TRANSFORMING TO THE FOURTH ERA OF SPACE EXPLORATION

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I. INTRODUCTION: THE FOUR ERAS OF SPACE EXPLORATION

Dr. Edward C. Stone, former Director of NASA's Jet Propulsion Laboratory, identified four eras of space exploration: the First Era of getting there; the Second Era of finding what is there; the Third Era of getting there often, landing, and getting back; and the Fourth Era of getting there and staying there.[1] A successful transition from one era to the next requires major alterations and transformations in the way corporations, governments, and whole industries behave and interact. This article describes the four major transformations—of the aerospace industry, of organizational relationships, of manufacturing, and within aerospace organizations—that are occurring as the industry transitions from the Third to the Fourth Era of space exploration.

A. *FIRST ERA: GETTING THERE*

During the First Era, the focus was on getting a spacecraft into and beyond Earth orbit. While previously rockets had gone up and come back down, the first satellite was Sputnik in 1957, followed a year later by the United States' first satellite Explorer 1. Subsequent missions focused on learning more about the Moon and flying by or orbiting planets.

B. *SECOND ERA: FINDING OUT WHAT IS THERE*

The Second Era focused on finding out about the environment beyond Earth orbit and on the planets, with spacecraft going into orbit around and landing or crashing onto other bodies.

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[1] Edward C. Stone, Transformation in the Third Era of Space Exploration, Presentation to the Highlands Forum in Carmel Valley Ranch, Cal. (Sept. 2, 1999).

All planets were visited except Pluto (when it was still a planet),[2] and over 85 space telescopes were launched.

C. *Third Era: Getting There Often, Landing, and Getting Back*

During the Third Era the focus was and is on longer stays, such as the Mars rovers, and bringing back material such as comet tail samples and Moon rocks. The Third Era was also the beginning of manned space exploration with Yuri Gagarin's orbital flight in 1961, Alan Shepard's sub-orbital flight the same year, and the Moon landings.

D. *Fourth Era: Going There and Staying There*

Finally, in the Fourth Era, the focus is on long-term stays in and beyond Earth orbit. While robotic exploration will continue, particularly of Mars with eventually a sample return, the emphasis will be on manned exploration. Russia's Salyut 1 in 1971 was the first space station. Currently flying are the International Space Station (ISS) (1998–present) and China's Tiangong-1 space station (2011–present). A primary goal of the Space Shuttle, to provide frequent, relatively low cost access to space, was never fulfilled, although the Shuttle played a key role in building the ISS.

Tourism using sub-orbital vehicles is likely to be next, with the first paying passenger flight predicted for 2013. Within a few years, commercial spacecraft will be taking astronauts to the ISS, with commercial orbital flights offered soon after. Eventually there will be privately owned orbital destinations, such as hotels, resorts, scientific laboratories, and manufacturing facilities. Hopefully the next two decades will see a return to the Moon and a manned exploration of Mars, with more permanent residences established on both bodies. Beyond that our crystal ball gets very foggy.

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[2] A mission to Pluto is planned for 2015. Hadley Leggett, *Pluto 2015: Journey to the Rim of the Solar System*, WIRED.COM, Nov. 11, 2009, http://www.wired.com/wiredscience/2009/11/new-horizons/.

II. Four Transformations Required

We are currently in transition between fulfilling the Third Era and beginning the Fourth Era, with each transition requiring a *transformation* in aerospace organizations. A transformation is *qualitatively* different from a *change*. A change can be considered incremental alteration, meaning the basic nature of something remains the same while specific aspects different. For example, getting a haircut is a change. In contrast, a transformation is an alteration in the basic nature of something. The metamorphosis of a caterpillar to a butterfly, especially as evoked by the image of the chrysalis stage, is a transformation. The first heavier-than-air flight by the Wright brothers was a transformational event. The transition from the Third to the Fourth Era of space exploration requires four transformations: (1) A transformation of the aerospace industry, (2) a transformation of organizational relationships, (3) a transformation of manufacturing, and (4) a transformation within organizations.

