NASA'S CAPABILITY EVOLUTION TOWARD COMMERCIAL SPACE

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ABSTRACT

We discuss how the space industry moved from a government dominated field to a commercially driven field. In the context of this industry shift, we explore how NASA's capabilities developed from its early hierarchical model, to the inter-governmental and then commercial network models. We refer in particular to NASA's organizational, cultural, relational and technological capabilities. These developments over time suggest that these are dynamic capabilities that respond to the demands of the external environment and to mission imperatives.

From Government Dominance to Commercial Space

What was once the province of the US and Russian governments has now become a global, multi-faceted, multi-stakeholder endeavor. Out of a value of US$ 383.5 bn of space activity in 2017, 80% (US$ 307.3 bn) was accounted for by commercial products, services, infrastructure and support industries. The US government accounted for 11.3% (US$ 43.3 bn) and other world governments combined for 8.5% (US$ 32.8 bn) of that amount[1].

Commercial space has been growing at an accelerating pace as the economics of the industry are changing to make offerings more affordable and accessible for industry, government and individuals. The development of re-usable launch vehicles (such as those developed by Space-X and Blue Origin), nano-satellites (weighing 10kg or less), and more efficient propulsion systems are all part of this trend.

The development of small satellites is creating more cost effective options for companies offering broadband, remote imaging and communication services[2]. According to the United Nations Office for Outer Space Affairs, there are 7,677 objects that have been launched into space since 1957[3]. The Union of Concerned Scientists (UCS) notes that the total number of satellites that are currently operating is 1,459. Of these, 593 are US satellites, 135 are Russian, 192 are Chinese, and the remaining belong to other nations. Of the 593 US satellites, 297 are commercial, 150 are military, 136 are government and 10 are civil[4].

The availability of expanded sources of financing is enabling new entrants to compete in the space sector[5]. There were 80 new space ventures created in the US during

the period 2000 to 2015. These received a total of $13.3 bn in funding during this period. Of this, $5.1 bn was debt financing, $2.9 bn was venture capital, $2.2 bn was the value of acquisitions, and $1.8 bn was private equity. The amount of funding ballooned from $1.1 bn during 2000-2005 to $6.1 bn during 2006-2010 and to $13.3bn during 2011-2015[6].

Continued development of the US commercial space sector will be affected by issues such as regulation and growth constraints placed by export controls[7]. In addition to NASA, there are several other agencies with commercial space interests and responsibilities, including FAA's Office of Commercial Space Transportation, Department of Commerce, Department of Defense, the Department of State, and the Federal Communications Commission. Despite relevant legislation calling for some relief from regulation of the space sector compared to other industries, the multitude of agencies involved creates red tape new entrants and established companies. Further, export controls currently limit the export of selected space technology since some items are regarded as dual-use in that they have possible military applications.

Even though much of current space-related spending is ultimately driven by government demand, ultimately commercial market offerings will predominate, especially if government policies support their development[8].

Why Commercial Space?

The commercialization of space has been a long standing policy of the federal government, that has instituted corresponding legislation. The Commercial Space Launch Act (1984) for example noted that: "private applications of space technology have achieved a significant level of commercial and economic activity, and offer the potential for growth in the future, particularly in the United States. ... the development of commercial launch vehicles and associated services would enable the United States to retain its competitive position internationally, thereby contributing to the national interest and economic well-being of the United States. ... the United States should encourage private sector launches and associated services." This and subsequent acts have also exempted the commercial space sector from certain types of federal regulation, to ease its expansion. Part of the state's concern has been not only to spur innovation in the space sector but also to accomplish things more efficiently given critiques of NASA's levels of efficiency as well as the state's own budget constraints[9].

Commercial space companies such as Space X and Blue Origin, even though they often license NASA technology, compete for NASA contracts and employ NASA scientists, can undertake certain tasks (such as transporting cargo to the International Space Station) more efficiently than NASA. For example, NASA used its cost estimation methodology (NASA-Air Force Cost Model or NAFCOM) to estimate the development costs if NASA was to develop the Falcon 9 rocket of Space X itself, using its traditional development model[10]. It was estimated that the costs would reach US$ 4 bn. Under more commercial assumptions in the model, where there is less involvement by the government and higher flexibility for the commercial partner, the estimated costs were US$ 1.7 bn. Space X announced that the development costs of the Falcon 9 (plus an earlier version, Falcon 1), were US$ 390 m, one quarter of the NASA's lowest estimate.

