Applying Disruptive Innovation Theory in Emerging Markets for Crew On-Orbit Transportation

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ABSTRACT

This paper applies Dr. Clayton Christensen's Disruptive Innovation theory to the emerging crew space transportation market as an analytical framework to enable characterization of interaction between firms in the market. The theory analyzes the impact of technology introduction strategies employed by firms in introducing new products and/or services. The theory describes the market accessed by products and services based on the performance characteristics demanded by customers and provided by the suppliers. Innovations (e.g. technologies or products) in the market are identified as 'sustaining' or 'disruptive' based upon how performance characteristics align with the attributes valued by customers. A disruptive technology can alter the market accessible to an established technology, given that appropriate strategic decisions are made by the firm offering the disruptive technology.

This paper analyzes the performance characteristics of crew space transportation systems, both existing and prospective new entrants, in order to identify whether the systems represent disruptive innovations and, if so, what type (low-cost or new market). This performance-based analysis of suppliers in the market is complemented by a qualitative assessment of the basis of demand for crew transportation services. Customer basis of demand analysis identifies the performance attributes (e.g. reliability, costs, etc.) which customers value in making purchasing decisions. Together this analytical framework will allow discussion of the alignment of transportation system to customer type (e.g. government, private-sector researcher, tourism). Strategies for entrant firms and the interactions between the markets they access can then be discussed once the crew transportation system are classified using the concepts of Disruption Innovation Theory.

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I. INTRODUCTION

A recent FAA workshop on Commercial Human Spaceflight found that "the key deterrents to new entrants into the commercial space flight market are that the technical, financial and economic barriers to market entry are very high and the market is both small and uncertain. However, these disincentives do not necessarily translate into a consensus among potential market entrants that there is no commercial space flight market."[i]

A better understanding of the dynamics which influence the development of this market will reduce the uncertainties surrounding its discussion. Accordingly, this paper employs a theory based analysis, Disruptive Innovation (DI) theory, first developed by Dr. Clayton Christensen of Harvard Business School, to describe industry-level structures and drivers. The framework that DI theory provides is intended to inform technical, financial and economic strategy surrounding the development and deployment of new technology within the crew on-orbit transportation (COT) market.

- Section 2 of this paper gives a brief description and overview of Christensen's DI theory.
- Section 3 characterizes both the supply and demand sides of the COT market through the lens of DI theory. Suppliers are described in generic terms of performance. To avoid the appearance of making complementary or pejorative comments about any specific company or entity, specific suppliers and launch vehicles in the COT market are not identified, except in Fig. 2 to support the discussion of that section. The demand side of the COT market is characterized by identifying major customer segments and evaluating their basis for demand vis-à-vis the supplier performance metric described.
- Section 5 concludes the paper by mapping customer basis of demand to the type of innovations represented in the COT market, and discusses the strategic implications for market development.

II. DISRUPTION THEORY OVERVIEW

This paper applies DI theory as an analytical lens to make an assessment of the COT market development. A brief description of DI theory follows; complete descriptions are available from Christensen's popular literature offerings.[5]

A. Market Structures and Forces

DI theory puts markets into a context of some measurement of a product's performance as a function of time, as shown in Fig. 1, on the following page, by the line labeled "performance available." Established firms compete in a given market by developing the performance metric to meet the needs of both high-end and low-end market customers. An aggregation of this demand distribution can be represented by the line labeled "performance demanded." The analytical approach represented by Fig. 1 allows customers to be identified as either over-shot or under-shot.

- ➢ An under-shot customer is one for whom the available performance on the market is less than what the customer needs to satisfy their performance requirements.
- ➢ An over-shot customer is one for whom the available performance on market is greater than what the customer needs to satisfy their performance requirements.

Over time the performance provided increases faster than the performance demanded, resulting in an overall performance surplus.

[5] See: (1) Christensen, Clayton M. The Innovator's Dilemma. Harper Business Essentials (1998, 2000). ISBN: 0060521996. http://worldcatlibraries.org/wcpa/isbn/0060521996; (2) Christensen, Clayton M. and Michael E. Raynor. The Innovator's Solution: Creating and Sustaining Successful Growth. Harvard Business School Press (September 2003). ISBN: 1578518520. http://worldcatlibraries.org/wcpa/isbn/1578518520; and (3) Christensen, Clayton M., et, Al. "Seeing What's Next?: Using The Theories of Innovation to Predict Industry Change. Harvard Business School Press (2004). ISBN 1591391857. http://worldcatlibraries.org/wcpa/isbn/1591391857