A. *Transformation of the Aerospace Industry*

Especially in the transportation area, space has been the exclusive domain of governments. Although commercial companies built the launch vehicles and spacecraft, the government, who owned and operated the craft, dictated their design and construction. Space exploration is experiencing a transformation from being a government monopoly to being commercial enterprise (currently) to being a space industry (future). The transformation began with the government's 2010 decision to cancel the Constellation program and, instead, to contract with private companies to deliver cargo and humans to the ISS in low Earth orbit (LEO, altitudes between 99 and 1,200 miles) at fixed prices.[3] This provided financial incentives for

[3] Kenneth Chang, *Obama Calls for End to NASA's Moon Program*, The New York Times, Feb. 1, 2010, http://www.nytimes.com/2010/02/02/science/02nasa.html.

private industry to develop LEO capabilities using their own resources and enabled the government to focus its limited funding on space exploration beyond LEO.

Before 1999 all launch facilities were government owned and operated. Since then a private company, Sea Launch, has been launching satellites from the equator using two specialized privately owned ships.[4] States are building spaceports, and some rocket developers are considering building their own launch facilities.

Companies are using their own funds to design, develop, and operate launch vehicles. Virgin Galactic, XCOR, Blue Origins, and Masten Space Systems are developing sub-orbital launch vehicles. Virgin Galactic, funded by Richard Branson, has designed a six-passenger two-pilot vehicle intended mainly for tourism at $200,000 per passenger.[5] XCOR has the Lynx which is a two-person vehicle designed to carry a pilot, one tourist passenger for $95,000, and scientific experiments.[6] Unique is the short turn-around time between launches. Blue Origin, funded by Amazon founder Jeff Bezos, is developing a vertically launched and landed spacecraft carrying one pilot and three passengers.[7] Masten Space Systems develops, tests, and builds suborbital reusable launch vehicles that have a vertical takeoff and vertical landing (VTVL vehicles).[8] Launched vertically, the vehicles are designed to autonomously go to about a nineteen-mile altitude, hover (which a sounding rocket cannot do), and then return safely under power to its launch site.[9] Masten is also developing the related guidance, navigation, and control software for VTVL vehicles.

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[4] Sea Launch, http://www.sea-launch.com/ (last visited Aug. 22, 2012).

[5] Virgin Galactic, http://www.virgingalactic.com/ (last visited Aug. 22, 2012).

[6] Press Release, XCOR Aerospace, RocketShip Tours to Sell Rides to Edge of Space Aboard XCOR's Lynx: RocketShip Tours Founder Jules Klar Says $95,000 Price Is Proof That Competition Is Lowering the Cost of Space Access (Dec. 2, 2008), *available at* http://www.xcor.com/press-releases/2008/08-12-02_RocketShip_Tours_to_sell_rides_on_XCOR_Lynx.html. *See* XCOR Aerospace, http://www.xcor.com/ (last visited Aug. 22, 2012).

[7] Blue Origin, http://www.blueorigin.com/ (last visited Aug. 22 2012).

[8] Masten Space Systems (Masten), http://masten-space.com/ (last visited Aug. 22, 2012).

[9] For an idea of what Masten's VTVL rockets can do, see Brian Dodson, *Masten Space Systems Takes Its Xaero Suborbital Rocket Out for a Spin*, GIZMAG, July 5, 2012, http://www.gizmag.com/xaero-suborbital-rocket-test-flight/23209/.

Two companies are currently developing orbital launch vehicles. SpaceX, founded by Paypal founder Elon Musk, develops the Falcon series of rockets and the Dragon capsule for commercial cargo and crew development capabilities.[15] The chart below reflects the cost per launch and amount of cargo in pounds carried to LEO with dollars adjusted for inflation. The cost to get the Space Shuttle to LEO and the cargo capability and cost per launch for the Saturn V rocket are included for comparison.

Launch Vehicle	**Payload to LEO**	**Cost per launch**
Falcon 1[10]	1,480 lbs	(rocket no longer available)
Falcon 9[11]	29,000 lbs	$54 million
Falcon Heavy[12]	117,000 lbs	$83-128 million
US Space Shuttle[13]	53,352 lbs	$1.5 billion
Saturn 5 (Apollo)[14]	260,145 lbs	$1.17 billion

Table 1: Cost per Launch to LEO with Cargo in Pounds (dollars adjusted for inflation).

