IAC-11.D3.4.3

# EVALUATING RESEARCH FOR DISRUPTIVE INNOVATION IN THE SPACE SECTOR

L. Summerer

*ESA Advanced Concepts Team, Keplerlaan 1, 2201 Noordwijk, The Netherlands, Leopold.Summerer@esa.int*

**Abstract**

Many governmental space activities need to be planned with a time horizon that extends beyond the comfort zone of reliable technology development assessments and predictions. In an environment of accelerating technological change, a methodological approach to non-core technology trends and potentially disruptive, game-changing developments not yet linked to the space sector is increasingly important to complement efforts in core technology R&D planning.

Different models and organisational setups for that purpose exist. These include, with varying links to space, the NASA Institute for Advanced Concepts (NIAC, operational form 1998 to 2007 and recently re-established), the Defence Advanced Research Projects Agency of the US Department of Defence, the MIT Medialab, the early versions of Starlab, the Lockheed Skunk Works and ESAs Advanced Concepts Team.

Some of these organisations have been reviewed and assessed individually, though systematic comparison of their methods, approaches and results have not been published. This might be related to the relatively sparse scientific literature on organisational parameters for organising disruptive innovation as well as to the lack of commonly agreed performance indicators for these. Innovation support systems in the space sector are furthermore organised differently than in traditional, open competitive markets, which serve as the basis for most scholarly literature on the organisation of innovation. The present paper intends to advance and to stimulate a discussion on the organisation of disruptive innovation mechanisms specifically for the space sector. It therefore uses the examples of the NASA Institute for Advanced Concepts and the ESA Advanced Concepts Team to analyse their respective approaches and compare results, leading to some proposed measures for the analysis and eventually evaluation of research for disruptive innovation in the space sector.

*Keywords:* disruptive technology, advanced research, space

## 1. INTRODUCTION

### 1.1. Scope

Governmental ambitions in space have been acting as a formidable technology pull since the early days of the space age. During the first two decades, practically each space mission required the development of new technologies and thus led to taking substantial risks. As von Brown has formulated it in a letter to then US Vice-President Johnson from 29 April 1961, before the peak of the space race: the Soviet Union was competing in the space race by putting a "*peace time economy on a wartime footing*" and to continue "*I do not believe that we can win this race unless we take at least some measures which thus far have been considered acceptable only in times of a national emergency.*"[1]

By the end of the Apollo programme, the situation had already substantially changed, though some legacy of the space race and thus its mechanisms for innovation remained dominant at least until the end the cold war and the collapse of the Soviet Union. The first highly visible and symbolic cooperation in space was the docking of Apollo and Soyuz in July 1975, a cooperation later intensified into the Shuttle-Mir programme in the mid 1990s and the still ongoing unprecedented international cooperation in the frame of the International Space Station (ISS), the largest international science project ever conducted. The move from cold-war driven competition to cooperation, and the associated change in motivations (measures acceptable only in times of a national emergency are not longer taken for space activities) had substantial consequences on the way space technology and innovation in and for space have been conducted. In parallel and similarly important, some space activities have generated a real new commercial market (e.g. telecommunications) and are now driven more by economic, market oriented decisions than by governmental ones. Space agencies (civilian and military), traditionally the main funding bodies for advancing space related technologies and concepts have been adapting to this change by diversifying its innovation and technology development strategies.

While the innovation environment has substantially changed, especially with a decreasing share of governmental, strategy- and defence-driven technology push, the difficulties for space applications and space solutions to remain competitive with terrestrial solutions have rather worsened: the consumer-market driven accelerated changes in information technology and the consequences of a continuation of Moore's law offer terrestrial solutions a dynamic and broad pool of technologies to frequently upgrade their systems and radically change their offers (frequent creative destruction) and a highly competitive, innovation driven supplier base with strong market incentives; while on the other hand space systems not only continue to experience relatively long development times, but also the requirement to remain competitive with once chosen technology during the entire lifetimes of space systems, a still dominant governmental quasi-monopsony, a highly concentrated, vertically integrated space industry with dominant prime contractors, relatively little incentives for independent, competition-driven industry lead investments into own R&D and even smaller incentives for R&D investments into potentially disruptive innovation.[2, 3, 4]

Governmental entities have therefore put in place mechanisms to compensate for some of these deficiencies inherent to the space sector. The present paper analyses two of these mechanisms, one in the US and one in Europe, both dedicated to supporting disruptive innovation for the space sector.

With some simplifications, one could classify space technology into three different kinds:

1. technology led by space as niche, unique application (many times shared by the defence sector)
2. technology, using space as a lead market
3. technology driven by terrestrial markets, adapted to space

A schematic representation of the evolution of the relative importance of these three kinds, simplified under the headings "space-only", "space-led", "space-also" is shown in Fig. 1.

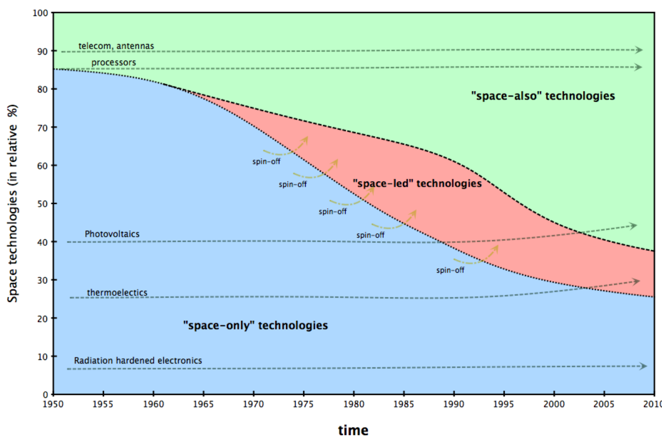


Figure 1: Schematic, symbolic representation of space technology categories in three different types: space-only, space-led and space-also technologies together with a few example technology area trajectories

With the maturation of the space sector, accompanied by the maturation of some of its key technologies, the relative share of space-only technologies has been gradually shrinking. At the same time, the initially dominant space technology spin-off activities have matured into a more complex spin-off / spin-in relationship between space and non-space technologies.

Interestingly, these quite substantial changes have led only to relatively smooth, gradual and cautious changes in the space technology management and innovation programmes of space agencies. These cover all three types of space technology categories displayed in Fig. 1, as all three still require some level of governmental support.

As all high-technology dominated sectors, the space sector also requires a healthy mix between technology programmes aimed at sustaining innovation and those aimed at potentially disruptive innovation. Ample scholarly literature exists on the first one, whereas the latter type has so far received relatively little attention specific to the space sector.[2] This paper attempts to contribute to rebalance this situation by providing an overview of two governmental tools aiming at disruptive innovation and a first tentative analysis of methods for evaluating disruptive innovation programmes for space.

### 1.2. Innovation Types

One of the earliest scholarly definitions of innovation dates back to the Austrian economist Schumpeter, who described it as "innovation implies bringing something new into use".[5] There are still scholarly debates on the best definition and apparent difficulties in finding a consensus across disciplines. Szajnfarber and Weigel have recently attempted an explanation of these apparent difficulties by relating the dynamics of innovation to the environment in which it occurs and the choice of the unit of innovation.[6]

The European Commission proposed the following definition in its 1995 Green Paper on Innovation: "Innovation is the renewal and enlargement of the range of products and services and the associated markets; the establishment of new methods of production, supply and distribution; the introduction of changes in management, work organisation, and the working conditions and skills of the workforce".[7]

One of the most used differentiations of the innovation process uses the type of impact the results of the innovation process create. This is done by distinguishing between processes of incremental and radical innovation (as defined by e.g. Ettlie, Bridges, and O'Keefe (1984)[8]) or sustaining and disruptive innovation, as defined by Christensen.[9, 10, 11]

In this definition, incremental innovation is characterised by small or relatively minor changes and improvements that do not alter in a substantial way the basic underlying concepts. Incremental innovation strives to optimise products and services. Contrary to this, radical innovation is based on a different set of engineering and scientific principles and intends to open up new markets and new potential applications.