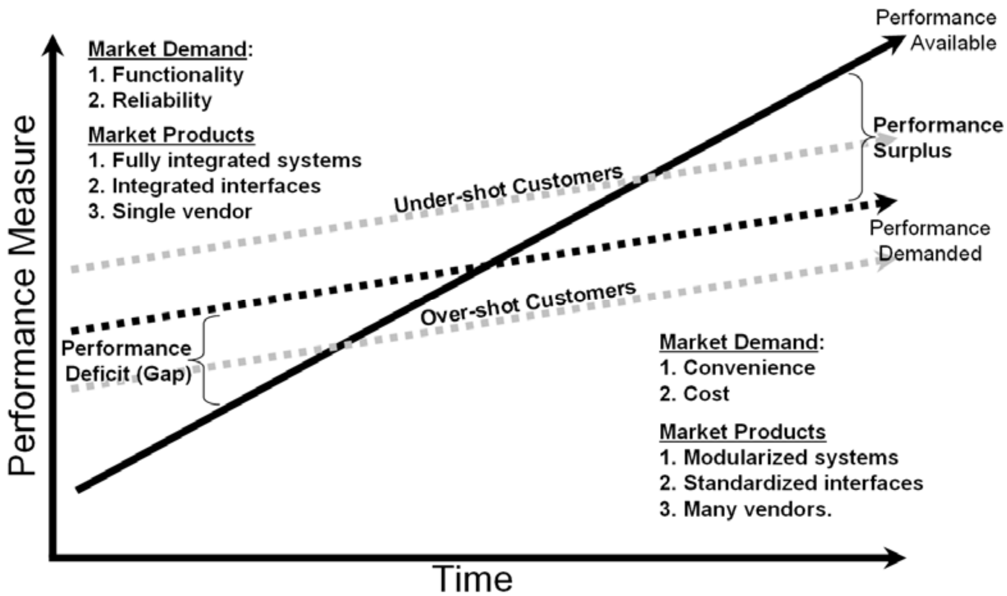

Figure 1: Christensen's Disruption Theory Performance Curve.

B. Types of Innovation

From the DI theory perspective, new entrants in markets can be differentiated by the type of innovation they represent, either "sustaining" or "disruptive."

1. Sustaining Innovations

Sustaining innovations are depicted on the market performance graph as a continuation in the performance increase along the established performance available curve. The tendency of sustaining innovations is to drive toward the upper-right corner of the chart, by meeting the increasing demands of current high-end market customers. Sustaining innovations can be evolutionary improvements of established technologies, or technological breakthroughs (also known as "revolutions") that raise the level of product performance, thereby meeting demands of the most demanding customers and allowing premium pricing and profit margins. This type of innovation can be introduced by new entrant or incumbent firms.

2. Disruptive Innovations

Disruptive innovations can be either "low-cost" or "new market." Disruptive innovations in general tend to be simpler, less expensive, and more convenient than products offered by the incumbent firms. Part of the allure of the disruptive innovation is lower costs that result from lower profit margins and lower profits.

Low-cost disruptive innovations tend to signal a change in the basis of demand from functionality and reliability to customer convenience and cost due to performance oversupply. The established market's leading firms' most profitable customers generally don't want, and, in many cases, initially can't use the disruptive product because it is lower in traditional performance metrics. Low-cost disruptions appear on the market performance graph as a new performance supply line that appears below that of the established market.

New market disruptions appear on a totally new performance graph by identifying a brand new performance metric that attracts customers that are new to the market. These customers are referred to as "non-consumers" because they were not part of the original marketplace.

C. Criticisms of Disruptive Innovation Theory

While recognized as a powerful framework for the evaluation of the strategic implications of technological innovations, DI theory has been criticized as being overly focused on supplier performance and not giving enough attention to the dynamics of consumer behavior.[ii] It has been suggested that, under DI theory, "the demand-side factors that drive the emergence of competition remain largely unstudied."[iii] DI theory typically involves the analysis of one or two performance metrics. However, "in many cases the number of performance dimensions is much higher and customers trade them off each other."[iv] In other words, customers evaluate products on several performance dimensions simultaneously as they attempt to seek the best value.[v] Thus, when applying DI theory it is important to complement the performance analysis with an evaluation of the determinants of customer purchasing behavior.

D. Customer Types

The preceding discussion alludes to several different types of customers. DI theory generally discusses three different customer groups, described by where they fall on the performance curve. These are: 1) over-shot, 2) under-shot, and 3) non-consumer. A fourth category is implied: satisfied customers for whom the performance provided in the market meets their needs.

III. CREW ON-ORBIT TRANSPORTATION MARKET CHARACTERIZATION

A. Market Definition

This paper focuses on an analysis of the emerging crew on-orbit transportation market. From a supply side perspective the COT market can be defined as "those who produce, are currently developing, or have the means to develop vehicles within which humans can reach orbital altitude and velocity and are able to return to the Earth."[vi] This paper will focus its analysis on the "job being done" by the COT systems, discussing through the lens of DI theory how the attributes which influence consumer demand choices relate to the performance of the COT system.

B. Supplier Identification

Providing COT services necessitates that the supplier provide a system that includes both an habitable spacecraft for the crew (the on-orbit segment) and a launch vehicle to place the crewed spacecraft into the desired orbit. The discussion in this paper will focus on the capabilities of the on-orbit segment – referred to in this analysis as the "COT spacecraft". Where the term "COT system" is used it meant to refer to the integrated on-orbit segment and launch vehicle.