Orbital Sciences designs and manufactures the Antares launch vehicle and the Cygnus cargo spacecraft. The Cygnus cargo spacecraft can deliver up to 6,000 pounds of cargo to the ISS.[16] Unlike SpaceX's Dragon capsule, the Cygnus is designed to burn up on re-entry.

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10 Falcon 1, http://www.spacex.com/falcon1.php (last visited Aug. 27, 2012) (Falcon 1 payloads are planned to be served by Falcon 9); Jason Mick, *Obama's Plan to Commercialize Space Flight Gets Boost from Falcon 9 Launch*, DAILYTECH.COM, June 7, 2010, http://www.dailytech.com/Obamas+Plan+to+Commercialize+Space+Flight+Gets+Boost+From+Falcon+9+Launch/article18636.htm (converting 670 kilograms to about 1,480 pounds with a conversion of 1 kilogram = 2.20462262 pounds).

11 Falcon 9, http://www.spacex.com/falcon9.php (last visited Aug. 27, 2012).

12 Falcon Heavy, http://www.spacex.com/falcon_heavy.php (last visited Aug. 27, 2012).

13 Falcon Heavy, http://www.spacex.com/falcon_heavy.php (last visited on Aug. 27, 2012) (converted to 53,352 pounds at a conversion of 1 kilogram = 2.20462262 pounds); Jeremy Hsu, *Total Cost of NASA's Space Shuttle Program: Nearly $200 Billion*, SPACE.COM, Apr. 11, 2011, http://www.space.com/11358-nasa-space-shuttle-program-cost-30-years.html ("A final tally of the space shuttle program's lifetime costs puts the price tag at $1.5 billion per flight, a new analysis shows.").

14 Kit Eaton, *Happy Birthday Saturn V, Still The Biggest Rocket of All*, GIZMODO.COM, Nov. 9, 2008, http://gizmodo.com/5079556/happy-birthday-saturn-v-still-the-biggest-rocket-of-all; Wikipedia, Saturn V, http://en.wikipedia.org/wiki/Saturn_V (last visited Aug. 27, 2012) ("In 1969, the cost of a Saturn V including launch was [U.S.] $185 million (inflation adjusted [U.S.] $1.17 billion in 2012).").

15 Space Explorations Technology (SpaceX), http://www.spacex.com/ (last visited Aug. 27, 2012).

16 Orbital Science Corporation, http://www.orbital.com/ (last visited Aug. 22, 2012).

There are no private companies currently developing launch vehicles just for deep space, although Falcon Heavy variants are planned for trans-lunar trajectory (35,000 pounds payload) and trans-Mars orbit (31,000 pounds payload).[17]

NASA has issued two contracts to deliver cargo to the ISS and three contracts to develop human transport vehicles. Under the Commercial Orbital Transportation Services (COTS) program, NASA contracted with SpaceX and Orbital Sciences for development of ISS cargo resupply vehicles, with milestone payments.[18] The Commercial Resupply Services (CRS) program issued fixed price contracts to the same two companies for twenty resupply missions.[19] The estimated cost for delivering one pound to LEO is $850 for the Falcon Heavy[20] versus about $21,000 for the Shuttle.[21] NASA's Commercial Crew Development (CCDev) has stimulated private development of crew vehicles to LEO and to the ISS. In August 2012, NASA selected one large publicly held company (Boeing) and two relatively young entrepreneurial companies (SpaceX and Sierra Nevada) for further development funding.[22]

There are even organizations focused on developing permanent residences on the Moon and Mars, such as The Lunar Explorers Society and The Mars Society.[23]

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[17] Rand Simberg, *The Tech Behind the New SpaceX Falcon Heavy Rocket*, POPULAR MECHANICS, Apr. 6, 2011, http://www.popularmechanics.com/science/space/rockets/tech-behind-new-spacex-falcon-heavy-rocket-5518955.

[18] NASA Commercial Crew and Cargo Program Office, About, http://www.nasa.gov/offices/c3po/about/c3po.html (last visited Aug. 22, 2012).