Similarly, but considering the effect of innovation on the market leaders (incumbents), when analysing why established market leaders and well-run companies tend to fail to understand and incorporate disruptive innovation, Christensen defines sustaining innovation as those changes that "foster improved product performance". While these can be incremental or discontinuous/radical in nature, they have in common that "they improve the performance of established products, along the dimensions of performance that mainstream customers in major markets have historically valued". [10] Market leaders usually champion this type of innovation.

Contrary to sustaining innovation, Christensen has defined disruptive innovations as those that "bring to the market a very different value proposition than had been available previously" and that generally "under-perform established products in mainstream markets" but offer new qualities that new, typically originally marginal customers value. Refined in a later work, Christensen and Raynor define disruptive innovation as "an innovation that cannot be used by customers in mainstream markets. It defines a new performance trajectory by defining new dimensions of performance compared to existing innovations. Disruptive innovations either create new markets by bringing new features to non consumers or offer more convenience or lower prices to customers at the low end of an existing market."[11] A slightly different, though possibly more elegant definition has been proposed by Daneels: "A disruptive technology is a technology that changes the bases of competition by changing the performance metrics along which firms compete."[12]

Disruptive innovation usually changes a product or service in ways that the market does not expect, typically by being lower priced or designed for a different set of users. It will often have characteristics that traditional customer segments may initially not want, but some marginal or new segment will value. Anthony associates the following keywords with a disruptive innovation: simpler, lower-priced, good-enough performance, great leap downward.

Radical innovation and disruptive technological changes tend to create difficulties for existing, established market players. Reasons for these difficulties include the high levels of uncertainties involved in radical innovation, the unclear customer basis and the usually negative feedback from the established, traditional customers with regards to the potential of the innovation for their products and services. These lead to an associated higher risk and lower return on investment. Despite being often fully aware of the changes, this makes it difficult for established organisations to quickly and early embrace them and re-orient the organisation towards such changes in order to lead instead of react to them. Therefore, even though disruptive technologies initially under-perform established ones in serving the mainstream market, they eventually displace the established technologies. According to this theory, this process leads to entrant firms that supported the disruptive technology displacing incumbent firms that supported the prior technology.[12]

In competitive, free market environments, this situation leads to opportunities for new entrants and usually small, specialised companies that can sustain their business model based on emerging niche markets and lower profit margins. It is therefore argued that the only way incumbents can embrace disruptive innovation is to create separate, independent entities, unconstrained by the core business.

Contrary to incremental innovation, which aims to optimise, radical innovation focuses on changes in the more profound domain of core concepts or base principles. These therefore tend to lead to or require radical changes in the whole structure, society, product, or service (plus its context; e.g., by opening up completely new markets). Radical innovation thus touches some of the basic assumptions, which are usually validated by experience and as such strongly anchored in organisations.

It would be pretentious to argue that the space sector as a whole and ESA are not subject to the same difficulty. It is hard to not only recognise but also to embrace, encourage and stimulate disruptive innovation. The decision mechanisms and required prudence when spending public funds tend to favour the security of opting for a known path forward, strengthening the incumbents and sustaining existing competence and employment levels. Furthermore, the space market has some particularities, which require further analysis; e.g. in space markets, there is relatively little margin nor incentive for space industry to develop and mature technology entirely on own funds, be it one that leads to sustaining or disruptive change. Most technology developments for space applications are therefore linked to governmental technology development programmes and embedded in usually consensus built roadmaps, thus putting even higher pressure on the governments in adopting the right balance.

### 1.3. Research on disruptive innovation in the space sector

When Christensens published the concept of disruptive innovation, initially labelled under the term "disruptive technology" in 1997, he triggered strong interest both from practitioners as well as from scholars. Since Christensen used the hard-drive data storage sector, a subset of the computer and IT industry, as one of his most illustrative examples of how incumbent, highly successful companies fail to respond adequately to early signs of disruptive innovation, it has had an especially strong impact in the fast evolving IT sector. The space sector and scholarly literature about innovation in the space sector have been largely ignoring the concept when it was published. One can only speculate on the reasons for this, which might be linked to the fact that traditionally the space sector is not very present in the scholarly literature on innovation due to the strong governmental involvement, a situation that is perceived as distorting the market and market-driven innovation. It might also be linked to the small size of the space market, or the limited amount of easily accessible data.[3]

It is well recognised in the commercial market, that firms need to engage in the process of revolutionary or disruptive innovation for their long-term survival.[9, 10, 13] While not governed by the same forces, similar mechanisms related to their respective and changing relevance for market needs govern public sector innovation.[4] Smyrlakis et al have shown how a simplified model of the European space sector can already explain the role and responsibilities of a governmental monopsonist on the innovation level of its supplier base.[14]

Henderson et al have shown, how difficult it can be for an established organisation to respond to significant shifts in the environment, throwing into high relief problems of cognitive framing and resource allocation, by exploring the role of embedded organisational competencies in shaping what Christensen has coined the "innovators dilemma".[10, 15]

Henderson et al demonstrated that in addition to the important role of senior management in recognising early on and reorienting the organisation towards recognising and adapting to disruptive changes, the legacy of proven organisational setups play a critical role in preventing timely change, including embedded customer or market-related competencies.[15] While

Henderson's analysis is focussed on competitive markets, the results of the work by Szainfarber et al on the close relationship between governmental monopsonist, industry and scientists in space science missions point towards a potentially similar, organisational situation in governmental markets.[2, 16]

Furthermore, Christensen explicitly showed that problems in technological competence could not serve as an explanation for the frequent failures of incumbent firms to adapt to disruptive innovation (He demonstrates that these had no technical difficulties in developing the next generation of product, in his example hard drives), but that decision making was too strongly influenced by the current demands and needs of the largest, core customers. It therefore proved to be difficult to allocate resources to initiatives that would serve new customers at lower margins, even if these were technically easily within the reach of the firm. In order to create industrial firms able to compete at world market, a process of substantial industrial consolidation has taken place in both Europe and the US, where the space industry is dominated by few big prime contractors, which receive the majority of the allocated governmental budgets for space programmes.[3]

It is worth noting that the approach adopted initially by Christensen has not only received a large, generally positive echo, it has also triggered some well founded criticism related to the methodology and the relative simplicity of the underlying concept.[12, 17] Danneels questions whether disruptive technologies were always simpler, cheaper, and more reliable and convenient than established technologies as described by Christensen, since e.g. there are also some mainstream customers valuing disruptive technology and disruptive technology emerging in the high-end market segment, not with lower performance.[12] Part of these critical comments of the initial concept have been addressed by subsequent publications by Christensen and Raynor, who added some granularity to the approach by differentiating between *low-end disruptions*, addressing the low end of an existing value network, and *new-market disruptions*, which create a new value network.[11] In this later framework, a new-market disruption is defined as *an innovation that enables a larger population of people who previously lacked the money or skill now to begin buying and using a product*.[11]

## 2. METHODOLOGY

### 2.1. Data sources

This paper relies on publicly available first hand data (publications, citations, programme announcements, budgets), on review papers and reports and the data these are using and on secondary scholarly articles. The sources of the data are provided in the text as references.

Most of the data concerning the original NIAC programme comes from an independent review by the US National Research Council, which published in 2009 a report which was originally asked for by the US House of Representatives in 2008, one year after the termination of NIAC after 9 years or operations. This relatively detailed review included conclusions and recommendations for a re-establishment of an entity similar to NIAC.[18] 'NIAC-2' has subsequently been created with slightly different functioning parameters and orientations under the office of the NASA Chief Technologist in 2010. Additional data are also taken from official final reports of NIAC and especially its the 9th annual and final report.[19] Where there are differences between these two, these are specified in the text. In general, the data from the NRC have been given higher credibility due to the later publication date as well as the independence of the review process.