Table 1, below, provides an illustrative listing of current and prospective COT suppliers. This list will be used for the performance based analysis contained in the remainder of this paper. The list is illustrative only – and not meant to be exhaustive.

Table 1: Illustrative List of COT Suppliers

Supplier	Launch Vehicle	On-orbit Segment	Maximum Time on Orbit	System Status
Blue Origin	Atlas V	New Shepard	Unknown	New Entrant
Boeing	Atlas V	CST-100	210 days	New Entrant
CNSA / PLA	Long March	Shenzhou	4 days	New Entrant
Excalibur Almaz	Multiple	Almaz / TKS	5 days	New Entrant
NASA	STS	Space Shuttle	18 days	Incumbent
NASA / Lockheed Martin		MPCV (Orion)	21 days	New Entrant
Roscosmos	Soyuz	Soyuz	200 days	Incumbent
Sierra Nevada Corporation	Atlas V 402	Dream Chaser	3 days	New Entrant
SpaceX	Falcon 9	Dragon	210 days	New Entrant

C. Supplier Performance

DI theory classifies innovations as "sustaining" or "disruptive" based on a market performance metric that can be graphically depicted to delineate "performance deficit" and "performance surplus" areas, each characterized by specific bases of demand. The performance characteristics of both incumbents and new entrants can be graphed. In

[6] For CST-100 On-orbit Time is based on expected mission profile, including maximum time docked to ISS with keep-alive power provided by Station. For Shenzhou On-orbit Time is based on actual mission data. For Excalibur Almaz On-orbit Time is based upon plan orbital space tourism flight mission profile. For Space Shuttle On-orbit Time is based on actual mission data. For MPCV On-orbit time is based on Reference Vehicle Design crewed mission duration as of January 2011. For Soyuz On-orbit Time is based on upon maximum reported orbital duration including ISS lifeboat role. For Dream Chaser Soyuz On-orbit Time is based upon expected performance of the HL-20, which the Dream Chaser is based upon. For Dragon On-orbit Time is based on expected mission profile, including maximum time docked to ISS with keep-alive power provided by Station.

[7] "System" refers to the collective of the launch vehicle and the on-orbit segment

the COT market the incumbents are the retired Space Transportation System (“Space Shuttle”) and the Soyuz. However, the Shuttle represented a capability suite within a single vehicle that will not be represented in new entrants, and given its retirement in 2011 cannot be considered as a true incumbent in this analysis. The Soyuz operates to service a customer – the ISS – for which the design has been specified to meet the performance characteristics of the Soyuz. In this case the supplier performance is not being shaped by customer preferences, rather the customer’s required performance attributes have been defined by the supplier system performance available. Additionally, the performance characteristics of neither the Soyuz nor the Shuttle are responsive to market conditions related to non-government customers.

Many potential metrics exist which might be used to characterize the performance of COT spacecraft. These metrics include: a tally of specific spacecraft attributes / characteristics (e.g. reusability, landing mode, number of crew seats, and size/number of windows), pressurized volume, spacecraft mass, and Maximum On-orbit Time (“$M_{\text{On-orbit Time}}$”). In this analysis, the performance metric chosen is $M_{\text{On-orbit Time}}$.

$M_{\text{On-orbit Time}}$ is defined as the maximum on-orbit duration of the COT spacecraft for demonstrated/actual (for incumbents) or planned (for new entrants) mission profiles. Although other performance attributes may also affect consumer basis of demand; $M_{\text{On-orbit Time}}$ is offered as a proxy metric indicative of overall spacecraft performance

The $M_{\text{On-orbit Time}}$ vs. time was plotted for each COT supplier shown in Table 1 using actual mission data, where available, and planned capabilities for systems not yet in operation. The result is shown in Fig. 2, below. Use of $M_{\text{On-orbit Time}}$ as the performance metric excludes the capabilities of the launch vehicle from the analysis. An analysis of launch vehicle performance for commercial cargo and crew space transportation markets is the focus of a forthcoming paper.[vii]