[19] Chris Bergin, *SpaceX and Orbital Win Huge CRS Contract from NASA*, NASASPACEFLIGHT.COM, Dec. 3, 2008, http://www.nasaspaceflight.com/2008/12/spacex-and-orbital-win-huge-crs-contract-from-nasa/.

[20] John K. Strickland, Jr., *The SpaceX Falcon Heavy Booster: Why Is It Important?,* NATIONAL SPACE SOCIETY, Sept. 2011, http://www.nss.org/articles/falconheavy.html.

[21] *See* Associated Press, *Critics Scrutinize Cost of Shuttle*, USATODAY.COM, Feb. 4, 2003, http://www.usatoday.com/news/nation/2003-02-04-shuttle-critics_x.htm; Keith Cowing, *Congress Is Using Bad Numbers to Trash a Business Case*, NASA WATCH, May 26, 2011, http://nasawatch.com/archives/2011/05/using-bad-numbe.html.

[22] Tariq Malik & Denise Chow, *NASA Awards $1.1 Billion in Support for 3 Private Space Taxis*, SPACE.com, Aug. 3, 2012, http://www.space.com/16890-nasa-private-space-taxis-funding.html.

[23] The Lunar Explorers Society, http://www.lunarexplorers.net/ (last visited Aug. 22, 2012) (website currently undergoing upgrades but is available); The Mars Society, http://www.marssociety.org/ (last visited Aug. 22, 2012).

In summary, there is a transformation of government control to entrepreneurial control and eventually to a real commercial industry. This is a similar transformation as the aircraft industry went through after the Wright Brothers first flight.

B. *Transformation of Organizational Relationships: Increased Competition and Collaboration*

1. *Increased Competition*

After the Wright Brothers first demonstrated powered flight in December 1903, the government stimulated the aircraft and airline industries with contracts for carrying the mail and for defense (especially during World War I). Boeing emerged in the 1950s as the largest manufacturer of commercial and military aircraft in the world. Today there is global competition for all aircraft sizes and types. Besides Boeing, major civil transport manufacturers include Airbus (France and Germany), Bombardier (Canada), Embraer (Brazil), and Tupolev (Russia). Comac (China) is actively developing a narrow-body aircraft like the Boeing 737. In addition, there are a number of United States and international business jet and general aviation manufactures.

Intense international competition exists in the military aerospace industry, with United States manufacturers Lockheed Martin, Northrop Grumman, Boeing, Raytheon, Honeywell, and Sikorsky Aircraft competing with companies such as Airbus, Dassault Aviation (France), Israel Aerospace Industries, Sukhoi (Russia), and Chengdu Aircraft Industry Group (China).

2. *International Supply Chain*

Today's aerospace parts can travel to many countries before final integration into an aircraft. Aerospace companies have had to learn how to market, sell, and deliver internationally, dealing with differences in cultures, business practices, languages, intellectual property rules, tariffs, and government regulations, such as International Traffic in Arms Regulations (ITAR)[24] and Export Administration Regulations (EAR)[25] in the United States. Companies are often required to be certified as meeting international quality standards, such as those set by the International Organization of Standards (ISO) for a variety of industries and the Society of Automotive Engineers International and European Association of Aerospace Industries for the aerospace industry.[26]

Suppliers are constantly faced with decisions concerning whether to locate sales and manufacturing facilities domestically or in or near the country of their customers and whether to use representatives, in-country employee salespersons, or transport United States-based salespersons back and forth. Another complexity of international trade is offset transactions where a supplier's country must purchase a certain amount of products from the customer's country.

3. *Increased Collaboration*

Simultaneously there has been an increase in collaboration, sometimes even between competitors. For example, instead of assembling an aircraft from components and sub-assemblies, Boeing outsourced the construction of major 787 aircraft sections, such as the wings, tail, and cabin, with Boeing putting the sections together. New levels of supplier skills and new types of collaboration between suppliers were required by this approach. The F-35 Joint Strike Fighter involves major suppliers from nine different countries and dozens of minor suppliers from other countries.

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[24] International Traffic in Arms Regulations, 22 C.F.R. §§ 120-130 (2011).

