. As launch costs fall and commercial space activities increase, the demand to reduce the dangers of collision with orbital debris will increase. However, as the cost of flight to orbit falls, the cost of removing debris from orbit will also fall. A variety of possible approaches to the problem of artificial debris in orbit have been discussed to date, including such approaches as salvage of larger objects, and laser deceleration of smaller obejcts (11, 12,13). Further research on these possibilities will clarify the most cost-effective approaches.

"Collision winter" prevention. As knowledge about the solar system has increased, understanding of some of the dangers facing the Earth has increased. One of these is the danger of collision with an asteroid large enough to cause climatic change. Koshiishi has calculated that collision with a body even 500 m in diameter could cause global climatic change on a catastrophic scale (14, 15).

Consequently, research aimed at preventing such a catastrophe is a justifiable use of taxpayers' money, though the scale of such funding must of course depend on the real size of the risk. Even if the probability of collision is small, the result of such work is potentially valuable. Consequently designing a system to prevent such a disaster on Earth would seem likely to be more popular, for example, than building an outpost on Mars for a small number of scientists, which would have no equivalent benefit for Earth.

Although this possibility has not been considered very deeply in the past, some interesting outline work on collision prevention has been done (16, 17). As launch costs fall, the cost-effectiveness and desirability of such a project will improve. That is, there is a small but real possibility of global catastrophe of a form that could be prevented only by using space technology. To date the necessary preventive measures have been too expensive to be realistic, but as their costs fall they become more realistic. In a scenario in which governments wish to perform some space activities for political reasons, such a project would seem more attractive than ones with less potential value to taxpayers.

Global sunshade. In view of the extreme cost to human society that would be caused by serious global warming leading to climatic changes and rising sea-levels, even a very expensive project such as construction of a large structure between the Earth and the Sun to act as a sun-shade might be cost-effective in the 21st century. Early and others have described structures of some millions of square kilometres, constructed from some hundreds of millions of tons of lunar-derived materials, that could reduce the Earth's insolation by a few percent (18, 19, 20).

Sea defences required to protect major cities around the world from rising sea levels would cost thousands of billions of dollars. Thus it would seem to be worth studying such a project at least in sufficient detail to estimate its cost. As a first approximation this will depend on the mass of material required, and more particularly on the mass to be delivered from Earth, and so on the cost of launch. Although such a large project is clearly well in the future, R&D work on large space structures to be used for other purposes will contribute to the evaluation of its feasibility.

Advanced technology development.
Governments are likely to continue their role in funding technology development in fields where private sector companies have inadequate incentive to work, but where some commercial benefit may be possible in future. To date, a large proportion of government space expenditure, particularly in Europe and Japan, has been in this category, particularly in relation to technology used in launch vehicles and spacecraft. This role can be expected to continue to the extent that taxpayers consider the results attractive, which will in turn depend on the objectives and their cost.

R&DTE infrastructure.
Development of space infrastructure useful for solving problems of concern to the public, such as environmental damage, may also continue. Where such work can help to establish profitable industries in the future, as for instance in government support for national aircraft industries, it may also continue to be supported. However, this of course depends on identifying appropriate commercial opportunities.

Requirements

The requirements for future reusable launch vehicles that would be needed for such projects as those mentioned above can be considered in terms of economic, technological and policy requirements.

Economic requirements

The economic requirements for the above projects are perhaps simpler to define, although the assessment of the cost of advanced technology to be introduced in the future is very difficult. The fundamental requirement is for much lower launch costs, combined with much higher reliability. The level to which launch costs need to fall in order for the above projects to be cost-effective has not yet been effectively calculated. That is to say, there is not yet consensus within the space industry about their relative commercial potential, as seen above, but consensus will be required if they are to be put into effect. For example it seems that the demand for space tourism would justify large investment in a vehicle with low operating costs, but would not justify investment in a vehicle with high operating costs, but this trade-off needs to be quantified in order to be useful.

However, even without knowing the required cost levels in detail, we know that reducing launch costs sufficiently far will certainly necessitate developing fully-reusable launch vehicles of appropriate design, and putting them into true "airline" operation. This will in turn involve a number of features.

Reusability. Repeated operation reduces recurring costs and leads to improved reliability through the collection of cumulative operating statistics. Reusability also means that no debris or discarded parts are produced in operation.

Increased launch frequency. Civil aviation has grown to a scale on which millions of flights are performed every year. This has reduced operating costs to just a small multiple of the cost of fuel.

Commonality. In principle, commonality with aviation industry infrastructure can reduce the cost of launch vehicle operations, but it can also raise launch costs by constraining vehicle design.