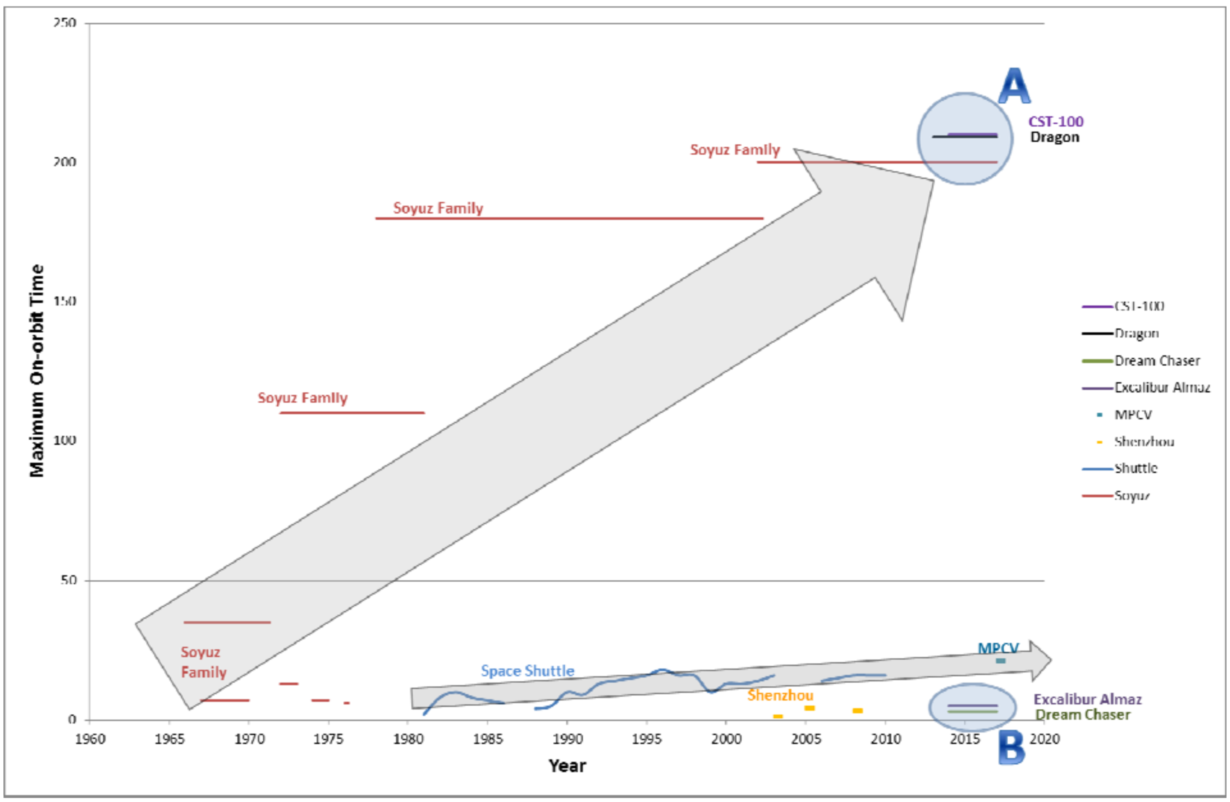

Figure 2: Increase in Maximum On-Orbit Duration for Selected COT Spacecraft

- The larger of the two grey arrows represents the established performance curve, providing transportation services to and from the ISS, in the form of the Soyuz vehicle. Over the time period represented in the figure the maximum on-orbit duration of the Soyuz has increased from approximately 10 days to the current 200 in its role as ISS lifeboat.
- The second grey arrow represents an additional established performance curve represented by the demonstrated on-orbit mission duration of the Space Shuttle. Not represented by the $M_{\text{On-orbit Time}}$ data are numerous other performance capabilities of the Shuttle (including cargo capacity, mission flexibility, crew

seats, and landing mode). Many of these performance attributes, represented in a single vehicle, will not be replicated in the new COT entrants analyzed in this paper. Accordingly, analysis of the Shuttle against alternate performance metrics might result in a performance curve that is not supplied following the Shuttle's retirement.

- Region A represents new entrants for which expected $M_{\text{On-orbit Time}}$ performance is similar to the existing performance curve demonstrated by Soyuz. These COT spacecraft represent sustaining innovations targeted at high-end – largely government – customers. Capabilities found in Group A represent performance oversupply for other, low-end customers, such as private space tourists.
- Region B represents new entrants for which expected $M_{\text{On-orbit Time}}$ performance does not align with either of the two existing performance curves denoted in the figure. These suppliers could represent a low-end disruptive innovation entering the overall COT market in a performance region which attracts overshot customers from the existing market.

D. Basis of Demand: Performance Attributes

DI theory suggests that consumers' decisions to be purchase a product or service follows a progression, where buying behavior is based on an hierarchy of attributes referred to as the "basis of demand" and which generally occurs in the following order: (1) functionality, (2) reliability, (3) customer convenience and (4) cost. Customers typically appraise products against each other by evaluating whether products meet their requirements in each successive basis of demand. The progression is typical, not absolute, meaning individual customer segments may follow variations of this hierarchy – for example evaluating cost before customer convenience.

Understanding the basis of demand provides a vector for understanding the performance position of a product, technology or service relative to consumer requirements. Table 2, below, identifies the performance dimensions within each basis of demand that influences customer purchasing behavior for COT systems.