Most of the data on the ESA Advanced Concepts Team (ACT) is taken directly from the publicly available website of the ACT, which includes all its scientific publications, information on the research network, *Ariadna* studies details, research partners and team members.[20, 21, 22]

Information regarding the research conducted by DARPA is coming from the website of DARPA as well as from scholarly articles written on and about its activities.[23, 24]

#### *2.1.1. Currencies*

The time span of the present evaluation extends from 1998 to 2010 and covers amounts in US$ as well as in €. Currency values have not been inflation adapted, neither for the 9 years of NIAC operations nor for the 9 years analysed for the ACT. In this context it is worth mentioning that neither NIAC nor the ACT have adjusted their grant values to inflation. US$ and €-values are furthermore not converted but left in their respective original values. The relative values of these two currencies have changed substantially over the assessment period. For historic exchange rate data, it is referred to e.g. [27]. The approach adopted here is considered sufficient for the purpose of this paper since both entities have dealt only with contracts in their respective currencies and thus relative purchase power changes would not have substantial impact on the 'domestic' value of the respective grants.

## 3. CASE STUDIES

### 3.1. NASA Institute for Advanced Concepts - NIAC

This section deals with the original NIAC, operational from 1998 to 2007. It does not take into account the recently re-established NIAC, for which only preliminary data are available.

#### *3.1.1. Origins and Goals*

In 1998, NASA created its Institute for Advanced Concepts (NIAC) with the aim to to "provide an independent, open forum for the external analysis and definition of revolutionary space and aeronautics advanced concepts to complement the advanced concepts activities conducted within the NASA Enterprises". In the words of NIAC, "*The NASA Institute for Advanced Concepts (NIAC) was formed to provide an independent source of revolutionary aeronautical and space concepts that could dramatically impact how NASA develops and conducts its missions. The Institute provided a highly visible, recognised and agency-level entry point for outside thinkers and researchers. The ultimate goal of NIAC was to infuse the most* *promising NIAC-funded advanced concepts into NASA plans and programs*".[19]

It was terminated by NASA in 2007. One year later, the National Research Council established a group of 12 experts under the co-chairmanship of R. Braun and D. Wiley to conduct an independent review of the achievements of NIAC. It can be reasonably assumed that the recommendations of this report ultimately lead to the re-establishment of NIAC within the Office of the NASA Chief Technologist.[18] Most of the statistic and procedural data on NIAC for this paper is taken from this review as well as from the final report of NIAC.[19] In the foreword of its last annual and also final report, the NIAC director summarises his view as "*NIAC has sought creative researchers who have the ability to transcend current perceptions of scientific knowledge and, with imagination and vision, to leap beyond incremental development towards the possibilities of dramatic breakthroughs in performance of aerospace systems*."

*3.1.2. Funding*

NIAC has been funded at approximately $4M per year, received a total of $36.2M from NASA, of which it spent 75% on grants[1]. While not specifically detailed, it is assumed that the remaining 25% or $8.9M were spent on internal organisation including its six person staff (situation 2007), the peer review process and USRA overhead costs.

NIAC followed a two phase innovation and project maturation process, which allowed anybody outside of NASA to submit grant proposals for

**Phase 1 grants:** lasting for 6 months and with funding between $50-75k, or

**Phase 2 grants:** lasting up to 2 years and dedicated to further concept maturation with a funding up to $500k.[2]

Phase 2 grants have been awarded after successful Phase 1 grants to provide further maturation. In total, NIAC has received about 1300 proposals[3] (1066 Phase 1 proposals and 129 Phase 2 proposals) out of which it awarded 168 grants, for a total of $27.3M. These were divided into 126 Phase I grants, 42 of which followed with more substantial Phase II grants. [18]

*3.1.3. Organisation*

NIAC has been operated to a certain extent external to NASA since it was established an Institute of the Universities Space Research Association, with its director reporting not to NASA but to the President of Universities Space Research Association (USRA). USRA is a private, nonprofit corporation under the auspices of the National Academy of Sciences (NAS). I has currently 105 colleges and universities as institutional members, all of which offer some space science and technology graduate programme.[28]

While less visible, the NIAC leadership also had strong, though indirect involvement from the U.S. military aerospace activities, DoD research facilities, and the Defense Advanced Research Projects Agency (DARPA), provided via ANSER through a subcontract. ANSER participated to the operation of NIAC and "enabled the Institute to have access to significant resources developed over decades of support to the government through the Department of Defense (DoD)".[28]

When it was formed, NIAC was managed by a high-level agency executive who was intended to be concerned with the objectives and needs of all NASA enterprises and missions. The NRC review concluded that when this cross-organisational aspect of NIAC was abandoned with the transfer of NIAC to a mission-specific directorate, NIAC lost its alignment with NASA's overall objectives and priorities.

NASA personnel were not allowed to compete for NIAC grants. The reported reason for this is that when NIAC was formed, there was adequate funding for development of novel, long-term ideas internal to NASA. Since this NASA internal funding, which was essential to pick up ideas from NIAC and develop them further within the regular NASA structures was gradually reduced, one of the recommendations of the NRC review board was to allow also NASA personnel and centres to compete with anybody else for NIAC grants.[4]

Administratively, NIAC grants were handled outside of the standard NASA contractual processes, since NIAC was operated on behalf of NASA as an institute of USRA. [28]

NIAC used a relatively transparent internet-based management environment and a peer review system for evaluating the proposals. It also published all its reports on the website allowing critical review.

*3.1.4. Impact Parameters*

The NRC review used several measures, including of qualitative as well as of quantitative character, to assess the success of NIAC. Ultimately, they were all directly related to the original goal of NIAC when it was created. Since NIAC had a 10 to 40 year planning horizon for its mission, it is not surprising that some of the concepts have not yet entered into either the relevant NASA mission directorate decadal surveys, strategic plans, or mission streams. According to the contract between NASA and USRA, a key contract performance metric was "that 5 - 10% of the selected concepts were infused into NASA's long range plans".[19]

*Additional subsequent funding.* One of these measures is the amount of additional funding generated by ideas emanating

[1] It is not clear to the author what the origin is of the discrepancy between the 70% mentioned in the NIAC final report and the 75% calculated in the NRC review. The latter one is taken as basis for this work.

[2] There is a discrepancy between the maximum amount of funding for phase II studies between the NIAC final report, which gives $400k as upper limit and the NRC review, which states $500k as upper limit for phase II grants. For the purpose of this paper, the latter value is taken since even if all 126 phase I and all 42 phase II contracts had received the maximum amount given by the NIAC final report, this would add up only to $26.1M and thus $1.2M short of the sum reported to be spent on all grants.

[3] According to the statistics in the NRC review, 1195 proposals were actually reviewed. The assumptions is that the remaining 114 or 9% of all proposals did not pass formal acceptance criteria and were thus rejected before the peer review process.

[4] This recommendation has been implemented in the new NIAC setup.

from NIAC projects after the projects had been finished. While there is no overall figure quoted in the assessment nor the final NIAC report, possibly due to lack of suitable data, the NRC review committee found that 14 NIAC Phase I and Phase II projects, which were awarded at total of $7M by NIAC, received an additional $23.8M in funding from a wide range of organisations. Among the 42 Phase II grants for maturing further advanced concepts, 12 (28.6%) had furthermore received additional funding from others than NIAC, the large majority (75%) coming from NASA.[18][19] The difference between the 25% of Phase IIs having received further validation by additional funding quoted in the final NIAC report [19] and the higher number quoted in the later NRC review [18] indicates that due to the long timeframe, this number is likely to increase even further over the years.

*Impact on NASA long term planning.* Three NIAC Phase II studies (7% of the Phase II awards) are reported to have impacted NASAs long-term plans, and two of these efforts have either already been incorporated or are currently under consideration by the NRC Astronomy and Astrophysics Decadal Survey as future NASA missions.[18] The conclusion therefore was that already when the assessment was made, the performance metric of 5-10% of concepts to impact NASA long-term planning has been fulfilled.