[25] Export Administration Regulations, 15 C.F.R. §§ 730-774 (2011).

[26] For a discussion of two aerospace related standards, ISO9001 from the ISO and AS9100 from the International Aerospace Quality Group, which supplements ISO9001 and was released by the Society of Automotive Engineers International and European Association of Aerospace Industries, see Eugene M. Barker, *Aerospace's AS9100 QMS Standard: Where Quality Control is Essential, This Industry Has Reached a Consensus*, QUALITY DIGEST, May 2002, http://www.qualitydigest.com/may02/html/as9100.html.

As the cost of space exploration has increased, there has been increased collaboration between nations, notably the ISS, which was built by sixteen nations.[27] Plans to return to Moon, to do a manned exploration of Mars, and to conduct other major space exploration projects are often assumed to require international collaboration. China, however, is proceeding on its own—to a certain extent because of the United States' refusal to permit China's involvement in international space activities such as the ISS.

The Aerospace & Defense Forum provides a communication and collaboration channel for companies, even those located in different countries, to discuss common business issues such as those described in this article.[28]

C. *Transformation of Manufacturing*

Aerospace manufacturing organizations are undergoing transformations in the way they operate, including the application of lean manufacturing principles, an increased need for supply chain management, and an increased emphasis on human factors and people skills.

1. *Application of Lean Manufacturing Principles*

Lean is rapidly being adopted throughout the industry to address customer demands for lower costs, just-in-time (JIT) delivery, and increased quality. One lean principle is anything that does not produce customer value is waste and should be eliminated, including any time a part (or paper) is not being worked on. After finding that 87 percent of their lead time was waste, a company employed lean principles to reduce waste by 35 percent. Another lean

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[27] *See* International Space Station, International Cooperation, http://www.nasa.gov/mission_pages/station/cooperation/index.html (last visited Aug. 26, 2012).

> Although the United States, through NASA, leads the ISS project, [fifteen] other countries are involved in building and operating various parts of the station—Russia, Canada, Japan, Brazil, and [eleven] member nations of [the European Space Agency] (Belgium, Denmark, France, Germany, Italy, The Netherlands, Norway, Spain, Sweden, Switzerland, and the United Kingdom[]).

The Encyclopedia of Science, International Space Station, http://www.daviddarling.info/encyclopedia/I/ISS.html (last visited Aug. 26, 2012).

[28] The Aerospace and Defense Forum, http://public.aerospacedefenseforum.org (last visited Aug. 22, 2012). The author is the co-founder of the Aerospace and Defense Forum.

principle is, instead of scheduling production to sales projections and in large batches to maximize machine utilization, production is matched to customer demand to minimize waste and thus minimize delivery time. JIT delivery requires suppliers to rapidly respond to varying customer needs, and thus, a much closer and more open relationship, including sharing of plans, open purchase orders, and co-location of a supplier's manufacturing or inventory facility, is needed.

Prior operating transformations, such as quality circles, management by objectives, and re-engineering, experienced a 70 percent failure rate, primarily due to lack of attention to the required organizational culture change. Companies converting to lean manufacturing need to heed this statistic.

2. *Increased Need for Supply Chain Management*

The major manufacturers' outsourcing of engineering, finishing, assembly, and cost risk is causing the supply chain to get longer and more complex, increasing its vulnerability to failure anywhere along the chain. In reaction, companies have shortened their supply chain and extended their management beyond direct suppliers to the entire supply chain. Customer requests for new supplier capabilities add to the complexity and intimacy and, thus, the customer resources required of each customer-supplier relationship. As a result, customers are drastically reducing their number of suppliers—as much as an 87 percent reduction for one major supplier.

The combination of lean manufacturing and the demand for more complex services requires a new type of customer-supplier relationship. The old arms-length subcontractor relationship (think of your relationship with most retail stores) will increasingly be obsolete, replaced by true partnerships (think of your relationship with your best friend) where both parties care not only about their own concerns, but also equally about those of the other party.

3. *Increased Emphasis on Human Factors and People Skills*

The Fourth Era, characterized by international and close collaboration, requires an improvement of people skills, especially to have diverse people work effectively together. This transition may be particularly challenging for the engineering-based, objective, and analytical managers of the aerospace industry.