Table 2: Basis of Demand Elements

<table>
<tr><td>Functionality
The responsiveness and adaptability of the COT to the customer's mission objectives

• Ability to dock to a space station and/or other spacecraft
• On-orbit maneuverability
• On-orbit duration
• 'In-flight experience' (e.g. size of windows, type of cabin accommodations, etc.)
• Research accommodations (rack space, power, environmental controls, etc.)
• Cargo capacity (upmass and downmass) in addition to crew seats
• Pressurized and habitable volume
• Number of seats
• Data and communications capacity</td><td>Reliability
The ability of the COT to safely reach orbit within the customer's defined orbital parameters and human health requirements.

• ECLSS parameters (e.g., thermal, atmospheric, etc.)
• Launch abort modes
• Launch and re-entry g-force experienced
• Landing modes
• Flight heritage</td></tr>
<tr><td>Customer Convenience
The COT's ease of use relative to customer needs.

• Schedule (including launch vehicle integration and payload processing)
• Ease and speed of access to payload upon return
• Political considerations</td><td>Cost
The price paid by the customer for access to the COT's services.

• Price
• Reusability</td></tr>
</table>

E. Attribute Based Characterization of the Crew On-Orbit Transportation Customer Segments

DI theory suggests that market demand can be segmented by describing potential customer groups by the job that they are looking for supplier to perform or provide, an approach known as attribute based characterization. The basic job a COT spacecraft performs is the successful transport of humans in Earth's orbit. Through attribute based characterization, specific customer segments representing variations on that basic performance function can be identified on the basis of the specific performance attributes they demand. These customer segments include: Space Tourism, Government Research, Corporate/Commercial Research and Spacecraft Servicing.

1. Space Tourism

Space tourism refers to the pursuit of spaceflight opportunities for the primary purposes of enjoyment, entertainment and/or personal achievement. According to NASA and the FAA, space tourists "either purchase a spaceflight opportunity themselves or through another private funding source (e.g., as a gift from a friend or family member, or through a sweepstakes)."[viii] Destinations for orbital space tourism include space stations (e.g. the ISS) or simply Earth's orbit itself. Individual customers within this segment are primarily private individuals.

An attribute characterization of the space tourism market segments can be summarized as follows:

- Functionality: For space tourism customers functionality (presuming the basic requirement to reach, and return from, Earth's orbit is met) can be defined in terms of destination, duration, and passenger experience (e.g. cabin environment, g-force experienced, etc.).
- Reliability: For space tourism customers, reliability can be described in terms of the safety of the COT system. The relatively small pool of previous space tourism customers has shown that there is a group of consumers willing to accept the inherent risks of human spaceflight; nonetheless safety will be an important factor in customer basis of demand for these services.
- Customer Convenience: It is likely that private individuals will be happy with a launch whenever it occurs, and will not be particularly sensitive to schedule performance. Accordingly customer convenience is likely a low factor as basis of demand. However, as competition in the market develops, schedule may increase in significance as a discriminating factor – especially if investor capital is at stake.
- Cost: To date, costs for individual space tourism opportunities have been high, as a result of limited flight opportunities and COT systems designed and operating to government performance requirements. Individually, the set of to-date space tourism customers could be characterized as early adopters, displaying low price sensitivity in exchange for access to the cutting-edge space tourism experience. As increased flight opportunities are made available by new entrant suppliers cost may become less prohibitive. Conversely if the new entrants do not realize lower-per seat price, price will remain a limiting factor. Emergence of low-cost disruptive innovations may increase the importance of cost as a basis of demand in the space tourism customer segment.

2. Government Research

The government research segment refers to the use of the space environment to conduct human-tended scientific research using government-employed astronauts. This research may to be long-term in nature, requiring a long-duration platform such as the ISS or short-term in nature, historically utilizing shorter duration platforms such as the Spacelab and Spacehab Space Shuttle modules.[ix] Individual customers include national governments – both those that have indigenous space transportation capabilities and those that don't.[8] The extant ISS crew on-orbit transportation needs of the ISS members represents a customer group with in this segment.

An attribute characterization of the government research customer segment can be summarized as follows:

- Functionality: Governments have traditionally placed high priority on performance requirements, including such attributes as docking precision, on-orbit duration capability, and systems redundancy. These functional requirements are often closely related to stringent government demands for reliability.
- Reliability: Government customers traditionally place very high value on reliability of COT systems, including stringent human-rating requirements and loss of mission and loss of crew standards.
- Customer Convenience: Governments traditionally have had low to medium requirements for schedule adherence. Government customers are often willing to trade schedule performance for gains in functionality or reliability attributes; and typically have the ability to pay costs associated with schedule delays.
- Cost: Historically governments have shown willingness to pay high costs in order to meet the high functionality and reliability standards they have developed for crewed spacecraft – placing cost lower than functionality and reliability as a basis of demand. However cost may be a more important consideration for emerging and developing nations seeking to launch an astronaut for reasons related to national prestige. These nations may place lower emphasis on functionality requirements.

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[8] The customer group which covers national governments without indigenous space transportation capabilities has been described elsewhere as the 'National Interest Market' or the 'Sovereign Client Market.'