*Network.* NIAC developed a community of researchers, inventors and entrepreneurs interested in principle in innovative advanced concepts. The larger number could be deduced from the total number of 1309 proposals received during in its 9-year lifetime. The inner circle of this network were those with whom NIAC actually engaged in real studies: The 126 NIAC Phase I studies (some of which were continued into Phase II studies) were led by a total of 109 distinct principal investigators. Each of these typically led a research team of 3-10 persons. In total, the number of persons directly engaged with NIAC can thus be evaluated as being between 300 to 1000 persons, 500-600 persons being probably a reasonably good guess of the actual number. Given that a total number of 1309 proposals have been received, and assuming that first, non-selected proposals and selected ones have roughly the same number of individuals contributing to the proposals (which is probably an over-estimation since usually more contributors increase the quality of proposals), second, there were only a negligible number of "random" proposals (e.g. quickly submitted ideas, usually by one persons who did not have/take the time and effort to explain and describe it in a structured manner), and third, that there were only a negligible amount of persons proposing in more than one proposal or proposing more than one idea (also probably leading to overestimation), then one could estimate that between 3900 and 13000 persons have been in one or the other way involved in submitting ideas on advanced space concepts to NIAC.

The grants spanned all categories of external entities with 41.7% going to universities, 44.0% being awarded to small businesses, 4.8% to small and disadvantaged business, 1.8% to historically black colleges and universities and minority institutions, 6.0% to large businesses and 1.8% to national laboratories.[5][19] Interestingly, while 45% of the actual attributed grants went to academia and only 40% to small businesses, the proportion of submissions was the inverse: 53% of the applications were from small businesses and only 33% from universities.[18]

*Media-coverage.* Both the review by NRC and the NIAC final report underline the importance of the success of NIAC in providing widespread positive publicity for NASA, including TV and media coverage and Internet interest.

*Encouragement of Careers in Science and Technology.* While no hard data is provided in the NRC review, the authors considered the "anecdotal evidence" substantial enough to conclude that the NIAC student undergraduate Fellows program and the media coverage of its activities motivated young people to pursue studies in engineering and science.

### 3.2. ESA's Advanced Concepts Team (ACT)

#### *3.2.1. Origins and Goals*

The ESA Advanced Concepts Team (ACT) has been created in 2002 with the mission to "*monitor, perform and foster research on advanced space systems, innovative concepts and working methods*".[21] As part of its task, the team has to deliver to ESA rigorous and rapid assessments of advanced concepts not necessarily yet linked to space. It is interesting to note in this context that the formulation of mission of the ACT is focussed on the means to achieve a goal, than on the goals and objectives themselves. The context of its creation, within the then directorate of Strategy and External Relations, provides the missing information since its task was "proposing the overall strategy and long-term vision of the Agency including, inter alia, ESA-wide policies relevant to the European strategy for space, advanced concepts, relations with ESA Member States, the EU and non-member States, and communication."[29] Even more specifically, the team was created reporting within this directorate to the head of the 'Advanced Concepts and Studies Office', responsible for "outlining, in coordination with the Agencys other directorates, a programmatic and technical long-term vision of the Agencys future development".

The time horizon of the team is not provided in numbers of years ahead but is defined relative to the horizon of all other ESA programmes and projects, by requiring the topics to be one step ahead. Therefore the 'golden rule' of the team is that if anybody else within ESA starts working on concepts and technologies addressed by the team, the team hands over these topics and moves on to new ones.

[5]The data between the NIAC final report and the NRC review differ slightly. The data from the NRC review are taken as more authoritative for this paper. The NIAC final report data are 45% to universities, 40% to small businesses, 7% to small and disadvantaged business, 2% to historically black colleges and universities and minority institutions, and 7% to large businesses. it is assumed that the total of 101% is due to rounding errors in the final report.

*3.2.2. Funding*

The ACT operates at an average annual funding of about €1M, provided entirely by the ESA General Studies Programme.[30] This figure includes its internal costs and overheads in form of salaries of its researchers as well as external research contracts, and thus varies slightly over the years, depending on the number of studies and the number of internal researchers present during that year.

External research contracts of the ACT are done within the *Ariadna* scheme, a mechanism for collaborative research between ACT and university researchers.[31] Three funding levels are associated to *Ariadna* studies:

**small studies** 15k€

**standard studies** 25k€

**extended studies** 35k€

These three *Ariadna* study types are not associated in any way to a sequence, but they are all three one-off studies with no follow-up studies within *Ariadna*. The type of studies are defined by the ACT depending on insight on how much time and effort would be required for the planned research.

While at its conception, these were associated with indicative durations of 2 months, 4 months and 6 months respectively, the reality of the first years of operations showed that these time constraints were not useful (e.g. standard studies lasting on average 9 months, more than twice the planned duration) and have thus been dropped entirely; the duration being decided on a case by case basis between the ACT researchers and the university research team. Given the prevailing importance of other factors, statistically there is no correlation between the duration of studies and their total funding.[31]

*3.2.3. Organisation*

The structure of the team took account lessons learnt from previous approaches within ESA and the the methods adopted by the NASA Institute for Advanced Concepts, DARPA, the central research and development organisation in the US DoD, the MIT Medialab, Starlab, by Lockheeds Skunk Works and some of its later imitators as well as of setups within highly innovative commercial companies not linked to the space sector such as Google Inc., IBM and others.[21]

Implementing these lessons learnt within the possibilities of the ESA environment, led in 2002 to the following main parameters of the ACT: The team was set up as a group of researchers, mainly research fellows (RF - post-doctoral researchers joining the team for two years) and young graduates (YGT - recent master-level graduates joining the team for one year), who originate from a broad variety of academic fields and aim at an academic career. The pursuit of highest scientific standards is therefore as much in their own interest as in the interest of the team. The steady renewal of researchers (one or two year periods within the team) allows a continuous, flexible adaptation of the teams competence base to the needs of ESA and to evolutions in science and technology. It is also the basis for fresh unbiased assessments and re-evaluations, while avoiding empire-building and preventing ESA career-considerations to influence the orientation and conduct of research.

The ACT relies mainly on the research ideas of its temporary researchers, and thus internal research. In the conduct of these, a mechanism to solicit universities (*Ariadna* scheme) has been developed which allows for joint research collaborations on very specific topics.[31]

The team can therefore be considered as a hybrid between an entirely internal, closed research team / think tank and a funding source for external researchers working on advanced concepts.

As far as known to the authors, the combination of temporary in-house researchers from a multitude of disciplines, the reliance on empowered young researchers who are encouraged to propose and relatively free to pursue new ideas, together with the framework to perform collaborative research in ad-hoc virtual teams is quite unique and innovative in itself. Recent initiatives have emerged at national level inspired by the ACT model.[32, 33]

Externally the team interacts almost exclusively with universities - specifically small, innovative research labs often with no prior link to ESA nor the space sector. Based on the analysis of success models of other innovation leaders, administratively, the team has always been situated at corporate level, outside of the mission and support directorates and independent from the core technical strategies and road-maps. Originally, the team has been created as an integral part of the General Studies Programme of ESA and it has always been contributing to the goals of the GSP.[30]

*3.2.4. Impact Parameters*

*Additional subsequent funding.* The total of all funds invested in *Ariadna* studies for universities since the scheme was created in 2004 and until 2010 amounts to €1.9M. While there is no precise tracking of all funding subsequently received by universities, the sum of those additional funds awarded to these same universities for follow-on work for which numbers are available amounts to €5.3M from non-ESA sources. ESA funds to continue *Ariadna* studies directly after their completion are the rare exception and add less than few hundred k€ to this total. The majority of this additional investment is taken by few high-flying activities, e.g. one €25k *Ariadna* study with a team with no prior knowledge in space led directly to a €3.5M EU FP7 project led by the same university team but now involving major European space industry). The overall financial leverage on investment by ESA on *Ariadna* studies is about 1:3 for the *Ariadna* scheme when taking into account only non-ESA funds, and roughly 1:3.5 when adding ESA funding to mature concepts further.