Life cycle cost vs acquisition cost. Minimising the development of new technology can reduce development cost, but may waste opportunities provided by using advanced technology. Thus reducing development cost may raise operating costs, and so the overall life-cycle cost of a vehicle.

In addition, in order to design appropriate launch vehicles, it will be necessary first, as in aviation, to decide their specification, defining the required performance. In order to do this, detailed information is required about future demand in the markets which the vehicle is to serve, which will be available only as a result of more detailed study of possibilities such as those discussed above.

Technological requirements

To state the technological requirements is more difficult than the economic ones. In particular, the precise requirements will depend on the traffic scenario that is envisaged, which depends on the expected level of demand in different possible markets. However, having decided on some possible scenarios, it should be possible to develop a detailed list of requirements, in terms of physical flight conditions, service conditions (that is, flight frequency, reliability, launch site geography, etc), price level, and so on.

The next phase is for engineers and manufacturers to design craft that are capable of fulfilling these requirements, or requirements sufficiently similar for customers to be able to accept them. This process is similar in principle to the development of a new aircraft. In the case of spaceplanes the main requirement will probably be to carry passengers, and limited cargo returning from orbit. The required size, physical conditions, flight frequency, etc, remain to be defined.

The main technological options for reusable launch vehicles are shown in Table 1, although the full range of possibilities and their details is of course very complex, as discussed in (21 - 35). In order to design a vehicle it is necessary to select the technological approach to be taken. One approach is to be conservative, using only near-term technology, and accepting poor operational capability in exchange for low project risk. The other approach is to develop advanced technology in order to achieve better mission capability, at the cost of greater project risk.

The technology required for single-stage air-breathing launch vehicles is not mature today, and will require some technological breakthroughs in order to become so. For the present it therefore seems logical to move towards a baseline vehicle based on rocket propulsion, though this may be partially "air-breatherized" in order to improve the propulsion performance sufficiently to match current structure technology. As also shown in Table 1, for the present the partially reusable MAKS concept would seem to represent the nearest term technology baseline vehicle.

Because the development cost would be high, and markets are currently small, it would be necessary for a fully reusable launch vehicle to serve the global market. Consequently, in order to make progress it is also desirable to agree on a common international approach.

Policy requirements

In order to advance spaceplane research, there are many choices that must be made, and cost-effective research must be targeted at a common objective. The manner in which this should be done, that is the best institutional structure for such work, is not clear, however. In the context of declining government space budgets, there are potentially major advantages to be gained through international cooperation. However, in order for international cooperation to be practical and effective, a number of requirements must be satisfied.

Consensus on vehicle concept. If consensus can be reached on an appropriate vehicle to develop, the range of new developments required can be minimized. Reaching consensus will require participants to avoid the "Not invented here" mind-set.

Avoiding duplication of effort. After the cold war era, it is less easy to justify government funding of space industry activity intended to develop a national capability that already exists in other countries.

Avoiding duplication of infrastructure. A large part of R&D costs are needed to pay for research facilities. Avoiding duplication, that is sharing, can reduce the overall cost of research facilities.

In order to reach mutual understanding of today's status on such matters, and to find a way forward which would be achieved effectively by international cooperative efforts, it would be desirable to convene an international panel of technical experts, supported by respective national spaceplane-related and hypersonic research program organisations, whose task would be to decide a collective plan of action. This is a very challenging objective, but in view of the increasingly difficult budget environment of national space industries, it would seem valuable to at least experiment with this approach. The major initial task of such a panel would be to perform trade-off studies on various reference concepts in order to narrow down the range of subjects for future study.

As in all industries, the potential advantages of cooperation are limited to the extent that participants foresee potential commercial advantage in the work. Commercial competition is an alternative approach to that described above, but it can be successful only when expected future profits appear sufficient to repay the estimated research and development costs. At present this is not true for the development of spaceplanes.

The history of the 1920s British experiment of parallel development of the R100 and R101 airships by private and government organisations is very revealing about appropriate and inappropriate roles for government organizations in the development of advanced-technology vehicles (36). The R100 airship development project carried out by a commercial company on a fixed-cost government contract was very successful. By contrast, the R101 was a parallel, government agency project with much greater funding than the R100. Not only was the R101's performance very poor, but it crashed disastrously, killing nearly everyone on board.

Thus it seems desirable to consider a range of possible institutional arrangements. For example it is an interesting question whether an analogue of the 1923 US Air Mail Act could be effective in improving launch services? Under this, the US government gave air-cargo contracts of agreed values to private companies which won them under competitive bidding. Government organisations provided neither the service nor the vehicles. This legislation was very effective both in developing successful commercial airlines, and in developing successful commercial aircraft manufacturers and their suppliers.