3. Corporate/Commercial Research

The corporate research segment is very similar in character to the government research segment – referring in this case to the use of the space environment to conduct human-tended scientific research using commercially-employed astronauts. As an additional distinction from the government market, research in this customer segment is conducted with an eye towards downstream commercially-relevant applications (e.g. pharmaceuticals research, materials science). Like the government segment, this research may be long-term or short-term in nature. This customer segment is largely prospective – with little historical activity to base analysis on.

An attribute characterization of the corporate/commercial research customer segment can be summarized as follows:

- Functionality and Reliability: Similar to government, corporate/commercial research customers will place high value on functionality and reliability of the COT systems as related to mission objectives. Space research, especially when requiring crew, is likely to be a high cost activity, and private sector customers will be seeking to maximize the likelihood of mission success, much as governments do.
- Customer Convenience: Similar to government, corporate/commercial research customers will likely place low to medium value on schedule adherence. It is worth noting that individual customers within this segment may place varying emphasis on schedule, for example an applied biomedical science experiment may be more time sensitive than a research and development experiment in materials science. This customer group will be willing to accept schedule slips in exchange for increased likelihood of mission success.
- Cost: It is likely the corporate/commercial research customers will place a higher value on cost as basis of demand than government clients. This customer group will need to demonstrate a return on investment from space-based research activities and thus will demonstrate an element of cost sensitivity that governments do not.

4. Spacecraft Servicing

Spacecraft servicing refers to the rescue, repair, or refueling of an inoperable spacecraft by a second, either robotic or crewed spacecraft. Customers for this type of mission would include government or commercial satellite operators. As NASA and the FAA note: "Rescue of satellites stranded in an incorrect orbit is a relatively advanced capability that could be supported by commercial crew transportation spacecraft."[x] To date, two commercial satellites operating in Low Earth Orbit have been repaired via a crewed mission - the Palapa B2 and Westar 6 satellites. In addition the Hubble Space Telescope has been serviced five times by crewed missions. An attribute based characterization of the spacecraft servicing customer segment can be summarized as follows:

- Functionality and Reliability: Mission success will be paramount in driving customer basis of demand for this service. Given the high investment costs of the both the spacecraft being serviced and a servicing mission itself; customers will require a high degree of confidence in a successful outcome. Functionality will be important, as servicing missions will require a certain degree of specialization and customization depending on the customer.
- Customer Convenience: Servicing customers will likely place low value on schedule adherence. This customer group will be willing to accept schedule slips in exchange for increased likelihood of mission success. However, customers must trade continuing lost revenue from the asset to be serviced against the potential mission success benefits of any schedule slips.
- Cost: Cost is also likely to receive low to medium emphasis from this customer group. In general the cost of a servicing mission should not exceed the replacement cost of spacecraft being repaired or likely revenue originating from the asset being serviced. However, customers may be willing to pay a price higher than the replacement cost if the service mission can be conducted in a rapid timeframe that saves lost revenue from the asset. As currently no incumbent COT system provides the functionality for a spacecraft servicing mission, DI theory suggests that suppliers will encounter customers who are easy to please on cost, assuming that the prior caveat is met.

IV. CONCLUSION: IMPLICATIONS FOR MARKET DEVELOPMENT

The market for COT is largely an emerging one, and in many cases discussion of the tendencies of prospective customers is speculative. The extant market essentially consists of government customers using government operated COT systems (and a small number of tourism and 'sovereign' clients). In general, the basis of demand upon which a customer segment makes their decision follows a set order. The specific basis for a given customer segment depends on how under- or over-served it is at some point in time. The concluding section of this paper analyses the identified customer segments on the grounds of how their basis of demand aligns with the COT spacecraft performance curve.

A. Evidence of Basis of Demand & Customer Type

Table 3, below, summarizes the attribute based characterization analysis of the COT customer segments, ranking customer basis of demand by performance attribute and classifying customer as overshot, undershot, non-consuming, or satisfied by the $M_{\text{On-orbit Time}}$ performance of the COT suppliers identified in Table 3.