This analysis of the *Ariadna* studies however represents only part of the overall picture since *Ariadna* studies represent in total per year between 18 and 39% of the total ACT budget (24% of the total ACT budget between 2002 and 2010), which is dominated by the personnel cost of the internal researchers. Therefore, while the *Ariadna* scheme offers an essential mechanism for the research of the team, most of the actual work of the team is done outside of *Ariadna* studies.[21]

*Impact on ESA long-term planning and strategy.* Contrary to NIAC, the ACT has not explicitly created with the goal to impact ESA's long-term planning and strategy. However, the ACT has been administratively always located outside of the core technical directorate and close to corporate strategy making (It started within the Directorate of Strategy and External Relations; most of its existence it has been located within the services of the Director General). Therefore, the results and competence of the team have always been used also to provide input to strategy.

In its function as internal think-tank, the ACT also attempts to identify trends, new research advances and events that have the potential to impact the future of space and describe these in form of internal reports. Their impact is not easy to quantify and thus this assessment remains largely qualitative. Examples of early identification of the team of topics of "future" interest which have since then materialised include the topic of suborbital and private spaceflight (report entitled "Is a second space age coming?" which was followed later by some studies on space tourism and related technologies as well as by an ESA-wide working group on the same topic, delivering a first coordinated coherent position of ESA on the topic.[34] Similar mechanisms have been at place for the topics of nuclear power sources for space, planetary protection aspects and the (then) emerging maturity of global optimisation techniques.[35, 36, 37] Reports and recommendations have been produced by the team several years before these topics have received the attention of mainstream ESA and most of the initial points and directions can be clearly identified in the subsequent roadmaps and technology strategy documents on these topics.[38, 39]

There is at least one area, where activities by the team had an immediate, directly traceable effect on a new programme of ESA: Activities and reports by the team on the (then) upcoming importance of the energy theme when energy was still receiving almost no attention in 2002/2003 have led to the introduction of the general theme of "space and energy" into the proposal of the integrated applications promotions programme to the ministerial council in 2008 and contributed to the preparedness of ESA for ongoing activities with the EC on the topic of space and energy.[40, 41]

Another aspect of how concepts and topics of the team are transferred to the core of the Agency is to consider the transfer of disciplines and general topics started by the team and then contributed to and taken over by other ESA departments. So far, three general disciplines have been started as such by the team and then taken up by other ESA departments (space nuclear power sources, planetary protection, global optimisation for trajectory design). The very different pathways these have taken indicates that there is no standard take-up mechanism.

*Network.* Since the team is based on a small number of internal researchers, an active network of universities and external researchers has been created. Since the topics of the team are located on the fringes of space activities and beyond these, such a network includes many research centres not specialised in space. This has turned out to be itself a valuable asset, especially since the space sector has been considered as a "lonely forerunner" for a long time and experienced difficulties in engaging and cross-fertilising with other sectors.

This research network is neither static nor fixed, but evolving with the team, its orientations and its members. One quantitative way to measure its size is represented by the more than 450 unique co-authors of publications published by the team and available on the website. These are persons that have actively worked with one or several researchers of the team in a successful project that led to a publication. It is therefore a conservative low estimate; the number of actual research contacts and loose co-operations is much higher.

Since practically all members of the team are temporary researchers, the alumni network is constantly growing. 69% of ACT members go back to academia immediately after leaving the team and of all the team members 54% of all past members remained within an academic career.

*Media-coverage.* There is no systematic analysis of the media coverage of research results from the Advanced Concepts Team. While the website contains some 60+ press clippings about the team, these are just a small fraction and mostly added before 2005. Since in general, the team does not make specific efforts towards communicating with the media, most of the appearances are triggered by university researchers involved in studies by the team.

*Encouragement of Careers in Science and Technology* . Similarly to NIAC, there is no hard data whether the team provides additional stimulus for students to start careers in science and technology. The only faint indicator of the higher than average attractiveness of the team could be taken from the over proportional number of applicants for vacant post-graduate positions.

## 4. COMPARISON OF GOALS, MEANS AND RESULTS

This chapter attempts a first comparison between the approaches adopted by NIAC and the ACT respectively. The comparison parameters will be covering

1. goals and objectives,
2. organisational structures and means to achieve these goals, and
3. results obtained in achieving these goals.

The comparison further needs to be taken with some caution related to the timeframes: while there is some overlap in the existence between NIAC and the ACT between 2002 and 2007, the organisational setups for both organisations have been defined with four years of time difference.

### 4.1. Comparison of Goals

While the wording of the mandates of the NASA Institute for Advanced Concepts and the ESA Advanced Concepts Team are not identical, the overall goals of the two mechanisms to perform research on potentially disruptive space concepts and technologies are comparable (see sections 3.1.1 and 3.2.1). In addition, both have similar time horizons, defined as 10-40 years for NIAC and defined as beyond the horizon of regular ESA programmes for the ACT.

While one of the explicit goals of NIAC has been to provide input and have an impact on NASA's long-term planning, this aspect is not explicitly stated for the ACT, while in practical terms this aspect is included in publications and presentations of the ACT. The reasons for this might related to the fact that it has been established directly within the organisation's entity close to strategy development. (see section 3.2.1)

### 4.2. Comparison of Organisational Means to Achieve the Goals

Even though the goals of the two entities are largely comparable, the mechanisms adopted by NIAC and ACT to achieve these goals show substantial differences:

*Funding entity versus internal research team.* While NIAC acts essentially as a funding organisation, the ACT functions mainly as an internal research think-tank, using funding only for colaborative peer research with academia. As a consequence, the ACT is constituted mainly of temporary internal researchers (10-15 persons), thus very frequent turnover and a constant change in competences and orientations, while operating NIAC was possibly by a smaller, 6 persons team, mainly administering the process.

*Role and location within parent organisation.* While the ACT is located administratively at the core of ESA, traditionally close to corporate strategy functions, NIAC has been practically outsourced to an independent university association. To the best of the authors knowledge, there is no public account on the reasons for this decisions. Interestingly, it is worth noting that based on the recommendations of the NRC assessment, NIAC-2 was re-created at corporate level within the office of the NASA Chief Technologist.

Both groups are thus organisationally not within the core technical establishment and largely shielded from main-stream technology roadmaps, priorities and goals. This follows one of the guidelines developed by Colarelli O'Connor in the context of 'major innovation': building upon concepts formulated by Bennet and Tushman and others Colarelli O'Connor concludes that major innovations cannot be expected in an organic environment, where flexibility, consensus building, and fluidity are the primary managerial mechanisms for accomplishing objectives, but that such groups must be physically and culturally separate from the main organisation.[42, 43]

*Sources of Ideas.* While NIAC relies entirely on research topics and concepts proposed by external entities, the ACT relies mainly on the collective insight of its researchers and solicits external ideas only on specific topics in the form of call for ideas. As a consequence, the breath of ideas and concepts considered by NIAC is larger more wide-spread than those of the ACT. In this context it is worth noting that the new NIAC allows also NASA internal ideas to be submitted.

*Contractual interactions.* The ACT limits its external contractual interactions to academia and academic research centres employing a fixed and standardised contractual frame. NIAC has been open to all entities, including industry. In practical terms therefore 100% of external research partners of the ACT are from academia, compared to about 42% of NIAC grants for academic teams. The NRC review of NIAC does not make any distinction between academic and non-academic entities in the account of the successes of NIAC's results.

*Maturation of advanced concepts.* NIAC uses a two-phase process, of which the second phase is a further maturation phase with almost an order of magnitude more resources and conditional on positive results achieved during the first phase. Therefore NIAC is involved in the selection, judgement and further maturation of concepts and technology.

The ACT approach does not include any further technology or concept maturation within the team, but relies entirely on others for this process.