SpaceX is an excellent example of the benefits of an increased emphasis on human factors. They have been able to produce results that NASA determined it could not do for twice the cost under the traditional NASA environment/culture.[29] SpaceX attributes its cost efficiencies to three primary factors: a smaller workforce, fewer management layers, and a simpler infrastructure.

Most companies' stated purpose refers to making a profit or making a product. SpaceX has a purpose much more compelling, originating with a concern that the human species is vulnerable to extinction as long it is confined to one planet.[30] Therefore, the purpose of SpaceX is to enable the human species to become a multi-planet species. Of course, one still has to make a profit to be able to stay around to fulfill one's purpose, but profit becomes a means to an inspiring end, not the end itself.

To have a multi-planet species, one needs low-cost, frequent access to space, and thus, one needs products that are reliable, reusable, and low-cost, i.e., one needs simple and modular designs. Because the entire SpaceX workforce, including the engineers (who elsewhere may view their work as never done, believing they can always "make it a bit better"), has bought into the company's multi-planet species vision, the employees are in general agreement and work

[29] NASA Associate Deputy Administrator for Policy, Falcon 9 Launch Vehicle NAFCOM Cost Estimates, August 2011, http://www.nasa.gov/pdf/586023main_8-3-11_NAFCOM.pdf (last visited Aug. 26, 2012).

[30] Patt Morrison, *OP-ED Elon Musk of SpaceX: The Goal is Mars*, LATIMES.COM, Aug. 1, 2012, http://www.latimes.com/news/opinion/commentary/la-oe-0801-morrison-musk-spacex-20120801,0,3838907.column.

toward making things simple, modular, low-cost and (in the future) reusable. For example, SpaceX uses only one launch engine—the Merlin engine. To provide increasing lift capacity, the three SpaceX rockets simply have an increased number of Merlin engines. The Dragon capsule, initially carrying cargo, will be modified to carry humans and scientific cargo or travel to the Moon. The Dragon's launch abort system can also be used as a landing system.[31] The common system, engines, and capsules benefit from the experience of many flights, increasing reliability and thus lowering costs.

SpaceX's Mission Control (which controls the vehicle after it launches) is *on* the manufacturing floor. Two glass walls and a flat floor (no VIP viewing area) provide an unobstructed view for employees to see preparations for and the actual mission. The resultant feeling of team and excitement cannot be measured.[32]

The organization is relatively flat. If there is a problem in manufacturing, one can go right to the relevant engineer's office located close by and get it fixed.

Despite the presence of many messy manufacturing processes, the SpaceX manufacturing floors gleam like a hospital's. The area is so clean that there are no intervening walls between the cafeteria and manufacturing. The response to the author's inquiry on who cleans the floor was, "We keep *our* floor clean ourselves." An impeccable environment encourages people to operate in an impeccable manner, resulting in higher quality, higher reliability, and lower cost.

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[31] Stephen Clark, *SpaceX Fires Powerful Abort Thruster for Manned Dragon*, SPACEFLIGHT NOW, Feb. 2, 2012, http://spaceflightnow.com/news/n1202/02superdraco/.

[32] *See* Video: SpaceX Launch—SpaceX Employees Watch Launch (SpaceX 2012), *available at* http://www.youtube.com/watch?v=TFr72S0tJRY. The video on SpaceX's YouTube channel (SpaceXChannel) shows employees standing outside mission control in Hawthorne, CA, celebrating the successful stage separation during the Dragon's historic COTS Demonstration mission May 22, 2012. The employees are on the production floor and the camera pans right to show mission control.