Table 3: COT Customer Basis of Demand Characterization

Market Segment	Performance Attribute	Customer Type	Evidence
Space Tourism (Orbital, Non-station)	Functionality	Over-shot	Current market supply for space tourism is of an approximately two week flights to the ISS. Market analyzes indicate demand at a lower performance level (shorter flight; non-station destination) at a lower cost subject to availably of COT systems.
	Reliability	Over-shot	
	Customer Convenience	Satisfied	
	Cost	Under-shot	
Space Tourism (Orbital, Station)	Functionality	Over-shot	Early adopters have shown willingness to accept risks and pay high prices. Existing behavior indicates duration of flight is not an important determinant of customer behavior. Customers would likely accept shorter duration flights at lower cost.
	Reliability	Over-shot	
	Customer Convenience	Satisfied	
	Cost	Under-shot	
Government Research (Orbital, Non-station)	Functionality	N/A	Non-consuming customer segment. Demand may be met by robotic spacecraft or replaced by ISS. Performance curve is best approximated by the Shuttle; upon which new entrants would represent a sustaining innovation.
	Reliability	N/A	
	Customer Convenience	N/A	
	Cost	N/A	
Government Research (Orbital, Station)	Functionality	Satisfied[9]	Incumbent systems fall within performance demanded. Customer requirements were developed with incumbent systems in mind. Sustaining innovations evidenced within performance graph.
	Reliability	Satisfied	
	Customer Convenience	Satisfied	
	Cost	Satisfied	
Corporate Research (Orbital, Non-station)	Functionality	N/A	Non-consuming customer segment. No incumbent COT systems provide this functionality. Thus, new entrants able to provide this functionality will find customers to have low price sensitivity. Price is likely to increase in importance as basis of competition as more competitors enter the market segment.
	Reliability	N/A	
	Customer Convenience	N/A	
	Cost	N/A	
Corporate Research (Orbital, Station)	Functionality	Satisfied[10]	When analyzed against $M_{\text{On-orbit Time}}$ basis of demand is similar to government and performance needs are met by incumbent systems.
	Reliability	Satisfied	
	Customer Convenience	Satisfied	
	Cost	Satisfied	
Spacecraft Servicing [for nominal human-tended repair of satellite]	Functionality	N/A	Non-consuming customer segment. No incumbent COT systems provide this functionality. Thus, new entrants able to provide this functionality will find customers to have low price sensitivity. Price is likely to increase in importance as basis of competition as more competitors enter the market segment.
	Reliability	N/A	
	Customer Convenience	N/A	
	Cost	N/A	

[9] An argument could be made that under different performance metrics (e.g. number of seats) this segment is undershot.
[10] An argument could be made that this segment is undershot in other performance metrics, such as number of seats, and flight rate.

B. Summary of Findings

The analysis represented in Table 3 represents the following overall findings:

- The orbital space tourism market segment (for both station and non-station destinations) is overshot on functionality and reliability; and satisfied on customer convenience. Thus, the basis of competition in this segment is on cost, where customers are also currently undershot. DI theory predicts this customer segment might be ripe for a low-cost disruptive innovation.
- The government research market segment, for orbital, non-station destinations is currently a non-consuming market. DI theory suggests that prospective customers in this segment would choose products on the basis of functionality – as no alternatives exist which would allow competition on any of the other bases of demand. Thus, the theory would predict that new market innovations targeting this segment are likely.
- The government research market segment, for orbital, station destinations is satisfied for all bases of demand. DI theory predicts that additional sustaining innovations will continue to be introduced to this customer segment.
- The corporate research market segment, for orbital, non-station destinations is currently a non-consuming market. DI theory would predict that new market innovations targeting this segment are likely.
- The corporate research market segment, for orbital, station destinations is satisfied – like the government research market segment. DI theory predicts that additional sustaining innovations will continue to be introduced to this customer segment
- The spacecraft servicing market segment is also a non-consuming segment. DI theory would predict that new market innovations targeting this segment are likely.

Working from these overall findings implications for COT market development can be discussed on a customer segment by customer segment basis.

C. Implications for Market Development and Firm Strategy

1. Space Tourism Market – Over-shot Customers:

Table 3 indicates that the space tourism customer segments represent over-shot customers in functionality and reliability. These customers basis of demand preferences are for lower launch costs at a lower performance level (shorter on-orbit duration) than provided by the current incumbent (Soyuz). Returning to Fig 2, capabilities represented in Group A offer a sustaining innovation to the current performance metric, and as such will continue to overshoot the space tourism market. The prospective disruptive innovation represented by Group B may satisfy the performance requirements of this customer segment. Firms in Group A could move down-market by a strategic determination to alter the expected mission profile to include shorter duration flights. Alternatively, Group A firms could access this customer segment via increased per vehicle crew seats (as compared to the incumbent) potentially resulting in lower per seat launch costs.[11] COT spacecraft designed to satisfy the up-market (government customer) basis of performance as an ISS lifeboat (e.g. >200 day $M_{\text{On-orbit Time}}$) may find a move down-market to result in a technically inefficient use of the COT system (on-orbit segment plus launch vehicle) and lower profit margins. DI theory predicts that these firms would thus elect to cede the low-end market to new-entrant firms.

2. Government and Corporate Research (Orbital, Station) – Satisfied Customers

The performance of the incumbent COT system meets the performance requirements of governmental customers seeking to support crew operations on the ISS by providing crew transport coupled with sufficient maximum on-orbit duration to serve as a lifeboat. Within Fig. 2, new entrant suppliers in Region A represent a sustaining innovation, continuing to serve the government-client crew transport market to ISS, within the $M_{\text{On-orbit Time}}$ performance curve represented by the incumbent. Given similar performance characteristics for functionality and reliability, customer behavior regarding use of new entrants versus the incumbent will be based on customer convenience and cost and customer conveniences. Suppliers in Region B represent a potential disruptive innovation – while their $M_{\text{On-orbit Time}}$ performance does not match that of the incumbent (or the new entrants in Region A), they may offer similar performance attributes (e.g. reusability, preferred landing mode) at a lower cost, and thus might attract the established market from below.