### 4.3. Comparison of Results

Table 2 summarises most of the quantitative comparison parameters of NIAC and the ACT.

#### *4.3.1. Follow-up of new concepts - additional funding*

Both approaches have generated a significant amount of additional follow-up funding. While there is no data for all of NIAC studies, the NIAC final report as well as the NRC report have selected 14 successful studies, which have received originally $7M from NIAC via phase 1 and phase 2 grants and which obtained $ 23.8M of additional follow-up funding. In the case of the ACT, a few high-value follow-up R&D contracts are dominating the additional funding: the ACT has spent € 1.8M on *Ariadna* studies, which in total have received about € 5.3M of external follow-up funding.

While in the case of NIAC studies, most (75%) of the additional funding following their studies has come from NASA via regular, other NASA programmes, in the case of *Ariadna* studies performed by the ACT, the large majority (more than 80%) of additional funding has been coming from non-ESA sources. This substantial difference is related to many factors, among which the different funding environments in the US and in Europe certainly play a role, but it could also be interpreted as related to one of the goals of NIAC, to impact NASA's long-term planning, which is absent from the ACT.

#### *4.3.2. Creation of advanced concepts research networks*

Both processes created a substantial network, which had not existed previously and which has proved to be in both cases useful to connect those interested and knowledgeable on advanced space concepts and to provide them with a common platform. While no exact figures exist, based on the reported number of proposals and reasonably estimates concerning team sizes (extrapolation from successful proposals to all proposals), the total amount of persons having been involved in submitting proposals to NIAC is likely much higher than the total number of individuals involved in submitting proposals to *Ariadna* call for

Table 1: Comparison of qualitative goals and operational means between the NASA Institute for Advanced Concepts (NIAC) and the ESA Advanced Concepts Team (ACT).

| | NIAC[1] | ACT |
|---|---|---|
| goals | - provide an independent source of revolutionary aeronautical and space concepts that could dramatically impact how NASA develops and conducts its missions;<br>- infuse the most promising NIAC-funded advanced concepts into NASA plans and programs | monitor, perform and foster research on advanced space systems, innovative concepts and working methods |
| time horizon | 10-40 years | beyond regular ESA programmes |
| means | - funding source<br>- externally conducted research | - Internal research team<br>- collab. ext. research contracts |
| main source of ideas | external, fully open calls | internal, temporary researchers |
| relation with parent organisation | - external<br>- liaison persons<br>- indep. of core technical entity | - internal<br>- within corporate functions<br>- indep. of core technical entity |
| follow-up of activities | - phase 2 contracts to successful phase 1 studies | - no follow-up mechanism;<br>- not involved in evaluation of own research results |
| external follow-up | mainly NASA contracts | mainly non-ESA contracts |

[1] evaluation based on the original NIAC, its re-establishment in 2010 with slightly different parameters is not taken into account in this table.

ideas and call for proposals. Under the assumptions made in section 3.1, between 3900 and 13000 persons might have been involved in some way in submitting ideas to NIAC, with a figure between 5000 and 6000 being most likely. NIAC having been operational for nine years, this amounts to between 550 to 660 person per year on average.

The 60 unique calls for proposals for *Ariadna* have received a total of approximately 180 proposals, with each containing a minimum of two researchers as a requirement, and in reality between 3 and 6. The total number of European researchers involved in *Ariadna* study proposals can therefore be estimated to be between 540 and 1080, with a likely number around 700 researchers, or 100 researchers per year on average.

While the number of researchers involved in writing applications cannot be considered as part of the actual network, the persons actually involved in selected studies and research cooperations leading to tangible results form the actual functioning network of researchers. In the case of NIAC, the selected 126 NIAC Phase I studies (some of which were continued into Phase II studies) are to be considered. As accounted for in section 3.1.4, these included 109 distinct principal investigators forming a total network of about 500-600 persons created during its nine years of operations, thus an average of 50-60 researchers added per year of operations. There are no accounts of publications and unique co-authorships for NIAC study results. In the case of the ACT, the 60 unique call for proposal studies have led to 90 actual studies (some being conducted in parallel), thus between 270 and 540 researchers under the above assumptions.

A more accurate result is however obtained by taking as basis the 450 unique co-authors of papers authored also by ACT team members. Taking as a basis the seven years of operations of the *Ariadna* scheme, this results also in about 60 researchers added per year. In case the time between the creation of the team and the creation of the Ariadna scheme is taken into account (since the team has already published also before the *Ariadna* research scheme had been put in place), on average 50 new researchers have been added per year to the active research network of the ACT.

## 5. DERIVED RECOMMENDATIONS AND PROPOSED EVALUATION PARAMETERS

### 5.1. Organisational Recommendations

Based on the comparison and preliminary analysis of the mechanisms used by NIAC and ACT, as well as taking into account some derived from DARPA, the possibly most successful

Table 2: Comparison of key quantitative data and characteristics between the NASA Institute for Advanced Concepts (NIAC) and the ESA Advanced Concepts Team (ACT).

| | NIAC(1) | ACT |
|---|---|---|
| created in | 1998 | 2002 |
| operational until | 2007 | today |
| operational years assessed | 9 | 9 |
| grant amount phase 1 | \$50-75k | € 15-35k |
| grant amount phase 2 | ≤ \$500k(2) | none |
| external partners | 42% academia<br>44% small businesses<br>6% large businesses<br>8% others | 100% academia |
| average funding per year | \$4M | € 1M |
| total funding | \$36.2M | € 7.8M(7) |
| funding to research grants | \$27.3M | € 1.8M |
| funding to research grants (in %)(3) | 75% | 24% |
| total number of research studies(4) | 168 (Phase 1: 126, Phase 2: 46) | 90 |
| external follow-up funding(5) | \$7M having led to \$23.8M | ≈ € 5.3M |
| ratio external follow-up / initial funding | missing data | 3 : 1 |
| research network(6) (number of researchers) | 500-600 | 450 |

(1) the data are based on the original NIAC and do not take into account its re-establishment in 2010 with slightly different parameters and no available data yet.
(2) see explanation in main text for difference between NIAC and NRC reports.
(3) the percentage value is based on the total funds spent over nine years and not the average of the annual percentages spent on external research contracts (their variation is from 11 to 39%); if furthermore excludes GSP study activities the team was conducting during the first years of its creation.
(4) The number for the ACT does not take into account research studies done without exchange of funds, but includes only those done within the *Ariadna* scheme.
(5) The NIAC value is based on a selection of 14 studies which had received substantial additional funding as reported by the NRC evaluation. The total value is not provided by the NIAC final report nor by the NRC evaluation.
(6) The number for NIAC is based on estimations of researchers involved in successful NIAC grants, while the number for the ACT is the number of unique co-authors of scientific papers authored by the team's researchers during their stay at the ACT.
(7) Numerically, the average annual funding of the ACT would be € 860k though due to the structure and functioning of the team, it required approximately two years before being fully operational and reaching the € 1M funding level, which is taken as a basis for this assessment.

disruptive innovation agency of the last decades [24], the following key parameters are proposed for the organisation of a successful entity mandated to provide the first steps, the "seeds" for disruptive innovation.

**Renewal of researchers** the organisation should include a mechanism for a regular renewable of key researchers and innovators, assuring a constant influx of new ideas, approaches and concepts is central; importance to not building up of heritage preventing new approaches to mature unconstrained;

**Risk taking** The organisational setup and reward system needs to encourage risk taking;

**Scientific Rigour** Research on potentially concepts and technology related to disruptive innovation tend to be outside of the scientific comfort zone of many researchers, lack established researcher communities and associated journals and thus recognition; scientific rigour and the right mix of competence is therefore key to guaranteeing an unquestionable methodological approach and to avoid drifting into the realms of science fiction.

**Interdisciplinarity** Disruptive, potentially game-changing developments tend to emerge on the fringes and intersections of disciplines.