On a grander and more meaningful scale, commercial space will be instrumental in helping humanity reach the longer term goal of becoming an inter-planetary species as advocated by entrepreneurs and luminaries such as Elon Musk, Jeff Bezos and Stephen Hawking. NASA's Global Exploration Roadmap indeed assumes the fundamental contribution of commercial space, along with government investments, as a cornerstone of humanity having the ability to reach beyond Low Earth Orbit to Mars and deep space[11].

NASA's Capability Evolution Towards Commercial Space

Since its early days, NASA has contracted with the commercial sector for the supply of specialized equipment and services. The Jet Propulsion Laboratory operated by the California Institute of Technology was a contractor facility before becoming part of NASA. NACA (the National Advisory Committee for Aeronautics), NASA's predecessor, allocated the contracts to private companies for the airframe (in 1955) and engines (in 1966) for the X-15, a hypersonic rocket-propelled aircraft. When NASA was formed in 1958 it continued the practice of working with the commercial sector. Then in 2006, NASA started the process for contracting out the construction and operation of Commercial Resupply Services vehicles, that would carry out unmanned resupply missions to the International Space Station. In 2010 NASA initiated the Commercial Crew Program, to contract out the creation and operation of spacecraft that could conduct manned missions to the International Space Station; to carry at least four astronauts, dock for 180 days and return them to earth. These

two programs provided seed funding, opportunity and impetus for more commercial companies to enter the space industry.

The space industry has been going through a structural shift from state dominance in earlier days towards commercial enterprise, lower barriers to entry, higher collaboration between state and commercial actors, and innovation in terms of its offerings. The traditional industry model was a hierarchical one, where commercial entities have been suppliers to state agencies that conceived of, led and carried out missions. The industry has been morphing to a network model where collaboration across commercial as well as state entities is crucial and where commercial entities can launch their own missions both as partners and as competitors. Government space agencies are contracting out more aspects of low earth orbit missions, and are focusing their resources on the bigger prize of deep space exploration such as NASA's planned mission to Mars[12].

Often the traditional hierarchical and new network models of NASA's relationship with commercial space are contrasted, as in Table 1 below. In the traditional model NASA was the prime contractor and exclusive customer, buying the technologies it needed with the relationship based on cost-plus contracts. NASA gave detailed specifications of what should be done and how, and incurred the total cost. The owner of the resulting technology was NASA. There was penetration of NASA engineers in contractor operations, with large amounts of control over what the contractors were doing, to ensure the meeting of specifications.

In the new, commercial-oriented approach, NASA enters a public-private partnership with fixed-price contracts, where it does not own the resulting technology. Commercial entities can sell their services to other customers. Costs are shared, with NASA paying for milestones reached. Rather than providing detailed specifications for the what and the how, NASA specifies high level goals, leaving the how to the commercial partners.

Program characteristic	Early space age approach	Commercial-oriented approach
Owner	NASA	Industry
Contract fee-type	Cost plus	Fixed price
Contract management	Prime contractor	Public-private partnership
Customer(s)	NASA	Government and non-government
Funding for capability demonstration	NASA procures capability	NASA provides investment via milestone payments
NASA's role in capability development	NASA defines "what" and "how"	NASA only defines "what", industry defines "how"
Requirements definition	NASA defines detailed requirements	NASA defines top-level capabilities needed
Cost structure	NASA incurs total cost	NASA and industry cost share

Table 1: The early space and commercial-oriented development approaches

Source: Adapted from NASA, 2012: 4[13]

While this binary comparison is useful, it also somewhat oversimplifies things. We advance discussion in this domain in two ways. First, we suggest that we can understand NASA's new approach in terms of an evolution over time, that includes a transitional phase in which NASA honed its capabilities and learning to be able to advance to the commercial network model. Second, we argue that NASA has been able to advance to this model by developing its *organizational*, *cultural*, *relational* and *technological* capabilities over time, so as to be able to work more effectively with commercial entities.

We outline the traditional approach, the transitional phase and the commercial network phase, each of which can be exemplified by an archetypal project: Apollo, International Space Station, and the Commercial Resupply Program respectively.