[11] Per vehicle crew seats available represents a performance metric distinct from that evaluated in this paper.

3. Spacecraft Servicing – Non-Consuming Customers

The performance duration dictated by ISS operational requirements, along with other complimentary functionality attributes, may enable some COT spacecraft represented in Fig. 2 to act as new market disruptors – accessing non consuming markets. One such market segment is the commercial human-tended spacecraft servicing market segment – currently non-consuming. The basis of performance demanded for this market segment, as identified in Table 3 matches the DI theory prediction for non-consuming markets where functionality and reliability are valued over customer convenience and cost. Service providers offering a crewed capability to capture and repair a nonfunctional satellite would thus offer a service that helps customers "do more conveniently what that are already trying to get done," – that is improve their ability to offer a reliable service or product from a satellite platform.[xi] This is a signal indicating a potential new-market disruption.

DI theory predicts COT service providers entering this non-consuming market would enjoy a significant first to market advantage, but would at the same time face large marketing and technical risks. They also face the potential pressure of competition from substitute services (e.g. robotic servicing technology). Most mission concepts for LEO are focused in an 8-14 day region closer to the performance curve represented by Shuttle, meaning there may be opportunity in the down market region.[12] Returning to Fig 2, offering a crewed satellite servicing product would represent an up-market move by COT suppliers in Region B and a down-market move by suppliers in Region A when analyzed against $M_{\text{On-orbit Time}}$. However, on-orbit duration is not likely the highest priority functional attribute for this customer segment – thus analysis vis-à-vis other performance metrics would be instructive.

4. Additional Findings – Undershot Customers

The analysis in this paper has identified no undershot customer markets (for the performance attribute being analyzed). The performance curve represented by the incumbent, along with a number of new entrants is in the upmarket market portion of Fig. 2 – providing a performance surplus relative to most customers' needs; and meeting the performance requirements of government customers. The finding that there are no undershot customers is not surprising as the government focused nature of incumbent systems has resulted in an emphasis on high levels of technical performance, at the expense of simplicity and cost efficiency.[13]

5. Topics for Further Investigation

The analysis contained in this paper is preliminary in nature, as the COT market develops additional refinement of the potential trends contained in this paper will be instructive. Topics for ongoing study include:

- A similar analysis using a different performance metric.
- This analysis considered only the COT spacecraft. Analysis of the integrated COT system (launch vehicle plus on-orbit segment) may yield different conclusions.
- Iterations on the current analysis may yield alternate conclusion as the performance capabilities of prospective new entrants evolve.

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[12] For discussion of notional crewed spacecraft servicing missions see the October 2010 NASA Goddard Space Flight Center "On-orbit Satellite Servicing Study Project Report."

[13] For more on this theme, see the "Report of the Commercial Human Spaceflight Workshop" hosted by the FAA in August of 2010.

REFERENCES

[i] FAA."Report of the Commercial Human Spaceflight Workshop." August 2010, p. 10. http://www.faa.gov/about/office_org/headquarters_offices/ast/media/Report%20of%20the%20Commercial%20Human%20Spaceflight%20Workshop.pdf

[ii] Adner, Ron, " When are Technologies Disruptive? A Demand-Based View of the Emergence of Competition," *Strategic Management Journal*, 23(2009): 667-688.

Danneels, Erwin, "Disruptive Technology Reconsider: A Critique and Research Agenda," *The Journal of Product Innovation Management*, 21 (2004): 246-258

Dombrowski, Peter and Gholz, Eugene, "Identifying Disruptive Innovation," *Innovations* 4-2(2009): 101-117

[iii] Adner, 2002: p. 669

[iv] Danneels, 2004: p. 249.

[v] Dombrowski and Gholz, 2009: p. 105

[vi] Cheetham, Bradley W. 2010. "Industry Structural Analysis of Commercial Crew To Orbit Sector." IAC-10-E6.3.1, 2010.

[vii] Davidian, et. al. IAC 2011.

[viii] NASA and the FAA. ."Commercial Market Assessment for Crew and Cargo Systems." 2010, p.15 http://www.nasa.gov/pdf/543572main_Section%20403%28b%29%20Commercial%20Market%20Assessment%20Report%20Final.pdf

[ix] FAA, 2010. p. 19.

[x] NASA and the FAA. 2010.

[xi] Christensen, Clayton M., et, al. *Seeing What's Next?: Using The Theories of Innovation to Predict Industry Change*. Harvard Business School Press (2004). ISBN 1591391857. http://worldcatlibraries.org/wcpa/isbn/1591391857