SpaceX is not the only organization to demonstrate the extraordinary benefits of an inspired and engaged workforce.[33] Other examples include Apple, Google, and the Housing Authority of the County of San Bernardino.[34]

D. *Transformation Within Organizations*

At the present time, all the organizational transformations required to go from the Third to the Fourth Era are not completely clear, and some transformations will be required of most business organizations. Those organizations that have still not completed Second to Third Era transformations will have a particularly difficult time in the current transition. The author's best guess of the Fourth Era transformations required are laid out in the following chart:

Third Era	Fourth Era
Small workforce	Even smaller workforce
3-5 year strategic plans	Multi-decade strategic plans
Formal relationships between functional departments (silos[35])	Highly informal and collaborative relationships between different organizational functions
Organizations of fixed functional departments	Organizations of teams that are created and disbanded as needed
Multiple management layers	Few management layers
Formal designated leaders	Distributed leadership
Formal vision and mission statements that are not implemented	Inspiration, doing things that are meaningful to the workforce
Oriented to Boomer and some GenX mindsets	Oriented to GenX and Millennial mindsets

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33 *How Investing in Intangibles—Like Employee Satisfaction—Translates into Financial Returns*, KNOWLEDGE@WHARTON, Jan. 9, 2008, http://knowledge.wharton.upenn.edu/ article.cfm?articleid=1873.

34 For background on the culture transformation of the Housing Authority of the County of San Bernardino, see Case Study #14: The Case of the Stepping Stones, http://www.frontier-assoc.com/open/cases/Case14.htm (last visited Aug. 26, 2012). *See also* Housing Authority of the County of San Bernardino, http://www.hacsb.com/ (last visited Aug. 26, 2012).

35 Functional departments within organizations, for example finance, marketing, sales, R&D, engineering, manufacturing, administration, etc., often operate with minimal collaboration and communication. This is referred to as "siloing," where each department operates within its own relatively isolated silo with a few formal connections to other silos.

Arms-length supplier relationships based primarily on price	Partnerships based on common interests
Excitement about space leading to interest in STEM (science, technology, engineering, and math)	Overcoming a low interest in STEM that results in a scarcity of engineers
Fit well-designed subsystems together and then make them work together	Use system engineering at the design stage to address how the subsystems will work together
Make a profit, beat the competition	Make a difference and make a profit
Government control with government design and ownership	Entrepreneurial control, and then market control with private company design and ownership
Government cost-plus contracts and fixed price development contracts	Fixed price service contracts
Traditional financing sources	Entrepreneurial and crowd-funding

Figure 2: Organizational Transformations to the Fourth Era of Space Exploration from the Third Era

As an example of companies already implementing an even smaller workforce, Masten has only ten employees, XCOR has only 20-30, and SpaceX has about 1700, compared to the tens of thousands on typical government space projects.[36]

There are currently three generations in the workplace: Boomers, Gen-Xers, and Millennials, with generational perspectives as different as people from different national cultures. Generational mindsets are *not* a matter of age—despite the common belief that "They will feel as I do when they are my age." For example, Boomers tend to be formal and avoid risk, Gen-Xers tend to be entrepreneurial risk-takers and self-oriented, and Millennials tend to be team players and oriented to making a difference. Gen-Xers becoming senior leaders and Millennials

[36] *The Space Shuttle Decision* noted that "it [took] a ground crew of 20,000 NASA and contractor employees to prepare and launch a Saturn V with its Apollo moonship." T.A. HEPPENHEIMER, THE SPACE SHUTTLE DECISION: NASA'S SEARCH FOR A REUSABLE SPACE VEHICLE 251-52 (NASA History Office 1999), *available at* http://history.nasa.gov/SP-4221/sp4221.htm (follow "Table of Contents" hyperlink).

moving into middle management will cause major shifts in how organizations operate and will exacerbate the generational conflicts. Each generation needs to learn about its own and other generational mindsets and gain the skills to allow the organization to benefit from diverse perspectives. Experienced Boomer engineers are retiring and Gen-Xers are being entrepreneurial, yet the Millennials exhibit a steadily diminishing interest and proficiency in STEM (science, technology, engineering, and math). Space exploration is threatened by an impending shortage of competent engineers, which hopefully will be reversed by many initiatives currently underway.

III. Conclusion

The current transformation is from government to rich entrepreneurs' control and ownership. The transition that is underway is in flux and is dependent on the industry overcoming the generational gap and problems such as the lack of STEM graduates. But, if the transformation is successful, it will see the emergence of a true commercial aerospace industry, one where retail (tourists) and commercial (company) customers outweigh government purchases and where the open market is the primary determinant of prices, what is successfully sold, and which companies survive.