Conclusions

In the new era which the space industry is facing, we need to clarify what commercial markets the space industry should aim to supply in future, and what role governments can and should continue to play in helping to make these markets accessible to industry. In addition, R&D in this field could benefit greatly from closer international collaboration. To this end we need to decide what vehicle it would be most appropriate to develop initially. To the extent that consensus can be reached concerning the best route to take, resources can be used more economically, and the limited government budgets available will achieve better results for the coming new space era.

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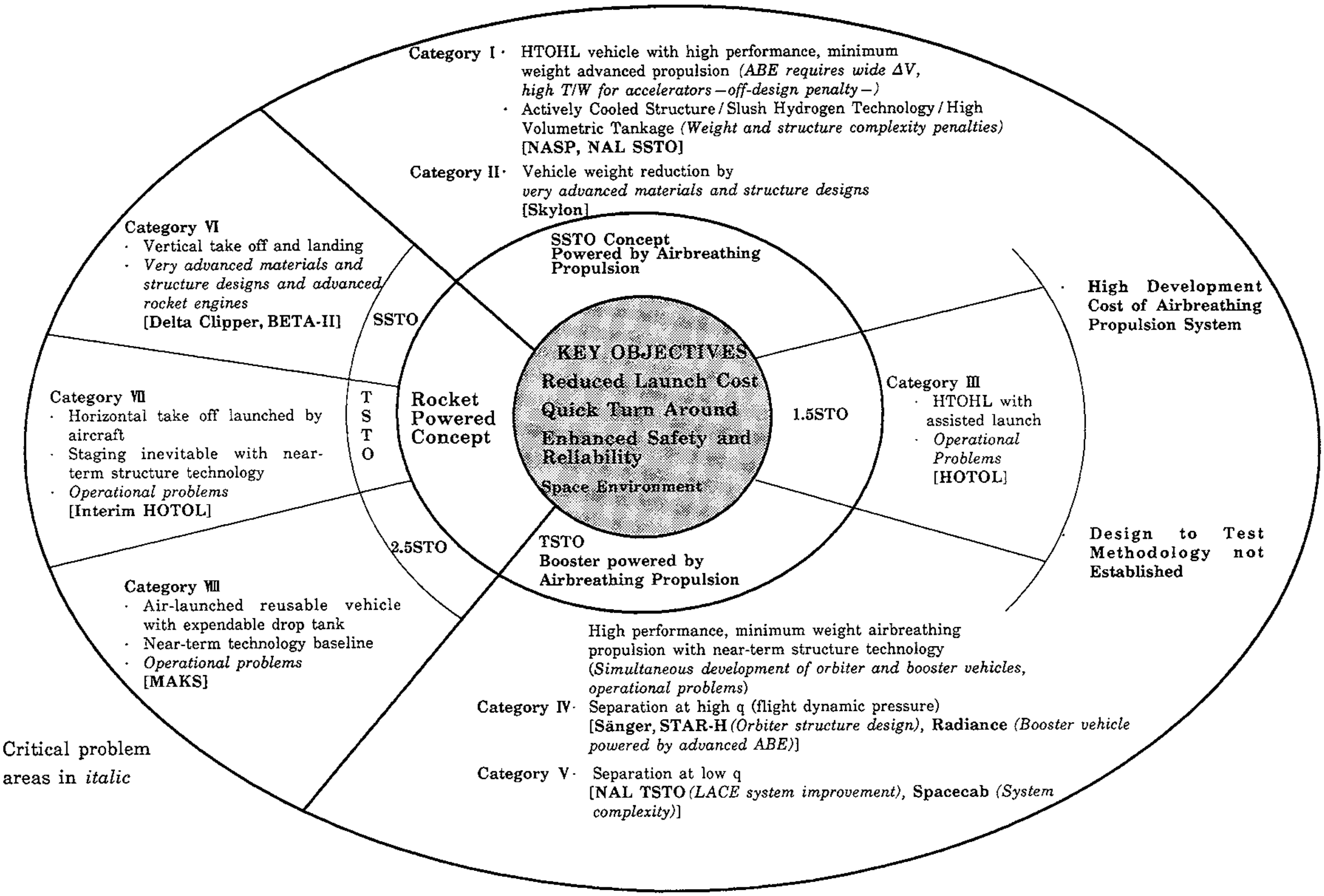

Note: Critical problem areas in *italic*

Table 1 **Spaceplane Reference Concepts Summary**