**Support from top management** Such teams and activities tend to be ridiculed, admired, not taken seriously, and seen as a threat by the core of the establishment - depending on relative interests at stake. Without clear support from top-management, including the shielding from core technical establishments, such groups struggle to survive, especially in successful organisations.

**Importance of academia** While SMEs and start-up companies seem to be key for disruptive innovation in a 5 to 10 year time-span, the most relevant ideas and concepts for

10-15+ years are first generated within academia and research centres.

## 5.2. Evaluation Parameters

The scholarly literature has not yet converged upon generally accepted evaluation parameters for disruptive innovation approaches. With hindsight, it is easy to qualify if and when an innovation has been disruptive or sustaining, radical or incremental. With hindsight, it is also easy to analyse and understand the reasons for why some actors succeeded and some others failed, deriving some general patterns.[9, 10, 44, 45]

The shorter the time spans of products and thus the faster the rate of change, the easier it becomes to generate data and underlying patterns, which might help for decisions regarding the optimal organisational structure to address them. For sectors with very long product cycles such as the space sector, which additionally is still relatively young, and dominated by governmental monopsony conditions, data on disruptive innovation policies and results are sparse.

The comparison between the NASA Institute for Advanced Concepts and the ESA Advanced Concepts Team therefore followed a straight forward, fact-based approach. These are now inserted into one method, proposed by O'Connor for the organisational setup criteria to prepare for major innovations, with the understanding that this reference can only serve as a starting basis for a discussion, leading potentially to an argued better understanding of the most appropriate method for the space sector.[43]

### *5.2.1. Preparation for 'major innovation' - organisational parameters*

While there is substantial scholarly literature on disruptive innovation, an emergent consensus on some of its key parameters, there are still widespread differences concerning how to best prepare for disruptive innovation in organisations. Furthermore the scholarly literature on this topic always assumes the mechanisms governing competitive markets. The space sector is however fundamentally different in this respect. Therefore the proposed conclusions derived in the scholarly literature might not be fully applicable as such to the mechanisms in the space sector.

An interesting approach is proposed by O'Connor, who proposes seven key system elements as being central to enabling what she terms 'major innovation' to happen.[43] The argument is based on the assumption that organisations are not be able to take full advantage of their internal resources for preparing for 'major innovation' if they continued to relying mainly on innovation champions. The important role of these passionate innovators has been well described in scholarly literature on innovation and it is argued that these need to be recognised and fostered by the organisation's management. However, O'Connor argues, based on advances in systems theory, advances in dynamic capabilities theory, and the management of innovation literature that organisations need to develop what she called a "dynamic capability" that includes the key innovators as only one element of an innovation system.[43]

The article then develops a framework for building such a dynamic capability for major innovation. Since in this context, major innovation has been defined by combining two very similar types of innovation, "radical innovation" and "really new innovation", a distinction not important for the purpose of the present paper, the proposed framework for major innovation can be considered a fully applicable to radical innovation and sufficient to also include disruptive innovation. Common to all of these are high levels of uncertainty on multiple dimensions, which require the organisation to move into unchartered territory, where "reliance on experience, current knowledge assets, and loyal customers is not an advantage".[43]

The proposed framework contains seven elements that together intend to form a management system rather than a process-based approach. It is argued that dynamic capabilities for such complex phenomena need to be considered in a systems fashion rather than as operating routines and repeatable processes.[43] These system elements are:

1. an identifiable organisation structure;
2. interface mechanisms with the mainstream organisation, some of which are tightly coupled and others of which are loose;
3. exploratory processes;
4. requisite skills and talent development;
5. governance and decision-making mechanisms at project, innovation portfolio, and innovation system levels;
6. appropriate performance metrics; and
7. an appropriate culture and leadership context.

This framework is intended to be applied at organisational level, therefore its usefulness in the frame of the analysis of the mechanisms and processes developed by both NIAC and ACT is related only partially to these mechanisms, partially to the role of these entities within the overall innovation framework of the respective parent organisations.

Based on the results of the general comparison as reported in chapters 2.1.1 and 3.2.4, the organisational setups chosen by both NASA and ESA correspond to the following of these elements: Both organisations use a clearly identified organisational structure, both have established clear interface mechanisms with the mainstream organisation, both allow exploratory processes and risk taking to happen and even encourage it, both have some performance metrics, even if those are defined wider than in the concept of O'Connor, and both have developed a specific, adapted culture and leadership context. The remaining two aspects, the requisite skills and talent development and the governance and decision making mechanisms at project, innovation portfolio and innovation system levels have not been included in the above assessment. These also have not been included as key aspects in the external review of NIAC and data related to these points is scarce.

## 5.3. Proposed Disruptive Innovation Evaluation Parameters for the Space Sector

The analysis of the present paper is based on data from the US and European space sector and especially two organisational units. Therefore the evaluation parameters proposed are necessarily reflecting the environment in which they have been developed and thus remain *a priori* solely confined to the space sector. Since they are however relatively high-level, it could be of interest investigating their extension to other sectors.

*5.3.1. a- Take-up of results by the parent organisation*

One of the key evaluation parameters needs to be the percentage of concepts, technologies, ideas and methods initially developed by teams in charge of preparing for disruptive innovation. Ultimately, the parent organisation needs to benefit from the activities of such groups and the direct take-up of results constitutes one clear measure. The right percentage of those ideas that are continued by the mainstream organisation with respect to those not taken up depends on where on the risk-benefit scale the parent organisation wants to position the team. High-risk high-return approaches are typically aiming at success rates in the area between 10 to 30%. The evaluation of this parameter needs to include the uncertainty related to the initial ideas and thus take into account potentially important evolutions (thematic) of themes over their initial maturation period.

*5.3.2. b- Impact on parent organisation*

While the first parameter is mainly related to the further funding of actual studies and topics pursued by such mechanisms and therefore quantitative, there are other impact parameters on the parent organisation which also deserve being included in such an evaluation. These include the infusion of methods, methodologies, approaches, and the impact on the parent organisation's 'culture' in general, as well as it's image and attractiveness.

*5.3.3. c- Take-up of results by independent 3rd party organisations*

While this parameter might not be relevant to other setups, mechanisms and structures set up by governments to support disruptive innovation tend to have a scope that extends beyond the mere provision of benefits to the mother organisation to include the larger sector. In this respect, both the ACT and NIAC, even if less explicit for the latter, have as scope to be beneficial to the respective US and and European space sector and not only to ESA and NASA. Therefore, this parameter should include the percentage of concepts, technologies, ideas and methods initially developed by such teams take up and further funded by other entities than their parent organisation.

*5.3.4. d- Impact on sector*

In addition to the quantitative fourth parameter, some qualitative impacts also need to be included in such an evaluation. These include the diffusion of ideas, concepts, methods and results from such teams to the sector in general.

*5.3.5. e- 'Resonance' of results*

The time horizon of disruptive innovation research conducted by both organisations analysed in the present paper is roughly 10+ years ahead. Due to the long planning perspectives of mainstream research and development programmes for space missions, one does not need to wait 10+ years for ideas from such teams getting inserted into mainstream activities, most of them still would enter only years after the initial activities. It is therefore useful to have intermediate parameters. These, labelled for the purposes of the present paper as "resonance of results", include the traditional parameters used for research activities: e.g. number and impact of publications, quotations.

## 6. CONCLUSIONS

Compared to other sectors, the implementation of mechanisms for preparing for disruptive innovation needs to take into account the specificities of the space sector and the specificities on how the space sector is currently organised: strong governmental influences close to governmental monopsony structures, few vertically integrated prime contractors, limited incentives for commercial companies to invest in disruptive innovation, very long lead times, long product cycles and a combination of very advanced technologies pushing the boundaries of what is technically feasible with inherent conservatism to avoid any non-mission enabling risks. The pursuit and stimulation of disruptive innovation therefore has been taken upon essentially by governmental entities.

The present comparison of the NASA Institute for Advanced Concepts and the ESA Advanced Concepts Team shows two mechanisms, distinct in their approaches while similar in their objectives. From their comparison, an attempt has been made to derive both organisational parameters as well as evaluation parameters for the organisation of supporting disruptive innovation in the space sector.