The Apollo program was initiated as a response to perceived Russian superiority in space and challenge of the US for long-term space leadership[14]. Substantial budgetary and organizational resources were allocated to the program by the government with the focused objective of accomplishing the challenge that President Kennedy posed in 1961: of getting a man on the moon and returning him safely to earth before the decade was out. In the Apollo program, NASA's organizational capabilities included technological knowledge that allowed it to develop detailed engineering specifications; large systems integration

imported from the military, and the ability to work with and supervise contractors[15]. There was a cultural belief in technological superiority and exceptionalism[16]. NASA's relationships with contractors were hierarchical, with NASA delivering specifications as Moses delivered the ten commandments. Technological capability development was agency-driven, with a unitary engineering architecture.

The International Space Station fostered and exhibited organizational capabilities of international collaboration and inter-governmental partnerships[17]. Culturally, the sense of technological superiority was still there, but now accompanied with greater cost consciousness. Relationally, the sense of hierarchical pecking order was supplemented by a cluster of international governmental organizations, with NASA as the orchestrator and influencer. Technologically, NASA leveraged international public investments, distributed technical responsibility and worked on developing shared technical interfaces, standards and protocols[18]. During this phase, NASA honed its learning of how to function in a cluster of partners rather than how to be the dominant party in a buyer/supplier relationship.

The Commercial Resupply Program was initiated to carry cargo to the International Space Station after the space shuttle was retired[19] and formed a substantial impetus for further development of the commercial space sector, including Space X that won the contract to resupply the ISS[20]. In the Commercial Resupply Program, NASA's organizational capabilities were focused on specifying end goals and ongoing partnering (public-private partnerships). Culturally there was higher commercial awareness and cost consciousness, as well as openness to solutions created anywhere within the network. Relationally NASA was part of a network of clusters rather than a single cluster, and acted as a catalyst for industry technology development. Technologically NASA leverages industry investments and initiates open innovation programs.

Table 2 below outlines the traditional, transitional and commercial network models:

Development approach	Traditional model	Transitional model	Commercial network model
Project examples	Apollo	International Space Station (1993-present)	Commercial Resupply Program (2006-present)
Selected sources	Beggs (1984) Siddiqi (2000)	DeLucas (1996) Kitmacher et al (2005)	Lambright (2015) Lindenmoyer & Stone (2010)
Organizational capabilities	Engineering specifications, Contractor supervision, Large systems integration	International collaboration, Inter-governmental partnerships (public-public partnerships)	Specification of end goals, Ongoing partnering (public-private partnerships)
Cultural attributes & capabilities	Technical superiority, Exceptionalism	Technical superiority, Increased cost consciousness	Commercial awareness, Cost consciousness, Openness to industry-sourced solutions
Relational capabilities	Hierarchy, Positional authority, NASA as Moses	Cluster, NASA as orchestrator, Exercise of influence	Network of clusters, NASA as catalyst for industry technology development
Technological capabilities	Agency driven investments, Unitary engineering architecture	Agency leverages international public investments, Distributed responsibility, Interfaces, common standards & protocols	Agency leverages industry investments, Initiates open innovation programs

Table 2: Evolution of NASA capabilities over time

Source: Authors

Development of Dynamic Capabilities at NASA

In order to understand NASA's evolution in its relationship with commercial entities, from its traditional contracting model to its current network model, we need to view it as a learning process where organizational, cultural, relational and technological capabilities were gradually honed towards that objective. Reaching this point is an important step in the process of focusing resources on reaching Mars and deep space. NASA's Global Exploration Roadmap[21] (particularly the end goal of reaching manned missions to Mars via progressively building on missions of increasing complexity) is predicated on dynamic capabilities, that evolve over time as a result of learning from experience.

It is clear NASA's capabilities have developed over time, and that the growth of the commercial-oriented approach has created impetus for further cultural and organizational change within NASA[22]. NASA for example now engages in open innovation[23], posing innovation challenges online in open competitions, as a complement to internal innovation

efforts. Given the substantial shifts in NASA's external and internal environment, it was suggested that the agency should take two steps. One, it should be given more flexibility to manage its infrastructure and human resources based on market-based, competitive principles. Second, that it should become a real network organization, effectively integrated both internally across its own field centres, and externally with commercial organizations, research centers, universities or think-tanks that produce space-related knowledge[24]. Such developments would be consistent with the commercial network model and would hone its commercial capabilities further. These developments are also crucial If humanity is to ultimately become an inter-planetary species as insurance for its survival, because they enable relevant space-related knowledge from wherever it is present to serve this goal.

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