---

## References


[1] W. von Braun, Wernher von Braun to the Vice President of the United States (Apr. 1961).

[2] Z. Szajnfarber, A. L. Weigel, Innovation dynamics of large complex technological products in a monopsony market structure: The case of ESA science missions, in: Atlanta Conference on Science Technology and Innovation Policy, 2007, pp. 19–20.

[3] C. Jolly, The space economy at a glance 2011, OECD Pub., Paris, 2011.

[4] L. Summerer, Specifics of innovation mechanisms in the space sector, in: Proceedings of the XX ISPIM Conference 2009, no. 978-952-214-767-7, ISPIM, Vienna, Austria, 2009.

[5] J. A. Schumpeter, Capitalism, socialism, and democracy, 5th Edition, Routledge, 1994.

[6] Z. Szajnfarber, A. L. Weigel, Stitching the patchwork quilt: Integrating the diverse literatures relevant to complex product innovation in a government monopsony, Tech. rep., MIT (2010).

[7] European Commission, Green paper on innovation, EC green paper, European Commission, http://europa.eu/documents/comm/green_papers/pdf/com95_688_en.pdf accessed April 2009 (1995).

[8] J. E. Ettlie, W. P. Bridges, R. D. O'Keefe, Organization strategy and structural differences for radical versus incremental innovation, Management Science 30 (6) (1984) 682–695, 10.1287/mnsc.30.6.682.

[9] J. Bower, C. Christensen, Disruptive technologies: catching the wave, Harvard Business Review 73 (1) (1995) 43.

[10] C. M. Christensen, The Innovator's Dilemma, Harward Business School Press, Boston, 1997.

[11] C. M. Christensen, M. Raynor, The Innovator's Solution, Harward Business School Press, 2003.

[12] E. Danneels, Disruptive technology reconsidered: A critique and research agenda, Journal of Product Innovation Management 21 (4) (2004) 246–258.

[13] F. Betz, Strategic technology management, McGraw-Hill, 1993.

[14] N. Smyrlakis, L. Summerer, L. Latronico, Innovation dynamics in a monopsony structure: Insights based on a simplified model of the european space sector, International Journal of Space Technology Management and Innovation (IJSTMI) 1 (1) (2011) 24–43.

[15] R. Henderson, The innovator's dilemma as a problem of organizational competence, Journal of Product Innovation Management 23 (1) (2006) 5–11.

[16] Z. Szajnfarber, M. G. Richards, A. L. Weigel, Implications of DoD acquisition policy for innovation: The case of operationally responsive space, in: AIAA SPACE 2008 Conference, 2008.

[17] S. Scherreik. When a guru manages money [online] (Jul. 2000). Bloomberg Businessweek Online | July 31, 2000 | When a Guru Manages Money [cited September 2011].

[18] R. D. Braun, D. S. Wiley, H. W. Brandhorst, D. C. Byers, D. Chinette, I. Chopra, F. D. Drake, O. A. Graeve, M. G. Jones, R. A. Moore, P. E. Muntz, L. R. Young, Fostering visions for the future: a review of the NASA Institute of Advanced Concepts, National Academies Press, Washington DC, US, 2009, http://www.nap.edu/catalog/12702.html.
URL `0-309-14052-8`

[19] NASA Institute for Advanced Concepts, NIAC - 9th annual and final report, Annual Report Performance Period July 12, 2006 - August 31, 2007, Universities Space Research Association and ANSER, Atlanta, GA 30308, US (Aug. 2007).

[20] ACT Advanced Concepts Team, http://www.esa.int/act (Aug. 2011).
URL `http://www.esa.int/act`

[21] L. Summerer, D. Izzo, G. Naja, I. Duvaux-Bechon, ESA's Advanced Concepts Team, ESA Bulletin (2010) 34–43.

[22] L. Summerer, G. Naja, M. Johansson, Space 2030 - research trends as input for long-term planning, in: Proceedings 59th International Astronautical Congress, Vol. IAC-08-D.3.2.6, Glasgow, UK, 2008.

[23] W. B. Bonvillian, Power play: The DARPA model and US energy policy, The American Interest (2006) 39–48.

[24] E. Fuchs, The role of DARPA in seeding and encouraging new technology trajectories: Pre-and Post-Tony tether in the new innovation ecosystem, Industry Studies Association - Working Paper Series WP-2009-01.

[25] R. Adams, J. Bessant, R. Phelps, Innovation management measurement: A review, International Journal of Management Reviews 8 (1) (2006) 21.

[26] R. Watts, A. Porter, Innovation forecasting, Technological Forecasting and Social Change 56 (1) (1997) 25–47.

[27] Frb: H.10 release - foreign exchange rates [online] (September 2011). see `http://www.federalreserve.gov/releases/H10/hist/dat00_eu.htm` [cited September 2011].

[28] Universities Space Research Association, About USRA | USRA: universities space research association, http://www.usra.edu/cs/about_usra (Aug. 2011).
URL `http://www.usra.edu/cs/about_usra`

[29] ESA, Directorate of strategy and external relations (D/SER), ESA/ADMIN(2002)13, rev.1 (December, 18 2002).

[30] European Space Agency. ESA - General Studies Programme [online] (2011). http://www.esa.int/gsp [cited September 2011].

[31] ESA Advanced Concepts Team. ACT - Ariadna [online] (August 2011). http://www.esa.int/ariadna [cited August 2011].

[32] M. Vasile. Advanced Space Concepts Laboratory - University of Strathclyde [online] (Sep. 2011). http://www.strath.ac.uk/space/.

[33] DLR - institute of space systems - advanced study group (ASG) [online] (Sep. 2011). http://www.dlr.de/irs/en/desktopdefault.aspx/tabid-7013/11633_read-27384/.

[34] A. Gálvez, G. Naja, Space Tourism - ESA's view on private suborbital spaceflights, ESA Bulletin 135.

[35] L. Summerer, ENSaF-Steps towards a european space nuclear safety framework, in: TRISMAC, ESA, Noordwijk, Netherlands, 2008.

[36] F. Ongaro, L. Summerer, D. Izzo (Eds.), Acta Astronautica - Global Trajectory Optimization. Results of the First Competition Organised by the Advanced Concept Team (ACT) of the European Space Agency (ESA), Elsevier, 2007.

[37] L. Summerer, E. Finzi, P. Messina, Nuclear power sources for space exploration: Status and prospective in europe, in: Proceedings 10th ISU Symposium on Space Exploration, ISU, Strasbourg, France, 2005.

[38] L. Summerer, K. Stephenson, Nuclear power sources: a key enabling technology for planetary exploration, Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering 225 (2) (2011) 129–143. doi:10.1243/09544100JAERO766.

[39] L. Summerer, F. De Winne, Considerations on safety and european options regarding nuclear power sources for space, in: Proceedings 1st IAASS Conference, Nice, France, 2005.

[40] I. Duvaux-Bechon, I. Sabater, 'Space & energy' - supporting EU policies, ESA Bulletin (142) (2010) 45–55.

[41] F. Ongaro, L. Summerer, Space and a 21st century energy system, in: Proceedings IAC'06, Valencia, Spain, 2006.

[42] M. Benner, M. Tushman, Exploitation, exploration, and process management: The productivity dilemma revisited, Academy of Management Review 28 (2) (2003) 238–256.

[43] G. Colorelli O'Connor, Major innovation as a dynamic capability: A systems approach, Journal of Product Innovation Management 25 (4) (2008) 313–330.

[44] J. F. Christensen, Corporate strategy and the management of innovation and technology, Industrial and Corporate Change 11 (2) (2002) 263. doi:10.1093/icc/11.2.263.

[45] C. M. Christensen, H. Baumann, R. Ruggles, T. M. Sadtler, Disruptive innovation for social change, Harvard Business Review 84 (12) (2006) 94.